WPS 0968

Policy Research

WORKING PAPERS

World Development Report

Office of the Vice President
Development Economics
The World Bank
August 1992
WPS 968

Background paper for World Development Report 1992

Biomass

David O. Hall

Local involvement and control is a prerequisite for the success of biomass programs, and there is no short-cut to their long-term planning and development.

Policy Research

WORKING PAPERS

World Development Report

WPS 968

This paper — a product of the Office of the Vice President, Development Economics — is one in a series of background papers prepared for the *World Development Report 1992*. The *Report*, on development and the environment, discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Copies of this and other *World Development Report* background papers are available free from the World Bank, 1818 H Street, NW, Washington, DC 20433. Please contact the *World Development Report* office, room T7-101, extension 31393 (August 1992, 31 pages).

In the last century, biomass fuels — mostly wood — provided most of the world's energy. Today biomass in all its forms (wood, dung, and agricultural and forest residues) supplies about 14 percent of our energy — most of it in developing countries, where biomass is the most common energy source. Biomass provides more than a quarter of China's energy, for example.

Rural areas in most developing countries depend heavily on biomass for energy. A dearth of biomass energy usually indicates other developmental and environmental problems. The difficulty in trying to ameliorate such problems is that bioenergy may not be a priority for local communities, which have more pressing problems or are unable to take the longer-term view toward rehabilitating their biomass resources.

But outside energy experts tend to focus on one aspect of biomass use to the exclusion of all others, and therefore many biomass energy projects and programs fail. Hall presents case studies showing that local involvement and control is a prerequisite for the success of such programs.

There is an enormous untapped potential for biomass, and bioenergy systems may be less irreversibly damaging to the environment than conventional fossil fuels. Bioenergy systems produce many but mostly local and relatively small impacts on the environment and their impact is more controllable.

There is no short-cut, however, to long-term planning and development of biomass energy systems. And the barriers are many: economic, social, and technological. Modernizing biomass technologies, for example — so biomass can be used for liquid fuel, electricity, and gas (in addition to its traditional use as a heat source) — involves land use issues that make implementation of biomass projects more difficult than projects involving more centralized energy resources.

But both traditional and modernized biomass energy systems need developing to produce preferred forms such as heat, electricity, and liquids. Biomass energy should be modernized more rapidly, and at the same time traditional biomass fuels should be produced and used as efficiently as possible — both in a sustainable manner.

Biomass

D. O. Hall,
Kings College London

Background Paper Prepared for the
World Development Report 1992

The World Development Report 1992, "Development and the Environment," discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

• First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.

• Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

Other World Development Report background papers in the Policy Research Working Paper series include:

Dennis Anderson, "Economic Growth and the Environment"

Dennis Anderson and William Cavendish, "Efficiency and Substitution in Pollution Abatement: Simulation Studies in Three Sectors"

William Ascher, "Coping with the Disappointing Rates of Return of Development Projects with Environmental Aspects"

Edward B. Barbier and Joanne C. Burgess, "Agricultural Pricing and Environmental Degradation"

Robin W. Bates and Edwin A. Moore, "Commercial Energy Efficiency and the Environment"

Wilfred Beckerman, "Economic Development and the Environment: Conflict or Complementarity?"

Richard E. Bilsborrow, "Rural Poverty, Migration, and the Environment in Developing Countries: Three Case Studies"

Charles R. Blitzer, R.S. Eckaus, Supriya Lahiri, and Alexander Meeraus,
(a) "Growth and Welfare Losses from Carbon Emission Restrictions: A General Equilibrium Analysis for Egypt";
(b) "The Effects of Restrictions of Carbon Dixide and Methane Emissions on the Indian Economy"

Judith M. Dean, "Trade and the Environment: A Survey of the Literature"

Behrouz Guerami, "Prospects for Coal and Clean Coal Technology"

David O. Hall, "Biomass"

Ravi Kanbur, "Heterogeneity, Distribution and Cooperation in Common Property Resource Management"

Arik Levinson and Sudhir Shetty, "Efficient Environment Regulation: Case Studies of Urban Air Pollution"

Robert E.B. Lucas, David Wheeler, and Hemamala Hettige, "Economic Development, Environmental Regulation and the International Migration of Toxic Industrial Pollution: 1960-1988"

Robert E.B. Lucas, "Toxic Releases by Manufacturing: World Patterns and Trade Policies"

Ashoka Mody and Robert Evenson, "Innovation and Diffusion of Environmentally Responsive Technologies"

David Pearce, "Economic Valuation and the Natural World"

Nemat Shafik and Sushenjit Bandyopadhyay, "Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence"

Anwar Shah and Bjorn Larsen,
(a) "Carbon Taxes, the Greenhouse Effect, and Developing Countries";
(b) "World Energy Subsidies and Global Carbon Emissions"

Margaret E. Slade,
(a) "Environmental Costs of Natural Resource Commodities: Magnitude and Incidence";
(b) "Do Markets Underprice Natural Resouce Commodities?"

Piritta Sorsa, "The Environment - A New Challenge to GATT?"

Sheila Webb and Associates, "Waterborne Diseases in Peru"

Background papers in the World Bank's Discussion Paper series include:

Shelton H. Davis, "Indigenous Views of Land and the Environment"

John B. Homer, "Natural Gas in Developing Countries: Evaluating the Benefits to the Environment"

Stephen Mink, "Poverty, Population and the Environment"

Theodore Panayotou, "Policy Options for Controlling Urban and Industrial Pollution"

Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-3 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

Table of Contents

A. Use

In the last century, biomass fuels, mostly in the form of wood, provided most of the world's energy. Today biomass in all its forms (wood, dung, and agricultural and forestry residues) supplies about 14% of our energy (55 EJ, equivalent to 25 mbod).[1] Official statistics seldom reflect global or individual country use of biomass. Over 80% of this biomass use occurs in developing countries, where biomass is the most common energy source (some 35% of total energy) and is used primarily as a non-commercial cooking fuel in rural areas. In China, for example, a rural population of 900m uses an average of 0.6t biomass per capita per year for domestic purposes; half of this is from fuelwood and the rest from agricultural residues and animal wastes. In all, biomass provides over a quarter of China's total energy.[2]

Rural areas of most developing countries are overwhelmingly dependent on biomass for energy in addition to all the other products derived from plants. When biomass is in short supply as a source of energy, this usually indicates other developmental and environmental problems. The difficulty in trying to ameliorate such problems is that bioenergy may not be a priority for local communities, who have much more pressing requirements and are consequently unable to take a longer term view toward the general rehabilitation of their biomass resources. Outside (non-local) "energy experts" mainly focus on only one aspect of biomass use to the exclusion of all others. This has happened frequently in the past and has led to many failed biomass energy projects and programs. As discussed later, numerous case studies show that local involvement and control are prerequisites for success; ideals of replicability, flexibility and sustainability can be achieved to catalyze development.[3]

Besides rural cooking, substantial use of commercial bioenergy occurs in urban areas and in small to medium scale agricultural and other industries, in addition to institutions, services and other large scale users of biomass. A number of developed countries use substantial quantities of biomass. The USA obtains almost 1.5 mbod from biomass including 9000 MW biomass electricity. Sweden gets about 13% of its energy from wood, residues and peat.

The annual photosynthetic production of biomass (representing stored solar energy) is about ten

[1] Scurlock and Hall (1990).

[2] Bureau of Environmental Protection and Energy (China) (1991).

[3] Hall and Rosillo-Calle (1991a).

times the world's total use of energy. Since it can be produced and used in an environmentally sustainable manner, while emitting no net carbon dioxide, there can be little doubt that this potential source of stored energy must be carefully considered in any discussion of present and future energy supplies, especially if environmental constraints for carbon dioxide-neutral energy feedstocks become a priority. The fact that nearly 90% of the world's population will reside in developing countries by about 2050 and that biomass is so important as an energy source in these countries, probably implies that biomass energy will be with us forever, unless there are drastic changes in world energy trading patterns.[4]

Biomass, however, presents a problem to planners because of the many socioeconomic implications of its diverse sources, end uses, and interactions with other land uses. Nevertheless, biomass energy provision is now being considered more favorably because of its role in the overall development process and because it is recognized that biomass can provide both traditional and modern energies such as electricity, liquid fuels and gases. A crucial question for future development and energy/environment interactions is whether biomass will continue to play such an important role in energy provision in developing countries as their populations and energy demands grow.[5] An additional consideration is that developed countries are using increasing amounts of biomass energy -- due partly to environmental considerations.

Because much biomass energy production and use today is inefficient in both natural resource and energy terms, the over-use and undersupply of biomass often has serious environmental and social consequences. However, biomass can be produced and used in a sustainable manner that is environmentally and socially acceptable, and stimulates development. This is especially so if biomass provides those modern fuels such as electricity, gas and transport fuels which are in such demand as societies switch away from traditional energy sources.[6] However, whether developing countries as a whole or individually have the land and management resources to modernize biomass while providing food, fodder and other commodities is difficult to answer since land use priorities vary tremendously, as do import and export policies for energy and for land products.

Notwithstanding the difficulties of assessing biomass production and use, we can learn from

---

[4] Hall (1991).

[5] Leach and Mearns (1988); Smil (1987); Smith (1987).

[6] Williams and Larsen (1992).

previous energy transitions, present patterns of biomass energy use and from the changing productivities of agriculture and forestry. We can also analyze present worldwide R & D trends for optimizing biomass provision of gaseous, liquid and solid fuels and how they comply with modern environmental requirements both at the local and global scale.

B. Biomass Resources & Potential

Although it is relatively easy to obtain country-wide data (albeit imperfect) on standing biomass resources, annual yields are nearly impossible to obtain for natural vegetation, especially in developing countries. Since trees outside the forest also form the main source of biomass for rural people, estimate sustainable yields is not simple. Once efforts are made to factor in access to biomass and site specific yields, it becomes evident that generalizations on biomass availability are highly problematic.

A rough indication of fuelwood and residue availabilities can be obtained, along with their theoretical potential for providing a country's energy needs based on varying yields and residue use.[7] Energy use (biomass and commercial) dependent on population and land area is aggregated. Energy requirements based on the present developing country average (35GJ/capita) and twice this figure[8], are calculated, as are the land areas theoretically required to provide 35GJ per capita at biomass yields of 10t/ha/year. Thus Africa would need only 5% of its land for biomass energy production to provide 35GJ/capita/year. In the developed world, N. America would require 30% of its land at 10t/ha/year to provide 310 GJ/capita, while the USSR would require 12% to provide 140 GJ/capita. In Tanzania, 14% of the land area at a yield of 5t/ha would have to be used in order to meet all energy requirements from biomass, while in Nepal some 65% would have to be used. This yield scenario is at the top end of the median range but excludes tropical plantations which can attain 20-25 t/ha per year and semi-arid regions where yields can be less than 1t/ha per year. In Section E below discusses land availability in the next century for both biomass energy and food production.

Obviously these theoretical calculations gloss over the many country, regional and site specific problems of achieving such goals. They do, however, emphasize the potential which many countries have to provide a substantial proportion of their energy from biomass produced in a sustainable manner.

What such analyses miss, however, are on-farm and village trees nearly all of which are grown

---

[7] Hall, Rosillo-Calle, Senelwa and Woods (1992).

[8] NB Even this doubled figure is still only half the West Europe average of 140GJ/capita.

for multiple purposes, of which fuelwood is just one -- fodder, fruit, construction materials, shade, green manure, medicines, and income generation are other important benefits.[9] A recent study of trees associated with a South Indian village (approximate area, 360ha; population, 1047) showed a density of 35 trees/ha with 57 species in evidence.[10] Fuel-only trees accounted for 4% of the trees, with twigs of all species being used as fuels. Interestingly, the study showed that coconut plants are not counted as "trees" and also that increasingly trees are being felled for sale to urban traders. This is a complex area of study but will become much more important as urban demands for fuelwood, charcoal and industries increase. How villages adjust to these new opportunities and problems in integrating agriculture and tree growing will be crucial to sustaining their environments.

Modern uses of biomass

The reputation of biomass energy as a poor quality fuel that has little place in a modern developed economy is entirely undeserved. Biomass should be considered a renewable with some of the advantages of fossil fuels; it can be converted to liquid fuel via ethanol, or electricity via gas turbines.[11] It can also become the basis of a modern chemical industry via synthesized gas or ethanol as is occurring in Brazil. Biomass can serve as a feedstock for direct combustion in modern devices and is easier to upgrade than coal because of its low sulphur content and high thermal reactivity. Conversion devices for biomass range from very small, domestic boilers, stoves and ovens up to larger scale boilers and even multi-megawatt power plants. Wider commercial exploitation on a sustainable basis awaits the development and application of modern technology to enable biomass to compete with conventional energy carriers. There is growing recognition that the use of biomass energy in larger commercial systems based on sustainable, already accumulated resources and residues can help improve natural resource management. If bioenergy were modernized, much more useful energy could be extracted from biomass than at present, even without increasing primary bioenergy supplies.[12]

In favorable circumstances, biomass power generation could be significant given the vast quantities of existing forestry and agricultural residues - over 2 billion t/yr worldwide. For example,

---

[9] Arnold (1990); Prinsley (1990).

[10] Ravindranath, Nayak, Hiriyur and Dinesh (1991).

[11] Larsen and Williams (1991).

[12] Hall, Mynick and Williams (1990); Williams and Larsen (1992).

studies of the sugarcane industry by Ogden et.al.[13] and the wood pulp industry by Larson & Svenningsson[14] indicate a combined power grid-export capability in excess of 500 Twh per annum. Assuming that a third of global residues could economically and sustainably be recovered by new energy technology, 10% of current global electricity demand (10,000 Twh/yr) could be generated. These authors conclude that efforts aimed at modernizing biomass energy should begin with applications for which economic analyses indicate there are favorable prospects for rapid market development, e.g. the generation of electricity from sugar cane bagasse, alcohol fuels from sugarcane, and the production of electricity using advanced gas turbines fired by gasified biomass.

C. Costs: Successes & Failures

The cost of biomass feedstocks and their end use costs are so site-specific that generalizations are very difficult. However, one can broadly classify biomass energy use into non-commercial (the majority) and commercial. Most biomass in rural areas is collected as a free good so that "costs" represent labor and social costs that do not incorporate any external costs resulting from possible resource depletion and environmental damage. As long as biomass can be obtained free, incentives to improve production or use efficiencies and to substitute commercial sources will be limited to special energy requirements such as lighting.[15]

The commercialization of biomass is proceeding rapidly in industrialized countries and in developing countries where urban users buy fuelwood, charcoal and dung; it is also occurring where agricultural and small scale industrial users depend on biomass to generate heat and power.[16] In addition there are the well known examples of ethanol production as a transport fuel in Brazil, the USA, and Zimbabwe.

The costs of commercial biomass fuels are often contentious: ethanol in Brazil, biogas in Denmark, electricity in Mauritius, charcoal in Rwanda, are all relevant examples. In the USA, current biofuel costs vary from $1 (for forest residues) to $4 (for herbaceous energy crops) per GJ and the aim

---

[13] Ogden, Williams and Fulmer (1990).

[14] Larsen and Svenningsson (1991).

[15] French (1984).

[16] Hosier, Boberg, Luhanga and Mwandosya (1990); Meyers and Leach (1989); Soussan (1991).

is to have biomass available at about \$2/GJ in the next century with a coal cost of about \$1.8/GJ; the liquid fuel goal is \$0.16/liter ethanol to be competitive with oil at \$25/barrel and electricity produced at 4.5 cents/kwh within the next 5-10 years.[17] At present between 60-80% of the cost of wood-based energy in the USA and Europe is due to harvesting, processing and storage costs, for which there are now proven cost reduction opportunities.

Comparing biomass fuel costs with fossil fuels is also difficult since there is no "level playing field". In developing countries especially, fossil fuels are often subsidized since their socioeconomic and environmental costs are seldom internalized. Direct comparison of fuel costs and prices can therefore be misleading; there are at present no reliably valid means for realistic comparison. It is possible that developments in environmental and macroeconomic accounting will facilitate future comparisons.

Since the recognition of the importance of biomass energy in the early 1970s, there have been many schemes and projects to help alleviate biomass shortages and to use wastes, residues, and other biomass to provide fuels of different types at an economic cost -- to rural and urban dwellers, agriculture and industry, in both developing and developed countries.

During this 20 year period there have been numerous proclamations of failure and success. In evaluating biomass projects there are a number of generalizations which may be derived from past experience. They focus mainly on certain specific issues: biomass production's land and labor requirements; that macroeconomic impacts of fossil and biomass fuels are difficult to compare; that socioeconomic interactions with biomass production and use can be complex; and that it requires patience to understand biomass projects if sustainable and robust conclusions are to be drawn.[18] Failures in implementation and economics have been attributed to projects involving fuel efficient stoves, biogas, gasifiers, rural electrification, fuelwood plantations, agroforestry, hydrocarbon plants, and others. Much of the criticism of such programs has been warranted and has helped focus attention on their shortcomings and previous uncritical acceptance.

Ideally, a successful biomass program should show sustainability, replicability and flexibility; it should also be economic in cost-benefit terms (externalities being incorporated in the calculus). The following list of "successes" is contentious and each project can be criticized for a number of problems:

- alcohol programs in Brazil and Zimbabwe
- electricity generation in California

---

[17] Fulkerson, Resiter, and Miller (1989).

[18] Hall (1991).

- straw use in Denmark
- landfill gas in the UK and USA
- biogas in Denmark
- gasifiers in Finland, Mali and parts of India
- stoves in Kenya
- coconut residues in Sri Lanka
- fuelwood in Nepal
- eucalyptus in Hawaii and Brazil
- willows in Sweden
- agroforestry in Rwanda and Gujurat (India)
- bagasse in Mauritius
- degraded land rehabilitation in Kenya
- charcoal in Minas Gerais (Brazil)
- municipal solid waste in Japan and Germany

In order to assess the economic and environmental viability of biomass energy, Hall & Rosillo-Calle (1991a) examine 22 schemes in 12 developing countries, as well as biomass projects in a number of developed countries. Criteria for selection are the availability of disaggregated economic data and/or length of project operation. As will be seen, there are very few operating projects which fulfil both requirements. Indeed the only operating technologies in specific cases which allow reasonably extensive analyses are ethanol, energy plantations, charcoal, biogas, and possibly gasification in developing countries, and in developed countries, ethanol, electricity from wastes and residues, short rotation forestry, and possibly biogas.

Three broad categories of biomass energy should be distinguished. Firstly, programs which are presently commercial (such as ethanol) can be analyzed in both developing and developed countries. These analyses point to certain necessities: first, good yields, both in the production and conversion phases, and second, a consideration of all economic factors (such as import substitution, energy security, subsidies, export policy) as well as social and land use policies. Other technologies which fall into this first category of commercial viability are charcoal, electricity from wastes and residues, and possibly short rotation forestry (including fuelwood energy plantations in some instances). However, these technologies are not necessarily all sustainable in an environmental sense nor viable without certain forms of subsidy.

A second category of technologies are those such as biogas, stoves, gasification and briquetting where demonstration and dissemination programs have been underway for many years, yet which are not always sufficiently robust to operate commercially. They can be considered as being at the "take off" stage but may not necessarily be successful either universally or in specific instances. Much will depend on local policies and on international energy factors.

A third category -- and one that has scarcely been analyzed in economic terms -- are projects such as those to rehabilitate degraded areas and/or provide biomass in its various forms to local people. Examples are the various social forestry and agroforestry projects, such as the Baringo Fuel and Fodder project and the Nepalese Community Forestry Program, which are definitely not economically viable when considered by conventional criteria, even though they may have been operating for many years. Though these projects are of crucial importance in many places, their problems are legion and cannot be considered in this brief analysis.

Is it possible to move from one category to another which is more commercially-viable? For projects in the third category, long term funding is essential if the techniques and technologies of project implementation are to be made sustainable and replicability is to be encouraged. Conventional economic paybacks are usually very tenuous, thus making it difficult to progress to the second category, where economic criteria are that much more important.

In the second category there are opportunities for entrepreneurs to operate and for costs to decline given technical improvements. Stoves, for instance, can be improved, their costs reduced and their marketing improved. Biogas digesters can be constructed with designs for lower cost and easier maintenance, and infrastructure for technicians and builders can be established. Such technologies still usually require some form of subsidy but the social costs and benefits are much more evident than in the third category. The policy and institutional changes required for wider dissemination are also more clearly discerned, and thus decisions are more easily taken and maintained.

The first category, which includes ethanol, electricity and others, is far easier to analyze -- although the conclusions of such analyses are frequently fiercely contested -- the Brazilian alcohol program being a case in point.[19] Generally the debate revolves around the extent of subsidy (if any) that is required to make these biomass energy systems economically viable in the conventional sense. If "externalities" such as employment, import substitution, energy security, environment and so on, are also considered then the economics usually change in favor of the biomass systems. The technologies used in this category are often universally available so that technology transfer to optimize production and conversion can be quite easy -- given the appropriate institutional structure and financial incentives -- especially in comparison with fossil fuels. Indeed a number of developing countries could relatively easily adapt and improve technologies for these so-called modern biofuels e.g. efficient ethanol distillation plants with low effluents, and biomass gasifiers plus turbines for electricity.

---

[19] De Groot (1989); Gowen (1989).

Given the results of an ongoing analysis of biomass energy projects in the developing world and, in particular, a detailed examination of four in India, Zimbabwe, Kenya and Brazil, it should be concluded that the requirements for successful biomass projects depend mainly on maximum participation and control by local people from the outset (including initiation, planning and entrepreneurial opportunities); they also need to receive short term benefits within a longer term context. Project implementation needs to ensure sustainability, flexibility, and replicability as integral components - excessive rigidity can be especially detrimental where economic benefits are difficult to calculate.[20]

Clearly there are numerous options for the production and use of biomass. The problems generally lie in the ability to have good productivities on a sustainable basis to provide both energy and other benefits that are desirable from several viewpoints -- economic, social and environmental. Generalizations are difficult and can only be derived from individual case studies which have been carefully analyzed over long time periods.

Ideally, what is needed for effective energy planning are biomass supply curves where the extent of the available biomass resource depends on the cost of the resource. Very few such analyses are available; those that are, come mostly from the US. For example, supply curves for Washington State (Bonneville District or the Seattle District) and the South-Eastern States have been published but are very location-specific. A recent study of the US by Mynick, in which he examines biomass energy from existing forests, short rotation forestry, herbaceous crops and residues, indicates that about 7EJ is available at minimal cost from forest manufacturing residues, agricultural wastes and MSW (municipal solid waste), while 19EJ (or 39EJ) is potentially available up to a cost of about $3.4/GJ (or $3.9/GJ) when all other types of biomass energy feedstocks are considered[21]; this compares to the present USA energy use of about 75EJ/yr and a levelized coal cost of $1.8/GJ projected for the period 2000-2030. In a study carried out for the US Oak Ridge National Laboratory it was estimated that comparable contributions to total potential US biomass supplies of 29.3EJ/yr in the period beyond 2030 would come from environmentally acceptable production (8.9EJ/yr), from growth in existing forests (9.5EJ/yr), and from biomass energy crops (10.8EJ/yr).[22]

A study of UK land potentially available for biomass forestry (yielding 10t/ha/yr), found a high

[20] Hall (1991).

[21] Personal communication with the author.

[22] Fulkerson, Resiter and Miller (1989); Hall, Mynick and Williams (1990).

sensitivity to fuel price; a 25% increase in fuel price, from 32 to 42 ECU/dry t (delivered), led to a projected ten-fold increase in the area of land available for short rotation forestry with coppicing species. This is due to the fact that under this higher price, coppice energy plantations nearly double their mean financial performance (calculated in terms of net present value).[23]

Many factors have to be considered when constructing supply curves. While some biomass residues are already being used for energy or other purposes, they could be used much more effectively with modern, energy-efficient conversion technologies. For example, in the cane sugar industry, bagasse is presently fully used in most parts of the sugar-producing world -- often very inefficiently -- merely to satisfy the steam and electricity requirements of sugar factories, and often just to dispose of it as cheaply as possible. But by employing energy-efficient steam-using equipment in the factory, by using biomass gasifier/gas turbines instead of inefficient steam turbines for electricity generation, and by using the tops and leaves of the cane plant (now often burned off just before the cane harvest) as well as the bagasse, it is feasible to increase electricity production from cane residues to more than 40 times onsite needs, while still meeting all onsite steam requirements for sugar processing.[24] Similarly, using residues from kraft pulpmaking for gas turbine-based power generation in energy-efficient pulp mills, can result in electricity production that is more than five times onsite needs.[25]

D. Potential for Future Cost Reductions

Modernization of biomass energy production and conversion should initially concentrate on applications where accelerated market development is most feasible. Thus electricity and alcohol production from sugarcane, the use of various gasified biomass feedstocks for electricity generation in advanced gas turbines, and enhanced (sustainable) yields from tree and herbaceous species, should probably all receive priority.

There are great opportunities, especially with biotechnology, for modernizing bioenergy production and end use. A good example is the success achieved in reducing ethanol production costs during the agricultural, fermentation and waste disposal phases. However, as is well recognized,

---

[23] Mitchell (1988).

[24] Ogden, Williams and Fulmer (1990).

[25] Larson and Svenningsson (1991).

translating basic research discoveries into commercial applications and social benefits, requires a complex set of interactions involving infrastructure and institutions, both of which many developing countries lack.[26] The real question is not, perhaps, whether a particular country should choose traditional techniques or new technologies, but rather whether it has the possibility of making this choice. R&D must take into account local, environmental and socioeconomic conditions in order to produce "bioenergy technologies for development and environment."[27]

The future cost of biomass energy will depend on many factors such as technical progress in biomass energy conversion and feedstock productivity. Developments will also depend on the general energy situation, especially the cost and available supply of commercial fuels. The focus should be on those modern bioenergy systems that are economic (when all factors are considered) and are environmentally acceptable, while ensuring that traditional biomass production and usage is sustainable and as efficient as possible.[28]

According to the USDOE, biomass energy technologies are in many instances still too costly in the US to compete with conventional fuels, and are usually too inefficient to contribute much to the needs of predominantly commercial fuel societies in the near future.[29] The major technological challenges with biofuels include:

(a) economically-viable production and delivery to conversion facilities of large quantities of biomass (e.g. 1000-2000 t/day from within 80 km at a cost of between $1.50 and $2.00/GJ - about $30-40 t/delivered, in the case of the USA);
(b) large increases in bioproductivity using less energy and capital (e.g. to produce 270 l ethanol per t dry matter, twice the current levels, at a total cumulative cost of about $0.26 to $0.32/l gasoline equivalent in the USA);
(c) to increase efficiency and decrease costs in harvesting, handling, and storage of biomass, and;
(d) the implementation of newly developed technologies such as combined cycle-

---

[26] NRC (1987).

[27] UNIDO (1983).

[28] Gowen (1989).

[29] Fulkerson, Resiter and Miller (1989).

gasification systems for electricity production and enzymatic ethanol production from ligno-cellulose feedstocks.

Kulp has pointed out that increased productivity is the key to achieving competitive costs and meeting the large feedstock demands of future biofuel conversion facilities.[30] Advances now include the identification of fast-growing species, breeding successes, intercropping and multiple species opportunities, new physiological knowledge of plant growth processes, and manipulation of plants through biotechnology applications. The capability exists to raise productivities 5 to 10 times over natural growth rates in trees and microalgae.[31]

Table 5 shows current and future costs and productivities of biomass systems in the USA. These costs and productivities have been obtained from biomass energy experiments on a variety of sites in various regions between 1978 and 1988. Given the size of the market and the role of American renewable energy technology, the data provide a good indication of future trends and requirements for biomass energy development. Future biomass prices are calculated on the basis of likely technological improvements and should attain competitive status with oil, natural gas, and perhaps coal at 1987 prices.

E. Sustainability Requirements and the Environment

If biomass is to play a major role in the energy economy, strategies for sustaining yields over large areas and for long periods are needed. However, the production of biomass, whether in natural stands or in planted forests, woodlots or dispersed trees, can be optimized in an environmentally sustainable manner.[32] Good management of resources at the micro or macro scale is the key to successful biomass production. The experience of sustaining high sugar cane yields over centuries in the Caribbean and in countries like Brazil and Ethiopia, suggests that this is feasible, although good management practices and new research will be required to achieve this goal. As yet, there is no equivalent experience with managing indigenous forests and woodlands to achieve high biomass outputs;

---

[30] Kulp (1990).

[31] Fulkerson, Resiter and Miller (1989).

[32] Beyea, Cook, Hall, Socolow and Williams (1992).

such research should receive a high priority.[33]

Achieving sustainable production and maintaining biological diversity without the need to infringe on good food-producing land, may require polycultural strategies -- for example, mixed species in various alternative systems with different harvesting strategies. At present, however, monocultures are favored for energy crops, in large part because management techniques in use today tend to be adapted from monocultural agricultural systems. Thus, polycultural and agroforestry systems warrant high priority in energy crop research and development. It needs to be demonstrated that: (i) yield optimization can be achieved with polycultures instead of monocultures to ensure some biodiversity; (ii) interplanting with N2-fixing species can decrease fertilizer inputs and leaching; and (iii) use of nutrient-optimized conditions can allow the use of existing species and clones.[34]

High levels of biological diversity may reduce pesticide inputs, assuming some of the land in biomass-producing regions is maintained "natural" condition. Various bird species, for example, require dead wood and associated insect populations for survival. Experience in Swedish forests suggests that maintaining a relatively modest fraction of forest areas in such natural reserves is sufficient to preserve a high level of species diversity. Research is needed to understand how best to achieve desirable levels of biological diversity under the wide range of conditions in which biomass might be grown for energy in the future.

The availability of high yielding clones should be seen as an excellent opportunity to improve yields overall and not as a problem of excessive uniformity. Much genetic diversity among tree species is presently available; hence, a mosaic of unrelated clones and mixed species (both indigenous and exotic) is frequently the safest strategy for long term sustainable yields. A poor strategy would be to use a mixture of only 2 - 3 clones. Moreover, a re-examination of such practices as pollarding, and more effort on optimizing coppicing practices, could markedly decrease land preparation and soil disturbances, especially in comparison to conventional agricultural practices. In both arid and moist environments there are often distinct advantages to maintaining soil cover and/or water retention at certain times of the year, such as the dry and monsoon seasons, and this will be reflected in long-term yields and reduced soil erosion. Water management strategies have generally been neglected in the past, but are crucial to sustainable plant production under rain-fed conditions.

While net biomass energy yields for short rotation tree crops are typically 12 times energy inputs,

[33] Cannell (1989).

[34] Hall, Mynick and Williams (1990).

it is both economically and environmentally desirable to reduce energy inputs. For example, the nutrient status of afforested lands might be maintained by recycling nutrients and by choosing suitable mixed species and clones. The promise of such strategies is suggested by 10 year trials in Hawaii, where yields of 25 dry tonnes/ha/yr have been achieved without N-fertilizer when *Eucalyptus* is interplanted with N_2-fixing *Albizzia* trees.[35]

Research can lead not only to improvements in present techniques for producing energy crops, but also to new approaches. For example, long-term experiments in Sweden have shown that: (i) in most forests, trees grow at rates far below their natural potential; (ii) nutrient availability is usually the most important limiting factor, and; (iii) optimizing nutrient availability can result in 4 to 6-fold yield increases. Growing trees under nutrient-optimized conditions thus makes it possible to achieve high yields with existing species and clones, thus facilitating the incorporation of pest resistance and other desirable characteristics, and the maintenance of a diverse landscape mosaic. To the extent that croplands and wastelands would be converted to energy crops this way, it may be feasible not only to maintain but to improve biological diversity.[36]

In the production and use of biomass, the aim should be to optimize productivities and energy efficiencies at all stages. It makes little sense to strive for high yields in production, harvesting and storage phases if the conversion efficiency of the feedstock into a useful energy carrier is not optimal. The great versatility of biomass as a feedstock is evident from the range of wet and dry materials which can be converted into various solid, liquid and gaseous fuels using biological and thermochemical conversion processes. In the conversion process, advantage should be taken of the favorable properties of biomass, such as its low sulphur content and high thermal reactivity, which allow for greater efficiencies and economic benefits.

Major expansions are needed for research efforts that relate to large scale sustainable biomass production; this will involve considerable time because of the extensive trials required for such research. However, in the decades immediately ahead, major bioenergy industries can be launched using residues from the agricultural and forest products industries as feedstocks. Residues can be used in an environmentally acceptable manner as long as monitoring, especially of soils, is carried out and the mineral nutrients and intractable organic effluents are returned to the growing site. This is done, for example, in the sugar cane ethanol industry where stillage (fermentation effluents) is returned to the fields

---

[35] DeBell, Whitesell and Schubert (1989); Hall, Mynick and Williams (1989).

[36] Hall, Mynick and Williams (1989).

in diluted irrigation water. Similar practices should be normal management practice wherever large scale removals of residues from agriculture and forestry are contemplated for energy production.[37]

The burning of biomass, whether in the home or outside, can have detrimental effects which need to be recognized and ameliorated.[38] These are especially serious with open fires in closed domestic situations where eye, lung and other problems arise. Biomass stoves should be improved both in terms of reducing emissions and improving fuel efficiency. Fortunately, biomass is a low sulphur fuel; further, it produces less NOx than fossil fuels and, when grown sustainably, is CO_2 neutral. These attributes, combined with its greater thermochemical reactivity, make biomass an attractive fuel especially compared to coal.[39]

Land Use

Biomass differs fundamentally from other forms of energy since it requires land to grow on and is therefore subject to the range of independent factors which govern how, and by whom, that land should be used. Biomass energy is often considered problematic because of its varied facets, and because it interacts with so many different areas of interest, such as land use rights, forestry, agriculture, societal factors, etc. For example, people differ in their attitude to land use: at one extreme are those who put biomass exploitation above all, whereas others are primarily concerned with environmental matters.[40]

There are basically two main approaches to deciding on land use for biomass energy. The "technocratic" approach tends to concentrate on the use of biomass for energy alone, ignoring the other multiple uses of biomass. This approach, starting from a need for energy, identifies a biological source and the site to grow it, and then considers possible environmental impacts. This generally ignores many of the local and more remote side-effects of biomass energy plantations and also the expertise of local farmers who know local conditions. The "technocratic" approach has resulted in many biomass project failures in the past.

The second approach may be termed the "multi-uses" approach; it asks how land can best be used for sustainable development, and considers what mixture of land use and cropping patterns will make

---

[37] Beyea, Cook, Hall, Socolow and Williams (1992).

[38] Smith (1987).

[39] Williams and Larsen (1992).

[40] Newman and Hall (1990).

optimum use of a particular plot of land in meeting multiple objectives -- food, fuel, fodder, and other societal needs. This requires a full understanding of the complexity of land use.

Since land for biomass energy production is so tied up with food production and environmental protection, these facets cannot be treated separately. The "food versus fuel" issue has been a hotly debated land-use issue. To many people the manufacture of fuel from crops carries a strong moral connotation that serves to make the subject somewhat controversial. In actuality, the subject is far more complex than has been presented in the past and which needs careful examination, since agricultural and export policies and the politicization of food availability are greater determining factors. "Food versus fuel" should be analyzed against the background of the world's real food situation (increasing food surpluses in most industrial and a number of developing countries) allied to the large production of animal feed, the increased potential for agricultural productivity, and the advantages and disadvantages of producing biofuels as part of the multiple benefits of land use.[41]

Other studies have shown that a great deal of land is available for biomass energy (at good productivities) without compromising food production.[42] These studies use a recent FAO report, which disaggregated total potential agricultural land resources (using water availability, technical and economic criteria) for 91 developing countries, and the International Panel on Climate Change III's predicted agricultural land requirements for food in 2025 (based on population growth predictions). Table 4 shows that developing countries have an estimated 995 Mha of land potentially available which, if it yields 10 t/ha/yr, could theoretically provide nearly three times their present energy requirements. A similar estimate for industrialized countries shows that biomass could provide 72% of their present energy use. In examining the data for developing countries we see that much land is available in Africa and Latin America but that Asia would have a "deficit" of 110 Mha based on these criteria of land availability for biomass production, after a 50% increased provision for food production. However, if yields of energy crops follow the historical trends of the present commercial crops (eg. cereals), with appropriate research and implementation policies, increasing biomass production could effectively be uncoupled from proportional increases in land requirements. Thus with the use of good management strategies and ongoing R&D, one can be fairly optimistic that land availability will not be the limiting factor in future energy provision strategies.

It is important to appreciate, however, that most developing countries are facing both food and

---

[41] Hall and Rossillo-Calle (1991a).

[42] Hall, Rossillo-Calle, Senelwa and Woods (1992).

fuel problems. Agricultural practices should be actively encouraged to take this into account and to evolve efficient methods of utilizing available land and other resources to meet food and fuel needs, besides the other products and benefits of biomass.

F. Socioeconomic Issues

Many social issues impinge on biomass energy; local employment, opportunities for entrepreneurs and development of skills, rural stability on an environmentally sound basis, local control of resources, and promotion of appropriate political and economic infrastructures. At the national level, development of institutions capable of R & D and integrated land use planning which encompasses the biomass dimension, seems essential if biomass is not to remain forever the poor, rural relation. Modernization of bioenergy production and use could bring very significant social and economic benefits to both rural and urban areas. Lack of access to a reasonable amount of energy, particularly modern energy carriers like electricity, gas and liquid fuels, limits the quality of life of many hundreds of millions of people throughout the world. Since biomass is the single most important energy resource in rural areas of developing countries (where over half of the world's people live), it should be used to provide for modern energy needs: agro-industry, irrigation pumps, refrigeration, lighting, etc.[43]

In addition, biomass energy systems should be perceived as providing substantial foreign exchange savings if they replace imported petroleum products; however, this issue is not always clear cut, and can depend on import substitution and export earnings. The cost of importing energy can be a substantial burden especially if a country's exports depend mainly on commodities. For example, Bangladesh, which derives about 90% of its energy from biomass, needed only 7% of its export income in 1973 to import fossil fuels; by 1981, this figure soared to 75%, then decreased to 24% in 1988 (World Bank Statistics). Since the Gulf crisis of 1990, petroleum costs in many countries have increased by 50% or more while commodity prices have declined. The reality of large import and export imbalances and energy insecurity has now been with us for 18 years. In countries like Brazil, with a long historical experience of bio-ethanol production technology and use, there are substantial savings in oil imports and also foreign exchange earnings from alcohol-related technology exports. Zimbabwe similarly saves foreign exchange on petroleum imports, while developing a technical infrastructure which leads to import substitution. Thus one also needs to consider net benefits to a country if local resources that are used for domestic energy

[43] Hall, Mynick and Williams (1990); Ogden, Williams and Fulmer (1990); Smith (1987).

production could instead have earned more foreign exchange through exports.

G. Conclusions

The permanence of biomass as a source of fuel can be debated. With an increasing proportion of the world's population residing in developing countries that lack fossil fuels and the means to import such fuels, it is essential that greater effort be put into the efficient production and use of biomass as a fuel; it is an available indigenous energy resource which can be readily upgraded at all stages of production and conversion. One of the difficulties in achieving a wider role for biomass-generated liquid fuels, electricity and gases (in addition to its wide traditional use as a heat source), is that biomass involves land use issues which make implementation far harder than for other more centralized energy resource strategies. There is an enormous untapped biomass potential, particularly in improved utilization of existing forest and other land resources (including residues), and in higher plant productivity. However, the enhancement of biomass availability on a sustainable basis will require considerable effort -- there is no short cut to long term planning and development in the biomass field.[44]

It also needs to be recognized that biomass is used as an energy source not only for cooking in households and many institutions and service industries, but also for agricultural processing and in the manufacture of bricks, tiles, cement, fertilizers, etc. These non-cooking uses can often be substantial especially in and around towns and cities. Rural-based village and small-sized industries are frequently biomass-energy driven and play a significant role in rural and national economies.[45]

Biomass energy is very site-specific and it is therefore not possible to make any generalization as to how biomass is produced, collected and used. For any conclusion to be valid it must refer to site-specific situations and incorporate an appreciation that biomass use for energy is only one part of wider development issues.

Biomass energy technologies have not been sufficiently stressed among the rural and urban poor who depend so much on bioenergy. "Governments seldom recognize the importance of biomass-based technologies; they are not considered serious alternatives to other energy technologies, and investment

---

[44] Goodman (1985); Hall and Overend (1987); Hall and Rossillo-Calle (1991b); Leach and Mearns (1989); Smil (1987).

[45] Hall and Rossillo-Calle (1991b).

to support them is not attractive because the benefits are usually delayed."[46] A recent FAO report on Asian countries notes that many governments do not appear to realize fully the significance of wood energy use in rural industries, the importance of these industries to national economies, their viable long term energy alternatives, and the opportunities presented by the potential development of woodfuel for industry.[47] Biomass-based technologies are only seen as possible long-range solutions, since growing biomass or organizing its production on any useful scale is believed to take too long. Additional reasons are lack of appropriate and consistent data to allow informed decision making, lack of skills, skepticism born of past disappointments, and failure to transfer the results of technical assessments to energy policy makers in ways which influence energy projections and implementation.[48] Planners and politicians are mostly concerned with short-term projects. It is also perceived that meeting the energy needs of the poor through biomass-based technologies will not in itself significantly reduce a nation's fossil fuel use unless large-scale, very specific projects are implemented, such as alcohol as a substitute for gasoline.

From an environmental viewpoint, "if biomass energy systems are well managed, they can form part of a matrix of energy supply which is environmentally sound and therefore contributes to sustainable development. When compared, for example, to conventional fossil fuels, overall the impacts of bioenergy systems may be less damaging to the environment, since they produce many, but local and relatively small impacts on the surrounding environment, compared with fewer, but larger and more distributed impacts of fossil fuels. It is these qualities which may make the environmental impacts of biomass energy systems more controllable, more reversible and, consequently, more benign."[49]

Nevertheless biomass energy still faces many barriers -- economic, social, institutional and technical. Biomass energy sources are very large and varied in nature, and the means of utilizing them vary greatly from the most simple (3-stone fires) to highly complex (eg. ethanol from wood). Thus the stages of development of biomass resources and their mechanisms of further development can be difficult to assess since they depend so much on local circumstances. Nevertheless both traditional and modernized biomass systems need development in order to provide present and future biomass fuels in preferred forms, such as heat, electricity and liquids. The modernization of biomass energy should be rapidly

[46] NRC (1982).

[47] FAO (1990).

[48] NRC (1982).

[49] Pasztor and Kristoferson (1990).

advanced whilst ensuring that traditional biomass fuels are produced and used as efficiently as possible and in a sustainable manner.[50]

[50] Gowen (1989); Grubb (1990).

References

AGRARWAL A., NARAIN S., (1990). Towards Green Villages, Centre For Science and Environment, New Delhi-110 019, India.

ARNOLD J E M., (1990). Tree Components in Farming Systems, Unasylva, 41: 35-42.

BEYEA, J., COOK, J., HALL, D.O., SOCOLOW, R., WILLIAMS, R.H., (1992). Towards Ecological Guidelines for Large-scale Biomass Energy Development. National Audubon Society, New York.

BUREAU OF ENVIRONMENTAL PROTECTION AND ENERGY (CHINA), (1991). China Rural Energy Construction System, It's Development and Utilization. Ministry of Agriculture, Beijing, P. R. China.

CANNELL M G R., (1989). Physiological Basis of Wood Production: A Review. Scandinavian J. For. Res., 4: 459-490.

DE GROOT P., (1989). Plant Power for the Future, New Scientist, 124 (1695): 30-33.

DeBELL D S, WHITESELL C D, SCHUBERT T H., (1989). Using N_2-Fixing *Albizia* to Increase Growth of Eucalyptus Plantations in Hawaii, Forest Science, 25: 64-75.

FAO., (1990). Wood Based Energy System for Rural Industries and Village Applications. Report GCP/RAS/131/NET, Bangkok, Thailand.

FRENCH D., (1984). The Economics of Bioenergy in Developing Countries. Bioenergy 84. Proc. Intern. Conference on Bioenergy, (eds) H. Egneus et.al., Elsevier Applied Science Publ. London, Vol. 5, pp. 161-177.

FULKERSON W, RESITER D B, MILLER J T., (1989). Energy Technology R&D: What Could Make a Difference?. Supply Technology, Energy Division, Oak Ridge National Lab., Oak Ridge TN37831-6285, USA.

GOODMAN G T., (1985). Energy and Development: Where do we Go from Here?. Ambio, 14: 186-189.

GOWEN M M., (1989). Biofuel v Fossil Fuel Economics in Developing Countries. How Green is the Pasture?. Energy Policy, 17: 455-470.

GRUBB M J., (1990). The Cinderella Options. A Study of Modernized Renewable Energy Technologies. Part 2- Political and Policy Analysis, Energy Policy 8: 711-723.

HALL D O, OVEREND R P., eds, (1987). Biomass: Regenerable Energy, John Wiley, Chichester.

HALL D O, MYNICK H E, WILLIAMS R H., (1990). Carbon Sequestration vs. Fossil Fuel Substitution- Alternative Roles for Biomass in Coping with Greenhouse Warming. Report No. 255, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ, USA; Nature, 353: 11-12.

HALL D O., (1991). Biomass Energy, Energy Policy, 19 (8): 711-737.

HALL D O, ROSILLO-CALLE F., (1991a). Biomass Energy Resources and Policy. (Biomass in Developing Countries) Report to the USA Congress Office of Technology Assessment, Washington D C. USA. (Draft).

HALL D O, ROSILLO-CALLE F., (1991b). Why Biomass Matters, Energy and Environment. Network News, 5 (4) _Special Issue, Biomass Users Network (BUN), P O Box 1800-2100, Montes de Oca, Costa Rica.

HALL D. O., ROSILLO-CALLE F., SENELWA A. K., WOODS J., (1992). Biomass For Energy: Future Supply Prospects. Chapter 13, in "Renewables for Fuels and Electricity," (eds) T.B. Johannson et al., Island Press, Washington, DC.

HOSIER R. H., BOBERG J., LUHANGA M., MWANDOSYA M., (1990). Energy Planning and Wood Balances: Sustainable Energy For Tanzania. Natural Resources Forum, Vol 14: 143-155.

KULP J L., (1990). The Phytosystem as a Sink for Carbon Dioxide, EPRI Report EN-6786, Electric Power Research Institute, Palo Alto, CA, USA.

LARSON E D, WILLIAMS R H.,(1990). Biomass-Gasifier Steam-Injected Gas Turbine Cogeneration. J. Engineering for Gas Turbines and Power, 112: 157-163.

LARSON E D, SVENNINGSSON P., (1991). Development of Biomass Gasification Systems for Gas Turbine Power Generation. In: Energy from Biomass and Wastes XIV. (ed). D L Klass, Institute of Gas Technology, Chicago, pp. 797-815.

LEACH G, MEARNS R., (1988). Beyond the Woodfuel Crisis. Earthscan Publications, London.

MEYERS S, LEACH G., (1989). Biomass Fuels in the Developing Countries: An Overview. Office of Scientific & Technical Information, USDOE, Oak Ridge, TN 37831, USA.

MITCHELL C P., (1988). Short Rotation Forest Biomass Plantations in the United Kingdom, in: Biomass Forestry in Europe: A Strategy for the Future, F C Hummel, W Plaz, G Grassi (eds), Elsevier Applied Science, London, pp.580-599.

NEWMAN D R, HALL D O., (1990). Land-Use Impacts. In; Bioenergy and the Environment, eds. J Pasztor L A Kristoferson, Westview Press, Boulder, CO. USA, pp.213-265.

NRC., (1982). Diffusion of Biomass Energy Technologies in Developing Countries. Board on Science & Tech. for Intern. Development. Office of International Affairs, National Research Council, National Academic Press, Washington D.C. USA.

NRC., (1987). Agricultural Biotechnology, Strategies for National Competitiveness. National Academic Press, Washington DC.

OGDEN J M, WILLIAMS R H, FULMER M E., (1990). Cogeneration Applications of Biomass Gasifier/Gas Turbine Technologies in the Cane Sugar and Alcohol Industries. Paper presented at the PACER Conference, New Delhi, India, April 24-26, 1990; Center for Environmental Studies, Princeton University, NJ, USA.

PASZTOR J, KRISTOFERSON L A (eds).,(1990). Bioenergy and the Environment, Westview Press, Boulder, CO.

PRINSLEY R T., (1990). Agroforestry for Sustainable Production- Economic Implications. CSC, Commonwealth Secretariat, London SW1.

RAVINDRANATH N.H.,NAYAK M.M.,HIRIYUR R.S. AND DINESH C.R.,(1991). "The Status and Use of Tree Biomass in a Semi-Arid Village Ecosystem", Biomass and Bioenergy, 1:9-16.

SCURLOCK J M O, HALL D O., (1990). The Contribution of Biomass to Global Energy Use (1987). Biomass, 21: 75-81.

SMIL V., (1987). Energy, Food, Environment, Clarendon Press, Oxford, U.K.

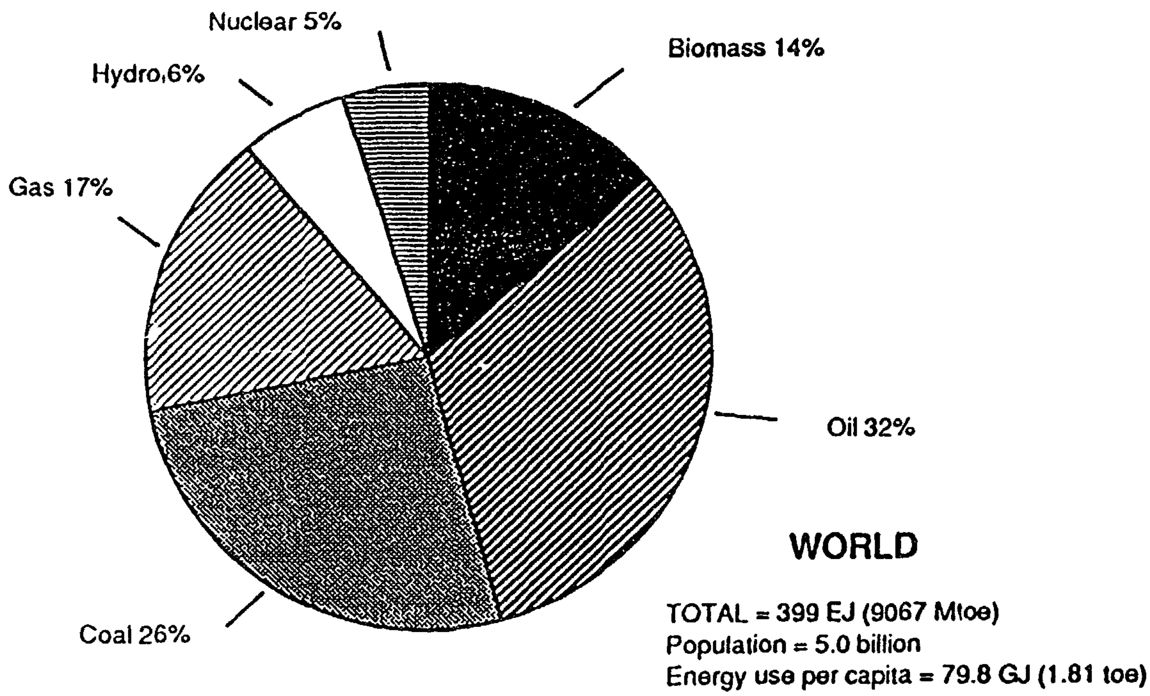
SMITH K R., (1987). The Biofuel Transition.Pacific and Asian Journal of Energy, 1: 13-31.

SOUSSAN J., (1991). Building Sustainability in Fuelwood Planning, Bioresource Technology, 35 (1): 49-56.

UNIDO., (1983). Industrial Development Strategies and Policies for Developing Countries, Doc.ID/WG.392/7, Vienna.

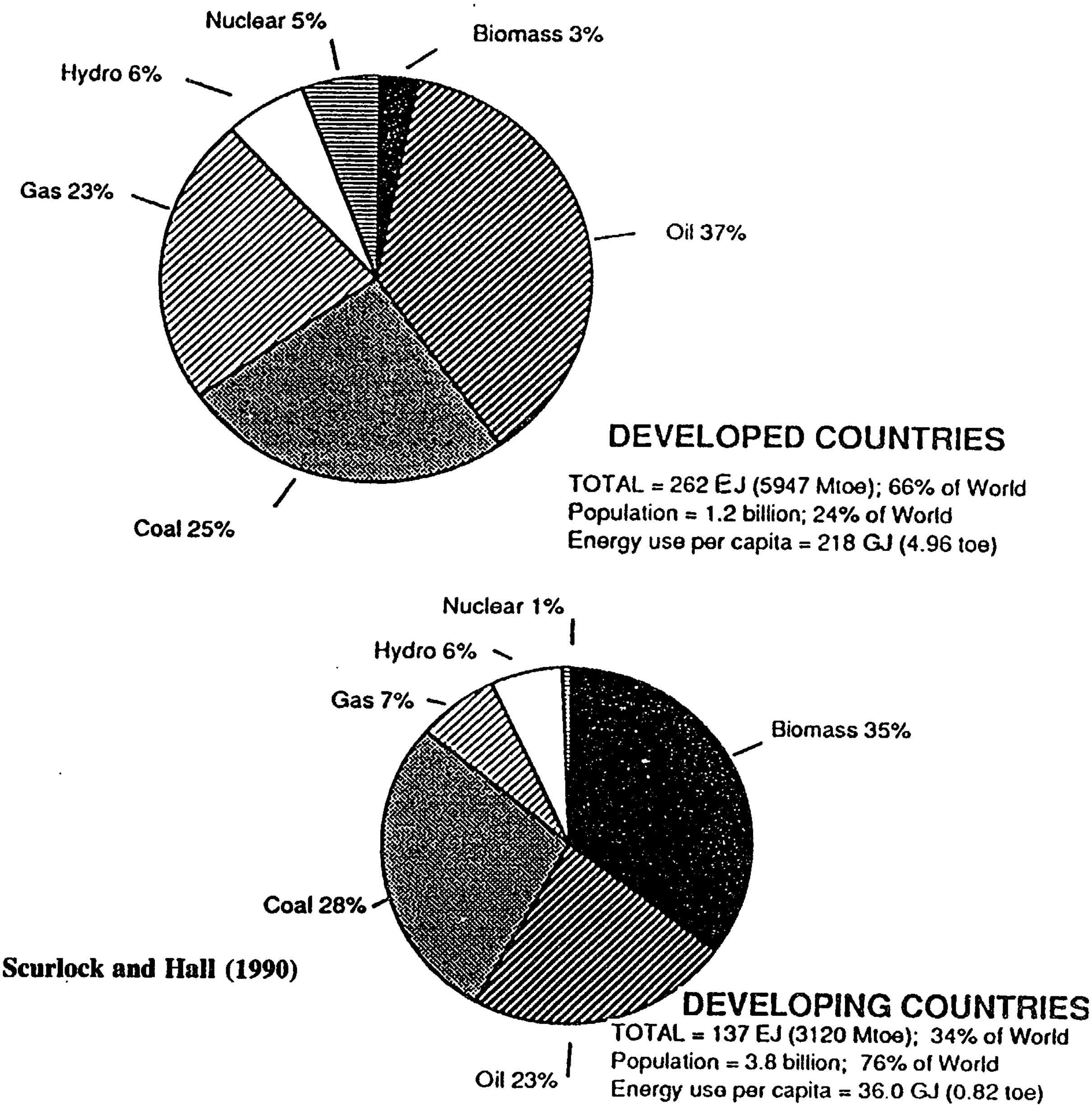
WILLIAMS R. H., LARSEN, E.D. (1992). Advanced Biomass Power Generation, in "Technologies for a Greenhouse-constrained society," (eds) M.A.Kuliaska, A. Zucker and K.J.Ballew, Lewis Publ., Baca Raton, pp. 105-158.

FIGURE 1 GLOBAL DISTRIBUTION OF ENERGY USE (1987)



Source: Scurlock and Hall (1990)

FIGURE 2 DISTRIBUTION OF ENERGY USE, BY REGIONS (1987)



Source: Scurlock and Hall (1990)

TABLE 1 Biomass Use per Capita, Biomass and Commercial Energy Use and Percentage of Biomass in the BUN's Member Countries and Other Selected Developing Countries

Country	Biomass Use per Capita		Biomass Use (10^6)		Commercial Use (10^6)	Biomass as% of Total Energy
	TWE	TOE	TWE	TOE	TOE	
Latin America						
Antigua	-	-	-	-	0.09	-
Argentina	0.18	0.06	5.75	1.99	41.55	5
Belize	-	-	-	-	0.06	-
Brazil	0.80	0.28	106.92	38.18	75.66	33
Costa Rica	0.79	0.28	2.01	0.74	0.97	43
Dominican Rep.	0.32	0.11	2.00	0.72	1.97	27
Guatemala	0.87	0.31	7.01	2.50	0.97	72
Haiti	0.66	0.23	3.43	1.22	0.21	85
Honduras	0.85	0.30	3.65	1.30	0.61	68
Jamaica	0.26	0.09	0.63	0.22	1.76	11
Mexico	0.34	0.12	27.00	9.62	98.33	9
Nicaragua	0.93	0.34	3.13	1.11	0.71	61
Panama	0.54	0.19	1.15	0.41	0.92	31
Guyana	1.44	0.51	1.14	0.41	0.33	55
St. Lucia	0.19	0.07	0.02	0.008	0.04	16
Uruguay	0.51	0.18	1.55	0.55	1.40	28
Africa						
Botswana	1.72	0.61	1.72	0.61	0.44	58
Burundi	0.76	0.27	3.61	1.29	0.07	95
Egypt	0.52	0.18	25.30	9.04	23.60	28
Gambia	0.80	0.28	0.60	0.21	0.07	75
Ghana	0.46	0.16	6.27	2.24	1.30	63
Kenya	1.32	0.47	26.91	9.61	1.57	86
Mauritius	0.96	0.34	0.96	0.34	0.40	46
Morocco	0.10	0.03	2.22	0.80	5.50	13
Mozambique	1.06	0.38	14.00	5.00	0.33	94
Nigeria	1.55	0.55	148.31	52.97	17.80	82
Rwanda	1.60	0.57	11.45	4.09	0.14	97
Seychelles	0.12	0.04	0.008	0.002	0.32	9
Somalia	1.03	0.37	4.76	1.70	0.28	86
Sudan	2.61	0.93	56.20	20.07	1.02	95
Tanzania	2.84	1.01	61.70	22.03	0.64	97
Tunisia	0.50	0.18	3.52	1.26	3.45	27
Zambia	0.94	0.33	6.25	2.23	1.30	63
Zimbabwe	1.15	0.41	9.56	3.41	4.50	43

TABLE 1 (CONT.)

Country	Biomass Use per Capita TWE	Biomass Use per Capita TOE	Biomass Use (10^6) TWE	Biomass Use (10^6) TOE	Commercial Use (10^6) TOE	Biomass as% of Total Energy
Asia						
India	0.75	0.27	569.52	203.40	154.00	57
Indonesia	1.08	0.86	177.00	63.21	32.90	66
Malaysia	2.84	1.02	44.20	15.79	14.50	52
Pakistan	0.86	0.31	83.06	29.67	19.40	60
Philippines	1.05	0.38	57.02	20.37	10.70	66
Sri Lanka	1.12	0.40	11.98	4.28	1.45	75
Thailand	1.61	0.58	13.74	4.90	18.33	21
Oceania						
Fiji	1.25	0.45	0.88	0.31	0.19	62
Vanuatu	-	-	-	-	0.02	78
W. Samoa	-	-	-	-	0.04	60
Selected Non Member Countries						
Bangladesh	1.02	0.37	101.50	36.25	4.80	88
Bolivia	1.12	0.40	7.18	2.57	1.45	64
China	0.59	0.21	619.14	221.12	559.00	28
Colombia	1.22	0.44	34.90	12.47	17.07	42
Ethiopia	0.80	0.29	34.12	12.86	0.85	94
Nepal	0.71	0.61	29.33	10.44	0.28	97
Peru	1.00	0.36	19.72	7.04	8.20	46
Senegal	0.44	0.18	2.87	1.03	0.66	61
Uganda	0.88	0.31	13.60	4.86	0.28	95
Zaire	0.79	0.28	24.10	8.61	1.45	86

Notes: TWE = Tonne wood equivalent (=15 GJ air dry).
TOE = Tonne oil equivalent (=42 GJ).
(Biomass data from various years and sources. Commercial fuel data from 1987.)

Sources: Biomass Users Network's Information and Skills Centre, Kings College London.
UN Energy Statistics Yearbook (1987)
World Resources - A Guide to the Global Environment, 1990-1991 for commercial fuel data

TABLE 2 Potential Land Requirements for Biomass Energy in Developing Countries

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 economic 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 biomass 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.

COUNTRY	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
	TOTAL LAND AREA LAND (Mha)	FORESTS & WOODLANDS (000 ha)	CROP LANDS (000 ha)	PASTURE (PERMANENT) (000 ha)	FOREST+ CROP+ PASTURE LAND (Mha)	FAO CLASSIFIED "TOTAL POTENTIAL" AGRICULTURAL LAND: LOW RAINFALL ('000 ha)	UNCER. RAINFALL ('000 ha)	GOOD RAINFALL ('000 ha)	NATURAL FLOODED ('000 ha)	PROBLEM LAND ('000 ha)	DESERT ('000 ha)	TOTAL (Mha)	PRESENT ENERGY CONS. (inc. FW) (10^6 GJ)	CROPLAND REQUIRED BY 2025** (Mha)	"REMAINING LAND" (col.XII-col.XIV) (Mha)	10 t/ha, BIOMASS ON "REMAINING LAND" (10^6 GJ)	% PRESENT ENERGY CONSUMP.	10% COL.XII VARIABLE BIO. PROD. @2,5,10&20 t/ha/yr	% PRESENT ENERGY (COL. XIII)
*DEVELOPING	6,084.8	1,914,673	706,286	1,385,689	4,007	161,387	216,690	385,540	263,128	999,687	30,418	*******	53,197	1,059	995	149,315	281	26,807	50
AFRICA	2,571.0	598,158	178,822	582,591	1,360	73,369	96,849	149,318	71,284	358,072	3,829	752.7	8,615	268	484	72,673	844	9,919	115
LATIN AMERICA	2,002.7	952,340	179,131	570,300	1,702	28,227	50,882	168,807	111,354	524,046	6,300	889.6	16,501	269	621	93,158	564	11,532	70
CEN.AMERICA	259.8	63,972	37,566	93,560	195	2,224	13,349	18,542	5,666	31,351	3,500	74.6	5,681	56	18	2,762	48	1,094	19
SOUTH AMERICA	1,742.9	888,368	141,565	476,740	1,507	26,003	37,533	150,265	105,688	492,695	2,800	815.0	10,820	212	603	90,395	835	10,438	96
*ASIA(-CHINA)	1,510.2	364,175	348,333	232,798	945	59,791	66,959	67,415	80,490	117,569	20,289	412.5	28,081	522	-110	-	.	5,356	19

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

NOTES: "TOTAL POTENTIAL" Land is defined by the FAO as all land which is phsically capable of economic crop poduction within soil and water constraints. (see UNCED Table 5c).
It excludes land which is too steep, dry or with unsuitable soils; also excluded is "potentially irrigatable" land (127 Mha, our decision).
**-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 also 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 "Land and Water Use Inventory, 1990," 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.XII 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 energy supply from biomass and India about 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 -110 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.
Cols. VI-XII; data from FAO, "Land and Water Use Inventory, 1990," Bruinsma, Rome. -"Total Potential" land definition (see above).
Col. XIII; Total present energy use; commercial + Fuelwood ONLY (FAO, "Forest Products Yearbook, 1989," Rome.)
Col. XIV; 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)
Col.XV; "Remaining Land," assumes that the increase in demand for cultivated land will take priority, and thus shows the land which would be available from total "Total Potential" land (col.XII) after future cropland requirements have been subtracted. (col.XII - col.XIV)
Col.XVI; estimates the potential for biomass energy production using "remaining land" from col.XV at 10 t/ha/yr (ie. 150 GJ/ha.)
Col.XVII; calculates the percentage of present energy use which biomass energy could supply should these assumptions hold true. (col.XVI/col.XIII)
Col.XVIII; calculates the potential for biomass energy production using 10% of each of the subcategories of "Total Potential" land (col.VI-XI):
Biomass productivities assumed: i)Low Rainfall and Deserts; 2 t/ha/yr, ii)Problem land; 5 t/ha/yr, iii) Uncertain Rainfall and Naturally Flooded land; 10 t/ha/yr, iv) Good Rainfall; 20 t/ha/yr.

Source: Woods and Hall

TABLE 3 Potential Land Requirements for Biomass Energy in Industrialized Countries

Land resources & energy use (fuelwood+commercial and recoverable residues) are compared to derive scenarios for biomass supply at 10 t/ha productivities. Yields of 10 t/ha are not necessarily realistic on all land but are chosen to represent a convenient midpoint for biomass production on a large scale in the future; in practice yields of less than 1 t/ha to more than 30 t/ha are presently experienced.

	I	II	III	IV	V	VI	VII		VIII	IX	X	XI	XII	XIII	XIV
INDUSTRILISED COUNTRIES	POPULA-TION (1987) (millions)	TOTAL LAND AREA (Mha)	FOREST+ CROP + PASTURE LAND (Mha)	HARVESTABLE RESIDUE ENERGY CONTENT (10^6GJ)	PRESENT ENERGY CONS. (inc.FW ONLY) (10^6GJ)	PRESENT PER CAPITA ENERGY USE GJ/cap.	TOTAL ENERGY CONS.@140 OR 310 GJ\cap\yr. (10^6GJ)	GJ/cap	LAND REQ'D @ 10 t/ha, TO SUPPLY 140 OR 310 GJ/cap (Mha)	% land area	10t/ha + 25% RESIDUES, TO SUPPLY 140or310 GJ/cap (Mha)	% land area	USE OF 10% FOR+CROP+PASTURE LAND FOR 140or310 GJ/cap @10t/ha (10^6GJ)	% energy cons. (present)	% energy cons. (140/310)
INDUSTRIALISED	1,191.8	5,360	3,689.7	39,442	239,293	201	166,852	(140)	1,112	21	1,047	20	55,345	23	33
N.AMERICA	268.1	1,833	1,131.2	16,058	92,976	347	83,118	(310)	554	30	527	29	16,968	18	20
EUROPE	493.7	472	378.5	11,334	65,643	133	69,124	(140)	461	98	442	94	5,678	9	8
USSR	284.0	2,227	1,549.2	9,534	59,341	209	39,759	"	265	12	249	11	23,238	39	58
ASIA	126.5	40	31.1	871	17,112	135	17,703	"	118	297	117	294	467	3	3
OCEANIA	19.5	789	599.6	1,645	4,224	217	2,727	"	18	2	15	2	8,994	213	330
WORLD	4,990	13,056	8,763	90,789	325,995	65	698,642	"	4,658	36	4,506	35	131,441	40	19

PASTURE = PERMANENT PASTURE (FAO definition) CONS = CONSUMPTION RESID. = RESIDUES FW = FUELWOOD+CHARCAOL ONLY (FAO definition)
CROP = CROPLANDS = ARABLE + PERMANENT CROPLAND AS DEFINED BY THE FAO

Source: Woods and Hall

TABLE 4 Total Land Potentials

Land & energy use (fuelwood + commercial and recoverable residues) are compared to derive scenarios for biomass supply at a productivity of 10 t/ha/yr. Yields of 10 t/ha are not necessarily realistic on all land but are chosen to represent a convenient global midpoint for biomass production on a large scale in the future; in practice yields of less than 1 t/ha to more than 30 t/ha are presently experienced.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII
COUNTRY	POPULATION (1987)	TOTAL LAND AREA	FORESTS+ CROP+ PASTURE LAND	HARVESTABLE RESIDUES ENERGY CONTENT	PRESENT ENERGY CONS. (inc.FW ONLY)	PRESENT PER CAP. ENERGY CONS.	TOTAL ENERGY CONS AT 35 & 70: GJ/capita -10^6 GJ-		LAND NEEDED @ 10t/ha TO SUPPLY ENERGY USE PER CAPITA AS SHOWN				10 t/ha,+ 25% RESIDUES (COL.IV): TO SUPPLY		USE OF 10% FOR.+CROP+PASTURE LAND FOR PRESENT ENERGY CONS OR 35 GJ/cap, @ 10 t/ha/yr.		
									35GJ/cap	% total land	70GJ/cap	% total land	35GJ/cap	% total land		%energy consumption	
	(MILLIONS)	(Mha)	(Mha)	(10^6GJ)	(10^6GJ)	(GJ/cap)	**35**	**70**	(Mha)		(Mha)		(Mha)		(10^6GJ)	PRESENT	35GJ/cap
DEVELOPING	3,799	7,645	5,020	51,347	86,702	23	132,969	265,898	886	12	1,773	23	801	10	75,296	87	57
AFRICA	589	2,957	1,641	8,355	12,052	20	20,621	41,241	137	5	275	9	126	4	24,619	204	119
CEN. AMERICA	143	265	198	2,514	6,009	42	5,022	10,045	33	13	67	25	29	11	2,964	49	59
SOUTH AMERICA	279	1,752	1,514	8,708	10,825	39	9,779	19,558	65	4	130	7	51	3	22,710	210	232
ASIA	2,780	2,637	1,622	31,632	57,648	21	97,314	194,627	649	25	1,298	49	596	23	24,332	42	25
OCEANIA	6	54	45	137	168	28	213	427	1	3	3	5	1	2	672	399	315
WORLD	4,990	13,056	8,763	90,789	225,979	65	174,661	349,321	1,164	9	2,329	18	1,013	8	131,441	40	75

PASTURE = PERMANENT PASTURE (FAO definition) CONS = CONSUMPTION RESID. = RESIDUES FW = FUELWOOD+CHARCOAL ONLY (FAO definition)

Source: Woods and Hall

TABLE 5 Potential Biomass Supplies for Energy in the US, as Estimated by the Oak Ridge Natural Laboratory(a)

Feedstock	*Net Raw Biomass Resource*[b] (EJ/year)	*Cost ($/GJ)* Current	Target
Residues			
Logging Residues	0.8	> 3	< 2
Urban Wood Wastes and Land Clearing	1.2	2	2
Forest Manufacturing Residues	2.1	1	<1
Environmentally Collectible Agricultural Residues	2.0	1-2	1
Municipal Solid Waste and Industrial Food Waste	2.4	2-3	< 1.5
Animal Wastes	0.5	< 4	3.5
Subtotal	8.9		
Biomass from Existing Forest			
Commercial Forest Wood	4.5	< 2	< 2
Improved Forest Management	4.5		< 2
Shift 25% of Wood Industry to Energy	0.5	2	2
Subtotal	9.5		
Biomass from Energy Crops			
Agricultural Oil Seed	0.3		
Wood Energy Crops	3.2	3	2
Herbaceous Energy Crops			
Lignocellulosics	5.5	4	2
New Energy Oil Seed	0.4		
Aquatic Energy Crops			
Micro-Algae	0.3		
Macro-Algae	1.1	3.5	2
Subtotal	10.8		
Total	29.3[b]		

[a] *Source*: Table 2.4-3, page 85, in W. Fulkerson *et al.*, *Energy Technology R&D: What Could Make a Difference? A Study by the Staff of the Oak Ridge National Laboratory, vol. 2, Supply Technology*, ORNL-6541/V2/P2, December 1989.

[b] These are biomass supplies net of estimated losses in production and handling, before conversion to fluid fuels or electricity.

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS948	Factors Affecting Private Financial Flows to Eastern Europe, 1989-91	Mohua Mukherjee	July 1992	R. Lynn 32169
WPS949	The Impact of Formal Finance on the Rural Economy of India	Hans Binswanger Shahidur Khandker	August 1992	H. Binswanger 31871
WPS950	Service: The New Focus in International Manufacturing and Trade	Hans Jürgen Peters	August 1992	A. Elcock 33743
WPS951	Piecemeal Trade Reform in Partially Liberalized Economies: An Evaluation for Turkey	Glenn W. Harrison Thomas F. Rutherford David G. Tarr	August 1992	D. Ballantyne 38004
WPS952	Unit Costs, Cost-Effectiveness, and Financing of Nutrition Interventions	Susan Horton	August 1992	O. Nadora 31091
WPS953	The "Pedigree" of IEC Conversion Factors for Per Capita GNP Computations for the World Bank's Operational Guidelines and *Atlas*	Michael Hee	August 1992	E. Zamora 33706
WPS954	How OECD Policies Affected Latin America in the 1980s	Chris Allen David Currie T. G. Srinivasan David Vines	August 1992	T. G. Srinivasan 31288
WPS955	OECD Fiscal Policies and the Relative Prices of Primary Commodities	George Alogoskoufis Panos Varangis	August 1992	D. Gustafson 33714
WPS956	Regression Estimates of Per Capita GDP Based on Purchasing Power Parities	Sultan Ahmad	August 1992	E. O'Reilly-Campbell 33707
WPS957	Carbon Taxes, the Greenhouse Effect, and Developing Countries	Anwar Shah Bjorn Larsen	August 1992	WDR Office 31393
WPS958	EC Bananarama 1992: The Sequel — Tha EC Commission Proposal	Brent Borrell Maw-Cheng Yang	August 1992	A. Kitson-Walters 33712
WPS959	Waterborne Diseases in Peru	Sheila Webb and Associates	August 1992	WDR Office 31393
WPS960	Agricultural Pricing and Environmental Degradation	Edward B. Barbier Joanne C. Burgess	August 1992	WDR Office 31393
WPS961	Economic Development and the Environment: Conflict or Complementarity?	Wilfred Beckerman	August 1992	WDR Office 31393
WPS962	Do Markets Underprice Natural-Resource Commodities?	Margaret E. Slade	August 1992	WDR Office 31393

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS963	Growth and Welfare Losses from Carbon Emissions Restrictions: A General Equilibrium Analysis for Egypt	Charles R. Blitzer R. S. Eckaus Supriya Lahiri Alexander Meeraus	August 1992	WDR Office 31393
WPS964	Toxic Releases by Manufacturing: World Patterns and Trade Policies	Robert E. B. Lucas	August 1992	WDR Office 31393
WPS965	Coping with the Disappointing Rates of Return on Development Projects That Affect the Environment	William Ascher	August 1992	WDR Office 31393
WPS966	Trade and the Environment: A Survey of the Literature	Judith M. Dean	August 1992	WDR Office 31393
WPS967	Transition Problems in Economic Reform: Agriculture in the Mexico-U.S. Free Trade Agreement	Santiago Levy Sweder van Wijnbergen	August 1992	M. Stroude 38831
WPS968	Biomass	David O. Hall	August 1992	WDR Office 31393