BIO-ENERGY AND THE ENVIRONMENT

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Abstract

Climate change, environmental degradation, agriculture decline burdened with heavy socio-economic implications and increasing energy needs for sustainable development and economic growth, have stimulated a frenetic search for acceptable solutions to improve this critical situation. Biomass production and utilization for energy has given rise to many discussions for its environmental impact. This paper presents a point of view that bio-energy could assume sustainable environmental features for our future.
The principal arguments of this paper are: bio-energy system and carbon emission —including confrontation of CO_2 emissions between a biomass electricity closed system and a coal-.based electric generation system —, soil erosion, fertilizer use, pesticide use, and biodiversity.

Résumé

Le changement du climat, la dégradation de l'environnement, le déclin de l'agriculture sont aggravés de lourdes implications socio-économiques et d'un accroissement des besoins en énergie pour un développment soutenu et pour la croissance économique. Ceci a stimulé une recherche acharnée de solutions acceptables pour améliorer cette situation critique. La production et l'utilisation de la biomasse pour l'énergie a suscité de nombreuses discussions quant à son impact sur l'environnement. Cet article présente le point de vue selon lequel la bioénergie est à même de présenter des caractéristiques environnementales dans le futur.
L'article défendra les arguments suivants: le système bio-énergetique et les émissions de carbone — en ce compris la comparaison des émissions de CO_2 entre les systèmes de production d'électricité par la biomasse et par le charbon — l'érosion des sols, l'utilisation des fertilisants, des pesticides, et la biodiversité.

Biomass appears to be an attractive resource because of its potential for energy supply: it could be the source of 30% of the world's energy by the middle of next century (IPCC, 1991). At the present time it provides 14 % of the primary energy supply and represents the fourth major source of energy in the world (2.5% in the European Community (EC); 15% Sweden; 4% in the U.S.A.; 7% Canada; 35% in developing countries; etc.) (1).

Recent interest in biomass derives from benefits in agricultural diversification and land management, sectoral integration, balance of trade and socio-economic improvement of depressed rural areas.

In the last few years, because of increased attention being paid to nature's decline and climate changes, the low environmental impact possibilities of the biomass system have made it seem more and more attractive, with a wide consensus calling for supplementary investigations on suitable and un-suitable effects of exploiting this renewable resource.

Some general environmental criticism against large scale biomass energy production and utilization schemes focus on the following points:

— Carbon balance would not be favorable
— Soil degradation is increased by increased erosion
— Excessive use of fertilizers and pesticides required
— Loss of biodiversity.

First of all in this paper it is assumed that in all scenarios forecasted, closed biomass energy systems respect sustainable development principles, that is, biomass energy not only provides significant amounts of uncontaminated vegetal resources, but also contributes to socio-economic improvement and takes into account all the necessary constraints imposed on the carrying capacity of the environment (2).

Carbon balance

In most modern, innovative, closed biomass systems, the global energy balance can be largely positive; that means, there is no contribution to the carbon build-up in the atmosphere. Most of the atmospheric CO_2 absorbed during the growth of biomass, is again released into the atmosphere during its conversion and combustion processes. Therefore, if biomass energy is used as a substitute for fossil fuels, there will result a net reduction in atmospheric concentration of CO_2.

This is supported by several detailed scientific studies. Some argumentation is reported in the following sections.

There are two options for affecting greenhouse gases through vegetation/land use management.

The first is to collect and store for long term (100 years) atmospheric carbon in forests through the photosynthetic process (3).

The second option is to grow and use biomass for energy in an endless cycle of atmospheric carbon «put and take» (4). High productivity biomass systems would require less land and reduce the forest areas needed for accumulating carbon, thus, saving forests in developing countries.

Results of a Peruvian study (5) show that large areas of forest clearing could be avoided by introducing sustainable new agricultural practices: biomass energy crops avoid forest clearing. In industrialized countries, biomass plantations may be located primarily on lands producing excess food. In developing countries these plantations may be located primarily on marginal, deforested or degraded lands not suitable for food production.

The well-known study on climate change by IPCC (6) concludes that the end use of fuelwood biomass, from a sustainable well managed short-rotation forestry (S.R.F.), can produce net reductions in CO_2.

In a recent study (7) for Shell International Petroleum Ltd., the carbon storage potential of forests was compared with the potential of energy plantations (S.R.F.). If a plantation is not cropped, carbon would continue to accumulate over the full time scale (hypothesized at 50 years), with a carbon cycle impact of about 400 tonnes/ha in 50 years - leveling off only after a century or more. If a plantation is cropped to generate electricity instead of using coal-based power plants, after 50 years the carbon stock is of about 200 tonnes/ha. The fertilizers and diesel fuel used to grow, irrigate and harvest the biomass have been taken into account. The conclusions of the study have been: «The biomass power option would have a larger carbon cycle impact than the carbon storage option in the medium-term as well as long in the long term».

Also, even in the case of ethanol derived from food crops (wheat, corn, sugar beet, etc.) used as an additive (5% in a mixture with gasoline) for transportation in unmodified engines, the CO_2 emissions from agricultural practices, to ethanol production and utilization, still presents a small advantage (e. g., decrease of 0.25% of the CO_2 emission in the European transport sector if 5% of total transport fuel is substituted) (4) compared to the use of 100% fossil derived gasoline

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In the best cases, 7-8 tonnes oil equivalent (T.O.E.) of fossil fuel consumption (e.g., for electricity generation) could be replaced by one hectare of cultivated area using new high-yielding C4 plants (high photosynthetic efficient annual crops), or woody plantations (S.R.F.).
New energy crops require less energy inputs than comparable conventional food-crops and could considerably dent the overall CO_2 emissions (8, 4).
Direct combustion of short rotation forests (taking into consideration harvesting and processing energy needs) will result in a net sequestration of up to 160 tonnes of CO_2 per GWh of power generation (9).
Energy crops grown on cropland offer the greatest benefits for long-term carbon reduction from fuels such as coal, oil, or natural gas.3 For example, an evaluation of U.S. carbon sequestration potential is about 1 to 2 billion tons (one American ton = 0.90718 metric tonnes) over a 20 to 30 year period. In contrast, 0.25 billion tons per year of net carbon emissions could be avoided using energy crops instead of fossil fuels (10).
Some estimates of global annual deforestation rates are over 15 million ha of land, where the estimated carbon release in the atmosphere is in the likely range of 1.5-3.0 Gt. (1)
Most of the time, these forests are never replanted so that the quantity of the carbon emitted by the combustion of wood increases atmospheric carbon stock.
For comparison, well managed forests and energy plantations can recycle atmospheric carbon indefinitely provided the biomass is grown on a continuous and sustainable basis and is then used in place of fossil fuels (4).
A study prepared for UNSEGED (United Nations Solar Energy Group for Environment and Development) by Johansson, Kelly, Reddy and Williams (1993)11 shows interesting economic possibilities in a scenario which hypothesizes the entire substitution of actual electricity generation (coal — 80% — and gas — 20% —) in Northern California, by biomass (45%), gas (about 4%), hydro (21%) and intermittent renewable sources (30%). The carbon emissions in this case would be 98% less than the conventional case.
Among electricity generating technologies, biomass from wood wastes/regrowth presents a CO_2 emission value close to zero metric tons of CO_2 per GWh generated. Geothermal, large hydro and solar thermal, represents between 2 to 5 tonnes/GWh; photovoltaic, wind and small hydro, is between 5 to 10 tonnes/GWh. The current fuel mix is over 600 tonnes/GWh. (12, 13)
Soil organic carbon is an important and complex issue. With respect to land use and biomass resource management, it is clear that any amount of biomass removed from the ecosystem will cause a proportional decrease in soil organic carbon. Also an establishment of bioenergy plantation will cause an increase of carbon storage in the soil (14) (mostly from the roots). The carbon soil flows need more study to quantify the contribution from different sources.
At present we know that the carbon stock in the soil amounts to 1,500 Gtonnes plus about 1,000-5,000 Gtonnes of carbon from fossil fuel. The carbon flows of the world biomass to the soil is about 60 Gtonnes/year and the soil releases about 65 Gtonnes carbon/year into the atmosphere (15).
The decomposing process of leaves, branches and roots, for some regions in the world, contributes most to the increase of carbon in the environment, and ought to be monitored attentively.
The ocean contributes to the control of carbon build-up in the atmosphere: it absorbs 102 Gtonnes, releasing 100 Gtonnes of carbon every year. The total carbon stock accumulated in the ocean is estimated to be 36,000 Gt.
A tonne of biomass during its life absorbs and releases about 1.6 tonnes of CO_2 (94-95 kg CO_2/GJ) including when biomass is burned. Also during photosynthesis 1.2 tonnes of O_2 (70 kg O_2/GJ), derived from the chemical splitting of water, is emitted into the atmosphere by biomass. The «vital role» of biomass is derived from O2 being constantly emitted. In the case of bioenergy systems, the O_2 provided by biomass is reutilized during its combustion without depleting the existing atmospheric oxygen stock. This is an important aspect that should be always considered.
Energy balance is a general indicator of carbon emissions.
In the new concept of a biomass integrated closed system for advanced electricity generation based on new energy crops, which takes into account all energy input requirements, from production through harvesting, transportation, drying, pretreatment, and conversion to utilization, the system shows energy ratios (output/input) which are largely positive (see Table 1 and Figure 4) (16).
A general discussion about other emissions is needed here. Pollutant emissions are sensibly reduced if new biomass energy products and suitable advanced technologies now available, are employed.
Liquid fuels from lignocellulosic materials (produced, for example, by «flash pyrolysis» conversion technology) contains less than 0.01 % of «S»: therefore sulfur emissions during combustion are inconsistent (17). These bio-fuels, if burned efficiently and completely, would emit low quantities of CO, NO and NO_x (50 ppm) (13).
The alkalis content in feedstock, which cause negative effects during conversion and fuel use, should be monitored and reduced by improvement in breeding and by improved conversion/use methods.
If biomass is used in a developing integrated biomass gasification (BG) technology (such as BG/combined cycle for electricity production) air pollutant emissions do not substantially differ from natural gas fired/combined cycle.

A specific example: bio-electricity vs. coal electricity

New biomass thermochemical conversion technologies such as integrated gasification with aero-derived gas turbine-steam turbine combined cycle (B/IGCC) or simple cycle (BG/GT) have just begun to be developed (e.g., Sweden is building a ~50 MWe B/IGCC, mostly using wood biomass, and Brazil a ~30 MWe B/IGCC, mostly using eucalyptus trees and in future also sugar cane bagasse) with some commercial application.
For the hypothesis which follows, this technology has been considered, in a fiber sorghum biomass electricity closed system.
The amount of CO_2 emissions, which are referred to this bio-electricity system, is emitted during the early establishment phase of the system. In the second phase, CO_2 emissions are reduced or eliminates depending on how much biomass electricity and bio-fuels (as well as other renewable energy resources) are substitute for fossil fuels employed to grow, harvest, pretreat and transport biomass.
From the data shown in **Table 1**, the results highlight that one hectare of biomass could produce 33,082 kWh/year (1654.1 kWh/tonne per year). An equivalent of 297.5 GJ of coal, with 40% plant efficiency [represents a 20-23% improvement over conventional coal units which should be feasible in the years 2000 by Coal/IGCC repowering (Sigel and Temchin, MIT ed., 1991) (18)], is needed to produce the same amount of electricity (33082 kWh).
Considering an emission factor of 94 kg CO_2/GJ (NOVEM, 1992) (19) for coal used in electrical generation (O.K. Sonju, IEA ed., 1991 (20), reported an emission factor of 103 kg/GJ) the CO^2 emissions from coal power generation will be 27965 kg/33082 kWh (about 0.84 kg/kWh). The CO_2 emissions from biomass system (**Table 1**) are 4072.6 kg/33082 kWh (about 0.12 kg/kWh)
Using biomass electricity instead of coal, the avoided CO_2 emissions are, in this case, about 23,892 kg (27965 kg minus 4073 kg. See also note **Φ** in **Table 1**).
Assuming that a 50 MWe biomass integrated gasification combined cycle conversion plant will be utilized at 6000 hrs/year operating time, 181,367.5 dry tonnes of biomass will be needed over a one year period for full power operation (plant capacity: ~30.2 tonnes of dry biomass per hour). This amount of biomass requires about 9070 ha of land.
The CO_2 emissions from the biomass closed cycle in the above hypothesized scenario (9070 ha and 50 MWe B/IGCC unit for electricity production) will be 36,938 t/year. To produce the same quantity of electricity the CO_2 emissions from a coal electric utility generating unit will amount to 253,597 t/year. The difference in CO_2 emissions represents about 216,000 tonnes.

Figure 1 is a comparison of CO_2 emitted between coal and biomass power generation (50 MWe/year during 20 years life time of the plant).

Table 1 and **Figure 2** show CO_2 emissions from one hectare of fiber sorghum during a cultivation cycle.

Soil erosion

Soil erosion is an important world wide problem. Europe alone loses about one billion tons of soil each year and about 15 millions hectares of European Community land are threatened by this phenomena (23, 24). The developing world is losing up to 20 million hectares of productive land due principally to erosion. Most soil erosion is ascribed to the impact of human activity on the environment. This includes deforestation without any re-plantation (in Asia the ratio between number of trees deforested and re-planted is 25/1!) and intensive agriculture, especially pastures.

Table 1 ***Biomass electricity closed system: energy and CO_2***
(Data are referred to one hectare~ of fiber sorghum⊗ per year).

Stages	Topics	Quantity+[16]	Energy Factors MJ/unit[16]	Energy Input GJ[16,19]	Energy Output GJ	CO_2 Emiss. Factors[19] kg/GJ♦	CO_2 Emiss. kg
PRODUCTION©	N	180 kg	65	11.70		56	655.2
	P_2O_5	80 kg	15.5	1.24		56	69.5
	K_2O	100 kg	8.6	0.86		56	48.2
	Ins./herbicides	2 kg	760	1.52		77	117
	Irrigation	1500 m^3	0.5	0.75		73	54.9
	Machines Op.	15 hr	173.3	2.60		73	198
HARVESTING	Harvesting	2 hr	1750	3.50		73	255.5
PRE-TREATMENT	Drying∝	20 t&	175	35.00		73	2555
	Pelletization	20 t	66.5	1.33		73	97.1
TRANSPORT△	Transport	7.6 Km	40[19]	0.30		73	22.2
CONVERSION IN ELECTRICITY#	Biomass	20 t&	17000	—	119*	-F	-F
TOTAL				58.8ϴ	119Ξ		4072.6Φ

~ A North Mediterranean pedo-climatic condition is assumed.
⊗ Productivity: 20 dry tonnes/hectare per year.
© Machine operation data include: ploughing, seed bed preparation, fertilization, seeding, weeding, pesticide treating, movement of equipment & materials, & lubricants.
+ The highest quantities are considered in this column for fertilizers.
♦ Fertilizer production emission factor corresponds to natural gas based fertilizers industry; for insecticides and herbicides are referred to petrochemical based pesticides industry; all other emission factors correspond to diesel fuel use.
∝ Including pressing.
& Dry tonnes (10% humidity).
△ 9070 ha is the production area (A=90,700,000 m^2) where the processing plants are located at the center. The mean farm-to-plant radial distance (d) is computed as: $d=\sqrt{\frac{A}{2p}}$, where p=3.1429.
Twice d is the mean round-trip value used.[21]
\# Integrated biomass atmospheric gasification with gas turbine-steam turbine combined cycle (B/IGCC).
* From 35% net efficiency of the conversion plant (38-40% can be achieved by the year 2000).
Φ The CO_2 emitted at this stage has been taken up by plants in the growth process. The CO_2 emitted by decomposition of residuals left in the field during harvest and during crop storage is equally assumed to be recycled each year back into the growing feedstock.
ϴ Some authors report that energy requirements for sorghum could decline by about 30%/dry tonne under future production methods.[22]
Ξ The energy ratio is 2; the energy balance is 60.2 GJ/ha.

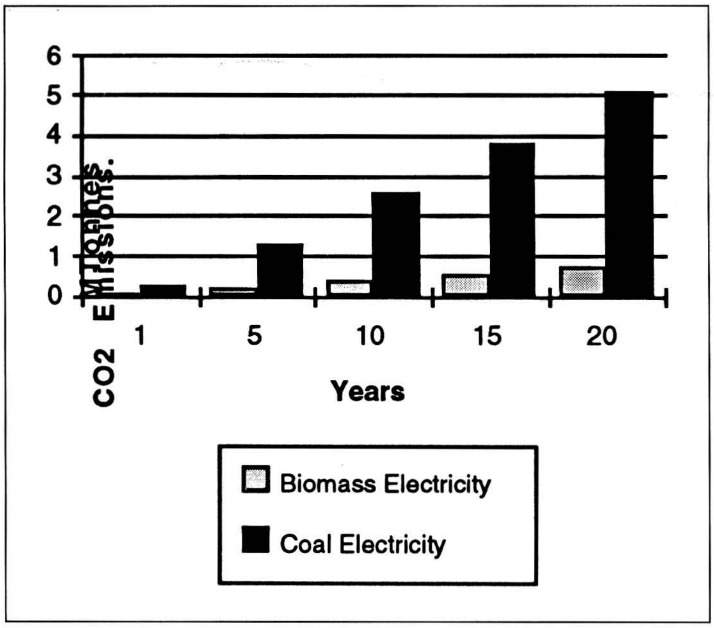

Figure 1 - CO_2 emissions comparison between fiber sorghum and coal in electric power generation (50 MWe).

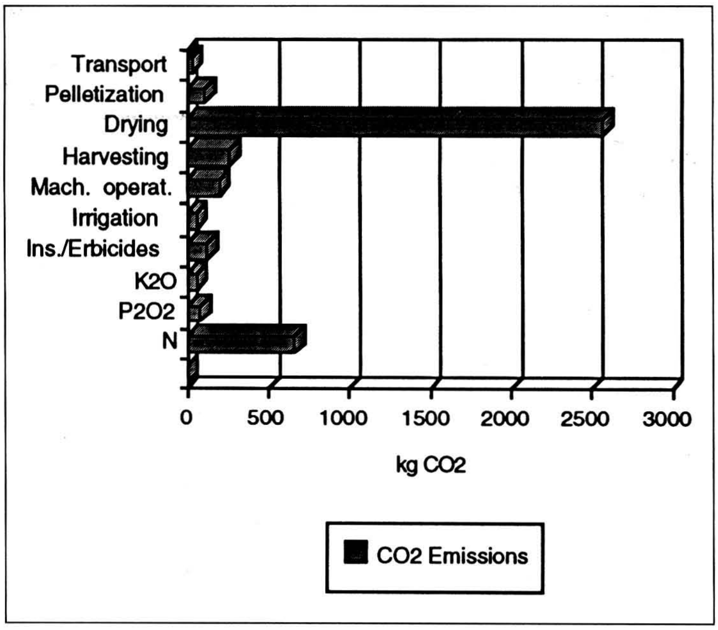

Figure 2 - CO_2 emissions per year by one ha of fiber sorghum.

Soil erosion is the result of many processes and soil characteristics including the relative degree of infiltration, topography, raindrop impact, run-off scouring and run-off transport capacity (25). Climate, including the distribution of rain throughout the year and the return period of erosive rains, vegetation and land management, intervene as primary influences and co-factors in determining soil erosion patterns and intensities (26).
Herbaceous bio-energy crops can increase soil erosion, due principally to intensive planting and harvesting activity, especially in certain lands (e.g., the erosion rate for corn is about 21 tonnes/ha/year). For those crops, cultivation methods as «minimum tillage» improves soil structure stability and, as a consequence, controls erosion incidence.
For perennial grasses the average erosion rates are low because planting is so infrequent; for highlands the erosion is even lower (about 0.2 tonnes/ha-year) (25).
Woody crops can contribute significantly to structural soil restoration. The annual rate of soil erosion can vary considerably from 2 to 17 tonnes/ha. Such rates may be reduced by the use of a groundcover or weed strips between tree rows or by other similar agronomic methods. Generally speaking, total annual erosion for S.R.F. would be as high as for herbaceous crops, like corn, during the first three or four years of the plantation; but it would be lower in all following years, until re-planting occurs (after 20-25 years).
According to Mitchell (1992) (27), the impact of S.R.F. on soils is strongly determined by the quality of management.
The beneficial factors in the case of well managed tree energy plantation, are due to:
a) disintegrating action by the roots;
b) physical and chemical effects from the decomposition of plant residues;
c) protection of the soil from the eroding action of the rain and wind;
d) protection of the soil from run-off effects.
A good and sustainable biomass energy production activity improves soil characteristics through better land use especially in areas which have been excessively exploited and/or abandoned.
The main results will be:
— soil erosion control
— improvement of the water infiltration, retention and atmospheric water cycling
— improvement of soil fertility
— reduction of fire risk
— increase of photosynthetic performance through the improved fertilizing stock
A combined action between sustainable crops and correct agronomic practices (i.e. minimum or no-tillage, controlled traffic, microdrains, furrow dikes,...etc.) can have positive synergetic effects against soil erosion (28).

Fertilizers and pesticides

Biomass, when grown intensively, may cause an increase of environmental damage if large quantities of chemical fertilizers (in particular nitrates) and pesticides are utilized.
Moreover, biomass by-products and waste may cause disposal problems and environmental hazards; their re-utilization could present difficulties. High yielding crops could cause significant variations in soil characteristics, if extended for a considerable period of time.
«Compost» (by forced humification) from biomass by-products would solve these problems, by disposing of the organic refuse and making available a humified product which would then be easy to handle and store, and which would increase crop production and contribute to the preservation of soil fertility (29, 16).
Another example of positive exploitation by the sustainable biomass systems, is the use of ash from bio-energy thermal conversion plants as an agricultural amendant and fertilizer. Biomass ash is alkaline, therefore has a pH-increasing effect, and is relatively rich in Ca, K (1-2%), Mg, Si, Fe, Al, and P (3-4%) (30). At the same time, there is growing interest in the utilization of sludge, waste water and leakage water as nutrients for energy plantations.
The choice of appropriate crops in rotation schemes and agricultural techniques could also be very helpful to minimize fertilizer and pesticide use.
Mixed cropping, interplanting with nitrogen-fixing species (e.g. actinorhizal trees), use of mycorrhizae fungi (which fix nitrogen), infrared radiometry monitoring (which permits knowledge of exact nutrient deficits), are only a few examples of useful agricultural techniques (30, 16, 31).
New C4 crops (e.g. miscanthus and sweet or fiber sorghum), are resistant to entomological attacks and present low fertilizer and water needs (up to 50% less than corn). Plants like Cynara Cardunculus (indigenous to the Mediterranean area and well adapted to dry conditions - e.g., no irrigation needs) does not require a nitrogen contribution during its first years of growth (32). These are examples of appropriate energy crops.
Nutrient losses to surface waters from biomass energy plantations are expected to be much less than those from agricultural lands they replace. Woody crops, for example, may require much less fertilization (and pest

management) if diverse set of plants are interplanted.
The application of herbicides, usually applied immediately after planting are required to control weeds. Herbicide applications are utilized for both tree plantation and conventional food-rowcrops (such as corn and soybeans) at about the same rates but, for tree plantation, herbicides after the initial two years would not be used again until seedlings are replanted after about 20-25 years (six harvests), in the case of S.R.F. However, there is a general consensus that insecticide use on forest cultivation would be too low to have any significant ecological impact (33).
Generally, well selected biomass crops require less pesticides than conventional food crops which need a great amount of pesticides during the ripening period.
According to an EC report (4), it can be concluded that some new high yield biomass (as C4 plants or improved wooden species for short rotation forestry method), requires much less fertilizers and pesticides than for traditional agricultural crops.

Biodiversity

«Biological diversity» encompasses all species of plants, animals, microorganisms and the ecosystems and ecological processes of which they are a part (34). Soil degradation by deforestation and monoculture is one of the main causes of loss of biodiversity. The relations between biomass energy and soil preservation have been presented in previous sections.
The impact of biomass energy on biodiversity is dependent, at the regional scale, on the measure in which the land is dominated by farmland, grassland, or forest.
Tree plantations could provide significant beneficial changes in regions dominated by land utilized for agriculture, highland, or pasture, providing for a greater number of microniches and a greater local biodiversity with some unique habitats for unusual species (30).
For example, significant increase can be expected in earthworm content, as well as in soil fauna, in poplar and willow stands, which were formerly soil of pine plantations (35).
The choice of appropriate crops and its management is important to biodiversity. In fact, inappropriate plantations will result in loss of biodiversity, but environmentally acceptable plantations which include such techniques as nitrogen fixation, genetic selection, breeding, species propagation techniques, etc., could produce worthwhile biodiversity preservation and other environmental benefits (36).
Furthermore, biomass is made up of a large variety of genetic cultures which, if judiciously, used need not result in difficulties (4), especially if continuous genetic improvement efforts are carried out.
The presence of organic matter in the soil

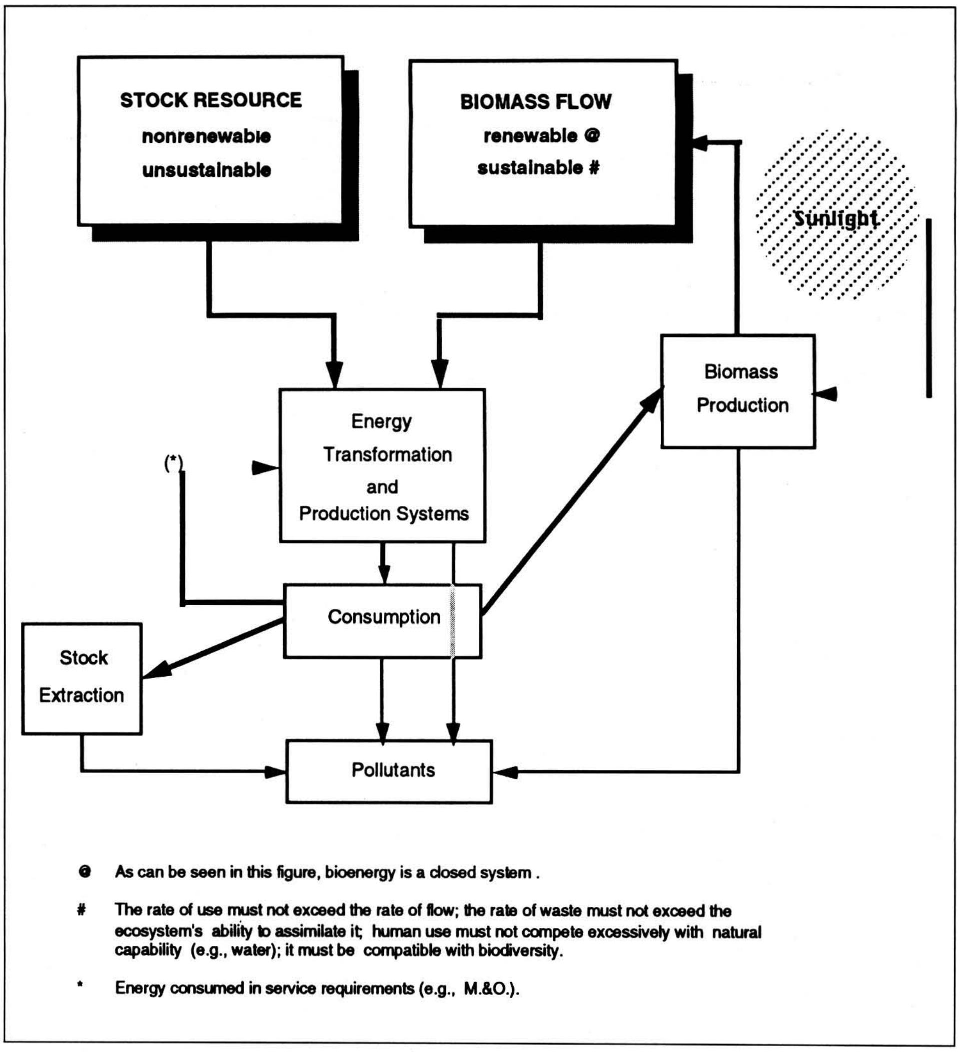

Figure 3 - Use of energy resources.

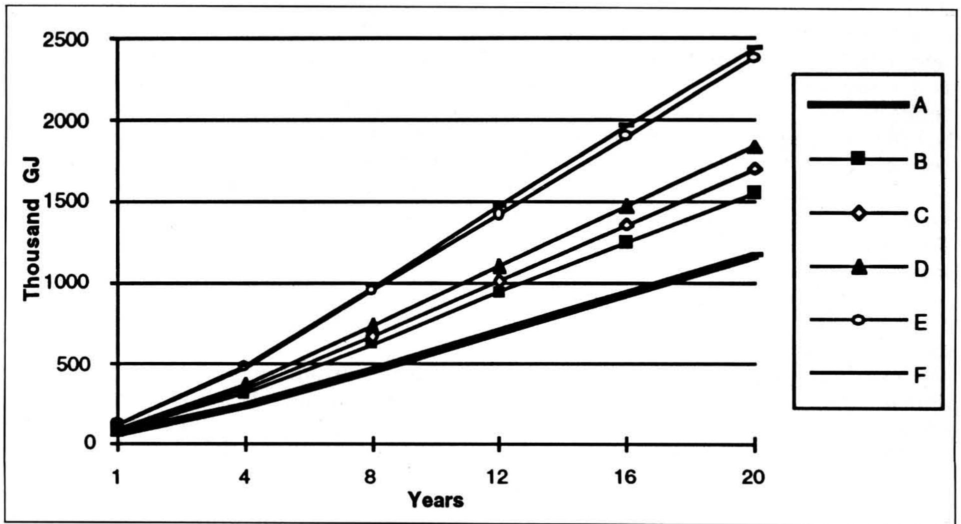

Figure 4 - Energy flow in some bioenergy system.

A: Inputs from 1000 ha of fiber sorghum energy system: 58600 GJ/year. This value differs from **Table 1** because the transport data has been modified to 1000 ha instead of 9070 ha in **Table 1**.
B: Output. Direct combustion in power station option: 23% net efficiency; 78200 GJ/year. Energy ratio: 1.33.
C Output. Pyrolysis oil fuelled in power station option: 23% overall efficiency; 85000 GJ/year. Energy ratio: 1.45.
D: Output. Pyrolysis oil fuelled in diesel power engines option: 27% efficiency; 91800 GJ/year. Energy ratio: 1.56.
E: Output. B/IGCC option: 35% net efficiency; 119000 GJ/year. Energy ratio: 2.03.
F: Output. Combustion/ceramic gas turbines option: 36% net efficiency; 122400 GJ/year. Energy ratio: 2.08.

promotes the increase of soil organisms and direct effects on metabolism and other processes. Biomass production systems can constantly recycle and/or add amounts of organic matter to soil and litter; therefore, biomass systems, established in degraded land, could provide excellent habitats for wild fauna.
However, the loss of biodiversity cannot be ascribed only to an eventual un-sustainable agro-bio-energy system. Human pressure on land and ecosystem, from food production to exploitation for industrial, chemical, mineral and energy resources, are all liable for damages to biodiversity in different proportions, depending on local situations. Globally, several technical and economic initiatives are needed in order to manage growing populations in a sustainable way and to meet demand of land for various human activities, assuring at the same time conservation of the environment and maintenance of biological diversity, which can be attained more by dynamic nature conservation rather than by strict and passive preservation.

Conclusions

If sustainable plantations and appropriate technologies are chosen, biomass energy closed system (**Figure 3**) could show the following environmental advantages:
— favorable carbon balance
— control of soil erosion
— low requirements for fertilizers and pesticides
— compatibility to biodiversity
There is no doubt that: a) adoption of biomass crops which are not compatible to the local environment, b) inappropriate agronomic interventions, c) indiscriminate use of fertilizers and pesticide, d) adoption of low efficiency and high pollutant, conversion/ utilization technologies,..... etc., can all give rise to an intensification of environmental damage.
In other words, the adoption of an unsustainable biomass energy open system, from biomass production to its process and utilization, could be the effects of a misunderstanding (and a big mistake) about a promising environmentally friendly sector.
It is important to make a comparison between bio-energy and fossil fuels resources (oil and particularly coal), also monitoring the quantity of CO_2 and other pollutants emitted during the extraction, mining, transport and processing (e.g. coal pulverization) of those conventional sources of energy.
Considerable amounts of CO_2 emissions can be avoided using biomass as a substitute for fossil stock resources: about 216,000 tonnes/year producing 50 MW of power. Favorable energy balances are achievable through new biomass conversion technologies (**Figure 4**).
A serious program for encouraging development of biomass energy on a small or a large scale, must include a careful investigation of all possible environmental aspects.
Definition of ecological guidelines and limitations, as well as adoption of specific regulations for bio-energy activities and strict controls of its application are suggested «in order to avoid environmental disaster and capture ecological opportunities» (3).
As a consequence of the horizontal dimension of biomass and considering agricultural needs, population growth, ecosystem and environmental degradation, energy deficit... etc., to which bio-energy may offer significant contributions, this sector is now located on a multi-interest/multi-policy area where the policy-makers begin to stir (37).
If the above strategic attributes are recognized, then some appropriate measures are needed to reduce the delay in the development and commercialization of bioenergy technologies in view of the urgency of such problems.
The first step is take measures to stimulate R&D and demonstration activities which would show the real potential and limits of this new sector. ●

References

(1) D.O. Hall, H.E. Mynick, Williams R.H. (1990): *Carbon Sequestration Vs Fossil Fuel Substitution*, CEES Report No. 255, Princeton University, NJ, USA.
(2) World Commission on Environment and Development (1987): *«Our Common Future»*, Oxford University Press, Oxford-New York, USA.
(3) J.W. Ranney (1992): *«Environmental Considerations in Biomass Resource Management for a Greenhouse-Constrained Society»*, Technologies for a Greenhouse Constrained Society, Edited by M.A. Kuliasha, A. Zucker and K. J. Ballew, Lewis Publishers, Chelsea, Michigan, USA.
(4) D. Wright (coordinator) et al. (1991): *«Biomass - A New Future?»*, Interservice Working Group, Commission of the E.C., Brussels, B.
(5) Sanchez (1991): IPCC, Quoted in Ranney (1992), op. cit, Ref. 3.
(6) IPCC, «Climate Change» (1991): World Meteorological Organization / United Nations Environmental Program, Island Press, Washington D.C., Covelo, CO, USA.
(7) Ph. Elliott (1991): Shell International Petroleum Company, «Forestry & Biomass Technology», Royal Institute of International Affairs, London, UK.
(8) P. Moncada P.C., G. Grassi and H. Zibetta (1992): *«La Valorizzazione della Bio-Energia: i Possibili Benefici nel Settore Agricolo ed Energetico»*, Rivista di Politica Agraria, Anno X, n. 1, Roma, I.
(9) S.J.B. Duff (1991): *«The Potential Role of Alcohol Fuels in Reducing Carbon Dioxide Emissions»*, Proceeding of the Bioenergy and the Greenhouse Effect, IEA and National Energy Administration Seminar, Edited by C.P. Mitchell, Nutek, Stockholm, Sweden.
(10) J.W. Ranney (1990): Unpublished briefing to the U.S. Department of Energy, Quoted in Ranney (1992) op. cit, Ref. 3.
(11) T. B. Johansson, H. Kelly, A. K. N. Reddy, R. Williams (1993): «Renewable Energy, Sources for Fuels and Electricity», Prepared for UNSEGED, L. Burnham editor, Island Press, Washington D.C., Covelo, CA, USA.
(12) J.L. Easterly P.E. et al. (1992): *«Comparative Economic Analysis of Biomass Power Production»*, Proceedings of the US-Canada Conference on Biomass, Orlando, Fl, USA.
(13) G. Grassi (1992): *«Report on the North-America Biomass Conference»*, CEC, DG XII, Internal Document, Brussels, B.
(14) US Department of Energy: *«A Workshop to Explore the Potential for Mitigating Global Climate Change»*, Quoted in Ranney (1992), op. cit, Ref. 3.
(15) G. Grassi and A.V. Bridgwater (1992): *«Biomass for Energy and Environment Agriculture and Industry in Europe»*, C.E.C., EUR Edition, Brussels, Luxembourg.
(16) P. Moncada P.C. and G. Grassi (1993): *«Sweet Sorghum - European R&D Results on Production and Pre-Treatment»*, C.E.C., EUR Edition, Brussels, Luxembourg.
(17) A. V. Bridgwater and M.-L. Cottam (1992): *«Opportunities for Biomass Pyrolysis Liquids Production and Upgrading»*, Energy & Fuels, n. 6, American Chemical Society, Washington D.C., USA.
(18) J.S. Siegel and J.R. Temchin (1991): *«Role of Clean Coal Technology in Electric Power Generation in the 21st* Century», J.W. Tester, D.O. Wood and N.A. Ferrari editors, The MIT Press, Cambridge, MA, USA.
(19) NOVEM (1992): *«The Feasibility of Biomass Production for the Netherlands Energy Economy»*, Netherlands Agency for Energy and Environment, n. 9210, Apeldoorn, NL.
(20) O.K. Sonju (1991): *«The Role of Combustion of Biofuels in Reducing the Release of Carbon Dioxide»*, Proceeding of the Bioenergy and the Greenhouse Effect, IEA and National Energy Administration Seminar, Edited by C.P. Mitchell, Nutek, Stockholm, Sweden.
(21) Elaboration from Solar Energy Research Institute, quoted in M.G. Bhat, B. English and M. Ojo (1992): *«Regional Cost of Transporting Biomass Feedstock»*, Proceedings of the Liquid Fuels from Renewable Resources Conference, American Society of Agricultural Engineers, St. Joseph, Michigan, USA.
(22) A.F. Thurhollow and R.D. Perlack (1991): *«Emissions of CO_2 from Energy Crop Production»*, Biomass & Energy, Vol. 1 n. 3, Pergamon Press, Oxford, New York, Seoul, Tokyo.
(23) Commission of the E. C. (1987): *«The State of the Environment in the Community»*, C.E.C., Brussels, Luxembourg.
(24) G. Bologna (1990): *«Il Pianeta Terra»*, Mondadori, Milano, I.
(25) C. Calzolari, G. Sanesi and D. Torri (1991): *«The Application of Soil Survey to Soil Protection in Italy»*, Soil and Groundwater Research Report I, Soil Survey, A Basis for European Soil Protection, CEC, n. EUR 13340EN, Edited by J.M Hodgson, Brussels-Luxembourg.
(26) D. Pimental and J. Krummel (1987): *«Biomass Energy and Soil Erosion: Assessment of Resource Costs»*, Biomass, n. 14, Quoted in ORNL and RF (1992), op. cit, Ref. 30.
(27) C.P. Mitchell (1992): *«Ecophisiology of Short Rotation Forest Crops»*, Biomass and Bioenergy, Pergamon Press Ltd, Vol. 2, N. 1-6, Oxford, UK.
(28) P. Moncada P.C. (1991): *«Biomass Cultivation and Soil Erosion»*, Irrigazione e Drenaggio, Bologna, I.
(29) M. Lineres (coordinator) et al. (1991): *«Assessment Study on Organic Fertilizers»*, European Network on Soil Fertilization and Conservation, C.E.C./INRA, Final Report, Bordeau, F.
(30) Oak Ridge National Laboratory and Resource for the Future (1992): *«Damages and Benefits of the Biomass-to-Electricity Fuel Cycle: Estimation Methods, Impacts and Values»*, Unpublished document prepared for U.S. Department of Energy and European Commission, Oak Ridge, TN, USA.
(31) L. Cutore and P. Moncada P.C. (1991): *«Infrared Radiometry as a Guide to Irrigation Management»*, Irrigazione e Drenaggio, Bologna, I.
(32) P. Moncada P.C. and G. Gosse (1992): *«Development and Exploitation of Annual Biomass Crops»*, Proceedings of the First Forum on Electricity Production from Biomass and Solid Wastes, Florence, Edited by CEC and ENEA, Brussels, Rome.
(33) J. Ranney, L.K. Mann and W. Hohenstein (1991): *«A Review of Environmental Issues for Energy Crops and Biomass Energy»*, Report prepared for the Environmental Protection Agency, Oak Ridge National Laboratory, Oak Ridge, TN, USA.
(34) McNeely J.A. et al. (1990): *«Conserving the World's Biological Diversity»*, The World Bank, World Resources Institute, I.U.C.N., Conservation International, W.W.F., Gland, Switzerland, Washington, D.C., USA.
(35) F. Makeschin (1991): Quoted in Oak Ridge National Laboratory and Resource for the Future (1992), op. cit, Ref. 30.
(36) S. Shen (1991): *«Biological Engineering for Sustainable Biomass Production»*, Biodiversity, Wilson Editor, Argonne.
(37) E. Koukios and D. Wright (1992): *«Bioenergy from Agricultural Sources in the European Community: Towards a New Agenda for the 90s»*, Biofutur, Elsevier, Paris, F.

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