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BIOENERGY FOR DEVELOPMENT:
Environmental & Technical Dimensions.

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Summary.

This study examines the present role of biomass in the world's energy supply and calculates the potential for future biomass energy provision into the next century. It looks at examples of present biomass production and conversion to both modern and traditional fuels. Environmental effects of biomass use are examined on the global scale, considering health and sustainable production practices. Policy issues are discussed at the local and international level.

Biomass can be converted into modern energy carriers through mature and novel conversion technologies and thus, has the potential to be a significant new source of energy into the next century. Biomass is a flexible feedstock capable of conversion into solid, liquid and gaseous fuels which can substitute for fossil-based fuels at relatively small scales of investment. It will also continue to meet its important traditional roles ie., cooking, heat, light, construction, etc. in the rural and urban sectors of developing countries. Many benefits may accrue from significantly increasing the use of modern forms of biomass energy. These may include the reduction of CO_2 emissions to the atmosphere if advanced biomass conversion technologies are used as a substitute fossil fuel-based technologies. Furthermore, the adoption of advanced biomass energy conversion systems may well be less costly than equivalent advanced fossil fuel-based systems. {Williams & Larson, 1993} A recent synthesis by Johansson *et al.*, {1993} estimate that biomass could provide about one fifth of electrical power and two fifths of direct fuel use by 2050.

Problems certainly exist and some of the new conversion technologies are still to be demonstrated. Also, without proper monitoring there is the potential for the unsustainable exploitation of the existing biomass sources, often at the expense of natural forests and woodlands. Biomass energy systems can be land and labour intensive and can thus significantly affect the local environment and socio-economic climate.

Biomass production is essentially modular and decentralised, providing substantial rural employment (both skilled and unskilled). It does not demand large capital investments which characterise other non-fossil based energies such as hydro-electricity and nuclear power.

Modern conversion technologies and management practices can provide non-polluting and convenient biomass-derived fuels at prices which range from highly-competitive to near-market. Technologies under development suggests there will be a long term requirement for biomass which can provide environmentally friendly energy from the local to the global level.

Sustainable biomass production requires detailed local-level planning and the central involvement of local people. Also, a long term commitment to implementation and monitoring is necessary if the multiple benefits of biomass energy are to be permanently realised. Such a commitment should be based on a realistic

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Biomass is defined as all forms of plant-derived matter (terrestrial and aquatic) other than that which has been fossilised. This includes: dedicated agricultural and forest products eg. fuelwood, sugarcane, rape seed, etc, agricultural and forestry residues, animal wastes- both dung and abattoir-derived, municipal solid wastes (MSW) including sewage, and peat where its use can be demonstrated to be renewable.

assessment of present biomass use and the potential size of the biomass resource. If these conditions are met then there is no need for conflict between future food and energy needs. In fact, if an integrated approach to the production of food and fuel is adopted, there could be benefits both from increased food and bioenergy production.

We estimate from detailed country studies that biomass currently provides about 14% of global primary energy consumption and could in the future theoretically supply the equivalent to about 3 times the present global energy demand. This scenario allows for increases in cropland area for food production by 2025. (see Tables 1 & 2). Based on these assumptions, there is a long-term practical potential for both Africa and Latin America to become net exporters of biomass fuels such as alcohols and hydrogen.

Uncertainties exist, but the effects of climate change may be beneficial to biomass growth through the synergistic effects of increased levels of carbon dioxide in the atmosphere in combination with increasing rainfall and temperatures. With the environmental incentives to shift away from fossil-based fuels to CO_2-neutral and low sulphur fuels, biomass energy should be seen as an entrepreneurial opportunity for producing environmentally acceptable and socially beneficial fuels.

Abbreviations.

Conversion Units. (all in Lower Heating Values, LHV). Except where stated "t" refers to an oven dry tonne of biomass (1,000 kg, 0% moisture)

Energy Contents.

1 t wood = 15 GJ (airdry, 20% moisture; 20 GJ, 0% moisture)
1 t Oil Equiv. (TOE) = 42 GJ
(MTOE = 1 million TOE)
1 t Coal = 30 GJ
1 t Charcoal = 28 GJ
1 bbl = 1 barrel oil = 159 l
=1/7 t (approx)

Acronyms.

BEDP = Bagasse Energy Development Programme (Mauritius)
BIG = Biomass Integrated Gasifier
STIG = Steam Injected Gas turbine
ISTIG = Intercooled STIG
CHP = Combined Heat and Power
CEST = Condensing Extraction Steam Turbine
GEF = Global Environment Facility of the World Bank
GHG = GreenHouse Gases
GT = Gas Turbine
GTCC = Gas Turbine Combined Cycle
MSW = Municipal Solid Waste
NPP = Net Primary Productivity (t/ha/yr)
NUE = Nutrient Use Efficient
PAR = Photosynthetically Active Radiation
PET = Potential Evapo- Transpiration
P/PET = Precipitation/PET
PV = Photovoltaics
RIGES = Renewables Intensive Global Energy Scenario {Johansson *et al.* 1993}
RME = Rape Seed Methyl Ester
SEDP = Sugarcane Energy Development Project (Mauritius)
SRWC = Short Rotation Woody Coppice.
WUE = Water Use Efficiency

International Units.

J = Joule
1 ha = hectare = 2.47 acres
t = metric tonne = 1,000 kg.
1 btu (British Thermal Unit) = 1.054 kJ
1 calorie = 4.19 J
1 kWh = 3,600 J
1 W = 1 Js^{-1}

n = nano = 10^{-9}
μ = micro = 10^{-6}
m = milli = 10^{-3}
k = kilo = 10^{3}
M = mega = 10^{6}
G = giga = 10^{9}
T = tera = 10^{12}
P = peta = 10^{15}
E = exa = 10^{18}

Chemical.

CO_2 = carbon dioxide
CH_4 = methane
CH_2OH = methanol
C_2H_4OH = ethanol
H_2O = water

C = carbon
N = nitrogen
P = phosphorous
K = potasium

1. Introduction.

Biomass energy has the potential to mitigate greenhouse warming through the provision of energy from a CO_2-neutral feedstock. With good management and growth strategies other environmental and developmental benefits may result from integrated bioenergy programmes. These benefits may include land rehabilitation, soil stabilisation, water-shed protection, decreased SO_2 and NO_x emissions, and the development of permanent rural industries and employment. In assessing the future role of biomass energy and greenhouse abatement scenarios, a detailed understanding of both above and below-ground carbon flows, and energy output to input ratios, is needed for each intended biomass crop. Also required is an appreciation of the potential damage which may result from uncontrolled development of biomass energy systems. Despite the potential benefits outlined above a significant biomass energy programme will not develop spontaneously due to a number institutional, technical and social constraints. Successful mechanisms to overcome these constraints need to be found. (see below)

A Future Role for Biomass Energy

Biomass could become a central part of future sustainable energy supplies. Both the economic and practical feasibility of such a developmental approach has been demonstrated by Johansson *et al.* {1993} in their Renewables Intensive Global Energy Scenario (RIGES). RIGES demonstrates that it is possible to provide energy for growth and development at no extra cost compared to conventional fossil-based systems. A reduction in global CO_2 emissions would occur as a result of such an increase in renewables-based energy supply of which biomass would be a significant energy resource.

Two recent studies have recently emerged which provide independent support for such an important economic claim. Kulsum Ahmed of the World Bank {1993} has shown that biomass conversion technologies are capable of providing modern energy carriers at costs comparable with equivalent oil-based carriers if oil is priced at about US$ 20 per barrel. An important conclusion of this report is that there is a strong downward trend in the costs of biomass based technologies which is likely to continue. Secondly, a Shell Co. report has shown the promise of biomass based electricity generating units (BIG/GT) which could be produced at the same or lower capital costs to fossil based units ie. at about US$ 1,500 per MW_e, if the anticipated results of an existing Global Environment Funded (GEF) project are achieved. {Elliott P., 1993}

To put the potential contribution of biomass in context, under RIGES by 2050, biomass would provide 17% of electrical power and 38% of direct fuel use. Altogether, "renewables" could supply 3/5 of electrical power production and 2/5 of direct fuel use by 2050 at the same or lower cost to future advanced fossil fuel-based systems. (see section 6)

Such a switch to modern bioenergy systems of the scale outlined above would have significant benefits to both developing and industrialised countries. In developing countries, the provision of affordable rural energy supplies will provide important improvements in both food and cash crop yields, mainly by enabling farmers to provide irrigation and agro-industrial energy at the various levels. Indeed, such rural biomass-based systems could provide the catalyst for self-sustaining indigenous rural development once constraints are removed (see below), also providing a sustainable energy source for urban centres. As such, modern biofuel technologies may actually aid developing country farmers to increase food crop yields at a faster rate than population growth. In so doing, indigenous biomass energy crops could help avoid the need to expand food production onto marginal land thus, negating potential food versus fuel arguments. {Williams, 1994}

A growing number of industrialised countries are beginning to view biomass-based energy systems as an important policy tool for addressing complex problems such as GHG emissions, rural development and energy security. Industrialised countries where biomass is providing a fast growing share of the energy sector include Austria, Denmark, Finland, France, Norway, Sweden and the USA. Sustainably grown biofuels are CO_2-neutral and low acid rain polluters and need large quantities of land. This land use intensity is regarded as a benefit as it allows policy makers a novel use for the excess cropland areas which are now emerging due to rationalisation of agricultural policies in Europe and North America.

A major facet of modern bioenergy growth and conversion facilities is their modularity at relatively modest scales (1 to 100 MW). Modularity is an important concept as it allows energy planners to provide small incremental additions to the production capacity as opposed to the large-scale (500 to 1,000 MW_e) fossil-based additions usually needed. For example, modern bioenergy conversion facilities are not prone to the economies of scale of existing fossil-based systems, thus, negating the necessity to add very large increments (500 to 1,000 MW) to the energy production capacity in order to benefit from those economies of scale. Thus, inaccurate supply and demand forecasting will not be as important with such biomass systems. In addition, the relatively large number of small biomass energy generating systems provides an inherent increase in supply security.

Constraints.

Why then have modern biomass energy technologies not been spontaneously and widely adopted and thereby obtaining a more significant share of the energy market?

The answer lies partly in the complexity and site specificity of the factors governing biomass growth and conversion. Whilst in developing countries traditional biomass use may already be highly important, present trends in its use are often unsustainable and of low efficiency. In industrialised countries, biomass use for energy up until the last few years has been restricted to niche markets where feedstock costs have been low or zero such as in sawmills, pulp and paper industries, etc.

Despite the site specificity of factors such as feedstock cost, proximity to market and likely market size, a number of general constraints to increased bioenergy use can be identified:

i) subsidies to competitors eg. kerosine, or fossil fuel derived electricity, the so-called "uneven playing field."

ii) scepticism over the reliability and economic feasibility of biomass energy projects due to a number of high profile biomass energy project failures. Often these failures were due to social incompatibilities or inflexibility of project aims and not necessarily concerned with the technology per se, however, the sentiment persists.

iii) a secure market must exist for biomass-energy products.

iv) traditional biomass conversion technologies are dogged by low conversion efficiencies and viewed more as a means of waste disposal than for energy production.

v) there is a lack of awareness by senior decision makers, potential users and financiers about the multiple benefits of bioenergy systems.

vi) bioenergy systems require co-operation between sectors which do not normally communicate. At the national level, the agriculture and forestry sectors must communicate effectively with the energy and land planning sectors. At the international level there needs to be an integrated approach between institutions such as the World Bank, the UN (including UNEP, UNDP, FAO) and multi-national companies which must also involve NGOs.

vii) at the local/village level there is a need for the strengthening or creation of a transparent organisational infrastructure so as to ensure technically sound biofuel systems provide effective and equitable returns to consumers and suppliers alike.

viii)the initial capital costs of conversion equipment may be higher than comparable fossil fuel systems, and potential financiers may be difficult to find despite the cheaper full life-cycle costs. There may also be little or no backup or operation and maintenance facilities due to the novelty of the technology.

Despite these constraints when full life-cycle costs and potential environmental and wider social benefits are accounted for biomass-based energy systems will, in many cases be the least-cost long-run option.

Environment & Management.

Besides potential greenhouse abatement benefits of biomass energy, its production can address many other "secondary" issues. {Ranney, 1992a} Such problematic areas which may benefit from large scale biomass energy are: soil erosion, raising habitat diversity, control of nitrogen run-off and the protection of watersheds. (see section 5)

Bioenergy is certainly no panacea for solving the world's energy problems since it is not without its difficulties. Indeed, the production of the biomass itself can be intensive in planning, management, labour and land. For sustainable growth, detailed planning will be required from local, to national, to regional levels. The inappropriate selection and site-matching of species or management strategies can have deleterious effects and lead to degradation and abandonment of land. However, the correct selection of plant species can allow the economic production of energy-crops in areas previously only capable of sustaining low plant productivities; simultaneously multiple benefits may accrue to the environment. Such selection strategies may allow synergistic increases in food-crop yields and decreased fertiliser applications whilst providing sustainable local sources of energy and employment.

Biomass Use for Large scale Energy Production.

The perception of biomass energy has changed recently in a number of industrialised countries. This has led to biomass gaining a growing and significant share of the primary energy sector in USA, Sweden and Austria (4%, 16% and 10% of primary energy respectively; see section 3). Biomass has previously been regarded as a low-grade, "poor man's" fuel, but is increasingly viewed as an environmentally and socially advantageous source of energy. In the newly industrialising countries, for example Brazil, biomass energy has always been an important traditional energy source, predominantly for the domestic sector. However, under the initiative of various programmes in a number of countries, such as for ethanol and electricity production, biomass energy has attained a significantly higher profile. With a better understanding of the negative aspects of biomass supply and methods for their mitigation, bioenergy is increasingly perceived by energy planners not as a problem, but as an opportunity for the sustainable provision of energy.

Global Warming.

The Intergovernmental Panel on Climate Change's 1992 Supplement (IPCC92) has found no evidence to markedly change their 1990 global warming predictions. They now state i) emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases. ii)modelling studies indicate that the mean surface temperature sensitivity to doubling CO_2 is unlikely to lie outside the range 1.5^oC to 4.5^oC, iii)the global mean surface temperature has increased by 0.3^oC to 0.6^oC over the past 100 years, and iv) the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more. Furthermore, of the 6.0±0.5 GtC emitted in 1989/90 from the two primary atmospheric CO_2 sources, mainly, the combustion of fossil-fuels and secondly, land-use changes, the latter change accounts for 1.6±1.0 GtC. A substantial proportion of the carbon emissions from land-use changes are derived from the 17 Mha yr^{-1} of tropical deforestation estimated to have occurred between 1981 and 1990, which is expected to continue {IPCC, 1992}.

However, the measured increase in the atmospheric concentration of CO_2 is not consistent with the calculated level of emissions from fossil fuel use and land use changes. These measurements indicate that either the level of emissions is exaggerated, which seems unlikely, or that more CO_2 is being reabsorbed, by an unknown mechanism, than estimated, ie. there exists a "missing sink." The destination of the so-called "missing sink" carbon is still uncertain. It is thought that not all this "missing" CO_2 has been absorbed into a large oceanic sink but that a terrestrial sink exists possibly resulting from a CO_2 fertilisation effect on vegetation growth. {Wigley 1992.} Even though there is some uncertainty over the extent of global warming the latest estimates only serve to make the arguments concerning "the precautionary principle" and the possible benefits from land rehabilitation of greater importance.

A Conflict for Resources?

Of greater certainty is that the global population will continue to increase. The IPCC92 revised estimates of population growth predict rises of between 1.27% and 2.28% per year or the equivalent of a gross increase of 44% to 80% by the year 2025 from 1990 levels. Population growth makes increasing both food and energy supplies of paramount importance. Potential conflicts between these resources must be assessed and planned for.

The perception that all development requires more energy per se, is not necessarily valid. Improvements in the efficiency with which energy is produced and used, have highlighted the importance of the services that energy can provide, as opposed to increasing total amounts of energy ie. less energy can be made to do more. Future policies for indigenous biomass energy production should ensure that improvements in income generation, provision of modern energy services and trade benefits are returned in a significant fraction to the local populations. This implies that the rural incentives and the infrastructure necessary for the sustainable development and provision of such biomass energy services are developed at the local level. (see section 3, Hosahalli)

However, the provision of biomass-based energy services should not conflict with land requirements for food production. Research indicates that the problem is not the size of the land resource, but its efficient management for biomass production in all its forms- for food, fuel, fodder, etc. (see sections 2 and 3.) Research on wood energy activites over the last decade (after the 1981 Nairobi Plan of Action) has shown that contrary to popular belief, "factors other than the use of fuelwood and charcoal are the chief causes of deforestation; processes such as farming, forest fires and the industrial use of forests are the chief causes." {FAO, 1993} Small increases in energy inputs (especially where none previously existed) will provide significant returns in yield improvements, effectively increasing land availability rather than competing for it, hopefully reducing the pressures causing deforestation and land degredation. Modern, efficient industrial and domestic energy conversion technologies are also required if full advantage is to be taken of the potential environmental, economic and health facets of biomass energy. (see chapters 4 & 5)

Energy Balances.

The high yields presently achieved by intensive agriculture require significant energy inputs and mechanical methods of production. For many crops under intensive management the energy required for cultivation and processing may exceed the energy content of the food produced. However, the energy output to input ratio of woody and fibrous energy crops is very favourable (in excess of 10 times and about 6 to 7 times for ethanol from sugarcane); for these crops high energy inputs can be rewarded with net increases in energy output. {Ledig, 1981; Gladstone & Ledig, 1990} In general, cereal crops give a positive energy return even under intensive management eg. maize contains 3.5 times the energy in the harvested grain alone than it requires to cultivate and process. However, some crops presently require more energy to produce than they return in the food produced eg, energy output to input ratios are: apples 0.9, lettuce 0.2, tomatoes 0.6 and cabbage 0.8 {Pimentel, 1984}. Note, however, that many of these calculations do not account for the energy content of the associated residues which are significant.

There are considerable opportunities to make farms and forests both net energy exporters and net carbon sequesterers. This potential has been highlighted

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"Sequester" is defined as the net removal of CO_2 from the atmosphere and subsequent storage in organic matter.

in a recent report by the USA Council for Agriculture, Science and Technology (CAST, 1992). It states that "a great opportunity for U.S. agriculture to help mitigate climate change lies (through the) stashing of carbon in soil and trees and displacing fossil fuel." CAST estimates that US agriculture could plausibly displace 8% of US energy with biomass fuels which would reduce total US CO_2 emissions by 10%.

However, where fossil fuels are used in the production of biofuels some CO_2 is inevitably emitted, even where this CO_2 is effectively re-absorbed through increases in standing carbon or in fossil fuel substitution benefits. In the future these emissions could be eliminated through the use of biofuels or non-CO_2-emitting renewables to supply the energy for growth and processing of the biofuels.

The Potential Biomass Energy Resource.

Given appropriate institutional and management policies biomass energy offers the opportunity for the provision of substantial amounts of energy. At the same time it can provide rural employment and environmental benefits. The adoption of biomass energy systems globally may, however, require changes in farming, forestry and energy-use practices. Initially, such energy systems would have to be based primarily on agricultural residues during the establishment and development of bioenergy plantations. The potential for sustainable energy supplies from such plantations is considerable. For example, energy plantations on only 3% of Brazil's land could theoretically provide much more than its current total primary energy consumption. It is now recognised that biomass presently plays an integral role in the energy provision of most developing countries. However, the future potential of biomass energy must be realistically assessed accounting for present (usually very inefficient) production and use, and the problems of future energy provision.

Prevailing climatic conditions in many developing countries lend themselves to high biomass yields if growth is not unduly limited by nutrient, water or pest and disease constraints. Many of these countries eg. Brazil, Zaire and Thailand are also well endowed with large potential land areas for biomass growth and could thus become net energy exporters. The development of the rural energy industries required would provide significant levels of employment and income generation.

2. The Potential for Energy from Biomass.

Theoretical Optimum Productivity.

The fundamental determinant of biomass productivity is the amount of sunlight falling on the leaves of the plant. The ability of the plant to utilise this resource is mediated by temperature, water and nutrient availability, the plant type and species, and the plant's ability to deal with pests and diseases. Plants absorb photosynthetically active radiation (PAR) in the wavelengths from 400-700 nm. PAR represents roughly 50% of the energy of the total incoming radiative energy. Of this energy, further losses occur through reflectance by the leaves and transmission through them, interception by non-photosynthetic components both within the leaves and by the branches, twigs etc, and efficiency losses with which the energy in absorbed photons is converted into chemical energy as fixed carbon bonds. These losses dictate a maximum theoretical photosynthetic efficiency of 6.7%, if total PAR is utilised throughout the year. {Bolton & Hall, 1992}

Besides water availability, temperature is of central importance since it governs the length of the growing season ie. C_3 plants grow optimally between 20 and 30^oC (and not below 0-5^oC), C_4 plants between 30^oC and 40^oC (and not below 10-15^oC). Thus away from the tropics temperature constraints can severely limit the length of growing season.

To grow, plants must absorb carbon dioxide for which the stomata must be open; however, due to the thermodynamics of diffusion, water can escape to the atmosphere at a faster rate than carbon dioxide can enter the leaf. Therefore, photosynthesis results in the loss of the water. This water loss is turned to the plants advantage as it is essential for transporting nutrients through the plant and also for structural and biochemical requirements.

A major source of carbon loss in C_3 plants occurs as a result of photorespiration which causes the loss of about 30% of the carbon already fixed through photosynthesis. C_4 plants (which have made structural and enzymatic alterations to minimise this loss) suffer negligible losses from photorespiration. Attempts to select C_3 species which have lower photorespiratory levels have been largely unsuccessful.

Theoretical calculations of the maximum potential yields for trees, all of which are from the C_3 group of plants, under conditions which are neither nutrient or pest/disease limited, show the absolute potential productivities possible. Thus for Plymouth (50^{o}N), with an annual average daily insolation of 11.1 MJ m^{-2}, temperature constraints reduce the theoretical maximum yield (without pest and disease losses) from 156 t/ha/yr to 50 (oven dry) t/ha/yr. {Hall et al. 1992}

Factors limiting Growth.

Temperature. As can be seen, temperature plays a central role in the productivities a plant can achieve and not surprisingly different plant species being adapted to different temperature regimes. Thus, C_3 species such as barley, willow and alder are adapted to temperate climates to maximise their growth under the prevailing conditions. Many deciduous temperate species lose their leaves when the temperature falls below levels at which effective photosynthesis can occur. Such plants thus minimise metabolic losses from the now redundant leaves and also avoid damage due to severe drops in temperature. However, the canopy must be quickly re-established at the beginning of the next growth season when high CO_2-fixation rates can be achieved. Perennial species can take advantage of their existing branch structure to redeploy their leaves at a faster rate than annuals; again ensuring a longer growing season. Leaves of evergreens can remain functional for two or more years, and so avoid the costs of annual leaf production, but such a strategy has a cost in terms of lower carbon dioxide fixation rates (due to factors such as thicker leaf cuticles and leaf shape needed to survive frost and snow) than either annuals or perennials. {Ledig, 1989}

Nutrition. Large areas of the world's soils are nutrient deficient. Nitrogen is one of the most important nutrient requirements for plant growth, and its uptake from the soil is required by all plants which are unable to fix atmospheric nitrogen. Inter-cropping trials with N-fixing species in tropical plantations have shown that it is possible to maintain high yields without the use of nitrogen fertilisers. For example, trials in Hawaii which mixed *Albizia* with *Eucalyptus* achieved yields of about 25 t/ha, slightly more than pure, well fertilised *Eucalyptus* stands. {Debell, 1989}

Nitrogen fertilisers are applied to the world's crops in ever increasing amounts and have been linked to many environmental problems (section 5). Other nutrients (mainly K and P) and trace-elements are required for healthy growth, but these are only required in relatively small quantities which need to be determined for individual sites.

There are many management strategies which can be adopted to minimise the use of fertilisers. These may include intercropping with nitrogen fixing species, and/or the returning of a portion of the crop's residues to the fields. For example, in the case of electricity and alcohol production from sugarcane, many of the non-organic nutrients removed from the fields at harvest (especially K) can be restored by irrigation with "stillage" (the liquid residue from alcohol distillation.) Further potential for nutrient recycling exists via the redistribution of the ashes from the combustion of the bagasse onto the fields. This has many potential environmental benefits (section 5.)

Plants also show considerable variations in nutrient-use efficiency (NUE) and, when conditions are not water or nutrient limited, also show differences in the efficiency with which they convert intercepted PAR into fixed carbon. Important gains in productivity may thus be made through the selection and genetic manipulation of species which are more efficient in their utilisation of resources, or more tolerant to the lack of them. This would allow increased productivities on present cropland and reasonable productivities on land previously considered as nutrient-stressed wastelands, large areas of which are in need of rehabilitation. (table 5)

Pests and Diseases. In general attacks on crops by pests are all too obvious and in common with fungal and bacterial diseases can be highly destructive if preventative measures are not taken early. In these situations it is common practice to spray with the appropriate prescribed pesticide if the farmer can afford them. Casual browsing by deer, rabbits, etc, can be more difficult to control and often needs physical restraints if the crop is not to be lost, especially during the early stages of growth.

Integrated pest management (IPM) strategies which incorporate biological control practices may allow "energy farmers" to minimise pesticide applications with concurrent reductions in pest levels and energy inputs. Such practices rely on integrating many risk abatement and management strategies {Raske & Wickman, 1991}. For example, a reserve area may be maintained in order to ensure that a stable population of predators is present in close proximity to the crop. Any pest outbreak may then theoretically be matched by an increase in the predator population thus minimising pest damage. (section 5.)

For forestry plantations it is now recognised that of equal importance to growth management strategies are strategies designed to make plantations more robust to diseases, pests and drought. Ledig and Kitzmiller {1992} suggest that in the face of environmental uncertainties "reforestation strategies should emphasise conservation, diversification, and broader deployment of species, seed sources and families." This approach is widely followed in Brazil's commercial plantations with a great deal of success. (see Chapter 3.)

Physical (soil & land). Soils are a key determinant of plant growth as they are the medium from which they gain their nutrients, water and physical support. Soils vary in texture, mineral content, pH and the ability to retain water and nutrients which can be, and often are, modified by the vegetation and bacteria growing on and within them.

Buringh {1987} has estimated that after eliminating land areas which are unsuitable for the growth of cereal crops even with the addition of fertilisers and pesticides, about 22% of the earth's surface is capable of sustaining cereal production (present agricultural land comprises about 11% of terrestrial area.) About 1/8 of this potential cereal land is qualitatively estimated to be of low productivity. The remaining (non-potential cropland) 78% of global land area may be capable of supporting crop production of other varieties, or cereal production under different management practices and is of considerable interest for biomass growth.

Harvesting and storage. These factors are important since losses from harvesting and storage can be the same order of magnitude as losses from pests and diseases. It is estimated that about 25% of above ground tree biomass is lost during harvest and transport. Pre-harvest food losses are estimated to be around 35% of the total production, and a further 10-20% is lost after harvest during transport, storage and processing. {Hall, 1984}. Whilst much can be done to increase the efficiencies at which harvesting is carried out through improvements in both management practices and equipment, there are environmental consequences if too much of the vegetative cover is removed from above the soil surface at the wrong time. For sugarcane production it is estimated that about 25% of the tops and leaves should remain on the fields after harvesting to protect the soils from rain and wind erosion and also to maintain organic matter levels of the soil {Carpentieri, 1992}.

Potential Global Productivities.

Present attempts to predict biomass productivities by both climate-driven and mechanistic models may be useful in estimating future biomass-for-energy scenarios. These types of models predict net primary productivity (NPP) patterns based on a range of limiting factors of which the ratio of Precipitation (rainfall) to Potential Evapotranspiration (i.e.P/PET) is generally dominant. PET is defined as the potential total amount of water which could be evaporated from the soil plus that transpired from leaves (pores fully open) at given conditions of irradiance, temperature, air movement and air humidity (units: mm H_2O/yr or mmol H_2O m^{-2} s^{-1}.) A P/PET ratio of <1 over a season or defined growth period implies that H_2O is limiting growth, while a ratio >1 implies that there is excess water which plants and soil cannot absorb and that run-off may occur. PET can be estimated from meteorological and soil data and by using energy-balance measurements which emulate plant canopy dynamics. However, due to differences between plant species, in both rates of transpiration and evaporation; P/PET can only be a rough guide.

The P/PET ratio incorporates both temperature and precipitation patterns to give plant moisture availability profiles; however, these are probably only consistent at country to regional level resolutions and not at the more global levels. For example, a Terrestrial Ecosystem Model (TEM) has recently been devised to predict global C and N fluxes and pool sizes. It has been applied to South America and has shown that on an annual basis availability of moisture was the factor which correlates most strongly with annual productivity (NPP). TEM estimates the mean NPP of the tropical evergreen forest region (natural growth) at 11.7 odt/ha/yr (oven dry tonnes) which can be compared with recorded local productivity values of forest plantations (unmanaged and managed) of 20-40 odt/ha/yr {Raich *et al.*, 1991; Brown *et al.*, 1991}. The TEM-derived productivity value was directly compared with the Miami model {Box & Meentemyer, 1991} (climate driven) which was then recalculated using the same parameters used to calibrate the TEM- this gave TEM values about 10% lower than the Miami model with the same spatial distribution of predicted NPP. Thus, despite fundamentally differing in their methodologies both of these approaches to vegetation modelling give similar results.

Future models will need to have much higher resolutions if they are to give useful optimum harvestable biomass predictions at a much smaller scale of thousands of hectares. Resolutions presently used in ecosystem productivity modelling are at the hundreds of thousands of hectares scale, or larger (0.5^o grid scales, 50x50 km). {Esser, 1991; Raich *et al*, 1991} The use of data aggregated from relatively few sites (and for natural vegetation only) in large scale models is a problem. Thus, extrapolating model conclusions to predict NPP values for managed biomass-energy ignores the effect of management practices on increasing biomass yields. Such model predictions are usually too low in their estimates of potential biomass productivities since they cannot yet factor in site-specific or regional determinants of yield limitation- these can only be derived from much more detailed empirical knowledge. Good management practices can overcome limiting factors of nutrient availability, pests, harvesting problems and even moisture availability, and raise NPP substantially on a long-term basis if the practices are sustainable. The challenge is to identify areas where biomass production appears most promising and to adapt the natural ecosystem models for use with biomass energy production when management is applied. Obviously the inputs required to improve site productivity at any given point, will need to be related to the expected returns.{Barros & Novais, 1990}.

A large scale model should also incorporate the effects of human interventions and changing land use systems. None yet exists (to our knowledge) which allows the theoretical limitations of P/PET and other factors to be partially mitigated. Practices such as the use of more water use efficient (WUE) species, intercropping, soil management techniques, both above and below ground, irrigation, etc, can be highly effective and will need to be accounted for in such models.

Plant WUE (measured as g carbon fixed per kg of water transpired by the plant) is highly variable between plant types and species (Fig. 2), but usually ranges from 3 to 7 g CO_2 fixed by photosynthesis (before metabolic losses) per kg H_2O, or expressed as t H_2O per t final dry matter, usually 500-1000 t per t. Biomass production can be increased without irrigation by selecting species better adapted to water limitations and by management techniques; improvements of 3-5 times in NPP have been recorded at a given moisture regime. An important consideration as atmospheric CO_2 levels increase during the next century, is whether this will improve the WUE of plant growth generally or only for certain types of plants e.g. C_3 plants. Even though experiments indicate that many plants increase their WUE at high CO_2 we do not yet know if this will be applicable to ecosystems or whether this occurs at the field (agronomic) scale.

The growing of biomass over large areas is believed to ameliorate the climate through the recycling of water and nutrients, through water-shed protection, and by providing a more stable microclimate. At present these self perpetuating mechanisms are largely ignored by vegetation models which do not allow for feedback between pixels (remote sensing units). It is these feedback mechanisms which are most affected by land use changes and need to be incorporated into future vegetation models at various scales.

Present Land Use and Availability.

The total land surface on the Earth is just over 13 billion hectares of which about _ is under forest and woodlands, _ under grassland + arable, and the final _ ("other") includes deserts, stony, steep (mountains) and ice-covered land. Increases in cropland have come mainly at the expense of forests and woodlands, with arable land estimated to have occupied 860 Mha in 1882 and 1,477 Mha today (1989) (11.3 % of the world's surface, table 4). At the same time forested land has decreased from 5,200 Mha to 4,087 Mha (31.2% of the world's land area). Buringh {1987} has estimated total potential cropland using productivity constraints for the 10 most commonly grown crops at just over 3 billion ha. Simplistically this means that, at present crop productivities, global food production could be doubled by utilising all this potential arable land. However, such a conclusion is a tenuous extrapolation since past trends in cropland expansion have often been at the expense of woodland, and generally onto less suitable soils. This implies that future yields will decrease as a result of the falling quality of land being brought into production. Furthermore, a substantial proportion of good quality cropland is expected to be lost to non-food producing uses, such as cities and towns. Nevertheless, if present trends in rising productivity were to continue (fig 3) and be applicable to new croplands, then far more than double present food production might be expected. For example, wheat yields in the UK have increased from about 2.5 t/ha/yr in 1945 to about 7.5 t/ha/yr in 1987 and are still increasing.

The success of the strong agricultural development programmes in both Europe and North America has led to large agricultural surpluses. The production of these surpluses has, however, proved economically expensive. For example, Wright *et al {1992}* estimate that payments from modern farm programmes in the US are costing "one and half times net farm income," whilst global agricultural subsidies were estimated to be about US$260 billion in 1990. If present policies continue as usual this will climb to US$ 300 billion by 2000. {Economist, 1992}

Significant areas of land presently used for intensive agriculture are not capable of sustaining modern intensive farming techniques, and are thus targeted for removal from arable production. It is estimated in the US that about 30 Mha had been removed from crop production by 1988. In the EC (12 countries) surplus agricultural land resulting from rising yields and changing agricultural subsidies may reach 15 to 20 Mha by the year 2000, and at least 40 Mha into the next century as crop productivities continue to increase.{NSCGP, 1992} These cropland areas are already being removed from intensive farming under EC and US "set-aside" schemes and the US "Cropland Reduction Scheme." {CAST, 1990; Brown L.R., 1992; Hall, 1992}. For practical and social reasons related to the rural economy and environment, this land represents a significant opportunity to initiate biomass energy production schemes, especially if coupled with the use of agricultural and forestry residues.

Wastelands & Potential land for Forests.

We consider wastelands to be land presently incapable of sustaining food production. This land has generally been degraded through changing methods of management, often towards more intensive and unsuitable forms of land use. A prime example is fallow land in shifting agriculture, where fallow periods previously lasted 30 or more years and may now be as little as 1 to 5 years.

Estimates of degraded and abandoned land generally lie between 700 and 1,000 Mha which is equivalent to about half the world's present arable land. The extent of this "available" land has led scientists to highlight its potential for use in mitigating the greenhouse effect by managing it to become a carbon sink. Wastelands are regarded as having a good potential for storing carbon in trees due to the relatively low levels of carbon in their soils and vegetation.

At good productivities (6 t Carbon/ha/yr equivalent to about 12 odt/ha/yr biomass) the reforestation of all this land could theoretically remove about 5 GtC from the atmosphere per year over the next 40 years, after which the rate of net absorption would decrease due to increasing tree maturity. Present emissions of CO_2 to the atmosphere are around 7 to 8 GtC/yr of which about 3 to 4 GtC appears as an atmospheric build up in the levels of CO_2. Sequestration programmes could therefore only be regarded as a temporary measure, buying time until other sustainable forms of energy or permanent CO_2 removal systems can be developed. However, productivities on degraded land are at present between 0.1 and 3 t/ha/yr {ETC, 1992}, (productivities in US commercial forests lie between 1 and 3 t/ha/yr). Thus, it would require large quantities of inputs in the form of management, fertilisers, pesticides and labour in order to raise the productivity significantly.

It is now increasingly realised that attempts to afforest land areas on the scales required (400-1000 Mha) for reasons aimed purely at absorbing

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The definition of "wastelands" is highly subjective. Table 5 gives a summary of the definitions given by each author. In general, such estimates try to define areas of land which have been used previously, but are now incapable of sustaining humans.

anthropogenically produced CO_2 may be misdirected.{Hall *et al.,* 1991; Hall, 1993; Nakicenovic *et al.*, 1993} Social, political and practical limitations to achieving high rates of reforestation are more likely to be overcome if there are concrete social and economic reasons stimulating revegetation at the local level. The development of an indigenous, modern biomass energy infrastructure, and the removal of obstacles such as subsidies to competitive fuels, may provide such a stimulus. (see chapter 6)

Estimates of the Mean Annual Increment (MAI) of wood at the global scale are becoming available with some accuracy, however, global estimates should be based on more dissagregated data at the regional and country level. Whilst average potential productivities of about 6 to 12 t/ha/yr are possible on rehabilitated lands it is questionable whether carbon sequestration by itself would provide sufficient incentive for the wide-scale forest establishment required to reverse atmospheric CO_2 increases. In order to achieve high productivities a variety of strategies will need to be employed. In most cases this will require a detailed local knowledge, extension services and continuing monitoring and research.

Much of the degraded land may be salt-affected, for example, Alpert *et al.,* (1992) estimate that about 950 Mha of saline land exists (table 5). 125 Mha of such land could feasibly be rehabilitated and is not presently used for agriculture or settlements. Massoud {1979} has also estimated that there is about 1,000 Mha of salt-affected lands.

Houghton estimates that there are 850 Mha of degraded lands available for rehabilitation, 350 Mha of which could come from land presently in the fallow cycle of shifting cultivation. Houghton only considered land which had previously been forests & woodlands and is now unused. Thus ignoring the fallow cycle land 500 Mha is theoretically available for immediate use since it is presently "unused." Another estimate from Myers (1989) that 200 Mha needs to be reforested mainly for watershed protection, and a further 100 Mha of wastelands are available, strongly support strategies for rehabilitating degraded lands. Myers states such strategies could have far reaching effects and need to be "carried out for reasons other than the greenhouse effect." {Myers, 1989}. (Table 5)

The estimates of the extent of degraded lands are in the same order of magnitude as the salt-affected lands; it therefore seems likely that some of these lands overlap and that a considerable proportion of the degraded land was abandoned due to rising salinity. High salt levels reduce the levels of nitrogen which is available to the plant, but nitrogen-fixing species are often tolerant to saline soils, and may achieve acceptable productivities on such land.

The potential for the use of saline land is considerable, for example, salt-tolerant plants can attain 3 to 7 tC/ha/yr with saline water irrigation. However, the use of saline irrigation may only economically realistic up to about 100 m above water level, due to increased costs for irrigation at higher altitudes. It is therefore estimated that only about 125 Mha of the salt affected lands will be of use {Alpert *et al.*, 1992}.

In other areas, in South-West Australia for example, where a saline water-table is close to or at the surface over large areas other remedies have been used to great effect. Due to intensive agricultural management practices which led

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MAI is defined as the net accumulation of above ground biomass through annual plant growth.

to the removal of deep rooted vegetation in favour of cereal crops the water-table in this region of Australia rose so inundating the topsoil with saline water. A two pronged approach was used to rehabilitate this land requiring the planting of the non-salt affected watersheds with low water-use-efficient trees and the salt affected regions with saline tolerant tree species. The water table has now been lowered enough (through increases in transpiration rates of these trees) in some areas to treat the topsoil and resume carefully managed crop production.

Recent estimates of land availability have suggested that less land may be available in practice, than previously calculated. Bekkering {1992} has calculated that 385 Mha only of land may be available in a total of eleven tropical countries after allowing for future land requirements for food production to 2025. Whilst this estimate uses the "carrying capacity" model for estimating future land requirements (which does not allow for improvements in productivity,) its predictions may be more accurate than previous global and regional level calculations. NaKicenovic *et al.* {1993} has attempted to distinguish between "suitable" land for reforestation and land which will actually be "available" for reforestation. He calculates that about 265 Mha is available for global reforestation programmes and a further 85 Mha for agroforestry.

We consider that reasons other than pure Carbon sequestration are necessary if land resources are to become available for revegetation programmes. Thus producing biomass as a substitute for fossil fuels will generate income and at the same time achieve a certain amount of carbon sequestration. Carbon-sequestration only programmes would also be costly. For example, NaKicenovic *et al.* {1993} estimates that the cost of a global plantation programme to sequester 120 GtC over the period 1995-2095 would be about US$ 520 billion (average cost = US$ 4.4 /tC). However, these cost estimates could be an underestimate "of the real costs by a factor of 2 to 3." {Nakicenovic N. *et al.*, 1993}

Land Reclamation Case Studies.

Severely degraded lands may require more intensive management if they are ultimately to be restored to their former productivity and provide useful outputs besides carbon benefits. The dominant factor affecting the success or failure of land rehabilitation schemes is the intimate involvement of and acceptance by the local inhabitants. The Baringo Fuel and Fodder Project in semi-arid Kenya, {de Groot *et al*., 1992} is an example of the progress, albeit imperfect, that can be achieved by this approach and the lessons which need to be learnt if significant land rehabilitation on the required scale is possible. Projects such as these must directly involve the local people in the planning and implementation phases. In the BFFP, previously fertile land had been devegetated through over-grazing, leading to severe erosion and desertification over a period of 50 years or more.

Baringo. This project which is based around the Lake Baringo in central Kenya has been running for over 10 years and relies on the use of solar powered electric fences to exclude grazing animals from the fields until they are well established and managed. Over 1,000 ha of fields have been planted with a variety of different tree and grass species which can provide both fuel and fodder. By allowing the vegetation in these fields to regenerate fully, a sustainable supply of fuelwood, grass for fodder (sustaining the livestock at the end of the dry season) and thatching is provided. An ancillary benefit is that these fields also play a role in carbon sequestration and soil stabilisation for the region as a whole.

The Baringo fuel and fodder project is not without its problems but has been successful in halting soil erosion within the fields. It has gained the support of the local population who continue to donate large areas of their land to be included in the project which is returned once revegetated.

Other projects. The KEITA project in Niger which is on the border line of the Sahara is also an example of the gains which are possible once the causes of deforestation are addressed and effective management practices are demonstrated to work. {FAO, 1992} Although the primary aim of KEITA is to halt desertification it recognises that there is little point in stopping desertification if it does not help the interests of the local inhabitants. It reinforces the conclusion that projects which do not involve the needs and aspirations of the inhabitants are probably predestined to failure. There is now so much scepticism about the chances of success of such aid projects that they are often abandoned as soon as the aid agency ceases to oversee the project (see below). In KEITA's case this meant that visible results had to be demonstrated quickly. This superficial requirement for speed initially necessitated the use of heavy machinery to demonstrate the effectiveness of bund building and tree planting in a similar manner to Baringo. Future projects should not need such machinery. Other key factors in the success of the project are the infrastructure which was put in place, thus insuring that any farm produce could get to the market, the agronomic practices which can be achieved without the use of heavy machinery and the recognition of the important role women play in the structure of the community. Despite these "successes" questions still remain about the cost-benefit performance of this project.

In Kerkhof's {1990} study of 19 agroforestry projects in 11 different countries in Africa, he identifies several factors which mediate in the success and failure of these projects. Primarily, the needs and aspirations of the local people must be sought and not assumed, and donor agencies must be willing to adopt long-term and flexible aims. Above all there is the need for local inhabitants to be involved at all levels of decision making, planning and extension, if large amounts of money are not to be wasted.

Land Availability.

There are two key questions which need to be addressed: i)is there sufficient cropland available to produce food for the world's expanding population? and ii)can biomass energy help enhance development and food production?

As seen above there are significant reserves of potential cropland available, but it appears that these resources are not distributed where they will be needed most if present predictions about the rate of population growth and areas for food production are realised. The IPCC's Response Strategies Working Group (II) {IPCC, 1990) has estimated that the need for cropland will increase in proportion to the World's rising population. Such an increase might require about 50% more cropland to be in production by the year 2025. We have analyzed data from the FAO's "Agriculture Towards 2010" project which assesses the potential cropland resource in over 90 developing countries. Data for China is not yet available, but will be essential for realistic global and regional assessments. We have estimated the potential global land resource based on this sub-set of countries, but without the Chinese data this extrapolation is limited to comparative purposes only. (see table 2b)

The FAO study (AT2010) took into account factors such as water availability, status of soils and the use of inputs such as fertilisers and pesticides. From this data we have calculated likely future cropland areas needed for food production in 2025. By subtracting these cropland requirements from the estimated total potential agricultural land resource for the three major developing regions, Africa, Latin America and Asia (excluding China), the theoretical remaining productive land in 2025 can be estimated (see Table 2). The potential energy production on this "remaining" land is then calculated assuming that such land is capable of yielding 10 air dry t/ha/yr of biomass (ie 150 GJ/ha/yr).

The area of land under cultivation is predicted to rise from the 706 Mha used in these 91 developing countries to 1059 Mha's or 40% of their potential cropland by 2025. These regional level figures disguise the local level problems which may occur when all the available cropland is already in use. For example, Asia (minus China) is already using 348 Mha and this is forecast to rise to 517 Mha in 2025; however, total potential agricultural land is estimated at only 470 Mha, and thus under these assumptions a deficit of -47 Mha is calculated by 2025. Africa which at present uses only a fifth of its potential cropland would still have 75% of its potential cropland remaining by 2025. Latin America is in an even more favourable situation, presently using only 15% of the cropland resource and 23% by 2025 (see Table 2a).

Asia therefore appears to be most at risk from population increases, being increasingly unable to meet its food requirements at present productivities. Many areas of Asia are densely populated and there seems little room for expansion into an over-utilised cropland. Previous attempts to reconcile this potential shortfall in Asia have centred on the gains it is possible to make through increased irrigation; in fact the area under irrigation has been rising steadily. However, water resources are increasingly limited with severe environmental problems resulting if this resource is overexploited. Withdrawals of water are nearing 20% of total run-off for both Asia and Europe. In 1986, 17% of the world's cropland was irrigated, and this is increasing by 0.9% annually. {Hall and House, 1992}

Significantly, at the global level, continued increases in the gross quantities of food production during the 1980's have not been achieved as a result of increases in cropland areas. (fig.9a) The gains in per hectare yields which have made this possible are borne out at the country level. In India, for example, the net sown area has remained virtually constant since the mid-1970's but at the same time total cereal production has risen from about 120,000 t to 200.000 t. (fig. 9b) Despite these apparent improvements there still appears to be a significant potential to raise these yields. (fig.3)

In fact there has been a steady improvement in both the quantity and quality of food produced if inequalities in food distribution and production are ignored. For example, globally, the average per hectare yield of cereals has increased by 20% since 1978-80 to 1990, and is up by 11% in Africa; however, the average yields for roots & tubers has fallen 5% globally, while it has risen by 16% in Africa over the same time period. {WRI, 1992}

Increases in productivity resulting from the selection of crops with enhanced water-use-efficient (WUE) and nutrient-use-efficient species offer the most promise in a resource limited environment. In the case of water, WUE's for C_3 plants are in the range of 2-6 mg CO_2/g H_2O which represents 300-1,000 t water per t biomass or an annual rainfall of 750-2,500 mm. C_4 plants have higher WUE's than most C_3

plants, for example, maize requires only about 300 tH_2O/t biomass produced.

Carbon Balances and Fossil-Fuel Substitution.

Significant areas of land are available for rehabilitation. If such land is to make a long term contribution to the reduction in atmospheric CO_2-levels the terrestrial carbon inventory will need to be raised permanently. Fossil-fuel use increases CO_2 levels in the atmosphere and is thus a carbon "source". Sustainably grown biomass for energy is nearly CO_2-neutral, depending on production and conversion methods. The production of fuels from annual crops results in lower emissions of net CO_2 compared to fossil fuels. {Turhollow & Perlack, 1991} The energy output:input ratios for both annual and perennial biomass energy "crops" are positive- the ratio can vary from just above 1:1 up to 20:1 depending on the system. The amount of CO_2 released by the fossil fuels used to power the machinery for growing, harvesting and processing the biofuel is fully accounted for in these ratios. Hence a positive biofuel output:fossil fuel input ratio (ie. >1) infers that when the biofuel is used as a substitute for fossil fuels it will result in reduced net CO_2 emissions.

If biofuel production is to be regarded as a sink, the total amount of carbon stored per hectare under the bioenergy crop must be greater than the level of stored-C in the vegetation previously on that land eg. where annual crops or degraded lands are replaced by sustainably grown forestry plantations. Also, where biofuels are used as substitutes for fossil-fuels, the biofuel can be regarded as a "sink" in terms of the avoided CO_2 emissions which would have arisen if that energy was derived from fossil fuels.

The size of the carbon sink is dependant on the level of vegetation already present on the land and the time perspective of the newly planted vegetation eg. the rotation length of a plantation and the likely length of time the land will be used for energy production. {Marland and Marland, 1992.} Increasing both the length of

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The term carbon inventory is used to describe the total mass of non-atmospheric carbon stored per hectare of land. In general it is practical to consider this carbon as the organically stored carbon held in living and decaying biomass of all types, both above and below ground.
A more rigorous definition would include inorganic forms of carbon held in the soils and rocks. Since this form of carbon normally cycles between the soil and the atmosphere very slowly (measured in millennia) it is often ignored in carbon balances. However, if exposed to atmospheric weathering from the rain, wind and sun it may be released far more rapidly than normal. We make no attempt to measure its significance.

Any change in land-use which leads to net emissions of carbon dioxide to the atmosphere can be regarded as a "C source."

A "Carbon sink" is defined as a process which leads to the net removal of CO_2 from the atmosphere. "Carbon neutral" is a process which has no overall effect on the levels of atmospheric CO_2. It is essential that the time scales within which they are used are also defined.

rotation and the productivities will result in higher average levels of standing carbon. {Schroeder, 1992}(also fig. 4) In pure C-sequestration terms the longer the rotation length the higher the average standing stock and therefore the greater the carbon stored. However, for energy production purposes the optimum rotation length may be shorter since the rate of tree growth falls off after a certain age, so reducing the annual productivity and economic return.

The benefits of C-sequestration may thus have to be balanced against those of C-substitution in the selection of the optimum rotation length. We consider that economically greater benefits will be gained from C-substitution since the plantation will produce a valuable commodity; practical rotation lengths will thus be shorter than the optimum for C-sequestration strategies. The costs of C-sequestration only strategies can be extremely high, with projected costs varying from US$ 2 to 56 per tC sequestered. {Moulton & Richards, 1990; NaKicenovic N., *et al.,* 1993; Hall, 1993}. The implementation of these strategies will also require large areas of land, of between 300 to 800 Mha, which may not be available unless useful products are provided to the local populations. (see section 2)

Crops with more than a one year rotation period in effect represent a reserve of standing carbon being grown to replace an annual harvest. A simple example of a 10 year rotation (on 10 ha), assuming a linear growth rate and a yield of 6 t C/ha/yr, shows that the amount of wood permanently being grown to replace 6 harvested tC/yr = 6 tC (1 year old)+ 12 tC (2 years old)+ 18 tC.... = 330 tC on the 10 ha. Thus, for one hectare to be harvested every year, a plantation with a 10 year rotation requires a minimum total area of 10 hectares. Once established, a plantation achieving a growth rate of 12 tC/ha/yr would have an average standing stock of 66 tC/ha immediately prior to harvest. (fig 4)

The most clear benefit, in C-sequestration terms, would be if the plantation was established in a desert with an existing standing stock of almost 0 tC/ha. Both the above and below ground levels of carbon would be raised significantly compared to the existing level. However, if the standing stock of the previous vegetation was greater than that of the new plantation then a net reduction in the standing-C levels would result. If, the plantation biomass were to be used as a fossil fuel substitute (or long-lived product), a net reduction to atmospheric CO_2 emissions would occur after a given time period. At higher levels of vegetation, prior to the plantation, the longer it would take for fuel-substitution benefits to redress the amount of CO_2 initially released. This results from the relatively large amounts of CO_2 which are released during the initial clearance through harvesting and transport losses. {Marland & Marland, 1992}.

The time perspective is also important. Longer rotation periods allow greater average plantation standing stocks. Of equal importance to the rotation length are the productivities gained. Higher yields result in higher average standing stocks, and also reduced unit costs. Figure 5 shows the average cost of plantation-derived fuelwood from the 5 bioclimatic regions of Northeast Brazil. The cost of the wood is clearly related to the yield, with yields below about 8 t/ha/yr proving relatively more costly. The Brazilian study is discussed in more detail in section 3.

Marland and Marland have explored the use of plantations for a fossil-fuel substitution plantation-based model (1992). They conclude that the three most important factors in assessing whether biomass energy plantations are effective C sinks are: i)the C inventory of the natural vegetation, ii)the productivity of the plantation and iii)the time perspective adopted. In areas with high standing stock carbon (eg. old natural growth forests) on low productivity land, the most favourable solution is simply to leave alone and protect the existing forest. The most effective plantations would be those which are established on sparsely vegetated land capable of high productivities, ie degraded lands and present good quality arable cropland (see above). The Marland and Marland model is mainly designed for US forestry conditions ie. 40+ year rotations, regarding coal as the primary fuel-substitution feedstock. Assumptions about the efficiency with which biomass-based fuels can substitute for fossil fuels influence the rate at which plantations can recover the carbon released to the atmosphere during initial tree harvest, haulage and storage. In their model, these parameters are set at 0.75 tC (coal-derived) substituted by 1 tC from biomass, and 0.375 tC for liquid fuels per tonne biomass C. Their coal substitution parameter assumes that biomass would be converted to useful energy at 60% the thermal efficiency of coal (the present average).

However, if the biomass is used in efficient domestic appliances or with advanced conversion processes then the ratio of fossil-derived C substituted by biomass derived C would improve(see section 4.). Using the more advanced technologies, the amount of useful energy obtained per kg of biomass-C (which is relatively more thermochemically reactive) would be equal to or greater than the amount of energy per kg of coal-C. Effectively higher yields could be gained, and the substitution ratio improved, if more of the forestry residues arising at harvest could be used. However, it is unlikely for environmental reasons that the proportion of residues left on the field should be reduced drastically. In the field, these residues decompose releasing CO_2 without providing any useful energy. Thus, even at relatively higher efficiencies of biomass conversion, one unit of biomass-C may still substitute for less than 1 unit of fossil-fuel carbon when the decomposition of residues is accounted for.

Extrapolation from this model can provide a large variation in results. It does however, show that at timescales of less than 30 years, only sparsely vegetated areas capable of high yields should be considered on pure carbon-sequestration terms. These assumptions are based predominantly on the lifetime of the plantation, and not on the rotation length, decreases in which might effectively increase the yield (for certain species), but decrease the average standing stock.

Therefore the most important points for the optimisation of fossil fuel substitution by biomass are: i) increasing the energy output:input ratio ie. raising the ability of biomass-derived fuels to substitute for fossil fuels; and, ii)raising the level of Carbon held in the biotic pool in order to absorb some of the carbon already emitted by fossil fuel use ie. increasing the terrestrial carbon sink. Accounting for soil carbon would make bioenergy plantations even more favourable as carbon sinks, but detailed data is not yet available on the interaction between changing uses of land and soil-C levels.

Energy Output:Input Ratios.

Energy ratios allow planners to determine whether the agricultural production of a crop is a net energy producer or consumer. Balance sheets detailing the energy inputs must take the whole life-cycle of the energy crops into account since investments in machinery and infrastructure will last more than one crop growth cycle. Detailed assessments of energy inputs would therefore include not only the fossil fuel inputs for fertiliser production and the machinery used for ploughing, planting, harvesting, storage and transport, but also the energy required for the manufacture of the machinery and infrastructure required for modern agriculture. Likewise outputs should include not only the energy return from the crop itself, but also the energy content of the residue production, eg. straw, husks, shells, stalks, etc. With intensive annual crops, lower output to input ratios can be expected due to the high level of inputs. However, such crops fit well into modern energy and agricultural markets and generally require less land per tonne of produce as a result of higher yields than perennial or woody crops.

Forestry plantation biomass production has been shown to have positive energy output to input ratio's of about 10 or more. In fact, Ledig {1981} has pointed out that for biomass plantations, increases in energy inputs are rewarded with net increases in energy outputs. The use of primary forest land would give a positive energy ratio. However, at higher levels of initial standing stock (eg. tropical forest) the loss in carbon to the atmosphere during clearance will probably not be recovered in terms of fossil fuel substitution benefits at timescales of less than 100+ years. Thus primary forests should not be considered as sources of biomass fuels.

For liquid fuels from biomass much smaller and sometimes negative energy input **:** output ratios are cited. For example, a study for the European Bureau for the Environment {Taschner, 1991} gives negative ratios for the production of ethanol from potato, wheat and sugarbeet, showing positive balances only when residues are accounted for. Integrated management approaches are essential if the production of such biofuels are to help ameliorate environmental problems and not increase them. It is therefore essential to adopt management strategies which maximise energy efficiency without compromising soil fertility.

To date very little research has been directed at maximising the production of the whole plant ie. residue production has previously been regarded as a waste-disposal problem and so much of the breeding work has been directed at raising the crop harvest index. Alexander {1985} states that if sugar breeders were to concentrate on optimising overall productivity in sugarcane instead of maximising the sugar concentration in the stem, then large overall gains are possible in both sugar production, and gross yield per hectare. Sugarcane alcohol plantations presently provide a positive energy ratio of about 4 for the Triangle programme in Zimbabwe and an average of 5.9 for the Brazilian Proalcool programme, which rises to 8.2 under the best conditions. {Scurlock *et al.*, 1991; Goldemberg *et al.*, 1992}

3. Rural Energy & Industry: Its Role in Sustainable Development.

Industrial Uses of Biomass.

It is difficult to over-estimate the range of uses and importance of different traditional and modern forms of biomass products and residues in both the rural and urban sectors of developing countries. The industrial sectors of developing countries consume an average of 40 to 60% of commercial fossil fuel supplies and also use significant amounts of biomass fuels. These biomass fuels are often sold on the commercial market. Industry also provides roughly 25 to 35% of rural non-farm employment. {OTA, 1991}

Whilst biomass production and supply is almost exclusively rural, its use in the urban sector is highly diverse, economically important and energetically vital. The consumption of other, more convenient fuels (especially kerosene) is widespread; however, fuelwood remains the dominant source of energy in many developing countries.(box 1) Biomass is used mainly in the form of charcoal and fuelwood, but agricultural residues, including dung and straw, are also important.

The uses of biomass include: physical- construction timber, poles (houses and fencing) and thatch; fibrous- mats and mixed with mud in hut walls; thermal- fuel for cooking, tobacco curing (requiring approx. 6-60 t of wood per t of cured tobacco produced, ie. 90 to 900 GJ/t), tea/coffee drying, brick and tile making (roughly between 1,500 to 19,000 MJ/1000 bricks; 500 to 6,300 MJ/t for 3 kg bricks), paddy parboiling (4.17 GJ/t), gur making (24.95 GJ/t, brown sugar) rubber making, coconut, bakeries, tanneries/cloth makers and charcoal in metal production and processing, pulp for paper making, food preparation in shops and restaurants and shops. (table 8 for various types of industrial biomass use.)

There is a large potential for increasing the level of energy services from biomass sources through the adoption of modernised forms of bioenergy production and the use of energy-efficient equipment, without proportional increases in the amount of biomass use. Such strategies may make one unit of biomass work for longer eg. cook more food from 1 kg of charcoal, or provide more services eg. light, water pumping, milling, etc. per unit of biomass consumed. (see Hosahalli village section)

Charcoal.

Charcoal use is wide-spread throughout developing countries, however, its increasing production and use is causing concern as unsustainable sources of wood are mined, destroying forests and eroding land. It is preferred by domestic users because of its convenience of use (small size, low weight) and quality of burning (constant heat, long lasting) compared to other accessible energy sources, such as firewood, crop residues and dung. It is preferred by industry and charcoal producers because of its energy density (about 30 GJ/t) and relative ease to transport compared to wood (small chunks which pack easily).

The charcoal industry often has a large infrastructure, based on an indigenous, if often unsustainable supply sources (ie. forests & woodlands). Charcoal's low price and convenience for transport and use means that attempts to induce industrial and domestic users to switch from charcoal to other fuel sources, mainly fossil fuels, are unlikely to succeed in the near to medium term in many developing countries.

During the 1980's, however, due to increases in the efficiency with which charcoal was produced from wood, and the switch to plantation derived wood from natural sources, Brazil has been able to significantly increase its charcoal use. Brazil has been able to achieve this increase without increasing charcoal production from natural sources. The Brazilian charcoal industry is discussed in detail below.

Brazil.

Large amounts of charcoal are consumed in the reduction and heating of iron ore for pig iron production. In 1990, Brazil consumed over 36 Mm^3 of charcoal of which 18.6 Mm^3 was for pig-iron production. Before 1975, virtually all the charcoal was supplied from native forests with increasingly detrimental effects to the environment, mainly resulting from the destruction of natural forests. This essentially free energy source allowed Brazilian pig iron to become highly competitive in the world markets; it was finally recognised, however, that the continued exploitation of natural forests at such a rate was unsustainable. In an effort to establish sustainable wood production for the charcoal and pulp + paper industries the Government introduced tax incentives for the commercial growth of plantations in its 1965 Forestry Act.

The consequences of this Act have been far reaching as it stipulated target percentages of total production (not quantities) which had to be reached within specified time periods (table 7). Presently all pulp and paper and 34% of charcoal production is plantation-derived, the wood being provided from an estimated 4 to 6 Mha of plantations, mostly *Eucalyptus*. By 1995, the plantation-derived charcoal percentage is required to rise to 100% according to Brazilian regulations; however, the effective total will only be around 80% due to a stipulated allowance for charcoal production from forest residues (see table 7).

Estimates of present plantation areas are complicated by the abandonment of young plantations which had been registered under the Act, or the death of parts of plantations (hence also resulting in lower than predicted productivities.) It is now believed that between 4 and 6 Mha of commercial plantations are in operation, with an increase of between 0.2 and 0.45 Mha/yr since 1970. {deJesus, 1990; Rosillo-Calle, 1992}.

Pandey {1992} has estimated a net area of plantations in Brazil (1990) of 6.1 Mha. This is dependant on the success rate for the establishment of plantations having been maintained at the 87% success level ascertained from the 1981-82 inventory of plantations. {Pandey, 1992} It may be reasonable to expect this success rate to have increased as the results of continuing R&D are incorporated into plantation management techniques, and hence net plantation areas may actually be higher than suggested.

Charcoal production. The efficiency with which wood is converted to charcoal has also benefited from the Brazilian regulations since the large iron and steel producing companies have been forced to obtain reliable supplies of plantation charcoal. This has inevitably led to many of them investing in the development of large plantation and charcoal production facilities. Such competition has resulted in the need for increased yields, efficiency and benefits from economies of scale. Most charcoal is still produced using internally heated beehive kilns (mud or brick, taking 9-50 m^3 wood), the technology of which is up to 100 years old and is often inefficient. (Ch.4, carbonisation) There is considerable room for improvement in efficiency, perhaps to over 30% of the weight of the original wood being converted to charcoal, so also reducing costs. Present conversion efficiencies are often below 20% by weight.

Larger kiln sizes can allow partial mechanisation of the charcoal making process by using forklift trucks to load and unload the kilns allowing faster overall production cycle times. For example, the 300 m^3 kilns now used by CAF in Bahia state can be loaded, carbonized and unloaded in 7 days, resulting in significant savings in labour and more socially acceptable weekly work patterns. The carbonisation process is also much more closely controlled increasing the efficiency of conversion. Many of the larger kilns also allow tar and oil recuperation which is sold as low-grade fueloil; this practice also results in less environmental damage from the leakage of these oils into surrounding soils.

Costs of wood production for charcoal are highly dependant on the original cost of the land, soil type, yield and relief. Harvesting costs can increase by up to 75% depending on the steepness of the land. The four main cost components in charcoal production ie. wood yields, harvest, carbonisation and transport, usually result in production costs above 1992 US$ 25 per m^3 charcoal (about US$ 3.5 /GJ). Transport costs are generally above US$ 0.0125 per m^3.km, and thus for average transport distances of about 300 km, total minimum delivered charcoal costs about 1992 US$ 4/GJ. In general, costs for industrially produced and delivered charcoal are in the range US$ 3.8 to 4.4 per GJ (US$ 27 to 31 per m^3). {Rosillo-Calle *et al.*, 1992}

Somalia.

Whilst the present political instability of this country makes continued monitoring impossible, detailed data obtained previously highlights many important aspects of industrial charcoal production in a poor developing country. It is thus included here.

In many countries, the demand for energy in the cities is having adverse effects on the livelihoods of the rural inhabitants who reside near the source of biomass to be exploited as a fuel. In Somalia, for example, the capital city Mogadishu consumed about 42,000 t fuelwood in 1983 or about 0.5 t/capita. Mogadishu's fuelwood production for domestic consumption was estimated to be about 17,000 t's, institutional (hospitals, schools, prisons, military) and for the industrial sector (eg. lime production) more than 29,000 t's. In contrast to Brazil where most of charcoal production is industrial, 95% of Somalian charcoal produced was consumed for cooking, and was mainly derived from small scale artisanal production, generally of low efficiency. Households in Mogadishu spent on average about 10% of all household expenditure on fuel, one third of which was for charcoal.

The concentrated urban purchasing power in Somalia and elsewhere (large centralised market) made it economically possible to transport fuels over long distances, and therefore spread the influence of the cities and towns further into the rural sector. Thus, the biomass supply resources were exhausted at ever increasing distances from the urban centres. The size of the market in Mogadishu resulted in its ability to absorb rising prices allowing low efficiencies in conversion of fuelwood to charcoal (often less than 15% by weight); the resulting high costs could be paid for through the gains in energy density of charcoal thereby facilitating longer transport distances compared to wood. Charcoal contains twice as much energy per tonne as wood, and is more convenient to package, hence over distances greater than 100 km the energy lost through conversion to charcoal is compensated for by its lower transportation costs per GJ. {Robinson, 1989). These factors expand the radius to which forests and woodlands can be exploited for urban energy provision. This analysis holds true in many other countries where natural vegetation can be regarded as a free feedstock for charcoal production.

In addition, whilst the exploitation of woodlands around Mogadishu was supposed to be carefully controlled (only trees above 15 cm dbh of certain species should be cut) monitoring was superficial, if it existed at all; the wood was therefore regarded as virtually "free". However, the rural populations nearby the woodland source (of the charcoal) noticed that when the selection criteria for suitable trees to be cut was not being followed, resupply was not ensured and degradation inevitably followed. Improper harvesting practices render such land areas prone to severe degradation as a result of loss of vegetative cover leading to soil erosion. Since the costs of restoring the land to its former productivities (if possible) are not met by the charcoal producers, they can simply afford to move to new sources of wood.

Thus, whilst regulations are an important tool in the control of such industries, they can be rendered meaningless without proper monitoring and institutional backup. (section 6, policies)

Ethanol.

The need for an economically competitive, indigenous and sustainable supply of liquid fuel for transportation has resulted in a number of biomass to ethanol projects in developing countries. Most of these projects have been based on sugarcane as the source of biomass. Sugarcane is the world's most photosynthetically efficient agronomic crop, utilising about 2-3% of the energy in the incident radiation for biomass production. Sugarcane is also associated with high levels of by-product formation eg. bagasse, molasses, stillage. Much of the by-product is either suitable for processing into higher value products (such as animal feed) or for use as energy (thermal, electricity).

This multi-product potential, including the ability to upgrade previously unwanted waste products into useful commodities such as electricity and animal feed, has resulted in renewed interest from international development funding organisations. For example, the Global Environment Facility is now funding two major projects involving the utilisation and optimisation of sugarcane for energy. It is presently providing funds for a Brazilian project (1992 US$ 30 million) for the production of electricity from both sugarcane and wood residues, and a Mauritian project (1992, US$3.3 million) to optimise the use of bagasse for electricity production (see Electricity section).

The potential of cane to produce products tailored to a changing market has been explored by Smith {1992}. Based on recent Puerto Rican data he suggests that the concept of a cane mill which produces ethanol, sugar, animal feed, fibre and recycles refuse would be economically viable. Such a plant would be theoretically able to provide an internal rate of return of 8.7% and a simple payback of less 7½ years, based on a plant life of 30 years in Puerto Rico. Instead of using bagasse residues solely for the production of steam, the majority of the energy required is derived from processed MSW. MSW disposers pay a significant tipping fee; once sorted, however, it could provide revenue from sales of scrap and energy from the combustible fraction. Whilst only 26% of sales are projected to be derived from ethanol, sensitivity analysis suggests that the wide range of products produced (ethanol, feed, fibre and scrap) make this type of plant relatively immune to inflation. {Smith, 1992}

Brazil.

Brazil has been producing ethanol for use as a fuel since 1903. However, after the introduction of government incentives under the 1975 "Proalcool" programme, ethanol has become a significant energy source (4% of total energy consumption). Ethanol is produced as a petrol substitute for the transport sector where it accounted for 18% of fuel consumption by 1987, with annual production now reaching 12 billion litres. It is sold as either a 22% ethanol (0.4% moisture):gasoline blend (Gasohol) for use in unmodified internal combustion engines, or as neat hydrated ethanol (4.5% moisture) for dedicated ethanol cars and light vans. In 1989, there were 4.2 million cars running on neat ethanol and about 5 million on gasohol. This programme has been successful at reducing Brazil's foreign exchange burden from imported liquid fuels. The share of the total energy market occupied by gasoline has dropped from 12% in 1973 to 4% in 1987 and is now equalled by ethanol (substituting for about 250,000 bbl oil/day). Total savings in oil imports between 1976 and 1987 are estimated at $12.48 billion whilst the total investment in the programme was only $6.97 billion. Presently ethanol costs about 18.5 US c/l with a high value of 23 c/l and low of 17 c/l (approx US $ 7.9 per GJ). At these prices ethanol (as gasohol) would compete economically with crude oil priced at US$ 24/bbl (1992 US$). {Goldemberg *et al.*, 1992}

Despite such an apparent lack of economic competitiveness, continued gains in productivity and efficiency have meant that subsidies and price controls are now regarded as detrimental to the viability of the private ethanol production companies and car manufacturers {Goldemberg, 1992}. Furthermore, straightforward economic analysis fails to account for the secondary benefits arising from this programme, such as indigenous employment, wealth generation and reduced atmospheric pollution in the cities.

Zimbabwe.

The Zimbabwean Triangle Programme was commissioned in 1980. Construction was carried out entirely in Zimbabwe using indigenous materials wherever possible. The final cost of 1980 US$6.4 million, made it one of the cheapest plants of its capacity to be constructed. However, this cost effectiveness was not at the expense of reliability, as it has run with few problems for over a decade. It has a maximum ethanol production capacity of 40 million litres per year with a target blend of 13% (ethanol:gasoline). Whilst originally having been conceived with strategic goals in mind, its performance in foreign exchange savings have been significant and is presently estimated to be reducing foreign exchange spending by over Z$4 million per year {Chadzingwa, 1987}. Furthermore, the alcohol presently costs little more than imported petrol to produce. {Scurlock *et al*., 1991}

Heat.

The provision of heat in temperate countries is a major source of domestic energy consumption, and often occurs when power production is most expensive ie. at night. Even the most efficient thermal power stations produce large amounts of low quality heat which is no longer useful for power generation. The use of this "low quality" heat, which is still of sufficient temperature to supply domestic heating systems, can significantly increase the overall efficiencies of thermal generating systems. In some countries, the development of district-heating supply infrastructure has allowed this "waste" heat to be sold as a commodity to the domestic market providing heat in winter. (see below)

Austria.

During the 1980's Austria increased the share of primary energy consumption provided by biomass from about 2 or 3% to about 10%. This rapid increase in biomass energy use is predominantly due to the successful promotion of District Heating plants powered by wood chips. The prime political motivation for this scheme continues to be concern about security of energy supplies, the environment and a wish to support the rural economy. It has been greatly facilitated by the decentralised form of government which exits in Austria, and the availability of large quantities of relatively cheap wood residues from forest industries.

The size of the present forest industry is mainly a function of the large areas of natural forests remaining in Austria. Presently, approximately 30% of its land area is forest covered, with individual states such as Steiermark, having an excess of 50%.

There are now over 80 to 90 district heating systems of 1 to 2 MW average capacity (compromising a total of 11,000 installations), producing 100 PJ (1,200 MW total capacity) which represents about 10% of total energy consumption in 1991. This is expected to increase to 25% of total primary energy consumption by the turn of the century. {Howes R., 1992}

The success of this scheme has required both supply and demand side incentives and regulations. Unlike the UK, for example, there are unlikely to be dedicated wood energy plantations in Austria in the near future because of the abundance of existing forestry residues. In particular the banning of practices such as landfill disposal of bark residues by sawmills now means that bark is being sold at 50 to 80 schillings per m^3 (approx. 1991 US$ 19-30/t). Sawdust and offcuts are sold at US$ 28 to $ 38/t. Commercial timber is sold at above US$ 40/t.

Supply-side incentives are available through the provision of grants for capital equipment. The Federal government provides 10% of the capital costs and the State government a further 3.3%. In addition, the Department of Agriculture provides an extra capital grant of 40% of the final cost if a scheme is set up by a farmer's group. Thus, incentives may be as high as 50% of total capital costs.

On the demand side the government will pay 30% of the heat exchanger costs. Further state grants may be available based on the connection fee (additional to the cost of the heat exchanger), charged in proportion to the heating capacity required by each house. In general this grant is sufficient to cover the connection fee for the average house (peak demand of 15 KW).

High capital costs for installed equipment (especially pipes) have rendered these schemes relatively insensitive to fuel price, with success a function of overall intensity of use (defined as kWh per km of pipe) and reliability of supply. Subsidies have in effect only reduced payback times from 14 or 15 years to 10 or 11 years. Thus, income received from domestic users covers all the running costs and a slight surplus; hence the long payback times.

The cost of the heat varies, but is in general similar to fossil-fuel (including electrical) heating. It is worth emphasising, however, that in regions where the cost of wood-fired district heating is greater than its alternatives, surveys indicate that people are willing to pay slightly more because they perceive that this money is returned to the local community. It may therefore indirectly benefit the consumer through increasing local wealth and economic activity. {Howes. 1992}

Combined Heat and Power (CHP).

Cost of connection is between Schillings 40,000 to 60,000, and thus a 30% grant is equivalent to 1991 US$ 1,100 to 1,700. [Exchange rates are assumed to 20 schillings = 1991 US$ 1.9]

Presently thermal conversion efficiencies of well run modern power stations are between 20-35% fuel to electricity. The maximum efficiencies of thermal conversion facilities (the "Carnot Limit", see chp 4) means that it is physically impossible for thermal technologies to raise their power generating efficiencies above 60%. Thus, many countries are now concentrating on methods of using the low-grade "waste heat" which cannot be turned into a higher value energy carrier. This heat may be ideally suited for space heating or even for the various heat requirements of an associated factory.

While the concept is certainly not new, the technologies being applied and developed are innovative. Both Sweden and Denmark now run significant programmes for the use of biomass powered CHP. (box 2 Sweden)

In 1991, biomass provided 25% of the fuel consumed in District Heat and CHP programmes. In total, biomass (including peat, 1%) provided approximately 15% of Sweden's primary energy consumption. {NUTEK, 1992} The CHP programme now provides 142 PJ (39.7 TWh) of energy, of which 93% is consumed as district heat and the rest for electricity.

There is now a considerable infrastructure in place, with over 8,000 km of pipes for heat distribution, and 2.4 GW of installed CHP capacity. Having curtailed the nuclear option for environmental and economic reasons, Sweden is pursuing methods to increase its energy production from renewable sources. In particular, it continues to invest large quantities of time and money in woodchip technologies both for present thermal technology, mainly for district heat supplies, and also gasification for CHP production from wood powered gas turbines.

Denmark (Biogas).

Denmark has a long standing tradition for the use of renewable forms of energy. It is presently best known for its widespread use of wind-generated electricity for supply to the grid. However, since the early 1970's it has also provided incentives for the use of cereal straw for heat and the digestion of animal manure to produce biogas.

The anaerobic digestion of animal manure for the production of biogas has many potential advantages. These range from the safe disposal of manure (presently a costly procedure for farmers due to stringent environmental regulations regarding its disposal) and to the production of electricity and heat.

However, during the 1970's all the digesters were of a technically simple design and based on single farms. This led to problems of maintaining stable conditions in the digester due to their relatively small capacity and low cost. Forty of such small scale digesters have been built but about 30 of them have since been abandoned. Nevertheless, animal manure still represents a significant problem and large potential energy resource.

The first large-scale biogas plant, Vester Hjermitslev, was constructed by the beginning of 1984 and nine more have since been built. It has a digester capacity of 1,500 m^3 (approx. 50 t manure per day) designed to produce 3,500 m^3/day biogas; it also included a wind turbine for electricity production. The plant was commissioned and run by a private company consisting entirely of members of the local village, who put up over 2/3 of the construction cost (DKK 12.4 M; 1992 US$ 2 million). The Danish government provided DKK 4 M. It was built as part of the North Jutland County Council's "village energy project," designed to bring a measure of energy self-sufficiency to its villages by providing electricity and heat.

The plant encountered a series of technical problems which never allowed it to meet its specifications, eventually resulting in its reconstruction in 1989. The costs of the years of development have resulted in the plant's debts becoming unserviceable, but the county council has arranged a moratorium. During the reconstruction extra pre-storage was added to enable the plant to use fish processing sludge. Since reconstruction the plant has increased its gas production substantially and an extra gas-powered generator has been added.

There are now nine more large-scale biogas plants running in Denmark with the latest plants have capitalising on the lessons from the previous plants. "Lemvig," the most recent plant to become operational (May 1992) was constructed in only 8 months. It was commissioned by a farmers co-operative who supply the manure; the plant manufacturers entered into a novel service agreement which makes them responsible for the operation and maintenance of the plant for five years. This contract also guarantees the co-operative a minimum budgeted profit. The total construction cost was DKK 40 M (1992 US$ 6.5 million) of which the government provided DKK 9.5 M ($ 1.5 million). There have been no serious problems in operation since its start-up.

Lemvig is the largest plant built to date (7,600 m^3) and is based on the continuous one-step design from a previous plant. It is a thermophilic (55^{o}C) plant, which uses a highly automated wood chip heating process to maintain the temperature of the digester. The biogas is supplied to CHP gas-engines in the nearby town via a 4.5 km low pressure pipeline, developed for land-fill gas systems.

In 1986, the Danish government recognised the potential for centralised biogas production and set up an Action Programme whose task it was to review the potential feasibility of the biogas programme. In June 1991, the Action Programme stated that "it would be possible to establish profitable centralised biogas plants without subsidies from the public purse." It did, however, qualify this remark by stating that economic feasibility would continue to depend on the present governments policy of not taxing biogas, which represents an indirect subsidy.

In 1991, only one plant realised enough income to break-even, whilst five have budgeted sufficient income to break even in 1992. (table 17) In the Action Programme's report the conditions necessary for profitability are stated as: 1) 10 to 25% of easily convertible organic material is added to the manure delivered (the main source is from source-sorted household waste and sewage sludge), 2)there must be a steady/reliable market, and the biogas must not be taxed, and 3)good management is necessary to keep down running costs and maintain high gas production levels.

The Danish government has continued its commitment to the biogas programme through the commissioning of the "follow-up programme," under which six or seven new large-scale plants will be established. It bases its renewed commitment to several factors:

1992 exchange rate of DKK 6.12 to US$1.

(a) The potential improvements in economic status through continued development, many of which are already being demonstrated.

(b) Presently only 2% (0.5 PJ) of the potential biogas production is being utilised (25-30 PJ).

(c) The need for farmers to dispose of their waste products in an environmentally acceptable way.

(d)Possible environmental benefits include: displaced CO_2 production from fossil fuel use, thus decreased net CO_2 emissions, and decreased methane emissions as this is now burnt in the collected biogas. Also, correctly timed applications of the digested sludge on farmers land, which take advantage of the increased availability of nitrogen in digested manure and increased nutrients from the household waste, results in reduced need for artificial fertilisers. A saving of both economic and energy inputs.

(e) The potential to distribute biogas through the existing natural gas pipeline network, possibly as a mixture (natural gas and biogas), resulting in considerable savings in transport costs, and siting problems with the digesters.

(f) Helps to dispose of household waste.

(g) Stimulus to the rural economy.

Electricity.

United States of America.

In 1987, the Public Utility Regulatory Policy Act (PURPA) was introduced requiring US Electricity Utilities to purchase electricity from other suppliers at the cost they "avoided." The "avoided cost" sets the price the utilities are obliged to buy electricity from independent suppliers. It is calculated as the marginal cost of electricity production from a new conventional power station, ie. equivalent to the cost (c/kWh) of producing electricity from new coal, gas or oil power stations. PURPA thus forced these utilities to procure electricity from suppliers who have alternative cheaper fuel supplies. The utilities were obliged to buy this electricity regardless of internal economic considerations ie. even if the most economic way of providing base-load and peak demand was through the use of electricity supplies from other sources, including their own power stations. {Turnbull, 1993} PURPA resulted in an explosion of co-generators who use waste materials and by-products as a cheap source of heat. These by-products are obtained from associated processing plants eg. saw mills, abattoirs, food processors and paper manufacturers, which then gain an income from a product which they may previously have had to pay to have removed. The scale of electricity production is generally small scale ie <50 MW. The guaranteed price at which the co-generators can sell electricity has made long term economic planning possible, thus making it easier to procure loans and calculate profits.

This Act is largely responsible for the present extent of electricity production from renewable sources; over 9 GW of installed capacity presently exists. In California, it has stimulated the growth of a market in biomass residues providing employment and clean energy. It is now being recognised that the use of these residues can help to reduce the level of US CO_2 emissions.

Concern over the present levels of US CO_2 emissions have resulted in a number of studies being published detailing possible mitigation strategies. {Trexler, 1991; CAST, 1992; Ranney, 1992a; Wright *et al.*, 1992} These studies have highlighted the potential for renewables in providing low cost (or even negative cost) options for the reduction in net CO_2 emissions. One study from the US Environmental Protection Agency suggests that the "US will probably come close to stabilising its CO_2 emissions at 1990 levels by the year 2000." This, it is hoped, will mainly occur through increases in energy efficiency, the promotion of which utilities now find more cost effective than the construction of new plants. {Global Climate Change Digest, 1992} The prospects for increasing the production of energy from dedicated renewable sources, in combination with increased efficiency of production and use, seem auspicious both in the USA and elsewhere (see below).

In the US, Hall *et al* {1990} estimated that advanced wood gasifier-based electricity production could be economically competitive with advanced coal gasifier-powered electricity plants. Much of the wood could theoretically be supplied from Short Rotation Woody Coppice (SRWC) on the 139 Mha of economically marginal and environmentally sensitive crop, pasture and under-stocked forest lands held by private owners other than the forest industry. Furthermore, this would have the effect of offsetting up to 56% of present US CO_2 emissions at negative cost. When compared with estimates for carbon sequestration, costing between US$20 and 40/tC by US forest plantations, or flue-gas CO_2 removal from coal-fired steam electricity plants (estimated for the Netherlands) of about US$120/tC, biomass substitution options look highly competitive. It should be noted that biomass feedstock costs are strongly correlated with growth rates (estimated by Moulton and Richards {1990} in the US to be 2.7 tC/ha/yr above ground productivity or 5.3 tC/ha/yr if roots and soil carbon production is included); if the productivity is halved then biomass feedstock costs are roughly doubled.

Brazil.

Historically, Brazil has relied on the development of large-scale hydro-electric projects to supply its increasing demand for energy. Electricity demand has grown at about 5% per year throughout the 1980's. In 1990, hydro electricity supplied about 96% of total electricity use (226,377 GWh). It thus satisfied the stated governmental aim of avoiding excessive reliance on imported fossil fuels. However, the most favourable sites have now been used. Further expansion of the hydro capacity seems limited due to increasing social and environmental costs and also physical and economic factors. For example, installation costs have ranged between 1988 US$ 100 and 2,700 per kWh and electricity production costs 1988 0.3 to 3.3 USc/kWh. Future costs are likely to be higher, ranging from US$ 1,000 to 3,200 per kW for installation, and from 1.8 to 7.8 c/kWh for production costs. {Carpentieri *et al.*, 1992}

There are also problems with the sheer size of the capital costs of such large scale dams. For example, the Itaipu dam was budgeted at $3.5 billion in 1975, but at final completion it is expected to cost US$ 21 billion, excluding interest payments. {Lenssen, 1992} Such problems have played a significant role in Brazil's continuing struggle with size of its foreign debt and the associated problems.

When compared to the likely costs of future hydro-electric schemes, the relatively low production costs and the smaller incremental nature of the installation costs, future biomass energy projects seem highly competitive and desirable. (see below)

Wood-based electricity. Under the conditions in Northeast Brazil, total life-cycle costs for fuelwood plantations are estimated to rise particularly sharply at productivities of less than 8 odt ha^{-1} yr^{-1} (17 m^3/ha). The average weighted cost (weighted by BCR distribution) is US$1.36±0.20 GJ^{-1} and falls to US$1.09±0.12 GJ^{-1} for the highest productivity zone, BCR I. The cost rises to $3.71 ± 0.89 GJ^{-1} for the worst zone, BCR V (fig. 5). At these costs, plantation-derived electricity could be extremely competitive with oil at present world traded prices.

The costs which are related to a given amount of energy generated can be shown graphically in the form of "supply curves." Such supply curves show the quantity of wood which can be produced up to a given cost and are valuable in providing data for a realistic economic comparison with alternative fuel sources (fig. 5b). For example, the Carpentieri *et al.* {1992} analysis predicts that over 86% of the potential wood production would be produced at an average cost of less than $1.35 per GJ, less than half the cost of oil.

The total potential energy production of this scheme, if all the available land were to be planted and expected productivities achieved, is 12.6 EJ yr^{-1}. Thus, there is considerable potential to meet future energy demand when compared to Brazil's total 1990 energy consumption of about 8.1 EJ {AEB91, 1992). Clearly a very large potential for such a biomass-based industry exists. Even if only a small portion of the total were to be realised, large amounts of energy could be produced.

One of the main advantages of modern conversion facilities are the relatively small scales at which electricity production would be possible. The biomass can therefore be converted to electricity obviating the need for excessive biomass transport costs. 30 MW is envisaged as the largest practical size of a power generating unit which can be economically supplied by plantations (due to restrictive transport costs at greater distances). Approximately 12,000 ha of plantation would

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In assessing the potential land areas available for forestry, Carpentieri has analyzed the Northeast region in detail, breaking it down into Bioclimatic regions (BCR's), using soil and rainfall, annual average temperature, water deficit and altitude parameters. Being sensitive to possible land-use conflicts, only land which is not at present being utilised for settlements and which is unsuitable for agriculture has been targeted. This land has been divided into five Bioclimatic regions (analogous to the FAO's Agroecological zones), each of which is estimated to be capable of supporting average productivities of 44, 33, 28, 15 and 6 m^3 ha^{-1} yr^{-1} for BCR's I through to V, respectively. The parameter most closely correlating to productivity was rainfall, and this was used as the dominant BCR allocation criterion.

The weighted average productivity for the NE was 26.6 m^3/ha/yr. All costs are calculated using a 10% discount rate, wood transported 85 km at 0.39 c/GJ/km and a plantation life time of 30 years.

Most of the cost variation is due to differences in potential land costs.

The price of crude oil is presently (Nov. 1992) about US$ 3.5/GJ @ $20/barrel and 42 GJ/t (LHV).

be required for each 30 MW unit. For economic reasons, these units will only be commissioned as demand requires, minimising capital costs (cf. large-scale hydroelectric plants.) Importantly, this modular approach also provides the chance to rectify technical problems before large capital investments have been made. Plantation biomass-to-electricity programmes would therefore allow energy planners to follow the electricity demand curve more closely, thus reducing costs resulting from periodic over supply- periods of oversupply are inevitable after the commissioning of each large-scale hydro plant.

Another benefit resulting from the requirement for large numbers of generating units is an increase in supply reliability. Increased reliability is due to the relative size differential between the production capacity of one plant and total production; thus the lack of one or two plants due to failure, will have relatively little effect on total production.

Sugarcane Electricity. The global energy content of potentially harvestable sugarcane residues is calculated to be 7.7 EJ {Williams & Larson*,* 1992}. Production of cash crops can be highly intensive in many developing countries, resulting in the production of significant amounts of residues. The energy content of these residues can equal or even exceed commercial energy consumption eg Mauritius, Belize. Residues therefore represent a large potential energy resource. (table 9)

The energy potential of sugarcane residues was also considered by Carpentieri *et al.* (1993) for the Northeast region of Brazil since the sugarcane residue resource is already available and essentially free. There are, however, sometimes opportunity costs associated with the bagasse resource since a part of it may already used as animal feed, paper making and fertiliser. Where conflict of use may exist, the relative benefits of the different types of use must be assessed.

In comparison with the potential for tree plantation biomass the size of the bagasse resource is relatively small. However, when compared to the present energy consumption of the Northeast Brazil (1.1 EJ), the bagasse resource could still provide an estimated 174 PJ yr^{-1} (16% of present energy consumption). The main importance of the sugarcane residues is their availability for collection and electricity production.

Energy production from bagasse is well characterised since the quantity, energy content and moisture content of bagasse produced per tonne of crushed cane varies little from site to site {Alexander, 1985}. Thus gains in the amount of useful energy produced from bagasse is likely to come from increases in conversion efficiency and biomass productivity. More recently, more attention has been given to the energy potential of the tops and leaves, the so called "barbojo." The efficient of use of this barbojo may be able to significantly increase energy production from cane. {Hall *et al.*, 1992; Carpentieri *et al.*, 1992; Williams and Larson, 1992; Howe and Sreesangkom, 1990; Tugwell *et al.,* 1988.}

Economic analysis shows that the conversion of sugarcane residues into electricity can be very competitive with alternative fuel sources. When factors such as transport, storage, drying and processing are accounted for residue-based electricity remains competitive. (table 11) The cost of using stored tops and leaves as an energy feedstock varies from 0.95-2.21 \$/GJ, whilst bagasse is in the range 0.28-1.68 \$/GJ. The variation between the costs for bagasse and barbojo arises because the barbojo is assumed to be collected and transported to the mills off-season, whilst the bagasse is a by-product of the sugar production. The bagasse is thus effectively transported free when the fresh cane stems are brought to the mills during harvest, whilst the barbojo requires separate collection and transport costs. The potential competitiveness of this indigenous source of fuel can be seen when compared to the fossil-fuel alternatives, ie. fuel oil, 1985 US$2.45-7.50 per GJ and coal, (imported and indigenous) US$ 1985 1.43-4.22 per GJ.

A similar study for Jamaica concluded that potential (present value) savings of US$ 270 M could be achieved if sugarcane residue-fired BIG/STIG were to replace state-of-the-art coal-fired CEST technology. Furthermore, if existing oil-fired plants were replaced, savings of up to US$ 300 million per annum might be feasible. {Tugwell, 1988}

India.

The perceived developmental advantages of widespread access to electricity have been translated from public demand into the political imperative that every village and farm in India should be connected to the national grid. To a large extent this has been achieved with over 80% of the 550,000 villages now grid connected. However, connection has required the construction of many thousands of km's of transmission lines at a cost of US$ 800 to 1,200 km^{-1} {Ravindranath, 1993}. Furthermore, during the 1980's, oil imports cost India US$ 36.8 billion, the equivalent to one third of all foreign exchange earnings, or 87% of its new debt. When the capital cost of the imported electricity generation equipment was included in this analysis, the total expense for energy amounted to more than 80% of foreign exchange earnings between 1980 and 1986. {Lenssen, 1992}

In addition, many of the villages connected to the grid only require small amounts of power and can also be distant from the power station. This combination of low loads and long transmission distances has led to a number of problems: i)high transmission & distribution losses, with a national average of about 22.4%, ii)low and fluctuating voltages (often below 180 V (estimated 20% of time) despite a nominal voltage of 220 V), iii) high operation & maintenance costs, iv)erratic supply and poor maintenance (power cuts are common), and v)the external costs of centralised power production including: CO_2, SO_2, particulate emissions, no provision of local employment or wealth generation. {Ravindranath, 1993}

The production of electricity in India is a significant contributor to Indian greenhouse gas emissions. Coal combustion accounts for 60% of total CO_2 emissions, with 70% of electricity production being coal-derived. Presently, the provision of electricity to villages consumes one quarter of total production. Electricity generation is responsible for a significant fraction of total Indian CO_2 emissions even at today's low levels of per capita electricity consumption (ie. 61 kWh/yr). {Ravindranath, 1993}

There are therefore several imperatives for the adoption of widespread decentralised systems for power generation. In addition to overcoming the above problems, such schemes should reduce the subsidies burden presently shouldered by the national government. {Reddy and Goldemberg, 1990} However, electricity production is expected to grow at 10% per year into the next decade. In fact, the constraint on growth is on the supply-side, with actual demand estimated to be much higher. {Grubb, 1990}

The adoption of decentralised power generation systems which use indigenous energy sources has been proposed as an environmentally, economically and socially beneficial model for the development of India's rural villages.{Ravindranath, 1993} Furthermore, all the lighting and power needs of India's rural villages could be met on only 16 Mha of land; a small area when compared to the estimated 100 Mha of degraded land potentially available for tree planting. Ravindranath (1993), has further estimated "that biomass conservation programmes such as biogas and improved cook stoves could provide more than 95 Mt of woody biomass. If gasified, this biomass could provide energy in excess of the total rural energy requirements." Thus, theoretically, no extra land would be needed.

The whole-hearted adoption of such small-scale systems (5 to 20 kW) by the villagers themselves will only be achieved if such systems can address their multiple needs at lower overall costs and more conveniently than present traditional methods. Such needs include the provision of water (primarily for drinking and then for irrigation), light (domestic and street) and shaft power for milling, with cooking considered a low priority.

According to Rajabapaiah *et al.*(1992) small scale decentralised systems in India could theoretically be both more cost effective than present centralised power production and less environmentally damaging. In fact, such systems could be beneficial to the environment in terms of decreases in the emissions of pollutants (including greenhouse gases) and in the rehabilitation of degraded lands if they were planted with energy forests.

The demonstration of three such schemes by the Centre for the Application of Science to Rural Areas (ASTRA), of the Indian Institute of Science in Bangalore, has shown the feasibility of such an approach. The projects are based in three villages in Karnataka state South India, namely, Pura, Ungra and Hosahalli villages.

The Pura village (population of 209) scheme was initially conceived as a biogas-for-cooking project requiring the collection and use of most of the villages cattle dung production. {Rajabapaiah *et al.*, 1992} Surplus gas would then be utilised for electricity production, mainly for lighting. However, problems with inadequate incentives for dung collection resulted is less gas production than planned. Initially insufficient gas was produced to cook all the villagers' meals and thus the villagers became disinterested in the project. Thereafter, the implementation of community-based management with a transparent decision making process altered the project's priorities. The provision of cooking gas was demoted in favour of the supply of clean water and, at the same time, fair returns for dung provision were allocated. The Pura village project now recuperates its operation and maintenance costs and is fully accepted and welcomed by the village as a whole.

This Pura village project demonstrates that local initiatives can be successful if they are adaptable and can take a longer term view over the provision of social and economic benefits.

Hosahalli, a nearby village, has demonstrated the feasibility of electricity production from the gasification of fuelwood for lighting, water-pumping, milling and for irrigation (future). Hosahalli is analyzed in more detail below.

Hosahalli: This is a small, non-electrified village of 42 households and a population of just over 200. As with Pura village, detailed discussions were undertaken between ASTRA and the villagers before the initiation of the scheme. The main aim of the project was to demonstrate the feasibility of small-scale energy plantations for the provision of sufficient wood to sustainably supply a 5 kW wood-gasifier. This wood-gas is then used in a diesel-engine as a substitute for diesel. The engine is connected to a 5 kW_e alternator which generates 3-phase (nominally 220 V) electricity to supply specified village energy services. The project funded the hardware, and initially aimed for the operation and maintenance of the system to be "self" funding. This is presently the case, and there are good prospects that developmental work, both hardware and social, will lead to full economic profitability and a reasonable payback period.

The project is being implemented in 5 phases:

I) growing 2 ha energy forest to provide a sustainable wood supply. The installation of the wood gasifier/diesel engine and generating system.
II) Electrification: the provision of lighting to all households (1x40 W fluorescent and 1x25 W incandescent bulbs) + 9 street lights.
III) Installation of a water pump and tanks for drinking water.
IV) Installation of a flour mill. (5 kW electrical).
V) Provision of water pumping for irrigation. (10 pumps x 3.7 kW_e/pump x 300 hr/yr/pump for flood irrigation).

The engine is modified to run on both diesel and wood-gas, however, starting requires the use of the diesel-only mode until the gasifier reaches operating temperature. Once the gasifier is operating the wood-gas produced completely displaces the need for diesel. An overall diesel displacement of 67% has been achieved when compared to the diesel saved if the engine were running on diesel alone. Presently a saving of 42 litres of diesel a month is being achieved. A diesel substitution level of over 85% is possible if the gasifier is run for longer periods which would have significant economic benefits.

Electricity for lighting has been supplied for 3 to 4 hours daily since September 1988, drinking water since September 1990 and the flour mill (2 hours daily) has been in operation since March 1992. This has been achieved with a reliability in the supply of power of 95%- a remarkable level of reliability when the consistently high voltage level provided is taken into account, in contrast to the erratic supply and fluctuating voltage of the central electricity grid. In addition to the provision of these services, two men have been employed full-time to cut and supply wood from the energy forest and to maintain the gasifier and engine; more recently a woman has volunteered to be trained in running the equipment.

A proper comparative economic analysis is made difficult because of the high level of subsidies given to centralised grid electricity. However, according to Ravindranath and Mukunda (1990), at the level of operation for lighting only (4 hr/day) the wood gasification system would only be economic, in terms of covering its running costs, if electricity is priced at Rs. 3.5 per kWh (14 USc/kWh). However, if the gasification system operates beyond 5 hr/day, the unit cost of energy becomes cheaper than the diesel-only system. For comparison, the current subsidised price of grid-based electricity is Rs. 0.65 (equivalent to about 3 USc/kWh). {Ravindranath, 1993}

An important aspect of this project is that the villagers are prepared to pay over twice as much for their electricity (approx. Rs. 1.3/kWh (5 USc)) because: i) the supply is reliable, ii)provision of ancillary benefits (clean drinking water, flour mill, etc.), iii)quality of supply (never below 180 V) and iv) emergence of self reliance (the formation of village management committee). This emergence of self reliance for the decentralised and small-scale provision of energy also plays an important role in the other two projects being implemented by ASTRA in Pura and Ungra.

At the present rate of diesel-substitution (42 l/month), the monetary savings are equivalent to Rs. 2,520/yr (US$ 101 /yr). This is the equivalent to a payback period of 9.5 years including the additional cost of the energy forest, gasification equipment and modification of the diesel engine. (table 15) However, the other benefits listed above, or the revenue from lighting paid by each household (Rs. 10/household/month) is not accounted for and would reduce the payback period. A general increase in energy demand in combination with a demand for more powerful lights is resulting in the gasifier being run for longer periods of time and therefore should result in decreasing running costs per kWh.

One concern voiced by the villagers was the amount of land which had to be devoted to the growth of wood for the gasifier. The eventual planting of 2 ha with 6 different species has resulted in an average annual yield of 6.9 dry t/ha/yr compared with a total use of only 10.2 t over the 32 month period (3.8 t/ha/yr). The productivity of this land is therefore considered more than sufficient to meet present and future demand. The excess wood can be used by the villagers or sold.

Estimates for India as a whole, show that the use of degraded land (or edges of fields) around many villages would not only provide more than sufficient area to supply present demand, but would also help to rehabilitate such land. In addition, the potential of this land to becoming a C-sink could be significant, whilst at the same time helping rural development. {Ravindranath, 1992} (see also Land Use section)

If such decentralised systems are to become widespread then the lessons learnt from these studies must be built into future policies aimed at their promotion. ASTRA emphasises that it is crucial to listen to and address the recommendations made by the users, and secondly, the continuing involvement of the community in the organisation and running of the plant is essential.

Similarly, in Hosahalli, community involvement was only secured when phase II was implemented and clean drinking water made available. Thus, both Pura and Hosahalli required a long-term commitment and flexible approach by ASTRA, which have given them the confidence to recommend that decentralised power production systems, based on the experiences from Pura and Hosahalli, be broadened to encompass a "cluster" of villages (of about 100 in total). This would allow the system to be realistically compared with grid electricity. The interconnection of the villages would allow increased reliability and profitability making decentralised power generation more desirable.

Mauritius.

Mauritius is a small island (1,865 km^2) off the East coast of Africa with a population of just over 1 million. About a quarter of the workforce is currently employed in the agricultural sector. Its primary export crop is sugar, and with the decreasing export value of sugar (and raw commodities in general) the government has been seeking ways to increase the overall value of its sugarcane crop. There is an emerging view of sugarcane as a multi-product crop, able to produce both food (sugar and animal feed) and energy (ethanol, biogas and electricity). Thus sugarcane is increasingly seen as an opportunity for development and not a hinderance.

Cane production in 1990 totalled over 5.5 Mt (fresh stems) but only one third (29%) of the potential excess energy from bagasse is presently being utilised. {Comarmond, 1992} However, whilst gross electricity production from bagasse increased from 27 GWh in 1980 to 71 GWh in 1991, total electricity production doubled from 355 GWh to 737 GWh in the same time period. Consequently, bagasse's share of electricity rose only slightly from 7.5% to 9.6%.

Prior to 1982, 16 of the 19 cane mills sold electricity during the milling season to the Central Electricity Board (CEB). All these mills used inefficient low pressure and temperature back pressure technology. {Comarmond, 1992}. In 1984, 14 of the sugar mills and 1 tea factory supplied 34 GWh of electricity to the grid. {Purmanund *et al.*, 1992} The main purpose of the technology used is to deliver process steam to power the mill and secondly, as a means of bagasse disposal. Even so, a total of 31 GWh of bagasse generated electricity was purchased by the CEB during 1981.

This inefficient technology is only capable of producing 300 kg of steam per tonne of cane (kg/tc), and thus the opportunities presented by newer technology (able to produce 550 to 600 kg/tc) were evident. The newer technologies do however, involved higher capital costs. In 1982, the Medine mill started operating a new 10 MW CEST system to exploit these potential benefits, and during the crushing season exported an additional 10 GW (2,770 kWh) to the CEB.

In 1985, the largest sugar factory in Mauritius, the Flacq United Estate Limited (FUEL) commissioned a modern steam boiler capable of burning both bagasse and coal, sufficient to deliver high temperature and pressure steam to power both the factory and a 24 MW CEST alternator. The dual-fuel ability of the FUEL boiler enables it to burn bagasse during the harvesting season and coal during the off-season. Total electricity production is approximately half (40 GWh) from bagasse and half (40 to 45 GWh) from coal.

All year round electricity production is obviously a more valuable commodity for the CEB than seasonal production. It results in the CEB needing less standby generating equipment to meet demand when seasonal production is not available. The CEB thus pays a premium for such electricity production; 100 c/KWh for permanent electricity production, 45 c/kWh for seasonal, and only 16 c/kWh for intermittent (wind, PV, tidal etc,). The tariffs paid by the CEB, are derived from the "avoided costs" that would be incurred if the demand were to be provided from CEB's own electricity generating plant ie. specifically the cost of electricity production from a 24 MW diesel powered generating plant. {GEF, 1992} In fact, current forecasts for growth in electricity demand have resulted in the commissioning of 106 MW of new fossil fuel generating capacity; in addition, two future 24 MW bagasse/coal plants have been ordered.

Funding for the two bagasse plants and the enhanced use of the sugar industries by-products is envisaged to cost about US$80 million over an eight year period. The funding will be allocated under the Bagasse Energy Development Programme (BEDP) which is a central part of the Mauritian Governments Sugar Energy Development Project (SEDP). Under the SEDP's US$55 million financing plan 48% of the funding (US$26.6 million) is from foreign sources, of which only US$3.3 million is provided by the Global Environment Facility (GEF). {GEF, 1992}

The GEF funding is specifically for technical and staff development (US$1.9 million) BEDP co-ordination and for environmental monitoring (US$1.4 million). In justifying this funding GEF states that "increased use of sugarcane biomass as energy in Mauritius will have significant environmental benefits." To this end it estimates that CO_2 emissions will be reduced, in terms of avoided fossil fuel emissions, from 75,000 t/yr to between 60,000 and 67,000 t/yr, and at the same time NO_x and SO_x emissions will be reduced from 4,000 t/yr to 1,000 t/yr.

The primary aim of the BEDP is to increase cane residue-derived electricity production from the present level of 70 GWh to about 120 GWh. This will exploit about 56% of the total potential from bagasse, but due to increased electricity demand bagasse is only expected to provide about 9% of total electricity production by the year 2000. {Comarmond, 1992}

However, if the full potential of sugarcane residues (bagasse and tops + leaves, and other crop residues) were to be exploited for electricity production, estimates of the potential resource for electricity production are much larger. A crude estimate of the theoretical total potential would be about 3,500 GWh (at 40% conversion efficiency, biomass to electricity) or 2,500 GWh at 30% efficiency. When compared with the CEB forecast of total electricity consumption of 1,678 GWh/yr {Comarmond, 1992} in the year 2000, bagasse and barbojo represent a significant energy resource.

Another independent estimate of the total theoretical energy potential from crop, forest and dung residues, based on 1984 data, is of 4,007.3 GWh (14.4 PJ).{Purmanund *et al.*, 1992} The energy value of cane tops & leaves (roughly equivalent to bagasse in weight) was not included in this study as it is presently either used as animal feed or left on the field to act as a mulch. However, the study did include the potential alcohol production from molasses (8% of the total energy derived from cane). If half the tops and leaves from the sugarcane were to be used, the total potential energy from residues would rise to about 5,833 GWh. Using the efficiencies assumed (see footnote 13) for conversion to electricity residue-based energy could produce approximately 1,400 GWh of electricity or virtually the total Mauritian electricity production forecast for the year 2000. {Comarmond, 1992}

Estimates of potential energy production from sugarcane residues, such as those cited above, do not attempt to estimate the likely effects of optimised strategies for both energy and food production. It is estimated that large potential gains in both sugar and fibre production could be achieved from sugar cane if breeding programmes concentrated on total biomass production and not simply increasing the sugar concentration in the stem. {Alexander, 1985} If likely increases in the efficiencies of conversion of biomass to useful energy (ie. electricity) are accounted for ie. the use of biomass gasification and gas turbine technologies (BIG/STIG) much larger potentials are estimated. For example, Williams and Larson (1992) estimate that by 2027, the electricity potential from cane in Mauritius could be 29 times (14,300 GWh) Mauritius's total 1987 electricity production (490 GWh). This figure is based on the assumption that cane production grows at 3.1% per year and

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If the Purmanund *et al.* {1992} estimate for conversion efficiencies is used, which assumes a boiler efficiency of 70% and a thermal conversion efficiency (heat to electricity) of 35%, then an electricity production potential of 982 GWh is estimated.

It is estimated that in Puerto Rico 30 to 50% of the tops and leaves should be left on the field. {GEF, 1992} that BIG/ISTIG technology is used with a conversion efficiency (biomass to electricity) of 38%. {Williams & Larson, 1992} It is interesting to note that the installed cost in 1989 US$/kW$_e$ for BIG/ISTIG is estimated to be between $ 870 and $ 1,380 which is lower than the present installed cost of CEST at US$ 1,520 per kW.

Employment Potential.

If rural communities are to prosper as a country develops then secure and financially beneficial rural employment must be a central theme. The history of agricultural development is often characterised by the reduction in man hours per tonne of produce harvested. The fall in manpower required in agriculture has accentuated, or is a direct cause of urban drift so exacerbating urban unemployment and related problems.

One trait of agriculture is the seasonality of the employment. In developing countries where the bulk of the harvest is often carried out manually this requirement for large numbers of temporary jobs during the harvesting season is regarded as socially damaging. Whilst the quality of the work may be poor it does at least provide some form of income where there might not otherwise be any. It should therefore not be the aim of any investment programme to destroy this important opportunity for income. Rather the aim should be to secure those jobs throughout the year in the most economically efficient way, possibly by providing alternative employment during the off-season.

The Carpentieri *et al.* (1992) study of biomass electricity in NE Brazil provided a detailed analysis of the manpower requirements for both the tree plantation and sugarcane biomass energy sectors. The sugarcane industry of the Northeast presently employs labour at the rate of 19.8 jobs per km^2 for on-season work and only 2.7 jobs per km^2 for off-season (permanent) employment. If in the future labour was to be employed to bale and collect the tops & leaves which would be done off-season (an essential activity if enough energy is to be produced from sugarcane residues), then the on-season requirement for jobs would hardly change at 19.6 jobs km^{-2} but the off-season requirement would rise to 23.7 jobs km^{-2} . At present only about 36,000 people are employed permanently by the sugarcane industry of the Northeast; however, if the industry became a combined sugar and energy production system the theoretical total number of permanent jobs is estimated to be more than 326,000. The seasonal requirement (harvesting period only) would fall from 272,600 to 55,800 people, with all the present seasonal jobs being absorbed into the extra permanent vacancies.

The tree plantation industry is much less labour intensive with an average requirement of 2.7 jobs km^{-2}. Approximately 12% of these jobs are needed for research and administration. In analysing the potential plantation requirements to supply the additional electricity demand for the period 2000-2015, 32,454 jobs would

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Biomass Integrated Gasifier/Intercooled Steam Injected Gas Turbine (BIG/ISTIG) technology is a derivative of BIG/STIG technology (section 4, Energy Conversion) and is used for the co-generation of process steam and electricity. BIG/ISTIG conversion efficiencies (biomass to electricity) are estimated at about 8% higher than BIG/STIG (30% efficient); however, commercialisation is expected to take longer.

be needed. This represents 9 % of the ultimate potential total if all the area identified as "free for forestry" in the Northeast were eventually to be planted for electricity production.

In the agro-ethanol industry, job quality is also comparable or higher to many of the main large-scale employers in Brazil. It is estimated that the ethanol industry in Brazil has generated 700,000 jobs with a relatively low seasonal component compared to other agricultural employment. Job security and wages are important for workers in this industry; they receive higher wages on average than 80% of the agricultural sector, 50% of the service sector and 40% of those in industry.{Goldemberg *et al.*, 1992}

One of the most important developmental comparisons is the investment cost per job created. For the biomass energy industries envisaged above, this lies between $15,000 and $100,000 per job, with costs in the ethanol agro-industry between $12,000 and $22,000. Such job creation costs compare with the average employment costs in industrial projects in the Northeast at $40,000 per job created, in the petro-chemical industry of about $800,000 per job, and for hydro power over $\$10^6$ per job. Lower job creation costs are one of the most significant benefits of biomass energy.{Carpentieri *et al.*, 1992; Goldemberg *et al.*, 1992}.

4. Bioenergy Conversion Technologies.

There are five fundamental forms of biomass energy use.

(1) the "traditional domestic" use in developing countries (fuelwood, charcoal and agricultural residues) for household cooking (eg. the "three stone fire"), lighting and space-heating. In this role the efficiency of conversion of the biomass to useful energy generally lies between 5% and 15%.

(2) the "traditional industrial" use of biomass for the processing of tobacco, tea, pig iron, bricks & tiles, etc, where the biomass feedstock is often regarded as a "free" energy source. There is generally little incentive to use the biomass efficiently so conversion of the feedstock to useful energy commonly occurs at an efficiency of 15% or less.

(3) "Modern industrial." Industries are experimenting with technologically advanced thermal conversion technologies which are itemised below. Expected conversion efficiencies are between 30 and 55%.

(4) newer "chemical conversion" technologies ("fuel cell") which are capable of by-passing the entropy-dictated Carnot limit which describes the maximum theoretical conversion efficiencies of thermal units.

(5) "biological conversion" techniques, including anaerobic digestion for biogas production and fermentation for alcohol.

In general, biomass-to-energy conversion technologies have to deal with a feedstock which can be highly variable in mass and energy density, size, moisture content, and intermittent supply. Therefore, modern industrial technologies are often hybrid fossil-fuel/biomass technologies which use the fossil fuel for drying, preheating and maintaining fuel supply when the biomass supply is interrupted.

Direct combustion processes.

Feedstocks used are often residues such as woodchips, sawdust, bark, hogfuel, black liquor, bagasse, straw, municipal solid waste (MSW), and wastes from the food industry.

Direct combustion furnaces can be divided into two broad categories and are used for producing either direct heat or steam. Dutch ovens, spreader-stoker and fuel cell furnaces employ two-stages. The first stage is for drying and possible partial gasification, and the second for complete combustion. More advanced versions of these systems use rotating or vibrating grates to facilitate ash removal, with some requiring water cooling.

The second group, include suspension and fluidised bed furnaces which are generally used with fine particle biomass feedstocks and liquids. In suspension furnaces the particles are burnt whilst being kept in suspension by the injection of turbulent preheated air which may already have the biomass particles mixed in it. In fluidised bed combustors, a boiling bed of pre-heated sand (at temperatures of 500 to 900^{o}C) provides the combustion medium, into which the biomass fuel is either dropped (if it is dense enough to sink into the boiling sand) or injected if particulate or fluid. These systems obviate the need for grates, but require methods of preheating the air or sand, and may require water cooled injection systems for less bulky biomass feedstocks and liquids. {WEC, 1992}

Co-firing.

A modern practice which has allowed biomass feedstocks an early and cheap entry point into the energy market is the practice of co-firing a fossil-fuel (usually coal) with a biomass feedstock. Co-firing has a number of advantages, especially where electricity production is an output. {

Firstly, where the conversion facility is situated near an agro-industrial or forestry product processing plant, large quantities of low cost biomass residues are available. These residues can represent a low cost fuel feedstock although there may be other opportunity costs.

Secondly, it is now widely accepted that fossil-fuel power plants are usually highly polluting in terms of sulphur, CO_2 and other GHGs. Using the existing equipment, perhaps with some modifications, and co-firing with biomass may represent a cost-effective means for meeting more stringent emissions targets. Biomass fuel's low sulphur and nitrogen (relative to coal) content and nearly zero net CO_2 emission levels allows biomass to offset the higher sulphur and carbon contents of the fossil fuel. {Demeter *et al.* 1993}

Thirdly, if an agro-industrial or forestry processing plant wishes to make more efficient use of the residues generated by co-producing electricity, but has a highly seasonal component to its operating schedule, co-firing with a fossil fuel may allow the economic generation of electricity all year round. Agro-industrial processors such as the sugarcane sugar industry can produce large amounts of electricity during the harvesting and processing season, however, during the off-season the plant will remain idle. This has two drawbacks, firstly, it is an inefficient use of equipment which has a limited life-time, and secondly, electrical distribution utilities will not pay the full premium for electrical supplies which can't be relied on for year round production. In other words the distribution utility needs to guarantee year round supply and may therefore, have to invest in its own production capacity to cover the off-season gap in supply with associated costs in equipment and fuel. If however, the agro-processor can guarantee electrical supply year-round through the burning of alternative fuel supplies (ie. coal and bagasse in Mauritius, see section 3) then it will make efficient use of its equipment and will receive premium payments for its electricity by the distribution facility.{GEF, 1992}

Thermochemical processes.

These processes do not necessarily produce useful energy directly, but under controlled temperature and oxygen conditions are used to convert the original biomass feedstock into more convenient forms of energy carriers, such as producer gas, oils or methanol. These carriers are either more energy dense and therefore reduce transport costs, or have more predictable and convenient combustion characteristics allowing them to be used in internal combustion engines and gas turbines.

Pyrolysis.

The biomass feedstock is subjected to high temperatures at low oxygen levels, thus inhibiting complete combustion, and may be carried out under pressure. Biomass is degraded to single carbon molecules (CH_4 and CO) and H_2 producing a gaseous mixture called "producer gas." Carbon dioxide may be produced as well, but under the pyrolytic conditions of the reactor it is reduced back to CO and H_2O;

this water further aids the reaction. Liquid phase products result from temperatures which are too low to crack all the long chain carbon molecules so resulting in the production of tars, oils, methanol, acetone, etc. Once all the volatiles have been driven off, the residual biomass is in the form of char which is virtually pure carbon.

Pyrolysis has received attention recently for the production of liquid fuels from cellulosic feedstocks by "fast" and "flash" pyrolysis in which the biomass has a short residence time in the reactor. A more detailed understanding of the physical and chemical properties governing the pyrolytic reactions has allowed the optimisation of reactor conditions necessary for these types of pyrolysis. Further work is now concentrating on the use of high pressure reactor conditions to produce hydrogen and on low pressure catalytic techniques (requiring zeolites) for alcohol production from the pyrolytic oil.

Carbonisation.

This is an age old pyrolytic process optimised for the production of charcoal. Traditional methods of charcoal production have centred on the use of earth mounds or covered pits into which the wood is piled. Control of the reaction conditions is often crude and relies heavily on experience. The conversion efficiency using these traditional techniques is believed to be very low; on a weight basis Openshaw estimates that the wood to charcoal conversion rate for such techniques ranges from 6 to 12 tonnes of wood per tonne of charcoal. {Openshaw, 1980}.

During carbonisation most of the volatile components of the wood are eliminated; this process is also called "dry wood distillation." Carbon accumulates mainly due to a reduction in the levels of hydrogen and oxygen in the wood.

The wood undergoes a number of physico-chemical changes as the temperature rises. Between 100 and 170^{o}C most of the water is evaporated; between 170^{o}C and 270^{o}C gases develop containing condensible vapours, CO and CO_2 . These condensible vapours (long chain carbon molecules) form pyrolysis oil, which can then be used for the production of chemicals or as a fuel after cooling and scrubbing. Between 270^{o}C and 280^{o}C an exothermic reaction develops which can be detected by the spontaneous generation of heat {Emrich, 1985}.

The modernisation of charcoal production has lead to large increases in production efficiencies with large-scale industrial production in Brazil now achieving efficiencies of over 30% (by weight).

There are three basic types of charcoal-making: a)internally heated (by controlled combustion of the raw material), b)externally heated (using fuelwood or fossil fuels), and c)hot circulating gas (retort or converter gas, used for the production of chemicals).

Internally heated charcoal kilns are the most common form of charcoal kiln. It is estimated that 10 to 20% of the wood (by weight) is sacrificed, a further 60% (by weight) is lost through the conversion to, and release of, gases to the atmosphere from these kilns. Externally heated reactors allow oxygen to be completely excluded, and thus provide better quality charcoal on a larger scale. They do, however, require the use of an external fuel source, which may be provided from the "producer gas" once pyrolysis is initiated.

Recirculating heated gas systems offer the potential to generate large quantities of charcoal and associated by-products, but are presently limited by high investment costs for large scale plant. {Emrich, 1985}

The main characteristics of a typical charcoal kiln in Brazil (internally heated) are shown in table 12.

Gasification.

High temperatures and a controlled environment leads to virtually all the raw material being converted to gas. This takes place in two stages. In the first stage, the biomass is partially combusted to form producer gas and charcoal. In the second stage, the CO_2 and H_2O produced in the first stage is chemically reduced by the charcoal, forming CO and H_2. The composition of the gas is 18 to 20% H_2 , an equal portion of CO, 2 to 3% CH_4 , 8 to 10% CO_2, and the rest nitrogen. {Makunda, 1992}. These stages are spatially separated in the gasifier, with gasifier design very much dependant on the feedstock characteristics.

Gasification requires temperatures of about 800^oC and is carried out in closed top or open top gasifiers. These gasifiers can be operated at atmospheric pressure or higher. The energy density of the gas is generally less than 5.6 MJ/m^3, which is low in comparison to natural gas at 38 MJ/m^3 {WEC, 1992}, providing only 60% the power rating of diesel when used in a modified diesel engine {Makunda, 1992}.

Gasification technology has existed since the turn of the century when coal was extensively gasified in the UK and elsewhere for use in power generation and in houses for cooking and lighting. Gasifiers were used extensively for transport in Europe during World War II due to shortages of oil, with a closed top design predominating.

A major future role is envisaged for electricity production from biomass plantations and agricultural residues using large scale gasifiers with direct coupling to gas turbines. The potential gains in efficiency using such hybrid gasifier/gas turbine systems make them extremely attractive for electricity generation once commercial viability has been demonstrated. Such systems take advantage of low grade and cheap feedstocks (residues and wood produced using short rotation techniques) and the high efficiencies of modern gas turbines to produce electricity at comparable or less cost than fossil-fuel derived electricity. Net atmospheric CO_2 emissions are avoided if growth of the biomass is managed to match consumption. The use of BIG/STIG (Biomass Integrated Gasifier STeam Injected Gas turbine) initially and BIG/GTCC (Biomass InteGrated Gasifier Gas Turbine Combined Cycle) as the technology matures, is predicted to allow energy conversion efficiencies of 40% to 55%. Modern coal electrical plants have efficiencies of about 35% or less. Combined Heat and Power systems could eventually provide energy at efficiencies of between 50% to 80%. The use of low-grade feedstocks combined with high conversion efficiencies makes these systems economically competitive with cheap coal-based plants and energetically competitive with natural gas-based plants. {Johansson et al., 1992; Williams and Larson, 1992} (see figs. 7 & 8).

Studies are continuing in the use of such technologies for the cost effective treatment of MSW eg. in the Netherlands a study by Faaij *et al.* {1992} considers that "gasification can become a strong competitor to anaerobic digestion, composting and incineration for biomass waste treatment." This is based on the use of BIG/STIG technology with the system gasification using Atmospheric Circulating Fluidized Bed (ACFB) technology. They expect the potential to be "realised within 4 to 7 years". {Faaij *et al.*, 1992}

Catalytic Liquefaction. This technology has the potential to produce higher quality products of greater energy density. These products should also require less processing to produce marketable products.

Catalytic liquefaction is a low temperature, high pressure thermochemical conversion process carried out in the liquid phase. It requires either a catalyst or a high hydrogen partial pressure. Technical problems have so far limited the opportunities of this technology.

Biochemical processes.

The use of micro-organisms for the production of ethanol is an ancient art. However, in more recent times such organisms have become regarded as biochemical "factories" for the treatment and conversion of most forms of human generated organic waste. Microbial engineering has encouraged the use of fermentation technologies (aerobic and anaerobic) for use in the production of energy (biogas) and fertiliser, and for the use in the removal of unwanted products from water and waste streams.

Anaerobic Fermentation.

Anaerobic reactors are generally used for the production of methane rich biogas from manure (human and animal) and crop residues. They utilise mixed methanogenic bacterial cultures which are characterised by defined optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide temperature range ie. above 0^oC up to 60^oC.

When functioning well, the bacteria convert about 90% of the feedstock energy content into biogas (containing about 55% methane), which is a readily useable energy source for cooking and lighting. The sludge produced after the manure has passed through the digester is non-toxic and odourless. Also, it has lost relatively little of its nitrogen or other nutrients during the digestion process thus, making a good fertiliser. In fact, compared to cattle manure left to dry in the field the digester sludge has a higher nitrogen content; many of the nitrogen compounds in fresh manure become volatised whilst drying in the sun. On the other hand, in the digested sludge little of the nitrogen is volatised, and some of the nitrogen is converted into urea. Urea is more readily accessible by plants than many of the nitrogen compounds found in dung, and thus the fertiliser value of the sludge may actually be higher than that of fresh dung.

Anaerobic digesters of various types were widely distributed throughout India and China. Extension programmes promote biogas plants as ideal candidates for rural village use due to their energy and fertiliser production potential along with their improved health benefits. Health benefits primarily arise from the cleaner combustion products of biogas as opposed to other biomass or fossil fuels which may be used in the domestic environment. (see section 5) These two countries now have an estimated 5 to 6 million units in use.

Reliability problems have arisen from a number of problems ie. construction defects, the mixed nature of the bacterial population, the digesters requirements for water and the maintenance of the optimum nitrogen ratio of the medium. Another problem is the digester's demand for dung, which may have alternative uses.

Modern designs have answered many of these problems and digesters are again becoming useful, especially with regard to the potential of digesters to remove toxic nutrients such as nitrates from water supplies; levels of which are now much more stringently controlled in many industrialised countries. The combination of energy production with the ability to enhance crop yields make biogas technology a good candidate for more widespread use now that reliable operation can be demonstrated. Recent Danish commercial experience with large scale digesters provides a useful example. (Section 3)

Methane Production in Landfills.

Anaerobic digestion in landfills is brought about by the microbial decomposition of the organic matter in refuse. The levels of organic matter produced per capita vary considerably from developed to developing countries eg. the percentage of Municipal Solid Waste (MSW) which is putrescible in Sierra Leone is about 90% {Steele, 1992}, compared to about 60% for US MSW. The reduced levels of putrescibles in US MSW are a result of the increased proportions of plastics, metals and glass, mostly from packaging {Slivka *et al.*, 1992}. Landfill-generated gas is on average half methane and half carbon dioxide with an energy content of 18 to 19 MJ/m^3. Its production does not occur under pressure, and thus recovery processes must be active.

Commercial production of land-gas can also aid with the leaching problems now increasingly associated with landfill sites. Local communities neighbouring land fill sites are becoming more aware of the potential for heavy metals and nutrients to leach into aquifers. Landfill processing reduces the volume of sludge to be disposed of, and the nutrient content, thus facilitating proper disposal.

Methane is a powerful greenhouse gas, with substantial amounts being derived from unutilized methane production from landfill sites. Its recovery therefore, not only results in the stabilisation of the landfill site, allowing faster reuse of the land, but also serves to lessen the impact of biospheric methane emissions on global warming.

Ethanol Fermentation.

Ethanol is mainly used as a substitute for imported oil in order to reduce their dependence on imported energy supplies. The substantial gains made in fermentation technologies now make the production of ethanol for use as a petroleum substitute and fuel enhancer, both economically competitive (given certain assumptions) and environmentally beneficial. For example, subsidies for alcohol production in Brazil are now becoming regarded as detrimental to the stability of the ethanol market, and thus obsolete. (section 3) In Zimbabwe, foreign exchange savings are seen as a major bonus, which along with the employment and environmental benefits have made the long term future and expansion of the this programme a priority for the Zimbabwean government. (see section 3; Sugarcane Electricity, Jobs)

The most commonly used feedstock in developing countries is sugarcane, due to its high productivity when supplied with sufficient water. Where water availability is limited, sweet sorghum or cassava may become the preferred feedstocks. Other advantages of sugarcane feedstock include the high residue energy potential and modern management practices which make sustainable and environmentally benign production possible whilst at the same time allowing continued production of sugar {Scurlock et al., 1992}. Other feedstocks include saccharide-rich sugarbeet, and carbohydrate rich potatoes, wheat and maize.

One of the most promising fermentation technologies to be identified recently is the "Biostil" process which uses centrifugal yeast reclamation, and continuous evaporative removal of the ethanol. This allows the fermentation medium to be continuously sterilised and minimises water use. The Biostil process markedly lowers the production of stillage, whilst the non-stop nature of the fermentation process allows substrate concentrations to be constantly kept at optimal levels and therefore fermentation efficiency is maximised. {Hall, 1991} Improved varieties of yeast, produced through clonal selection techniques have also raised the tolerance levels of the yeast to alcohol concentrations, again improving efficiency.

Recent advances in the use of cellulosic feedstock, may allow the competitive production of alcohol from woody agricultural residues and trees to become economically competitive in the medium term. (table 13) Since 1982, prices have fallen from about US$ 45 per GJ (95 c/l) to about US$ 13 per GJ (28 c/l) for ethanol, and for methanol, projected prices have been reduced from US$ 16 per GJ (27 c/l) to $15 per GJ (25 c/l) and could fall to prices competitive with gasoline produced from oil priced at US$ 25 per barrel. {Wyman *et al.*, 1992}

Biodiesel.

The use of vegetable oils for combustion in diesel engines has occurred for over 100 years. In fact, Rudolf Diesel tested his first prototype on vegetable oils, which can be used, "raw", in an emergency. Whilst it is feasible to run diesel engines on raw vegetable oils, in general the oils must first be chemically transformed to resemble petroleum-based diesel more closely.

The raw oil can be obtained from a variety of annual and perennial plant species. Perennials include, oil palms, coconut palms, physica nut and Chinese Tallow Tree. Annuals include, sunflower, groundnut, soybean and rapeseed. Many of these plants can produce high yields of oil, with positive energy and carbon balances.

Transformation of the raw oil is necessary to avoid problems associated with variations in feedstock. The oil can undergo thermal or catalytic cracking, Kolbe electrolysis, or transesterification processes in order to obtain better characteristics. Untreated oil causes problems through incomplete combustion, resulting in the build up of sooty residues, waxes, gums etc. Also, incorrect viscosities can result in poor atomization of the oil also resulting in poor combustion. Oil polymerisation can lead to deposition on the cylinder walls. {Shay, 1993}

Generally, the chemical processing required to avoid these problems is simple, and in the case of soybean oil may be carried out in existing petroleum refineries. The use of diesel powered vehicles is widespread throughout agriculture, and biodiesel provides an environmentally friendly, CO_2-neutral alternative. It is now being widely promoted in the EC and elsewhere, as its use does not require major modification to existing diesel engines. {Shay, 1993}

5. Environmental Interactions.

Biomass is produced using widely varying strategies related to site specific parameters, the scope of which makes it difficult to provide more than general guidelines or principles. It is essential that strategies for sustainable biomass growth are developed for each ecological region, however, research is already highlighting benefits and some areas of concern with large-scale bioenergy plantations.

Very little detailed and reliable environmental data is presently published on the impact of large-scale plantations. One notable exception has arisen from a collaboration between a multinational company and a leading NGO, namely Shell International Petroleum Company and WWF, which has resulted in the recent publication of the "Tree Plantation Review." {anon, 1993} However, to our knowledge there are four major conferences planned during 1993 specifically targeting this issue. The research for these conferences should supply sufficient data to provide coherent guidelines for the establishment of environmentally sympathetic and sustainable bioenergy programmes. A synopsis of present environmental knowledge is provided below.

Health.

Atmospheric pollution must be decreased for health and global environmental reasons. To be successful, this requires action at the individual house, community, regional and global levels. Woodfuel use (specifically firewood) has been associated with many respiratory diseases and specifically linked to chronic bronchitis and lung/throat cancer. These are associated with: i) the emission of particulates (large airborne particles) and ii) carcinogens released from the wood through combustion. Products of Incomplete Combustion (PICs) can be adequately dealt with through the use of more efficient stoves and ventilation, and is the subject of numerous reports and aid projects. Such stoves deal with the problem in two ways.

Firstly, increased efficiency requires more complete combustion so reducing the concentrations of particulates and carcinogens. Secondly, the controlled air flow which is required for efficient combustion, often needs an externally vented flue thereby reducing the concentrations of PIC's within confined cooking areas. {Smith, 1991, 1990} These improvements are of particular importance as the effects of indoor pollution may be delayed (and be cumulative) so afflicting mothers and young children.

It is important to note that such health problems are more a result of inefficient cooking conditions and equipment than simply the fuel source; for example, the widespread use of low-grade coal in China has significantly increased the rate of lung cancer. {Smith K.R., 1991} Some fuels, such as kerosene, are inherently lower PIC fuels and are perceived to be advantageous to health. {Ellegård, 1991}. However, improved health and development can result from improvements in the efficiency and the quality of conversion systems eg. improved cooking stoves and fuel sources, and not just from a change in fuel type.

Global warming.

Biofuels provide an opportunity for the provision of the modern fuels and services required for development, whilst at the same time avoiding fossil-fuel derived CO_2 emissions. However, present intensive agricultural methods can only be used for the production of liquid fuels eg. diesel from rapeseed, if the associated residue production is used for energy. Thus the use of C-flows and energy output**:**input ratios to monitor net CO_2 production must be integral to the study of the Greenhouse effect and the development of strategies for energy provision. (Chapter 2)

Other by-products arising from the production and use of biomass energy are involved in the complex physics and chemistry of the greenhouse effect. These include methane emissions, mainly from rice paddy cultivation and also landfills; however, emissions are directly related to management practices and soil type, and thus have the potential to be reduced substantially. {IPCC, 1992}

Bioenergy systems emit less sulphur dioxide (since they are naturally low in S, table 16) and nitrous oxides (NO_x) than equivalent fossil-fuel derived energy. SO_2 emissions are implicated in acid rain and increased nutrient depletion from soils. On the other hand, sulphate aerosols, derived from SO_2 emissions to the atmosphere, have been shown to play a role as cloud condensation nuclei, and are thus postulated to moderate the global warming effect. Hence, increased use of bioenergy would theoretically reduce the levels of SO_2 in the atmosphere thus removing this negative feedback effect. {IPCC, 1992.}

Increases in the levels of all the major greenhouse gases result from land clearing (devegetation), and thus well managed biofuel programmes which lead to revegetation will result in the decrease of greenhouse gases. Land-use changes which result in a permanent increase in the level of the carbon inventory (vegetation) will thus play a role in ameliorating the greenhouse effect (see section 2, and below).

Environmental benefits of correctly managed biofuel production.

These benefits may include: soil and watershed protection, raising or maintaining biodiversity (see below), CO_2-neutral fuel source (or C-sink), low S content, lower NO_x's, maintenance of the hydrological cycle and promotion of rural development (including the provision of permanent skilled and semi-skilled employment). It is a decentralised and modular approach, allowing the flexibility to avoid environmentally degrading facets as they are encountered.

Initially, it is envisaged that the use of intensively farmed modern row crops for energy eg. rape to Rape seed Methyl Ester (RME), will continue to increase. The ease with which biodiesel (such as RME) fits into the present farming and energy transportation infrastructure ie. it is derived from an annual crop (rape) and can be run in unconverted diesel engines, will result in a rapid increase in its use.

The environmental and productivity advantages of perennial woody biomass crops should result in annual bioenergy crops being regarded only as a transition to sustainable agroenergy production based on perennial crops. Continued R&D and monitoring should result in the confidence to transfer woody perennial crops from the trial plot to the farmers field once a demand for bioenergy has been established. The transition to biomass-derived energy sources will also be facilitated by the rationalisation of the tariff and subsidy structures allowing renewable energy to become economically competitive with fossil fuels. (chapter 6)

Land degradation may occur where an incorrect vegetation type is chosen for a particular bioclimatic (agroecological) zone leading to erosion, leaching, or the mining of water resources. Land-use conflicts, eg. the replacement of tropical forest with intensive monoculture farming, or even for use as grazing land as has happened on a large scale in South America, may result in continuing land degradation. Well managed biomass plantations would provide a sustainable alternative land use, and may be able to upgrade the productivity and quality of degraded lands.

In the US, the instigation of the Conservation Reserve Programme (CRP, established by the 1985 Food Security Act), has been credited with reducing soil losses on fragile farm land under this scheme from 8.5 t/ha/yr to 0.6 t/ha/yr. {CAST 1990} Soil stability models suggest that biomass systems can provide very stable land management systems, with the possible exception of annual row-crop energy production. With soil formation rates of between 2 and 5 t/ha/yr perennial biomass agriculture would be sustainable in terms of soil retention. {Ranney, 1993}

Careful siting of perennial energy plantations may result in nitrogen filtering benefits, due to the high nitrogen retention ability of these plantations compared to annual crops. The N-filtering capacity could theoretically be used to protect low lying water courses from excessive nitrogen leaching from intensively managed annual crop fields. The nutrient run-off may in some circumstances provide sufficient nitrogen for the biomass crop, whilst buffering the water-course from the detrimental effects of excessive nitrification. {Ranney, 1993}

The production of stillage from sugarcane provides a good example of a noxious effluent resulting from biofuel production. The dumping of raw stillage into convenient watercourses has caused considerable environmental damage, as the stillage is both highly acid and nutrient rich. Its uncontrolled dumping has caused algal blooms increased chemical oxygen demand (COD) and biological oxygen demand (BOD). Novel methods of stillage disposal have allowed its use as an organic fertiliser, allowing reductions in the levels of artificial fertiliser application. In fact, the Triangle project in Zimbabwe has used stillage to substitute for an estimated US$ 1.1 million per annum of K-fertilisers. There have also been un-quantified benefits in reductions of P and N fertilisers which are also highly concentrated in stillage. {Scurlock *et al.*, 1991}

Instead of dumping waste stillage into nearby watercourses, stillage is now diluted and reapplied to the fields in carefully controlled quantities in both Brazil and Zimbabwe. The soils in the fields are monitored to match the soil type and nutrient requirements with the quantities of stillage to be applied. In addition, sugarcane-stillage is providing a supplementary energy source from the production of biogas from secondary digestion in Brazil, Puerto Rico and India.

Increased nutrient recycling may prove essential in sustainably managed plantations. Thus, the ash produced from the combusted biomass should be applied to the plantation to ensure that inorganic nutrients are recycled, further reducing the need for fertiliser inputs. Studies on the recycling of nutrients via the returning of ash to the harvested plantation areas are already under way in Sweden at the Vattenfall (60 MW) biomass-powered Integrated Gasifier Combined Cycle demonstration project for which construction is scheduled to start in 1993 and operation by 1996. {Lindman et al, 1992; Williams and Larson, 1992)} Reduced combustion temperatures may help to retain most of the inorganic nutrients in the ash, and modern conversion technologies may be able to operate at such low temperatures.

Where degraded land is to be rehabilitated or significant growths rates are required, the use of exotic species can be justified. For example, *Eucalyptus* was planted in the highlands of Ethiopia, on degraded soils which would no longer support any indigenous vegetation. As a result, some areas now have soil of sufficient stability to support indigenous vegetation once more. However, it is our belief that indigenous species should be used in preference to exotics wherever possible. The use of exotics will probably occur in combination with fast-growing exotics since indigenous species may already incorporate significant resistance to local stress conditions, pests and diseases. They may also respond well to management practices normally used with fast-growing exotics. Thus, indigenous species can be used as a risk abatement strategy, protecting the plantation from complete destruction by disease or drought. The use of a wide range of species and clones is now viewed as an essential risk abatement strategy for the same reasons as the use of indigenous varieties.

Biodiversity.

Bioenergy plantations show improved biodiversity over previous vegetation type if the plantations are grown on degraded or arable land. Replacing indigenous forest or natural habitats with SRWC would undoubtedly lead to a decrease in biodiversity. Unless the carbon sequestration benefits outweigh the loss in biodiversity the use of natural forest systems may be environmentally detrimental. This would almost certainly be the case if slow growing tropical rainforests with high standing stocks are replaced with plantations. (section 2.)

Rehabilitation of degraded land with multi-purpose species (inc. agroforestry) is a long term process but can lead to undoubted improvements in both the quality of the environment and benefit the local people (see Kenyan Baringo project, chapter 2). One interesting aspect revealed through a study of 19 Agroforestry projects in Africa, showed that local farmers were far more interested in fruit trees, or trees which could be used as construction poles rather than trees specifically for fuelwood. {Kerkhof, 1990} Thus, it can be seen that projects which aim to encourage local populations to promote revegetation schemes need to utilise multi-purpose species which provide for the diverse requirements of the local people. The establishment of multi-product systems will also result in increased diversity.

Increases in the variety of species planted would habitat diversity especially for insect and bird populations. Agroforestry can offer a wide range of products on relatively small areas of land. For example, a Thai farmer who used to rely on intensive agriculture, but became disillusioned with the diminishing returns from hybrid crops, switched to agroforestry techniques. In doing so he reduced the area of land he "cultivated" from 200 rais (about 30 ha) mostly planted with rice to 9 rais (1.35 ha). He now has 413 species of food and medicinal plants which require minimum tillage. This switch resulted in large increases in both biodiversity and security for the farmer and his family in terms of the supply a highly varied and nutritious diet even in drought years. {BUN, 1992} Agroforestry systems offer the potential for highly productive and diverse land uses, even on marginal land. However, these systems are by no means pre-destined to success. The promotion of agroforesty will require considerable governmental backing, including: the provision of extension services, seedlings, site specific research and inter-departmental cooperation. {Erskine, 1991} However, the sustainable production of food and energy may be highly efficient using agroforestry systems, and thus deserves more attention.

Biological control of pests and diseases. A few biological control agents readily fit into modern pest and disease control practices. For example, *Bacillus thuriengensis* (BT) can be applied by spraying crops and plantations with the bacterial application, or the spraying with a solution of the purified crystalline toxin which has powerful anti-lepidopteran properties. Such spraying has been widely practised over the pine forests of Scotland and elsewhere. Systemic insecticides which selectively kill only those pests which consume the host and not the pests' predators should be developed and made more widely available as part of an integrated pest control strategy. The use insect herbivores to control outbreaks of weeds has also been tried extensively, however, success has generally been limited to the control of accidentally introduced exotic weeds and pests. {Crawley, 1989}

Other forms of this sort of strategy aim to provide agrarian reserves where indigenous predators can exist at naturally low levels, increasing with pest outbreaks. Once the pest outbreak has been contained the levels of predator will naturally die back, but a reserve will be maintained in the reserve area to respond to future outbreaks. Foresters now recognise the efficacy of such approaches, and it is has become common practice for them to leave decaying branches etc within the plantation. Decaying material harbours insects and can sustain a high and diverse level of bird life useful for similar reasons to the agrarian reserves discussed above. {Beyea *et al.*, 1992}

The benefits of longer rotation lengths can accrue not only in terms of carbon storage, but also in raising the levels of biodiversity. Habitat recovery studies on temperate short-rotation plantations show that between 3 and 5 years after planting woodland species of birds and soil microfauna start to occupy the plantation, and that diversity is increased if the plots are connected to native woodlands, due to edge effects. {Ranney, 1993}

Research to date, cited in Ranney {1993}, indicates that bioenergy systems offer a significant improvement over other land uses, especially in terms of reducing soil erosion and increasing biodiversity. However, the interaction between bioenergy systems and natural ecosystems is dynamic and complex. Novel strategies are required which can only be derived from increased research, development, monitoring and the utilisation of local knowledge. Nevertheless, preliminary results suggest that woody plantations can provide a diverse habitat for woodland bird species if management strategies incorporate reserves of natural woodland. Furthermore, such reserves may provide economic returns through decreased need for pesticides and fertilisers. More intensive bioenergy production may provide fewer environmental benefits. Certainly the commercial viability of IPM appears to be demonstrated in the commercial plantations of Brazil.

Ethanol. Brazil and Zimbabwe both adopted a sugarcane-alcohol programme in order to produce ethanol for use as a petrol substitute. An immediate benefit stems from the higher octane level of ethanol compared to petrol, thus negating the need to add lead as an anti-knocking agent. High lead levels have been implicated in the lowering of children's IQ levels in inner cities of industrialised countries. However, the use of ethanol as a vehicle fuel has been associated with increased Formaldehyde emissions a suspected carcinogen.

Soil-carbon cycles.

Whilst very little work has been done to enable the provision of accurate estimates over large regions, studies on Loblolly pine and spruce-fir plantations (35 and 65 year rotations) may allow broad generalisations for all plantations.

For both the Loblolly and spruce plantations soil carbon diminished over the first 10 to 20 years after establishment. However, differences occur in the rate of decomposition under different climatic regimes. For temperate regions, vegetation decays more slowly than tropical regions due to lower ambient temperatures. Typically, loblolly pine plantations in the warmer southeast of the US have soil carbon levels between 5 and 10 tC/ha whereas, in the spruce-fir plantations of the colder northeast US soil carbon levels range between 15 and 20 tC/ha. Thus small changes in the rates of decomposition and overall levels of soil carbon over wide areas could be a significant sink or source of atmospheric CO_2. {Birdsey, 1992} Levels of soil organic carbon may also be important in aiding plant productivity, due to faster rihzospheric recycling of nutrients, but very little quantitative data exists to confirm this belief. {Ranney, 1992b}

Bioenergy plantations which use coppicing species over short rotations would probably represent a hybrid between clear-cut plantations (with rotation lengths of 30 to 100 years) and annual crops. Short rotation energy coppices are harvested every 5-12 years however, their roots systems are left alone to allow fast regeneration in the next growth season. Decreasing growth rates require new root stock about every 30 years. Thus, the only physical disturbance to the below ground carbon store is through the compaction of the soil by the heavy machinery used during the harvest. Should this prove important, strategies to minimise soil disturbance can be adopted, such as harvesting when the soil is frozen or dry.

6. Policy, Socio-economics and Institutions.

There is a very large potential for future biomass in energy provision strategies which is clearly demonstrated by Johansson *et al.* (1992). In fact, their Renewables Intensive Global Energy Scenario (RIGES,see summary) envisages that biomass-derived fuels will not only cover all the predicted increase in direct fuel-use by 2050, primarily in developing countries, but will also substitute for fossil-fuels as their use in industrialised countries decreases due to environmental concerns and increasing costs.

Presently, if traditional "non-commercial" forms of biomass use are ignored, biomass consumption accounts for an insignificant share of global energy use; however, by 2050, it is predicted to provide about 38% of direct fuel-use and 17% of electricity. In all, "renewables" are expected to provide 2/5 of direct fuel-use and 3/5 of electricity production at a cost comparable with other fuels. RIGES projects that global electricity supply will double by 2050, direct fuel use will increase by one third and CO_2 emissions would drop to 3/4 of the 1985 level in the same period. {Johansson *et al.*, 1992}

When considering the environmental and social imperatives for such a shift away from fossil fuels, now believed highly desirable by a consensus of scientists {IPCC, 1990}, the tools and incentives required must be found. It is widely accepted that a significant shift to a renewables-dominated energy sector will only occur once:

(a) Subsidies to fossil fuels are removed or mitigated creating a so-called "level playing field for energy;"

(b) Links between energy and agriculture are recognised. If the world's increasing population is to be fed, then yields must continue to increase, and this will require more energy. Policies which encourage rural development, including the ready availability of a sustainable and indigenous energy supply are much needed in both developing and industrialised societies.

(c) The external costs of the present fossil-based energy systems, which are significant, are incorporated into the market. Full life cycle cost-benefit analysis of all forms of energy production systems which incorporate such "externalities" are necessary if (a) above is to be realised. For example, studies from Germany estimate the cost of these external effects including acid rain, NO_x, particulates, etc., on the temperate forests at about DM 10 billion (US$ 6.25 billion) resulting from the degradation of 60 to 70% of forest cover. {Tributsch, 1993} The highly espoused "polluter pays principle" requires that regulations are observed and constant monitoring is ensured, thus necessitating the creation or strengthening of institutions which must have the ability to enforce such remits.

Internalisation of Externalities.

A few economists are now grappling with the problems involved in incorporating the "externalities" of fossil energy production into the market place Energy consumers such as the electrical utilities, and ultimately the individual consumers must become accountable for their energy consumption. Ascertaining and allocating precise costs may prove very complicated. For example, who should pay for the reduction in value of a house built in forests (where the view and environment considerably enhanced its value) which have now become degraded to such an extent that the proximity of these forests detracts from the house's value.

The problem is exacerbated by the potential number of polluting sources, their distance from the house (which may even be international) and conflicting views on the exact impact of such pollution.

Possibilities for national level strategies include the levying of a Carbon tax on C-emitting fuels or tradeable permits which could create a market for externalities. Both of these "tools" are in use, carbon taxes in Sweden, Netherlands, Finland and tradeable permits in USA. {Pearce, 1991}

Carbon Taxes.

Such a tax could be levied on all fuels in proportion to the amount of CO_2 emitted per unit of energy produced. Attempts to widen the carbon tax to all European countries have been hindered by those who fear that the initial extra costs of energy to industry will be punitive for exports. The concept has also been heavily resisted in North America for similar reasons.

Developing countries are not significant emitters of Greenhouse Gases and regard any such price interventions as detrimental to their development. They regard the industrialised nations as being responsible for Global Warming, and therefore industrialised countries should pay for its remediation.

In the European Community, work is continuing on the introduction of a carbon tax in all its member states however, such a tax has proved to be extremely politically sensitive. Within the EC there are presently two lines of argument over the level of taxation required for it to be effective.

The most studied policy proposal would impose an increasingly punitive tax on fossil-fuels (dependant on the carbon emitted per unit of energy produced), effectively doubling the price of oil by the turn of the century. Economic modelling of the effects of such a tax on GDP conflict. One model indicates a rise in GDP may be expected due to the stimulative effect of an indigenous energy industry (mainly agro-energy) on the economy, despite higher overall energy costs to industry. Thus, whilst energy costs may be higher, the increased payments are retained within the country resulting in a net rise in GDP.

More recently, a second policy option has emerged, which suggests that the level of carbon taxation need not be punitive (ie. high enough to force energy users to become more efficient, change fuels, etc.,). Sufficient revenue could be raised from a relatively low level of taxation if it was re-invested in energy-efficient and renewable technologies R&D (especially bioenergy), to enable these technologies to provide an economically competitive alternative to fossil-fuels- "accelerated development." Therefore, the desired reduction in fossil fuel use will be achieved indirectly. One prerequisite of such a low C-taxation level is that for the present, bio-fuels and renewables should continue to enjoy lower levels or zero taxation if they are to remain competitive.

Under such a tax system where the revenues from the tax on fossil fuels are returned in part to its competitors (alternative non-CO_2 emitting sources of energy), this return represents a subsidy. However, it is not in the long term interests of the renewables, and specifically the bio-fuels sector, for this subsidy to be viewed as a permanent form of support. For biofuels to become increasingly competitive and efficient, un-ending funding could lead to lethargy and stagnation, removing the incentives for further development, whilst continuing to represent a burden for the tax payer. It is for this reason that the independent alcohol producers of Brazil have now come to regard further subsidies and support from the Brazilian government as detrimental. {Goldemberg *et al.*, 1992}

Currently, carbon taxes in the Netherlands (US$1.30 per tC), Finland's tax (US$6.10 per tC) and Sweden's (US$40 per tC) have the same primary objective of reducing CO_2 emissions but, have different secondary objectives. The Netherlands uses the relatively small revenue raised for environmental protection. Finland's carbon tax resulted from an overhaul of its general taxation policy and Sweden's much larger tax was made possible by a 50% reduction in its energy tax, but was accompanied by NO_x and SO_x taxes. {Barrett, 1991}

On a broader scale, it is difficult to predict the effects of a C-tax, which could have many knock-on effects. For example, one possible effect of a significant C-tax levied in Industrialised countries might be a lowering in demand for fossil-fuels and hence a drop in world oil prices. This might have the effect of increasing the use of these fuels in developing countries, possibly offsetting any reductions in the Industrialised countries' emissions.

The precise effects of such taxes continue to be uncertain, but estimates on a level of C-tax which would have the effect of lowering carbon emissions by 20% by 2000 to 2005, indicate that the price of oil would have to increase by at least 50% if not doubled. There is considerable uncertainty as to what level of C-tax alone is needed to be effective and the potential size of revenues raised. This has led to the realisation that such C-tax derived revenues may be more effective in assisting the development of alternatives to fossil fuels, than a punitive C-tax alone. These revenues could be used to fund R&D and to pay for "levelling the playing field," thus facilitating a rapid transition to sustainable energy systems.

Revenue-neutral C-taxes are now being studied, which may include a commensurate reduction in say, corporation tax, Value Added Tax or as in the case of Sweden, the energy tax. In this way distortions to the economy usually experienced with the introduction of a new tax are minimised, and may even help to compensate for previously unaccounted distortions such as the environmental costs of energy use. {Barrett, 1991} However, it is our belief that the revenues raised from a C-tax should be used to facilitate the introduction of a sustainable energy production and use sector, realising the potential to reduce energy costs and accrue many social and environmental benefits simultaneously.

Tradeable Permits.

Tradeable permits would create a market for reductions in the emissions in GH gases, and could theoretically be operated at the national or international level. Such schemes could operate on the international level by providing permits to emit a given quantity of Greenhouse gases per capita, for example the global average of 1.4 tC/cap/yr. Countries which were emitting more than the permitted levels of CO_2 would have to buy them from countries which were emitting less than the global average. This system would heavily favour countries with high populations and low per capita energy consumption, such as India and China. Another option might be to distribute permits per unit GDP which would favour the industrialised nations.

Tradeable permits offer the cheapest policy for Greenhouse gas emissions reduction, however, difficulties in the equitable distribution of such permits on an international level may be insurmountable. Such difficulties are due both to the amounts of money which might be involved and because of the unequal distribution of energy resources and population. {Markandya, 1991} In addition, many environmentalists view the introduction of such permits as a right to pollute, which they consider to fundamentally wrong.

Hidden costs & subsidies.

Besides the environmental externalities of fossil-based energy there are a series of other associated external effects. For example, the cost of securing supplies from politically unstable regions can be extremely high eg. the cost of "securing" supplies from the Persian Gulf is estimated to be US$ 15 billion a year for the USA to maintain its naval fleet on station. {Hubbard, 1991}

In many developing countries, the foreign exchange costs of energy and the associated capital costs of the equipment necessary to use it, represent a substantial proportion of total foreign exchange earnings and debt. A stable price for energy therefore continues to be a crucial policy objective in these countries. (see India, section 3)

On average the consumers of electricity in developing countries pay only about 60% of the actual cost of electricity production, and yet commonly electricity is only consumed by the richest section of the community in these countries. {Lensson, 1992} In some countries the perceived developmental advantages of low or very low electricity prices have resulted in tariffs which are so low as to completely inhibit the introduction of any other competing energy sources eg. in Tanzania the electricity tariff is 0.1 c/kWh or about 1/50th to 1/100th of the actual cost of production. In India, preferential tariffs for centralised electricity production and distribution are regarded as detrimental to the adoption of indigenous, decentralised electricity production schemes which can be reliable and efficient and economically competitive. {Ravindranath, 1993} Tariff-reform is now viewed by the World Bank as essential for realistic future energy policies in some developing countries.

Attention has now turned to alternative large scale zero CO_2-emitting energy production technologies ie. nuclear and hydro power. If the full life-cycle costs of nuclear power include the high capital costs and the "safe" decommissioning and disposal of wastes, many experts now recognise that the nuclear option is not cost effective. The prospect of nuclear weapons proliferation is also causing widespread concern and civil opposition. There may also be health and social aspects, including ensuring the physical safety of power plants, which may substantially inhibit the growth of nuclear power.

Increasing the amount of power produced by large-scale hydro-electric schemes is also a much studied alternative to fossil fuels. However, further significant gains in hydro-electricity production may only be at a significant social and environmental cost. The cost of re-location of large numbers of people and the flooding of significant areas of agricultural land, the increasing marginal cost of electricity can make such hydro-schemes uncompetitive when compared to the alternatives, including biomass. (Brazil, section 3) Furthermore, the high capital costs, long construction and payback times and low indigenous employment generation prospects combined with increasing international environmental awareness, is reducing the likelihood that hydro power will be "the" answer to the energy needs of many countries in the future. However, it will undoubtedly continue to play a significant role in future energy provision policies.

Regulations.

The success of some carefully planned regulations, suggests that a more widespread use of regulations may be likely. Regulations can be used to promote energy efficiency and alternative fuels which may be more environmentally friendly, such as biomass. If sufficiently monitored and enforced, regulations can meet their stated aims. The uncertainties involved with market driven policies such as C-taxes and tradeable permits are more problematic.

The USA has had recent experience with the introduction of regulations specifically directed at increasing energy efficiency on both the supply and demand side. The Public Utility Regulatory Policy Act's (PURPA) main aim was to remove the incentives for utilities to supply increasing power to their customers, and thus gain from increased sales revenues. This act legally obliged utilities to incorporate so-called "avoided costs" economics into their planning portfolio. On the supply side, avoided cost economics required utilities to procure electricity form other sources at the cost they would otherwise incur if they were to produce the electricity from their own new generating plant. It thus emphasised efficiency in terms of reducing production costs, and at the same time inhibited such utilities from under-cutting cheaper small-scale producers (predominantly electricity produced from wastes and residues <50 MW). It has resulted in a large increase in power generation from the renewables sector (both biomass and wind power. (USA, section 3)

In the UK, the Non Fossil Fuels Obligation (NFFO), which was originally designed to protect the nuclear power sector during its abortive privatisation programme, resulted in the promotion of renewable energies. The government has stated that it wishes to see a target of 1,000 MW of installed renewable electricity generating capacity by the year 2000, with about 500 MW of projects committed so far. {ETSU, 1991} NFFO guarantees premium prices for electricity produced from renewable sources up to a given date, presently 1998. However, with the increasingly short time in which new projects have to cover their establishment costs, as the deadline draws nearer, has resulted in NFFO being renewed twice. Doubt exists about its further renewal and new investment is stalling.

The main beneficiaries of NFFO to date have been those technologies nearest to commercialisation ie. wind power, landfill gas and MSW; however, continuing RD&D into woody biomass and agricultural residues shows increased promise (below). It should be noted that the revenue for NFFO is generated via a 10% tax on electricity consumed, virtually all of which is presently used to subsidise nuclear power.

Energy Efficiency.

In developing countries, where energy efficiencies tend to be much lower, relatively large gains can be made cost effectively according to Lenssen {1992}. He cites many examples eg. a retro-fit programme aimed at improving the efficiency of irrigation pumps in India in the mid 1980's "reduced electricity consumption in 23,000 pumps by a quarter, and the improvements paid for themselves in less than six months." However, tariffs are so low that individual farmers have little incentive to make such savings themselves.

China reduced its growth in energy use from 7% to 4% annually by redirecting 10% of its energy expenditure to energy efficiency programmes, without slowing growth in industrial production. A similar return on investments was achieved in Brazil where its National Electricity Conservation Program (PROCEL) spent US$ 20 million over four years, and achieved savings in reducing the need for extra power production capacity and power lines in the order of US$600 million to $ 1.3 billion. Such savings could equally be made in any other developing or industrialised country. {Lenssen, 1992} In fact, Sweden expects to double its electricity efficiency, and other European countries expect to achieve CO_2 emissions reduction targets almost entirely through increased efficiency. {Fickett *et al.*, 1990} A switch to biofuels will aid such countries to achieve their targets relatively more easily and cost effectively. Biofuels are now being viewed far more positively in the EC, for example, its economic and social committee "considers that biomass is the only renewable energy source which will be able to make a substantial contribution to the replacement of conventional fuels." Furthermore, the EC has preliminary plans for the production of 11 MTOE of biofuels (462 PJ) from 7 Mha. {EC Economic and Social Committee, 1992)

Land Availability.

As seen in section 2 ("land availability" and "wastelands"), there are considerable areas of land available for the production of biomass. The utilisation of this land could have many economic, environmental and social advantages, which will require careful planning, incentives and monitoring. In the industrialised countries much of the land being removed from agricultural production could profitably and responsibly be used for energy production because of the associated benefits of such land use. {Ranney, 1992b}

Schemes such as the EC's "Set-aside" policy which requires farmers to leave 15% of their land fallow, and the USA's "Cropland Reduction Programme" (CRP) are making significant areas of land available for industrialised countries. There is a need to find a profitable use for this land as it represents an opportunity to re-invigorate the rural economy. Biofuels offer such an opportunity.

In the UK, Short Rotation Woody Coppice (SRWC) qualifies for "set aside" land and is thus eligible for the "Woodland Grant Scheme" which provides farmers with a sufficiently large grant to cover all the establishment costs of energy coppicing for the first year. {ETSU, 1991} Despite such incentives, farmers will not grow the wood unless profitability can be demonstrated- this requires the creation of a stable market. Thus the establishment of a significant woody biomass energy sector will require the close co-ordination of both the supply and demand-sides.

In Brazil, for example, woody plantation-derived industrial charcoal production was only established on a significant scale once the iron industry was "forced" to ensure its supply of charcoal from a sustainable source. Therefore, most wood-energy plantations are owned and run by the iron producing companies themselves. (Ch.3) Once a conducive atmosphere has been insured by policy implementation and extension, as in Austria and California, (chp. 3) growth in the production and use of biofuels can be very fast.

Some countries in Asia (see section 2) appear to have only small or none existing land resources to invest in biomass energy programmes. Nevertheless, strategies such as agroforesty, the promotion of efficient forms of energy conversion technologies and the use of agricultural residues and wastes leaves has a significant potential to be tapped. For many of these countries arable land areas have not increased since the 1980's or earlier, but food production has continued to increase. (see fig 9)

Latin America, Africa in general, and several other forest-rich countries in Asia have large areas which could, under specific conditions and long-term policies, be utilized for biomass energy generation. Overall criteria and policies to this end are suggested later in this chapter.

In general, developing countries could gain substantial revenue from more thorough management of woodlands through the development of larger forestry services. Such management of existing natural resources should ensure continued protection for those resources through funding monitoring and sustainable utilisation whilst alternative biomass programmes are initiated.

Institutions.

There is now a greater need for institutions to formulate clear energy goals and provide independent information. In order for any change-over from fossil fuels to biofuels (and renewables in general) to be beneficial, in both economic and environmental terms, there is a need for efficient policies and regulations. Institutions must provide the enabling capacity required to ensure that regulations are adhered to and to analyze data from monitoring in order to revise policies as required.

For countries which do not have the capital necessary to invest in energy efficient infrastructure, institutions must help "develop a regional forum which will greatly improve its position in bidding for international funds," according to Davidson {1992}. Presently, there appear to be many institutions but most are too fragmented and poorly supported to adopt such a strong and enduring role. Examples of such institutions are AFREPREN (Africa), APENPLAN (ASIA), KENGO (E.Africa), ITDG (7 countries), ENDA (W.Africa), ZERO (Zimbabwe) to name but a few. These institutions all need skilled and professional personnel and priority funding on a long term basis if they are to provide the expertise to act as a catalyst for sustainable biomass use.

For example, the African Energy Policy Research Network (AFREPREN) was originally set up in 1989 to overcome the crisis management of energy which became endemic during the late 1970's and 1980's. It has provided a research base and forum for energy policy makers to meet and work with energy researchers in order to clarify existing energy problems and define long term developmental goals. The continued development of such institutions will be essential to implement sustainable energy schemes directed at development.

On a broader global level institutions must be strengthened to provide more detailed information on potential environmental problems caused by the build-up of greenhouse gases and on feasible sustainable land use strategies to counteract such problems. For example, the FAO's Agro-Ecological Zones study is providing a much needed data base on potential productivities of the different ecological zones in a number of selected developing countries. Nevertheless, for this information to be useful to farmers or even national planners, the resolution of its Global Information Systems (GIS's) needs to be much higher. Also, for a global analysis many more countries need to be included in the AEZ study.

In conclusion, there is a need for longer term funding and a coherent development plan for institutions, and there may also be a need for a new institution to "assist and co-ordinate national and regional programmes for the increased use of renewables," as called for by Johansson *et al.* {1992}

Policy Options at the Country Level.

The country and site specificity of factors which are central to successful biomass energy production make the provision of a detailed list of policy options, regulations and institutional changes a very difficult task. Most facets of biomass production and use differ from region to region. For example, potential productivities will change not only from country to country but also site to site. Economic, social and institutional factors also differ widely, particularly policies for subsidising specific fossil fuels for socio-developmental reasons ie. kerosene and diesel. A comprehensive pro-active system of regulations, institutions and incentives will be difficult to instigate prior to the formation of a significant modern bioenergy system.

It is for this reason that much development is now focused at a more local level for the generation of largely self-sustaining biomass energy programmes. Through the provision of incentives, venture capital and an integrated monitoring programme, the adoption of sustainable biomass-for-energy systems can be made an attractive option at both the small and large scale. Since biomass systems can be implemented on a modular basis, increasingly larger projects can be formulated as technical and management strategies are proven and the benefits accrue from the initial incentives. To start with, the monitoring and regulatory infrastructures should not be too difficult or stringent, and should be tailored to fit the scale of the biomass programme. Nevertheless, the long term objectives need to be clearly stated from the beginning of such programmes.

Large scale biomass energy schemes will not occur through private sector involvement unless a clear economic return can be demonstrated and risks minimised. The benefits of private sector participation at an early stage should include faster commercialisation of new technologies, reduced public sector funding, increased competition, and possibly more cost effective prices for the new technologies. However, longer term, higher risk R&D will not usually be attractive to the private sector unless they can be assured of good returns eventually, and therefore renewable energy technologies may require continued governmental support. Large scale biomass systems will need to compete with state-of-the-art commercial systems already in use and will thus need to be highly efficient and economically optimised. The problem may be that large private institutions and companies may pay less attention to the needs of local people than indigenously derived, small scale biomass systems designed for rural situations.

For such small-scale rural systems, security and quality of energy supply coupled with lower running costs, especially for the provision of modern energy services are most important. These considerations may make purely economic considerations of secondary importance to the social and developmental benefits derived from the indigenous provision of energy and employment. For example, the provision of electricity from village wood-lot supplies in Hosahalli village, South India, provides electricity costing about four times the heavily subsidised centrally produced grid electricity; however, it has many advantages to the villagers including a reliable and secure energy supply. (Chp 3) In such small scale rural systems social factors may outweigh overt economic considerations, with the provision of rural employment and indigenous wealth generation being more important.

Even in larger scale systems such considerations may be important. For example, the biomass-fuelled district heat programme in Austria appears more expensive than fossil fuelled alternatives. However, the perception that the extra "cost" is recycled into the local community (ie. fuel costs are paid to local farmers and foresters, as opposed to external fossil fuel suppliers) has made the state and local government willing to pay the extra cost. They perceive that much of the extra expense is returned to the community through increasing local development.

An essential partner to the development of sustainable biomass energy production systems is the monitoring programme. Such a monitoring programme should provide information on the effectiveness of existing regulations and incentives. Monitoring may thus allow dynamic feedback adjustments in order to ensure both environmental and economic sustainability.

At the country and regional level, the development of incentives and monitoring, combined with a long term and continuous developmental approach, should result in sustainable biomass energy provision. The need for a "bottom up" approach is made essential by the complexity and diversity of opportunities and obstacles which cannot be addressed comprehensively through "top down" pro-active policies and regulations. A top-down approach could lead to excessively bureaucratic and overburdened institutions unable to cope adequately with the diversity of demands placed upon them.

7. Conclusions.

There are three major factors to consider if biomass is to play a significant role in future (to 2050 at least) energy supply scenarios.

Firstly, the supply of the biomass energy feedstock has the ability to improve the efficiency with which agricultural and forestry land is used in developing countries. In industrialised countries, the supply of biomass energy feedstock could provide non-food feedstocks from marginal and excess agricultural land, large areas of which are planned to be set-aside in the near future. Biomass has the potential to rejuvenate stagnant agricultural sectors.

Secondly, with prudent management practices biomass production offers the opportunity to address multiple environmental concerns eg.: land degradation, biodiversity, CO_2 emissions, other GHG and acid rain pollutants, and local and regional health problems.

Thirdly, in developing countries and historically in industrialised countries biomass has traditionally been the only affordable energy source, often free, to the poorest sections of the community. Now, with the latest advances, both technical and socio-economic, biomass energy in conjunction with other renewable energy technologies is becoming economically competitive with fossil-fuel energy systems. It is interesting to note that whilst the costs of biomass energy technologies and feedstocks will continue to fall in real terms, {Ahmed, 1993; Elliott, 1993}, the costs of fossil fuel supplies and technologies are predicted to increase for the foreseeable future with the possible exception of coal {Williams, 1993; The Economist, Sept. 1993}

Nevertheless, before biofuels can emerge to occupy a significant segment of future energy supplies a number of constraints must be overcome. These include technical, social, economic and institutional problems; however, these constraints can be addressed given time and sufficient resources. (see below and section 6)

Land Availability.

The growth of biomass supplies for energy production on a significant scale is both land and labour consuming. However, at the smaller scales relevant to rural communities in developing countries this is not necessarily the case since both food and fuel production can be integrated in complementary land use systems

In fact, at the small to medium scale (100 kW to 1 MW) sufficient amounts of energy can be provided from agricultural residues and non-arable land to supply villages energy needs for water pumping (domestic and irrigation), lighting and cooking. The provision of irrigation can greatly increase food and cash crop yields, implying that at this scale the use of indigenous biofuels can be land-neutral rather than consuming land resources. Furthermore, the production of excess biomass can be converted to higher value energy products eg. charcoal or electricity, which can be sold on the open market. Firewood and charcoal are already significant income sources in rural areas.

At the larger MW scale, land use conflicts could occur where dedicated energy plantations are required to supply a central conversion facility ie. where a market for biofuels is stimulated. Since biomass is a low energy density fuel high transport costs require that the conversion facility tries to secure supplies from as close to the plant as possible. Thus, measures to protect the small farmer near to such a plant may be necessary. Such measures may include guaranteed prices for any biomass supplies the small farmer might provide to the plant and anti-monopoly laws to avoid the conversion facility procuring all neighbouring land. However, such concerns must also be measured against the benefits accrued by such a plant ie. increased rural employment (at all skill levels), a secure market for agricultural products and the provision of cheap indigenous supplies of energy.

Environment.

The production of biofuels has the potential to have both positive and negative effects on all three major global environmental issues today, namely, land degradation, climate change and loss of biodiversity.

The extensive and increasing areas of degraded lands provide an opportunity for woody biomass species to be used economically for their rehabilitation. Whilst some of this land may have initially been degraded through the mining of indigenous wood resources often to supply urban charcoal markets, the establishment of multi-purpose bioenergy plantations can be a sustainable means of returning this land to productive use. Management strategies and policies required to provide the incentives for rehabilitation require resources to ensure future modes of land use are sustainable.

The sustainable production of biofuels and the use of present agricultural and forestry derived residues can play an important role in reducing the need for GHG and acid rain emitting fossil fuels. Sustainably grown biofuels are CO_2-neutral and low in sulphur and the recycling of the ashes arising from combustion reduces the need for fertilisers. Wider revegetation programmes aimed at reabsorbing atmospheric CO_2 may result in large quantities of low cost biomass being available which should be used as a substitute for fossil fuels or to produce long lived products.

Economics.

In both industrialised and developing countries, close to source, biomass feedstocks can be competitive compared to fossil fuel feedstocks. Typically, biomass feedstocks can cost between $1 and $3 per GJ, which can be compared with oil costing roughly $2 per GJ at US$ 20 per barrel.{Hall *et al.* 1993} What has been missing, as succinctly put by Elliott {1993}, "is a conversion technology capable of delivering this energy to the market competitively on a modest scale appropriate to biomass." The ultimate high value energy carrier is electricity. Companies in industrialised countries are prepared to pay up to sevens times more per unit energy than electricity's alternatives because of its ease and versatility of use. Reliable and high efficiency technologies are now beginning to emerge which are capable of transforming biomass to electricity and other energy carries eg. biogas, ethanol, at the correct scales (5 kW to 100 MW) to be economically competitive with equivalent fossil fuel derived energy carriers. {Ahmed, 1993; Elliott, 1993; Ravindranath, 1993}

Of particular interest is a GEF funded multi-national research project in NE Brazil aimed at the accelerated development of Biomass Gasifier Integrated Gas Turbines for the generation of electricity from dedicated tree plantations and sugarcane bagasse. With reliably estimated average sustainable wood feedstock costs of US$ 1.65 per GJ and projected capital costs for the gasifier and gas turbine module of about US$ 1,300 to 1,500 per 30 MW_e unit, this system is expected to be competitive with future hydro-power generation projects and cheaper than present fossil fuel powered systems.

An important attribute of such biomass systems at the national planning level is the modular ability to add small increments of power generating capacity at a time thus minimising risk and reducing the capital investments relative to fossil fuel plants. This modularity will allow planners to follow the demand curve more accurately, thereby reducing the need for long term projections which are notoriously inaccurate and also increasing the reliability of the network at the same time.

Further important attribute of biomass energy systems is that with sufficient continuing research and development the cost of the biomass feedstock will continue to decrease. For example, in Brazil, since the inception of its sugarcane ethanol programme in 1975 costs of ethanol have been decreasing by 4% to 5% per year through increasing sugarcane productivity and decreasing ethanol production costs.

Constraints.

As a result of the site specific factors which affect biomass energy projects, constraints to the widespread uptake of biomass energy systems range from the local, to national, and regional levels. However, to a large extent enabling policies which remove constraints at the global/regional and national levels will have the most immediate effect. Such policies must engender the communication between the different institutions and governmental sectors involved with the establishment of a significant and sustainable biomass energy programme ie. the agricultural, forestry, land planning and energy sectors. It is important to note that there are often no effective communication channels between these sectors/institutions which can represent a significant constraint to new biomass energy projects. {Williams, 1994}

Other important constraints include a lack of funding, the need for a "level playing field" for biomass energy, a lack of understanding of novel biomass energy technologies and therefore no backup or O&M facilities and above all a failure to appreciate fully the potential benefits which may result from significant bioenergy programmes.

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Table 1 **Present Energy Consuption (Commercial + Biomass): Global Summary**

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
	POPULATION (1987)	PRESENT COMMERCIAL ENERGY CONSUMPTION (1988)						FUELWOOD (ONLY)	BIOMASS (ALL)	TOTAL PRESENT ENERGY CONSUMPTION		PRESENT TOTAL GJ/capita/yr			FUELWOOD or BIOMASS % TOTAL ENERGY CONSUMPTION		
	(MILLIONS)	COAL (MTOE)	OIL (MTOE)	GAS (MTOE)	NUCLEAR (MTOE)	HYDRO (MTOE)	TOTAL CONS. -LHV- (10^6GJ)	**FAO** (10^6GJ)	**EFNE** (10^6GJ)	FUELWOOD + COMMERCIAL (10^6GJ)	BIOMASS + COMMER. (10^6GJ)	GJ/cap **FAO**	GJ/cap **BUN**	GJ/cap **EFNE**	FW **FAO**	BIO **BUN**	BIO **EFNE**
DEVELOPING	3,828	746	630	222	12	66	70,430	15,730	-	86,160	-	23	36*	-	18	(43) 35*	-
AFRICA	586.5	71.4	72.1	28.1	0.3	3.3	7,363	4,481.5	-	11,845	-	20	-	-	38	(77)	-
CEN. AMERICA	141.7	5.7	94.0	28.0	0.0	3.0	5,488	504.0	-	5,992	-	42	-	-	8	(16)	-
SOUTH AMERICA	279.6	15.6	107.5	48.0	0.5	26.7	8,328	2,419.5	-	10,748	-	38	-	-	23	(31)	-
ASIA	2,814.5	653.4	354.2	117.8	11.6	33.1	49,146	8,263.2	-	57,409	-	20	-	-	14	(42)	-
OCEANIA	5.8	0.1	2.3	0.0	0.0	0.1	105	62.1	-	167	-	29	-	-	37	-	-
INDUSTRIALISED	1,193	1,309.3	2,201.8	1,374.6	397.0	323.4	235,456	2,895.3	-	238,351	-	200	218*	-	1.2	3*	-
N.AMERICA	269.6	505.7	867.1	516.6	160.1	132.3	91,636	1,319.0	4,022	92,955	95,658	345	-	355	1.4	-	4.2
EUROPE	494.6	331.3	692.1	262.3	151.0	106.9	64,832	608.7	1,050	65,441	65,890	132	-	133	0.9	-	1.6
USSR	283.1	358.27	378.84	537.97	42.50	56.00	57,690	930.00	1,617	58,620	59,993	207	-	212	1.6	-	2.7
ASIA (note1)	126.5	76.3	229.5	39.2	43.4	18.9	17,106	6.3	-	17,112	-	135	-	-	0.04	-	-
OCEANIA (note2)	19.5	37.70	34.30	18.50	0.00	9.30	4,192	31.39	-	4,223	-	216	-	-	0.7	-	-
WORLD	5,021	2,055.6	2,831.9	1,596.6	409.4	389.5	305,885	18,626	55,000*	324,511	-	65	80*	-	6	14*	-

CONS. = CONSUMPTION   FW = FUELWOOD   est. = BUN estimate

* Scurlock & Hall estimate in "The Contribution of Biomass to Global Energy Use," BIOMASS,21,75-81,1990.

-They estimate Developing countries use 36, Developed 218 & World 80 GJ/capita and that biomass provides 35%, 3% & 14% of the Worlds energy respectively.

()= BUN data only from 55 countries (see sources)

ASSUMPTIONS: 1 Tonne of Oil Equivalent (TOE) = 42 GJ;   1 GJ = 10^9 joules;   BIOMASS/FUELWOOD = 15 GJ/t (air dry 20% moisture)

Fuelwood (FW) in this table is equivalent to the FAO's definition of Fuelwood + Charcoal ONLY; no other form of biomass use is estimated.

Notes:
1) ASIA here means total for Japan + Israel ONLY
2) OCEANIA here is total for Australia + New Zealand ONLY
-for hydro and nuclear statistics regional totals may not add as data source did not provide a comprehensive breakdown for all countries.
Hydro = hydro + geothermal
-Column IX shows data gained independently from the FAO/UN by EFNE (see below.)
-Column XI uses Biomass consumption data from EFNE.

SOURCES:
(UNSO),UN Statistical Office, "Energy Balances and Electricity Profiles 1988," NY. (Developing Country Commercial Energy Data)
UN, "Energy Statistics Yearbook, 1987," NY. (Developing Country & USSR Commercial Energy Data)
BP, "Statistical Review of World Energy, 1990," London. (Western Europe, N.America and Japan Commercial Energy Data)
OECD/IEA, "World Energy Statistics and Balances, 1985-1988," Paris. (Eastern Europe and Israel Commercial Country Data)
(FAO), Food and Agriculture Organisation; "Forest Products Yearbook 1989," Rome. (Fuelwood use data)
(EFNE) J.Molle; Euroforum New Energies, Proc.EEC Congress, Saarbrucken (1988), Publ. A.S.Stephens, Bedford, UK. (Biomass use data)
(BUN) Biomass Users Network & Skills Centre, Kings College London (see also Scurlock & Hall, 1990, above)

Table 2: The Regional potential for biomass production in a number of developing countries using only that land defined by the FAO to be suitable for agriculture and forestry as determined by physical, water and social constraints (see footnotes). Yields of 10 t/ha are not necessarily realistic on all land but are chosen to represent a convenient global midpoint for bimass production on a large scale in the future; in practice yields of less than 1 to more than 30 t/ha/yr are presently experienced.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI
REGION (112 countries Total)	TOTAL LAND AREA (Mha)	FORESTS & WOODLANDS (000 ha)	CROP LANDS (000 ha)	PASTURE (PERM-ANENT) (000 ha)	FOREST+ CROP+ PASTURE LAND (Mha)	"TOTAL POTENTIAL" AGRICULTURAL LAND FAO AEZ-CLASSIFED						PRESENT ENERGY CONS. (inc.FW) (10^6 GJ)	CROPLAND REQUIRED BY 2025** (Mha)	"REMAINING LAND" (col.XI- col.XIII) (Mha)	10 t/ha, BIOMASS ON "REMAINING LAND" (10^6 GJ)	% PRESENT ENERGY CONS-UMPTION
						LOW RAINFALL ('000 ha)	UNCER. RAINFALL ('000 ha)	GOOD RAINFALL ('000 ha)	PROBLEM LAND ('000 ha)	NATURAL FLOODED ('000 ha)	TOTAL (Mha)					
*DEVELOPING	6,448	1,995,501	724,082	1,546,015	4,266	108,412	297,161	547,343	1,452,016	313,785	2,719	53,746	1,086	1632.594	244,889	456
AFRICA	2,935.5	682,561	200,276	742,180	1,360	57,219	156,765	268,767	486,060	121,105	1,090	12,055	300	789.502	118,425	982
LATIN AMERICA	2,016.5	961,273	179,441	570,752	1,702	11,844	54,935	198,402	762,237	131,342	1,159	16,824	269	889.5985	133,440	793
C. AMERICA	264.8	65,605	37,868	94,002	195	1,048	16,141	28,083	46,772	8,754	101	5,998	57	43.996	6,599	110
S. AMERICA	1,751.7	895,668	141,573	476,750	1,507	10,796	38,794	170,319	715,465	122,588	1,058	10,826	212	845.6025	126,840	1,172
*ASIA(-CHINA)	1,495.6	351,667	344,365	233,083	945	39,349	85,461	80,174	203,719	61,338	470	24,867	517	-46.5065	-	-

* does not include China CONS. = Consumption FW = Fuelwood and Charcoal only.

NOTES:

"TOTAL POTENTIAL" Land is defined by the FAO as land which is phsically capable of crop poduction within soil and water constraints. It excludes land which is too steep, dry or with unsuitable soils.

**-IPCC III, calculates that demand for cropland in developing countries will increase by 50% by the year 2025. Present cropland area (col.III) from the FAO "Production Yearbook, 1989," is therefore increased by 1.5 times to give future likely land area under cultivation.

The regional classifications used here miss a total of 50 countries including China, South Africa and much of the Carribbean whose combined population is over one billion people.

China is not included in the developing country totals.

This table highlights the need for detailed local level data and the benefit of greater disaggregation of global data collection. A direct comparison of the FAO's "Production Yearbook, 1989," land classification (Col.V) and their new "AEZ, Agriculture Towards 2010, 1992," inventory (Col. XI) shows moderation of predicted land requirements for biomass energy. Thus using Col.V data & assuming a 10 t/ha yield would provide Botswana with over twenty times their present energy requirement. However, if Col.XI data is used the figure drops to a far more realistic level of about one fith present energy requirements if ONLY "good" land is used. In some countries, however, notably India and Bangladesh, predictions for potential biomass supply come well below recorded values eg. Bangladesh now obtains about 80% of its present supply from biomass and India abour 50% cf. 28 & 25% for respective predicted values. This is due to the high level of agricultural residue use which dominates the domestic supply scene.

The negative land area of -47 Mha for Asia (-China) assumes no increases in productivities to the year 2025 as it is only a linear extrapolation of existing food production trends.

In India for example, there are extensive areas of degraded land (150 Mha) which could be productive for biomass growth given appropriate policies.

ASSUMPTIONS:

1 Tonne of Oil (TOE) = 42 GJ, 1 GJ = 10^9 joules.
BIOMASS/FUELWOOD = 15 GJ/t (air dry 20% moisture)

SOURCES:

Cols. I-V from FAO; "Production Yearbook, 1989." Rome.
CROPLAND = Arable & Permanent Cropland, FORESTS & WOODLANDS = Forests & Woodlands, PASTURE = Permanent Pasture (FAO definitions, 1990).
Cols. VI-XI; data from FAO, (1992) "AEZ; New Inventory, AT2010" Fischer G., & van Velthuizen H., Rome.
-"Total Potential" agricultural land definition (see above)
Col. XII; Total present energy use; commercial + Fuelwood ONLY (FAO, "Forest Products Yearbook, 1989." Rome.)
Col. XIII; Cropland required by 2025, assumes a 50% increase in demand for cropland in Developing Countries (ref, IPCC-III) and no change for Industrialised countries. (therefore, col.III * 1.5)

Table 4. Global Land Use 1882-1989.

	1882		1981		1989	
Category	Mha	(%)	Mha	(%)	Mha	(%)
Arable Land	860	6.6	1,469	11.2	1,477	11.3
Grass-Land	1,500	11.4	3,172	24.3	3,304	25.3
Forest Land	5,200	39.8	4,090	31.3	4,087	31.3
Other Land[a]	5,517	42.2	4,346	33.2	4,208	32.2
Total[b]	13,077	100	13,077	100	13,077	100

Source: FAO Production Yearbooks 1982 & 1990.

[a] "Other Land" includes, desert land, stony, rock and steep land in mountains, ice caps (polar regions).

[b] Does not include water covered land such as lakes, rivers and marshes.

Potential Land For Reforestation

Source	Total Available Area Mha	Comments
Houghton & Woodwell[a] (1989)	**850**	**350** Mha of which "could be returned to fores if permanent agriculture were to replace shifting cultivation
Grainger[b] (1988)	**758**	**2007** Total degraded tropical land area of which available land area is estimated at: **203** Fallow Forests **137** Logged forests **87** Deforested watersheds **331** Desertified Drylands
Myers[c] (1989)	**300**	**200** Mha "needs reforestation for reasons other than the Greenhouse effect. **160** Mha of the **200** Mha above, from upland watersheds which urgently need reforestation, the rest required as woodlots.
Massoud[d] (1979)	**1,000.5**	Based on UNESCO soil map of the world (1973), Massoud estimates the total land area affected by soils by region. Definitions of the levels of salt and its effect on plant growth are species and climate dependant and should be treated with caution.
Alpert *et al.*[e] (1992)	**952**	Estimated as the total area available for halophyte culture. **125** Mha of the above is assumed to be feasible due to restirictions for saline irrigation.
Bekkering[f] (1992)	**385** (11 Tropical countries)	Theoretical land available in 11 Tropical countries out of 117 estimated to have excess land available when Forest area is considered as unsuitable, and agricultural land is also subtracted.
NaKicenovic *et al.*[g] (1993)	**265**	**84.5** Mha extra is considered as available for agroforestry. Global estimate, which distinguishes between land considered "suitable" and that which is likely to be "available."

Sources.
[a] Houghton & Woodwell (1989).
[b] GRAINGER (1988).
[c] Myers (1989)
[d] Massoud (1979)
[e] Alpert *et al.*, (1992)
[f] Bekkering, (1992)
[g] NaKicenovic *et al.* (1993)
Synthesised by J.Woods.

TABLE 7. 23 August 2005

EVOLUTION OF CHARCOAL CONSUMPTION IN BRAZIL.

('000 m^3)

YEAR	CHARCOAL FROM NATIVE FORESTS	%	CHARCOAL FROM PLANTED FORESTS	%[a]	TOTAL
1978	13,317	88	1,833	12	15,150
1979	15,116	87	2,184	13	17,300
1980	16,866	85	2,777	15	19,644
1981	15,577	81	3,654	19	19,230
1982	14,929	80	3,732	20	18,660
1983	18,423	82	4,087	18	22,510
1984	24,597	83	5,010	17	29,607
1985	26,085	83	5,501	17	31,586
1986	29,049	82	6,065	18	35,114
1987	27,726	81	6,624	19	34,349
1988	28,563	78	8,056	22	36,619
1989	31,900	71	12,903	29	44,803
1990	24,355	66	12,547	34	36,902

Source: (ABRACAVE, 1990 & 1991)

[a] Decree No.97.628 (of 12/4/89) reqired that the percentage of charcoal to be obtained from plantations must be as follows:
1989 = 40%
1990 = 50%
1995 = 100%
However, the same decree allows the production of 20% of charcoal from forest residues and hence in actual practice the maximum amount of charcoal to be produced from plantations would not be over 80% of total, as from 1995 onwards.

Table 8: SOME USES OF BIOMASS RESIDUES.

Source	Type	Use as Domestic Fuel	Industrial Uses	Competitive End Uses	Suitability for Transport	Future Availability
Coconut	Fuelwood		Bricks, tiles; Bakeries	Construction (15)	Good	Stable
	Shells	Ironing	Charcoal	latex cups (20)	Fair	Stable
	Husks	Cooking		Fibre (20) Fertiliser (80)	fair	Stable
	Leaves	Cooking		Cadjans (20)	poor	Stable
Natural Forest	Fuelwood Charcoal	Cooking	Bricks Tiles Bakeries tea rubber coconut hotels Pig Iron		Good	Declining
Rubber	Fuelwood	Cooking	Bricks Tiles Bakeries Tea Rubber Coconut Hotels		Good	declining
Home Garden	Fuelwood Shells Husks Leaves	Cooking Ironing Cooking Cooking		Poles (5) Fertiliser (100) Cadjans (15)	Fair Poor Poor Poor	Rising Rising Rising Rising
Tea	Fuelwood Biomass	Cooking Cooking	Tea	Fertiliser (20)	Fair Poor	Rising Rising
Palmyrah	Fuelwood Biomass	Cooking Cooking		Thatching Fencing (30)	Good Poor	Rising Rising
Cinnamon	Fuelwood	Cooking		Vegetable sticks (?)	Good	Rising

[a] Source: Howes (1989).

[b] Estimated percentage consumed by alternative end use in parentheses.

Table 11. SELECTED SUGARCANE AND PLANTATION WOOD FEEDSTOCK COSTS IN VARIOUS DEVELOPING COUNTRIES

Country	Feedstock Costs in US$/GJ			Electricity Production Costs c/kWh[e]	
	Sugarcane		Plantation Wood	Technology	
	Tops & Leaves	Bagasse		CEST	STIG
Brazil[a] (1992) constant 1988 US$	1.19(CEST)[f] 1.49(STIG)	1.18 (CEST) 1.68 (STIG)	1.09-3.17 (for the Northeast Region.)	13.45-7.06	6.70-4.40
Thailand (1990)[b]	1.68-1.45	-	-	-	-
Costa Rica (1988)[c]	0.95-1.42	0.28-1.10	2.51-3.17	4.8-5.1	4.1-4.0
Jamaica (1985)	0.58-2.02	0.97-2.21	1.00-1.50	4.8	-

Source: Tugwell *et al.* (1988).

[a] Costs of both the biomass feedstock and electricity vary as a result of predicted increases in productivity from the present (52 t/ha/yr) to future sugarcane yields (71 t/ha/yr.) The efficiency with which the tops & leaves are collected is also predicted to improve from about 50% of total production presently to about 75% of total production in the future with further gains limited for environmental reasons.
Ethanol in Brazil now (1992) costs about US$7.9/GJ or an average 18.5c/l.

[b] These prices are competitive with oil costing US$ 2.19/GJ or US$19/barrel.

[c] Costs vary here due to increasing transport distances; even at further distances sugarcane residues are competitive with fossil fuel alternatives estimated to cost (constant 1985 US$): US$2.45-3.84/GJ for fuel oil, US$2.35-3.09/GJ for imported coal and US$3.79-4.22/GJ for indigenous coal.

[d] The cost (1985 US$) of sugarcane residues is dependant on the processing technology, with briquetting generally costing less than pelletizing. In Jamaica, also, the costs of biomass fuels are competitive with fossil fuels: residual fuel oil, US$2.9-4.00/GJ; Distilled fuel oil, US$5.4-7.50/GJ; and imported coal, US$1.43-2.08/GJ.

[e] Electricity costs are estimated from the feedstock costs of the biomass. For sugarcane residues the feedstock is derived from both the tops & leaves and bagasse produced from crushed sugarcane.

[f] CEST stands for Condensing Extraction Steam Turbine which is a robust and mature technology of relatively low efficiency (25-35%) compared to STIG (Steam Injected Gas turbine, about 40% efficient).

Table 12 1994

Main characteristics of a Typical Charcoal kiln[a]

Kiln diameter volume (base)	5m
Nominal kiln volume (wood)	36 - 44 steres (1)
Operating cycle	
Loading	4 hrs (2 men)
unloading	5 hrs (2 men)
Carbonization	96 hrs
Cooling	96 hrs
Yield	
Charcoal (db)	33% (in weight)
Volumetric conversion efficiency rate.	1.8 - 2.0 steres per 1m^3 charcoal(2)
Wood humidity.	25 - 30%
Charcoal production efficiency.	1.8-2.4stere/ha/yr
Useful life of kiln.	4 years
Annual charcoal production (appx).	5,400 m^3
Volumetric efficiency charcoal to pig iron.	4.2-3.2 (3)

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[a] Source: Rosillo-Calle *et al.* (in press)

notes

(1)Between 21.7-26.5 m^3 (1m^3 =1.66 steres) However, this ratio varies in practice according to the type of wood- e.g. one stere of dry eucalyptus wood is about 0.6 m^3, although this is not always the case.

(2)The volumetric conversion efficiency rate varies considerably, depending on the type of kiln, management, wood characteristics etc. Efficiencies of 2.2-1.6 are also common.

(3)Volumetric efficiency charcoal to pig iron depends on many factors - from charcoal quality (eg density to the type of the pig iron kiln. In the most modern kilns efficiencies of up to 2.6 m^3/charcoal per one tonne of pig iron have been achieved. In the future an efficiency of 1.9 m^3 charcoal (and even better) can be expected to be achieved.

Sources:
Rivelli Rezende (1989), Neto (1991), Grupo Itaminas (1989).

Table:15 1994

Hosahalli (S.India). Wood Gasifier Based Electricity Generation.

	Capital cost of 5 kW wood gas-based and diesel system (Indian Rupee's[a])	
	Woodgas System	Diesel-only System
Gasifier[b]	16,000	-
Engine + Genset[c]	28,600	28,600
Voltage Stabiliser + Accessories	6,000	6,000
Wood Cutter	3,000	-
Building	5,000	5,000
Energy Forest	5,000	-
Total	63,600	39,600

Source: Ravindrinath (1993).

[a] The 1992 exchange rate is assumed to be Rs. 25 = US$1.

[b] Life of gasifier is taken to be 50,000 hours and maintenance cost is taken as 5% for an operation level of 20 hours a day.

[c] Life of the engine is taken to be 20,000 hours and the annual maintenance cost is taken as 10% for 20 hours of operation a day.

Table 16: 23 August 2005

Compositional data and heating values for biomass and coal (dry basis).[a]

Feed stock	**Proximate analysis percent by weight**			**Ultimate Analysis Percent by Weight**						HHV	kg N per GJ	kg C per GJ[b]
	Volatile	Fixed carbon	Ash	C	H	O	N	S	Ash	GJ/t		
Biomass												
Red Alder	87.10	12.50	0.40	49.55	6.06	43.78	0.13	0.07	0.41	19.30	0.07	25.7
Black Locust	80.94	18.26	0.80	50.73	5.71	41.93	0.57	0.01	1.05	19.74	0.29	25.7
Poplar	82.32	16.35	1.33	48.45	5.85	43.69	0.47	0.01	1.53	19.38	0.24	25.0
Douglas fir	87.30	12.60	0.10	50.64	6.18	43.00	0.06	0.02	0.10	20.37	0.03	24.9
Casuarina	78.94	19.66	1.40	48.61	5.83	43.63	0.59	0.02	1.59	19.44	0.30	25.0
Euc. Grandis	82.55	16.93	0.52	48.33	5.89	45.13	0.15	0.01	0.49	19.35	0.08	25.0
Leucaena	80.94	17.53	1.53	49.20	6.05	42.74	0.47	0.03	1.51	19.07	0.25	25.8
Sugarcane Bagasse	73.78	14.95	11.3	44.80	5.35	39.55	0.38	0.01	9.91	17.33	0.22	25.8
Coal												
West Kentucky bitumin-ous	33.12	48.18	18.7	65.78	4.62	4.86	1.26	4.74	18.4	27.81	0.45	23.6
Illinois No. 6 Bitumin-ous	37.50	43.40	18.1	65.34	4.20	6.59	1.02	4.55	18.3	26.67	0.38	24.5
Wyoming subbitum-inous	44.68	46.12	9.20	68.75	4.89	15.55	0.89	0.69	9.24	26.78	0.33	25.7
East Texas Lignite	44.55	38.86	16.6	60.98	4.45	15.82	1.08	1.08	16.6	24.36	0.44	25.0

a. Williams & Larson (1993)
b. calculated from data in table.