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Clean Energy for Development and Economic Growth : Biomass and Other Renewable Energy Options to Meet Energy and Development Needs in Poor Nations

Policy Discussion Paper for the
Environmentally Sustainable Development Group (ESDG)
of the United Nations Development Programme (UNDP)

Table of contents

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Executive summary

This paper explores the linkages between renewable energy, poverty alleviation, sustainable development, and climate change in developing countries. In many developing countries, the lack of access to convenient and efficient energy services is a major barrier to achieving meaningful and long-lasting solutions to poverty. Of course, providing quality energy services will not, in itself, eliminate poverty. Nevertheless, when poor people and communities obtain access to convenient and efficient energy services, one major barrier to poverty reduction can be lowered or removed. **Renewable energy technologies using biomass, wind, solar, hydropower and geothermal energy sources can provide energy services for sustainable development based on indigenous sources, with almost no net emissions of greenhouse gases.**

In most developing countries, **conventional approaches to energy service provision – state-run utilities and extension of the national electrical grid – have not proven successful**. To date, most developing countries have financed their energy sectors with loans from bilateral and multilateral lending institutions. For various reasons, these institutions have heavily favored fossil fuel and large hydroelectric power, which have left developing countries with large burdens of debt and taken a significant toll on the local and global environment, while providing only a small fraction of people with adequate energy services.

Poor families in developing countries still rely on traditional fuels – wood, crop residues and dung – for cooking, heating and productive activities. They are limited in their ability to do more than satisfy basic needs. The lack of access to clean and convenient energy services in rural areas limits economic opportunities and drives people, most frequently male household members, to seek employment in towns and cities. This leads to increasing numbers of female-headed rural households, and adds to the burdens on poor women and children, who already expend a great deal of effort in gathering wood and other traditional fuels, as well as meeting the other subsistence needs of the household.

Unsustainable use of traditional biomass fuels is associated with significant health and environmental costs. Smoky, unvented fires for cooking and heating lead to high concentrations of indoor air pollution which cause acute respiratory infections, tuberculosis, adverse pregnancy outcomes, and lung disease. Women who are doing the cooking, and their young children, are the ones who are most affected. Open fires also contribute to atmospheric accumulations of greenhouse gases, particularly carbon dioxide. Deforestation adds to fuel wood scarcity and environmental degradation, and limits carbon dioxide absorption by trees.

Policies that focus on small-scale decentralized renewable energy systems, coupled with greater access to information, technical training, credit and markets, have the potential to succeed in promoting sustainable development, including economic opportunities and environmental protection, where conventional approaches have failed. Recent technical advances in renewable energy-based power generation, accompanied by rapid growth in production and dramatic reductions in costs, place renewable energy technologies in a favorable position in comparison with conventional fossil fuel systems, in an ever-expanding variety of applications.

A combination of sound national and international policies and genuinely competitive markets – the so-called level playing field – can be used to promote clean energy systems. However, there still remain numerous technical, social and market barriers, on the local as well as global level, preventing wider deployment of renewable energy systems. Such barriers must be understood and dismantled in order to take advantage of the social and environmental benefits of a shift from conventional to renewable technologies. Renewable energy sources have had a difficult time breaking into markets dominated by large-scale, fossil fuel-based systems. In part this is because renewable energy technologies are only now being mass produced, and have had high capital costs relative to more conventional systems. It is also partly because coal, oil and gas-powered systems, as well as large hydroelectric dams have all benefited from a range of subsidies over the years.

Renewable energy technologies tend to be characterized by low environmental costs which, in an ideal world, would help them compete with conventional technologies. But, of course, many of these environmental costs are "externalities" that are not priced in the market. Further internalization of these costs, through the provisions of the Kyoto Protocol and other energy and climate change policies, would encourage the spread of renewable energy systems.

Our discussion includes all types of renewable energy technology, but **we place special emphasis on biomass-based energy systems**. While biomass fuels are likely to remain the primary energy source for most poor people, improved stoves and cleaner fuels can reduce fuel requirements and adverse health and environmental impacts. Meanwhile, improved technologies for use of biomass in small commercial and industrial applications can make modern energy installations economically viable in rural and peri-urban areas of developing countries, since businesses have larger energy demands than households and are better able to mobilize capital.

Biomass energy has a number of unique attributes that make it particularly suitable to climate change mitigation and community development applications. Biomass fuel sources are readily available in developing countries, particularly in rural areas, and do not have to be imported. Biomass-based industries can be a significant source of jobs in rural areas, and sustainable land management activities can promote biomass regrowth, allowing more carbon dioxide to be absorbed from the atmosphere. [See box on the benefits of bioenergy.]

By promoting biomass energy to provide clean and efficient "modern" energy services in the form of solid, liquid, and gaseous fuels as well as electricity, the governments of developing countries can address many of the negative aspects of current unsustainable biomass consumption. Moreover, taking that step now does not require devoting large amounts of land to bioenergy crop production, which can potentially conflict with other land uses, particularly food-crop cultivation. Significant amounts of energy can be derived from underutilized agricultural, agro-industrial, and timber wastes, which include bagasse from sugarcane processing, sawdust and off-cuts from the timber industry, fruit pits and prunings from orchards, coffee husks, rice husks, and coconut shells. Using these resources for energy generation would allow countries to gain valuable experience through learning-by-doing while continuing with basic research in energy crop production.

A variety of technologies can convert solid biomass into cleaner, more convenient energy forms such as gases, liquids and electricity. Direct combustion remains the most common technique for deriving energy from biomass for both heat and electricity. Advanced domestic heaters obtain efficiencies of over 70 per cent with greatly reduced atmospheric emissions. Electrical power is commonly generated in steam cycle plants often located at industrial sites where the waste heat from the steam turbine can be recovered and used in industrial processing. Combined heat and power systems provide higher efficiencies than systems that only generate electricity.

Combustible gas can be produced from biomass through a high temperature thermochemical process - gasification - that involves burning biomass without sufficient air for full combustion, but with sufficient air to convert the solid fuel into a gas. The resulting gas can be burned directly for cooking and heating uses, or used in internal combustion engines or gas turbines for producing electricity or shaft power. The systems range from small-scale technologies suitable for household or village use, to large grid-connected power or combined heat and power facilities.

Combustible gas can also be produced from biomass through the biological processes of anaerobic digestion, either in specially-designed digesters or in landfills. This biogas can be used to provide energy for cooking and space heating, and to generate electricity. Biogas digesters have been widely adopted in India and China, and other developing countries.

Liquid fuels produced from solid biomass can be used to replace petroleum-based fuels. The most widely produced liquid biofuel today is ethanol, which can be produced from fermentation of any carbohydrate crop. Sugarcane and corn (maize) are the most common ethanol feed stocks though cassava, sorghum, and other root crops have also been considered.

Conversion of biomass to energy carriers like electricity and transportation fuels can give biomass a significant commercial value and potentially provide income for rural economies. But transforming bioenergy into a renewable source of high-quality fuels and electricity will not happen without the establishment of enabling policy environments and adequate public and private sector investment.

In addition to the lack of energy services, which limits opportunities for many people in developing countries, there are numerous environmental problems associated with energy development. These problems are both local and global in nature. Among the most pressing of these environmental problems is global climate change. Policy makers in many developing countries are aware of the need for climate change mitigation, but they are generally more concerned with providing basic services to populations, including energy, as well as clean water and basic health care and education. They also hold that the industrialized countries have been emitting greenhouse gases for well over a century and should bear the brunt of the costs of climate change mitigation.

The Kyoto Protocol to the UN Framework Convention of Climate Change recognizes the responsibility of industrialized countries to take the lead in reducing greenhouse gas emissions. Currently, most of the greenhouse gases added to the atmosphere by human activities are the result of carbon dioxide from fossil fuel combustion. Over two thirds of those emissions come from industrialized countries. But greenhouse gas emissions are increasing in developing countries much faster than in industrialized countries as a result of growth in both population and national economies. **If developing countries follow the path taken by industrialized countries in building energy generation infrastructure, they will likely exceed industrialized countries in net greenhouse gas emissions within one or two generations**. And if that path continues without a significant shift toward renewable-based energy generation, there will be little hope of stabilizing greenhouse gas accumulations even if industrialized countries meet the modest goals set by the Kyoto Protocol.

The Clean Development Mechanism (CDM) under the Kyoto Protocol offers a means through which industrialized countries can work towards compliance with their commitments to reduce greenhouse gas emissions by supporting sustainable development projects in developing countries. It is likely that a number of CDM projects will target the energy sector, as well as land use and forestry activities. **Biomass energy projects can meet the requirement of fostering sustainable development, due to their numerous positive environmental and social impacts, including improvement of degraded lands, creation of employment opportunities and raised living standards for poor communities.**

In order to ensure that CDM projects in fact promote sustainable development as well as climate change mitigation, projects must be guided by meaningful public participation and local benefit-sharing policies. Clear guidelines are needed so that the many competing uses of land areas supporting biomass projects are considered, including the livelihoods of indigenous and marginalized communities, different ethnic groups, and women. In addition, in order to establish a critical knowledge base for sound and profitable bioenergy management, there needs to be a collaborative partnership among researchers, governments and industries in developing as well as industrialized countries. **Lessons can be drawn from joint UNDP and World Bank efforts in climate change mitigation projects under the Global Environmental Facility, and from case studies such as those included as part of this document.**

Biomass and bioenergy – advantages for climate change mitigation and poverty alleviation:

Local resources: Biomass energy systems rely primarily on locally available resources and eliminate the need for imported fuels

Participation: Local nature of fuel supply can encourage local participation through job creation and fuel supply contributions, as well as local ownership, investment, and project management

Jobs: Biomass energy production is relatively labor intensive and the stages of energy production provide far more local jobs, skilled and unskilled, than comparable energy technologies

Flexibility and multiple use: Biomass energy generation can be based on a variety of feedstocks which allow for multiple crops to be grown. Land used to produce bioenergy crops can support multiple uses in order to meet changing local needs.

Stores carbon: standing stocks of biomass store carbon above-ground, below-ground, in leaf litter, and in the soil. The overall carbon accounting strongly depends on what the prior land use was.

Land degradation: If bioenergy stocks are planted on degraded lands, they have the potential to bring long-term improvements in soil quality and fertility.

Ecosystem services: Growing biomass can provide numerous ecosystem services including the control of soil erosion, sustaining the hydrological cycle, and providing habitat for wildlife.

Introduction: Renewable energy, global warming and sustainable development

Conventional energy sources based on oil, coal, and natural gas have proven to be both highly effective drivers of economic progress, and damaging to the environment and to human health. Perhaps the gravest challenge currently associated with energy use in all nations is the need to reduce greenhouse gas emissions.

The potential role of renewable energy technologies in transforming global energy use, and addressing climate change concerns, is enormous. Energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services, based on a mix of readily available, indigenous resources that result in almost no net emissions of greenhouse gases.

The costs of solar and wind power systems have dropped substantially in the past 30 years, and continue to decline. The economic and policy mechanisms that support the widespread dissemination and sustainable markets for renewable energy systems have also rapidly evolved. Future growth in the energy sector will be primarily in renewable technologies and, to some extent, natural gas-based systems, rather than in conventional oil and coal-based sources.

Renewable energy systems are usually implemented in a small-scale, decentralized model. As an alternative to centralized power plants, which require customized onsite construction, renewable systems based on solar photovoltaic (PV) arrays, windmills, biomass or small hydropower, can be mass-produced at low cost and tailored to meet specific energy loads and service conditions. These systems also have fewer environmental impacts than larger, more centralized power plants that, in some cases, have contributed to serious ambient air pollution and acid rain, as well as global climate change.

In developing countries, heavy reliance on imported fossil fuels also represents a huge financial burden. Energy sector development in developing countries, with few exceptions, has focused on large hydro systems and fossil fuels, despite the fact that many developing countries are rich in biomass, wind, solar, and smaller, less environmentally and socially disruptive hydro resources that could power their economies and improve their living standards.

Renewable energy sources currently supply somewhere between 15 per cent and 20 per cent of the world's total energy demand, mostly in the form of fuelwood used for household energy needs in developing countries. New renewable energy sources (solar energy, wind energy, modern bio-energy, geothermal energy, and small hydropower) currently contribute about two per cent of the global energy mix. Studies indicate that in the second half of the twenty first century their contribution might increase dramatically, with the right policies in place. This will only occur, however, if energy projects and policies are evaluated and implemented based on their overall social, economic, and environmental merits.

Use of bioenergy resources in developing countries can build local capacity to meet energy needs, and also provide significant employment and development opportunities.

This document provides a resource guide on biomass and other renewable energy options, case studies, and a set of recommendations for international energy and climate policy organizations, national governments, non-governmental groups, and local communities.

1- Energy and the poor

The majority of the world's poor families have no alternative but to rely on traditional biomass fuels – wood, crop residues, and dung – to produce energy for household uses, small-scale commercial activities and income generation.

Cooking represents the largest end-use of biomass energy in many developing countries (Dutt and Ravindranath, 1993; Kammen, 1995a, 1995b). For many years, wood collection for cooking was thought to be a direct cause of deforestation and desertification, particularly in Africa. However, research has largely failed to find direct links between household fuel consumption and land degradation, except in localized cases where commercial charcoal production is a dominant household energy supply strategy. While the fuel wood-deforestation link has been largely discredited (Leach and Mearns, 1988), deforestation caused by timber sales, expanding cultivation, and charcoal or fuel wood production, does place extreme pressure on rural biomass resources and reduces the biomass that poor people are able to use for their own needs.

The most common method of cooking throughout rural areas of the developing world is the open hearth or three-stone fire, which typically transfers only 5-15 per cent of the fuel's energy into the cooking pot. For many years, development agencies have promoted more efficient cook stoves. Ironically, many 'improved' stoves failed to raise efficiency in actual field use while many others have been rejected for numerous non-technical reasons. Still, there have been successes, such as the Kenyan Ceramic Jiko (Kammen, 1995a; Crewe, 1997). Improved stoves have been successfully disseminated in several countries in addition to Kenya, but in other countries, where stove projects have failed, technical, social, and market barriers have prevented their wide-spread adoption. It is troubling that after more than two decades of improved stove programs, most of the world's poor people continue to cook on unimproved stoves (Kammen, 1995a, 1995b; Barnes, 1994; Smith et al., 1993; UNDP, 1997).

Poor households generally spend more money buying, or more time collecting, each unit of energy they consume compared to wealthier households (Dutt and Ravindranath, 1993). They are limited in their ability to do more than satisfy basic needs because value-adding activities require energy inputs – electricity, shaft power, and controlled process heating – that are simply not available through simple combustion of solid fuels.

Heavy reliance on biomass energy in poor urban and rural communities of the developing world is unlikely to change in the near future. Fuel switching occurs principally in urban areas where alternative fuels are available. A large-scale rural energy transformation to fossil-fuels is unlikely for economic reasons and undesirable in terms of increased greenhouse gas emissions. But there are alternative ways to utilize biomass energy that are cleaner, more efficient, and more convenient, and that can support sustainable development.

1.1 Rural-urban energy linkages

Nearly every developing country has a rate of urban growth that outstrips the base rate of population growth (World Bank et al., 2000). Not only are cities growing in size, but they are growing faster than the populations in the rural areas that provide the food and raw materials necessary for urban growth. One of the underlying causes of rural-urban migration is the fact that development priorities favor urban centers (Lipton, 1976). Lack of access to clean and convenient energy sources limits economic opportunities in rural areas and drives people, most frequently male household members, to seek opportunities in towns and cities. This leads to increased numbers of female-headed households, and additional time and labor burdens for women and children in rural areas.

Growing urban populations place increased demands on biomass resource areas. For example, in Kenya, in one year, an urban household cooking exclusively with charcoal uses between 240 and 600 kg of charcoal. This amount of charcoal requires between 1.5 and 3.5 tons of dry wood to produce. The charcoal sold in Nairobi usually originates from arid and semi-arid regions where tree cover is sparse. The national government owns, but does little to control access to, the forests where charcoal production takes place. Charcoal producers pay no stumpage fees, so their urban customers need pay only for labor, transportation, and handling of the charcoal, plus the mark-ups charged by numerous middlemen (Kituyi et al., 2001a and b).

The detrimental effects caused by loss of tree cover are borne by rural populations. Since charcoal is a popular urban fuel and a huge revenue generator, prohibition of charcoal production would be extremely unpopular. An alternative to government control is local community control of forest resources. This would channel charcoal revenues into local communities and promote sustainable land management practices.

Growing urban populations also intensify the demand for fossil fuels and electricity. Increases in demand must be satisfied by additional imports of fossil fuels and electrical power, which places a strain on the country's balance of trade and costs dearly in foreign exchange. Rapid urbanization also creates a demand for more intensive agricultural production, which involves costly and energy- intensive inputs, thereby favoring wealthier farmers or big agri-businesses, disempowering small-scale and subsistence agricultural producers, and promoting further rural-urban migration.

1.2- The energy mix in urban and rural areas

Poor urban households often rely on a mix of commercial energy sources, including fuel wood, charcoal, kerosene, liquefied petroleum gas (LPG) and electricity. Energy end uses range from subsistence needs like cooking, space heating, and lighting to income generating activities and entertainment. The mix of sources and quantity of energy that urban households use can change depending on domestic and international fuel markets, fluctuating household incomes, and seasonal conditions that affect labor markets and fuel availability.

Poor rural households usually have fewer energy options. The higher cost of, and lack of access to, commercial forms of energy, and the lower incomes characteristic of rural populations, compel rural households to rely more heavily on traditional fuels, and limit the diversity of possible end-uses. Non-traditional forms of energy that poor rural households have access to are usually limited to dry cell or lead-acid batteries, which are highly specialized in the applications and extremely costly in terms of price per unit of delivered energy. In addition to energy storage devices like batteries, solar photovoltaic (PV) panels have become an available in a small but growing number of rural areas throughout the developing world. While such systems remain too expensive for poor families, the prices have come down considerably and in some instances, innovative financing mechanisms have been developed that make the systems affordable for a larger number of households. We discuss this aspect of PV in more detail in section 5.2 below.

1.3- The 'energy ladder' and household fuel switching

Analysts use a simple model, the 'energy ladder' (Smith, 1987; Leach and Mearns,1988; Leach, 1992; Masera et al., 2000), to describe a hierarchy of household energy options characterized by traits such as cost, energy efficiency, cleanliness, and convenience. Fuels which are available for free or for very low cost, such as wood, dung, and crop residues, are the dirtiest and the least convenient to use. Cleaner, more convenient fuels tend to transfer heat more efficiently, are easily controlled over a range of heat outputs, and are much costlier. They may require large lump payments for the fuel as with LPG, or large up-front expenditures for the stove, as with gas and electric cookers.

Problems with the energy ladder model arise from the simplified way that the model is applied to policy-making, and the mistaken conclusion that fuel choice is determined by purely economic factors. An increase in household income will not necessarily be spent on cook stoves or fuel. Moreover, complete switching, where one fuel totally substitutes for another, is rare. Cultural preferences may cause a household to retain a particular fuel / stove combination to cook certain foods or to use on special occasions. Finally, ease of access and consistent availability of fuels are both important factors that determine the extent and / or permanence of fuel switching in any household.

1.4- Energy services for the poor

In developing countries, commercial energy in the form of grid-based electricity and fossil fuels is often unavailable in rural areas, and even many urban residents do not receive reliable energy services. While there is little doubt that 2-3 billion people in developing countries use traditional biomass fuels to satisfy their basic needs, there is a great deal of uncertainty surrounding their consumption and its effects on personal health, and local and global environments. Data on household fuel consumption is difficult to acquire and unreliable. Traditional biomass fuels may be collected, or obtained commercially from other individuals or small businesses.

A common small-scale commercial energy source used in developing countries is battery power. Disposable dry cell batteries allow people to use handheld flashlights and play transistor radios. Larger lead-acid batteries, the type used in the ignition systems of cars and trucks, provide more electrical capacity and can be recharged repeatedly. Commercial energy service options for the poor also include off-grid electric power technologies for household or commercial applications. The most common ones are diesel powered generators. Solar photovoltaic (PV) panels are becoming increasingly common as costs come down and markets develop. Less common off-grid renewable options include small (micro) hydroelectricity systems, wind turbines, and biomass-powered electric systems.

A relatively new concept in energy provision for the poor, which can utilize one or more decentralized technologies is the Energy Service Company (ESCO). Usually, when decentralized energy technologies are introduced in rural areas, the hardware is bought by the end-user(s) with cash up-front or through financing. The buyer assumes the risk of ownership and is responsible for operating and maintaining the hardware. In the ESCO model, a private company, or community-based organization, enters into a contractual agreement with community members to provide them either with hardware or energy services. The company may have support from the government, the national utility company or an outside donor.

1.5- Energy and the poor: Conclusions

Lack of access to modern energy services is inextricably linked to poverty and the lack of fulfillment of other needs such as shelter, food, health care, education, secure land tenure, access to agricultural inputs, credit, information, and political power. Access to energy is a necessary, but not sufficient ingredient in poverty alleviation.

In most developing countries, conventional approaches to energy service provision - state-run utilities and the extension of the national electrical grid – have not proven successful. Policies that bring access to information, credit, and jobs, implemented in tandem with the introduction of small-scale decentralized energy systems, have the potential to succeed where 'conventional' approaches have failed. Renewable energy technologies that rely largely on local resources are particularly suited to this approach.

In many cases, providing energy services to poor communities is more expensive than providing it to better-off communities because of geographical remoteness, high risk, poor payback, or low base demand. Poor communities may also have difficulty attracting private energy suppliers. However, energy service provision can involve indirect benefits like increased rural productivity, reduced rural-urban migration, and a potential decrease in pressure on rural energy resources with associated environmental benefits. These benefits could outweigh the incremental costs of energy provision, and fully justify some subsidies from an outside party (the government or a donor), in order to level the costs of service provision and make it an attractive investment for the private sector.

2- Biomass and bioenergy for household use: Resources and impacts

Biomass is used by households in developing countries for food, fuel, fodder, fibre, feedstock, and fertilizer (Leach, 1992). Policy decisions or interventions aimed at enhancing or modifying biomass energy options will inevitably affect other areas of biomass utilization. In designing policy, it is therefore crucial to assess the potential impacts of the policies on all possible users, as well as on all possible uses, of biomass resources.

2.1 Sources of household biomass

Biomass for household energy use is gathered from roadsides, natural woodlands, or communal wood lots. It can be grown on the homestead in private wood lots, intermingled with food crops, pruned from fruit trees or windbreaks, collected from fallow fields and grazing areas, or 'poached' from restricted state forests and nature preserves, which are often situated in areas of historical community access. When the primary household fuel is biomass, energy supply strategies are inseparable from land management strategies, and thus dependent on political and socioeconomic issues like land tenure and tree tenure, markets for land and labor, norms governing property and land use, and rules of inheritance. Even at the community level, access to biomass resources (and energy services) is not determined simply by technical or economic questions; social relations mediated through gender, ethnicity, and class play an important role.

2.2- Impacts of household biomass use

The World Energy Assessment (UNDP et al., 2000) divides the chief environmental impacts of household biomass use into two broad categories: impacts resulting from biomass harvesting and impacts resulting from biomass combustion. Harvesting of fuels has a direct impact on the physical environment, while combustion results in emissions that can simultaneously place a burden on human health and on the atmosphere.

2.2.1- Biomass and society: Gender, fuel and resource control

The largest impact of changes in biomass usage patterns at the household level will certainly be on women and children, who expend the greatest effort in the acquisition of wood fuels and other biomass resources. Greater demand for biomass will almost certainly increase the monetary value of biomass, making it less available to the poorest people, especially women. Increased prominence of biomass energy will likely attract entrepreneurs and business persons, and in most nations those individuals are generally men. In a number of settings, this process will drive women to more marginal roles, and reduce their employment and economic opportunities (Agarwal, 1994). While the means to address this are often complex, a simple rule is that multiple stakeholders, even those often silent or silenced, need to be explicitly engaged and included in plans to develop any given resource sector. The urgency grows when we see that sharp divisions along gender and ethnic lines occur in both the informal, cash-poor sector and the formal, capital-rich sector of economy and society.

2.2.2- Environmental impacts of household biomass use

Considering the strong linkages between biomass consumption for fuel and biomass utilization for other end-uses, it is impossible to implicate household energy demand as a direct cause of environmental degradation. Deforestation is more often the cause of fuel wood scarcity than the effect of too much household fuel consumption. Nonetheless, once forest land is degraded or lost entirely, fuel wood consumption and scarcity can act as a feedback process that prevents the recovery of the forest, or leads to further degradation. If trees are insufficient to meet demand, then some households may turn to agricultural residues or animal manure. This shift can reduce supplies of traditional fodder for livestock, lower the quality of the animals' manure as fertilizer, reduce the availability of crop residues for fertilizer, and leave top soil unprotected from erosion when crop residues are removed. To satisfy household energy needs, both tree cover and soil quality may be sacrificed, leaving rural households impoverished and more susceptible to economic or environmental shocks.

One way to safeguard against this type of degradation is to vest control of forest resources in local communities. Land degradation is the result of social as well as physical processes, which must be considered in their local and historical context in order to identify, understand, and mitigate environmental problems (Blackie and Brookfield,1987; Peluso,1999).

Trees planted within the household compound or interspersed with crops or grazing land carry multiple benefits including, but not limited to, fuel wood, fruit, fodder, building material, shade, wind-breaks, and natural fencing. Some leguminous tree species can be interplanted with crops or on fallow fields to fix nitrogen and restore soil fertility. And all trees, including trees planted in agroforestry systems, can be used to sequester carbon though the permanence of the carbon-sinks is not guaranteed and has to be addressed (Kartha, 2001).

Intensifying biomass utilization can have multiple impacts on the environment. Principal environmental concerns include soil erosion and loss of nutrients as biomass is repeatedly harvested. In addition, loss of biodiversity may occur in cases where certain species are favored for energy production or where energy crops replace natural woodland or forest and the local hydrology also may be affected. All of these concerns are manageable in theory, though local conditions will vary and need to be addressed on a case-by-case basis. Obviously full impact assessments should be conducted before any project goes forward. If steps are taken to minimize these and other impacts, the benefits of intensified bioenergy production should outweigh the costs.

Environmental effects of household biomass combustion also extend to the global arena, since household biomass combustion results in greenhouse gas emissions. Under optimal conditions, combustion of biomass results in the emission of water vapor and carbon dioxide. Water vapor, the most prevalent greenhouse gas in the atmosphere, is quickly incorporated in the hydrologic cycle with no measurable warming effect, and carbon dioxide, the most common anthropogenic greenhouse gas, is absorbed by new plant growth through photosynthesis. Therefore, if biomass is harvested in a sustainable way so that long-term stocks of biomass are not depleted, and burned in ideal combustion conditions, it is effectively greenhouse gas neutral.

However, in hearths and stoves commonly used in developing countries, combustion is never ideal. Under these conditions, hundreds of compounds are emitted in addition to carbon dioxide and water (Smith, 1987; UNDP, 2000). These compounds include large amounts of carbon monoxide, methane, non-methane hydrocarbons, and particulate matter, as well as small amounts of many other pollutants. Carbon monoxide, methane and non-methane hydrocarbons all affect the radiative balance of the atmosphere to an equal or greater extent than an equivalent amount of carbon dioxide (IPCC, 2001). Moreover, these non-carbon dioxide greenhouse gases are not absorbed by photosynthesis and remain in the atmosphere despite new biomass growth. Preliminary research has shown that as a result of incomplete combustion by common household cooking devices, **cooking with biomass can release more greenhouse gases than cooking with clean burning fossil fuels like kerosene and LPG**. See UNDP et al., 2000 or Smith, 2000b and 2000c for more details on this research.

In an important link between climate change and public health, exposure to many of the compounds released by incomplete biomass combustion is quite harmful. Improving combustion efficiency of household cooking devices therefore will mitigate both greenhouse gas emissions and severe public health problems. The health aspects of the equation are discussed in more detail below.

2.2.3- Health impacts of household biomass combustion

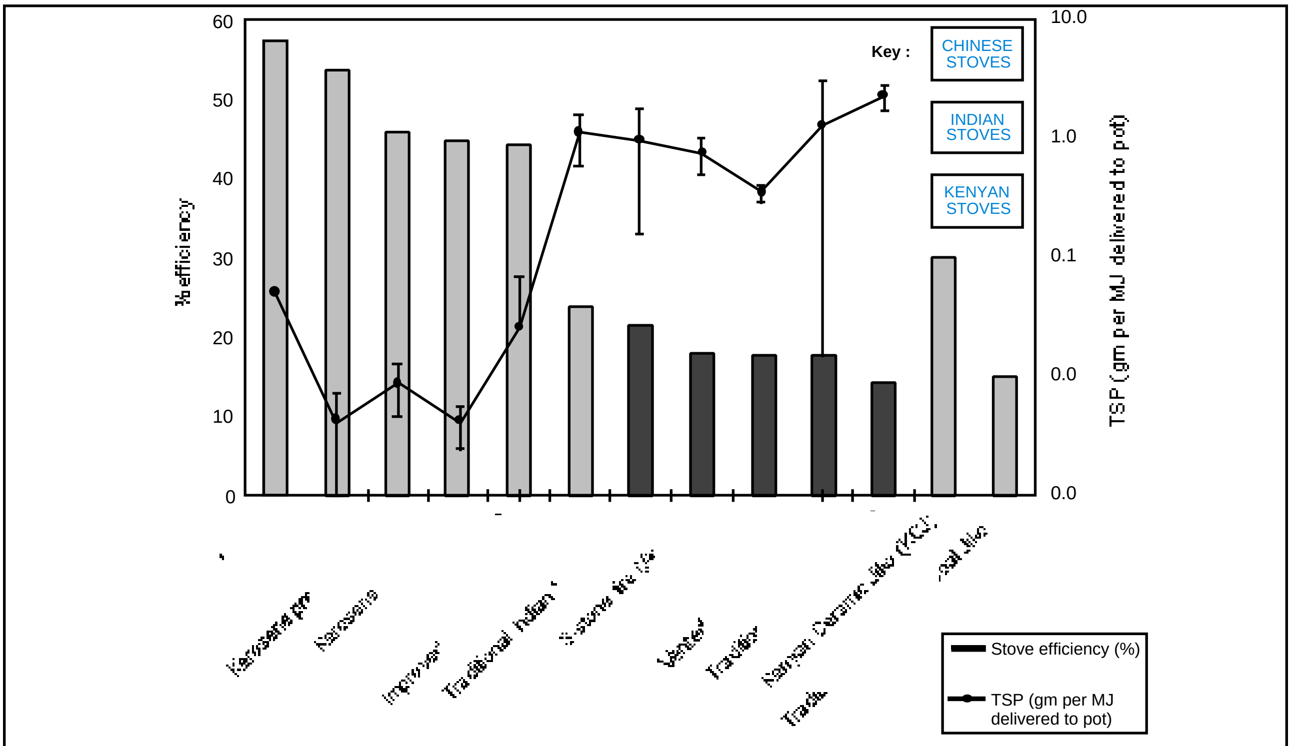
Because of the high concentrations of indoor air pollution resulting from biomass combustion and the large number of people affected, rural areas of developing countries suffer the greatest exposure globally to particulate matter and other solid fuel combustion emissions (Smith, 1993). Wood smoke contains hundreds of different compounds, including a number which are carcinogenic. In addition, small-scale biomass combustion emits large amounts of particulate matter, including fine particles less than 2 microns in diameter. These particles penetrate deeply in the lungs and are thought to cause more health damage than larger particles (Raiyani et al., 1993; Bruce, et al., 2000). The effects of high levels of exposure to these chemical compounds and particulate matter include a number of possible health impacts: acute respiratory infections; tuberculosis; adverse pregnancy outcomes; chronic obstructive lung disease; and several types of cancer (Smith, 1993).

The strongest evidence of causal linkage between biomass combustion emissions and ill health is with acute respiratory infection in children (Smith, et al., 2000a; Ezzati and Kammen, 2001; Bruce et al., 2000). It is the primary cause of morbidity and mortality in children under five, causing more deaths and ill health globally than either malnutrition, diarrhea, or childhood diseases like measles and mumps. Children of this age group are most affected because they spend a large amount of time indoors, close to the women of the household who do most of the cooking.

Emissions generally decrease, and efficiency improves, as cooking devices move along the 'energy ladder' discussed above. Accordingly, policy interventions have targeted both improving biomass stoves and encouraging the use of alternative fuels. The most common alternative fuels are non-renewable fossil fuels like kerosene, natural gas, and LPG. Renewable alternatives like biogas will be discussed in detail below. Figure 1 shows a comparison of the particulate emissions and efficiencies of different stove technologies from China and India, with the emissions and efficiencies of two types of wood burned in a three-stone fire and the efficiencies of two improved Kenyan charcoal stoves included for comparison (Zhang et al., 2000; Smith, et al., 2000c; Kammen, 1995b).

Figure 1

Emissions factors and Efficiencies of Various Traditional and Improved Cookstoves



All data are from Zhang, et al., 2000, except the biogas stove and 3-stone fires, which are taken from Smith, et al., 2000c, and the charcoal stoves, which are taken from from Kammen, 1995 (no emissions factors available). Error bars show +/- one standard deviation, based on, in most cases, three measurements.

There is a tension between the desire to move away from traditional biomass combustion and the desire to avoid increasing reliance on fossil fuels. Fossil fuels are costly, rely on imported resources, and require expensive stoves, which are often imported as well. It is also argued that a switch to fossil fuels results in an increase in greenhouse gas emissions. However, as we discussed above, this is not necessarily true. It depends strongly on the sustainable harvest of biomass fuel and on the efficiency of combustion, which is usually quite poor in household stoves.

Improved biomass stoves can improve combustion efficiency and reduce emissions considerably, though not in all cases. Stove performance is highly variable, depending strongly on user behavior, fuel characteristics, and household microenvironment. Even when 'improved' solid fuel stoves do offer real improvement, they rarely reduce harmful emissions to the level of 'clean' liquid and gaseous cooking fuels. The resulting pollutant levels from improved stoves like the Kenyan Ceramic Jiko and the Maendaleo stove still result in ambient indoor concentrations of pollution that are well above standards set for outdoor air in industrialized countries (Ezzati, Mbinda and Kammen, 2000).

2.3- Household use of biomass: Conclusions

More research and policy discussion is needed to determine the threshold of exposure below which morbidity and mortality from biomass combustion emissions fall to acceptable levels, and to determine the most appropriate stove/fuel combinations, technically and socially, to reach that level of emissions. Biomass fuels will likely remain the primary energy source for most poor people in Africa, South and Southeast Asia, and, with coal, for people in China as well. A rapid switch to cleaner burning fossil fuels is extremely unlikely. It also may not be desirable because of the greenhouse gas emissions and unfavorable trade balances that may result. However, a gradual transformation of biomass utilization, away from burning raw biomass in smoky open hearths and simple metal stoves to cleaner, more efficient biomass energy conversion devices and/or fuels derived from biomass feedstock, is both more likely, and arguably more desirable (Ezzati and Kammen, 2001). There will be multiple benefits for short-term public health, by reducing indoor air pollution, as well as long-term environmental health, by reducing or eliminating greenhouse gas emissions. In addition, managing biomass resources for energy production can bring ancillary benefits to rural populations, including the restoration of degraded lands and creation of rural livelihoods by through jobs and income generating opportunities.

One necessary, though not sufficient, condition for successful biomass/bioenergy transformation is clearly defined land and tree tenure rights. Local communities must be confident that any improvements they initiate will not be taken over by state or corporate interests, and that they will be justly compensated if and when the resources under their control are used by outsiders. In addition to well-defined rules of tenure, program for biomass utilization and modernization will need to be flexible and adaptable to local needs, include the full participation of target populations, and have support from both the national government and the international community.

The Future Role of Biomass

Modernized biomass energy is projected to play a major role in the future global energy supply. Estimates of the technical potential of biomass energy are much larger than the present world energy consumption. If agriculture is modernized up to reasonable standards in various regions of the world, several billions of hectares may be available for biomass energy production well into this century. This land would comprise degraded and unproductive

lands or excess cropland, and preserve the world's nature areas and quality cropland. The table below gives a summary of the potential contribution of biomass to the worlds energy supply according to a number of studies by influential organizations. Although the percentile contribution of biomass varies considerably, depending on the expected future energy demand, the absolute potential contributions of biomass in the long term is high, from about 100 to 300 EJ per year.

Role of biomass in future global energy use according to 5 studies (Source: Hall, 1993; UNDP et al., 2000)

Source	Time frame (Year)	Projected global energy demand (EJ/year)	Contribution of biomass to energy demand, EJ/year (% of total)	Remarks
IPCC (1996)	2050 2100	560 710	180 (32%) 325 (46 %)	Biomass intensive energy system development
Shell (1994)	2060	1500 900	220 (15%) 200 (22%)	- Sustained growth* - Dematerialization+
WEC (1994)	2050 2100	671-1057 895-1880	94 - 157 (14 -15 %) 132 - 215 (15-11 %)	Range given reflects the outcome of three scenarios
Greenpeace (1993)	2050 2100	610 986	114 (19 %) 181 (18 %)	Fossil fuels are phased out during the 21st century
Johansson et al. (1993)	2025 2050	395 561	145 (37 %) 206 (37 %)	RIGES model calculation

** Business-as-usual scenario; + Energy conservation scenario*

3- Biomass energy beyond the household: Scaling up

3.1- Small and medium commercial businesses and institutions

Biomass energy is used for many commercial and small industrial applications in rural and peri-urban areas of developing countries. It is the principal source of energy for institutions like schools, health clinics, and prisons, and it is an important input in larger energy intensive agro-industries like sugar refineries, sawmills, and pulp and paper manufacturers. At the small rural level, commercial applications of bioenergy are usually limited to providing process heat for productive value-adding activities like tobacco curing, tea drying, beer brewing, fish smoking, and brick firing. While these may seem like negligible activities, taken in aggregate they represent a significant amount of wood fuel consumption as well as an important source of rural employment.

In many cases, fuel wood is harvested from natural woodlands that are owned and, in theory, maintained by the state. If harvesters pay little or no stumpage fees, the supply-price of wood fuel can be artificially low because replacement costs are not internalized (Boberg, 1993; Ribot, 1998). However, the harvesters may be only the first step in a long supply chain; prices per unit of energy delivered to the end-user are often still higher than fossil fuels. Alternatively, fuel for small and medium commercial and institutional consumers can be supplied from land cleared from cultivation, from larger commercial farms, or from woodlots or plantations that were established specifically to supply wood fuel. Larger agro-processing industries often maintain their own fuel wood plantations, usually in the form of fast-growing tree species like eucalyptus.

Fuel wood and charcoal markets have been in existence for quite a long time and exist in a variety of forms, from highly organized vertically integrated markets to unorganized piecemeal operations. Some are tightly regulated by the state while others are completely laissez faire markets. These variations have been explored in detail by a number of authors (Leach and Mearns, 1988; Hosier, 1993; Ribot, 1998).

Alternative biomass fuels for households and small businesses have long been discussed by energy development analysts, but have seen very little commercialization. In Zimbabwe, due to recent kerosene shortages, some markets, gas stations and hardware stores, now sell an ethanol-based gel fuel made from sugar cane and starch, and small metal stoves designed especially for the fuel. A second alternate fuel available in some African urban markets stems from an old idea: briquetting or pelletizing. Dissagregated biomass, like sawdust, bagasse, and nut shells, generally has very low energy density and very poor combustion characteristics. Compression creates a fuel that is easy to package and transport and that has uniform size and moisture content, which burns much more efficiently. To date, most attempts to commercialize biomass waste briquettes have failed because they cannot compete with charcoal or fuel wood. However, there are some notable exceptions. Case Study 3 illustrates the example of a private company in Kenya that is briquetting charcoal dust gathered from charcoal vending and distribution sites throughout Nairobi and is currently expanding its business to the production of carbonised briquettes made from bagasse.

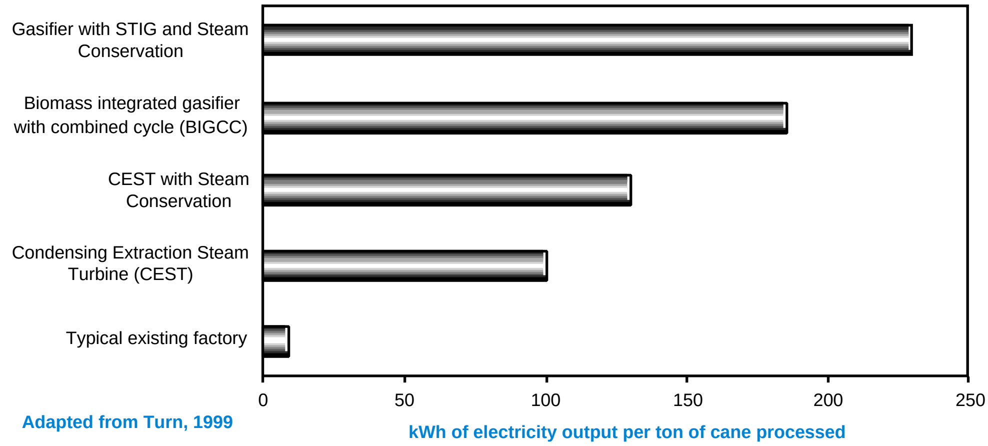
3.2- Potential to transform commercial and institutional biomass-based energy systems

Like households, most small and medium commercial businesses and institutions in developing countries consume solid biomass fuels in simple combustion devices with low efficiencies and high emissions. Rural businesses and institutions provide an untapped opportunity for transforming bioenergy consumption in developing countries. Demand for electricity in the domestic sector is small and intermittent, and any capital-intensive modern energy installation will likely have low capacity utilization if it targets household consumers alone. Small businesses and industries like grinding mills, carpentry shops and food processors, as well as institutions like schools and health clinics, have larger energy demands that are more predictable and consistent. Therefore, they represent a potential base-load that would make a modern energy installation economically viable. They are also able to mobilize capital better than individual households, and hold lower risk for the prospective energy service provider. Currently, there are technologies under development, or nearing the commercial stage, that are designed specifically for small and medium scale energy applications. For two concrete examples of different technologies that are currently filtering into rural applications, see: Case Study 1: Modular Biopower for Community-scale Enterprise Development, and Case Study 2 : Scaling-up Biogas Technology in Nepal.

In addition, large industries that rely on biomass for raw material inputs also represent a largely untapped opportunity. Some industries, principally sugar refineries, pulp and paper manufacturers, and sawmills, use their biomass wastes to produce process-heat and/or electricity. But many of them operate inefficiently, and have little incentive to optimize their energy production or sell to excess power to other consumers. Figure 2 shows some characteristic conversion efficiencies for a range of available technical options.

Figure 2

Comparison of technical options for generating electricity from sugar cane



Adapted from Turn, 1999

Very few developing countries currently exploit sugarcane or other biomass-based power generation for public sale. One exception is Mauritius, where roughly 30 per cent of the island's installed generation capacity is at sugar refineries. In 1998, the Mauritian sugar industry exported 195 GWh of excess electricity to the national grid – roughly 14 per cent of the national power production (Beeharry, 2001). Most factories export power only during the harvest season, but three large companies have dual-fuel boilers that can provide power to the national grid throughout the year by burning bagasse during the harvest season and burning coal off-season.

3.2.1- Liquid fuels from biomass: The case of ethanol

Ethanol is produced by fermentation of sugars, most frequently from maize or sugarcane. Ethanol produced from sugarcane in developing countries has been used primarily as a transportation fuel. It also may be used as an industrial input, or sold for export. Brazil has been a world leader in ethanol production, though several countries in Africa have also had experience producing ethanol. Ethanol from sugarcane can replace a fraction of imported fossil fuels with a locally grown renewable energy source, improve a nation's balance of trade, assist with rural job creation, and reduce pollution emissions. The Brazilian ethanol experience has been characterized as largely positive, though it has had its share of setbacks. See Case Study 4: Ethanol in Brazil, for a more detailed discussion. Kenya, Zimbabwe, and Malawi have also produced ethanol from sugarcane, with mixed results (Eriksen, 1995; Karekezi and Ranja, 1997).

3.2.2- Energy from woody biomass - an example from California

Wood wastes and agricultural residues also offer an immense and untapped source of power. An example from an industrialized country, the United States, suggests one strategy to develop this resource. In the state of California, in 2000, there were 29 wood waste burning power plants, ranging in capacity from less than 5 MW to over 50 MW, that contributed a total of 600 MW to California's energy mix. These power plants rely entirely on wood waste: sawmill residues, agricultural pruning and thinning, forest residues, and urban wood waste. The disposal of this waste under optimized combustion conditions has led to a significant reduction in conventional air pollution and greenhouse gas emissions. In the absence of controlled combustion for power generation, the biomass fuel would have been burned openly, landfilled, or composted. Each of these alternative disposal techniques is more polluting than controlled combustion.

California had an aggressive policy of favorable tax breaks and subsidies for renewable energy technologies throughout the latter half of the 1980s and early 1990s. This example shows that favorable policies combined with readily available, well-tested technologies can have substantial results in establishing a large amount of renewable and sustainable generating capacity.

3.2.3- Supplies of biomass for commercial and industrial use

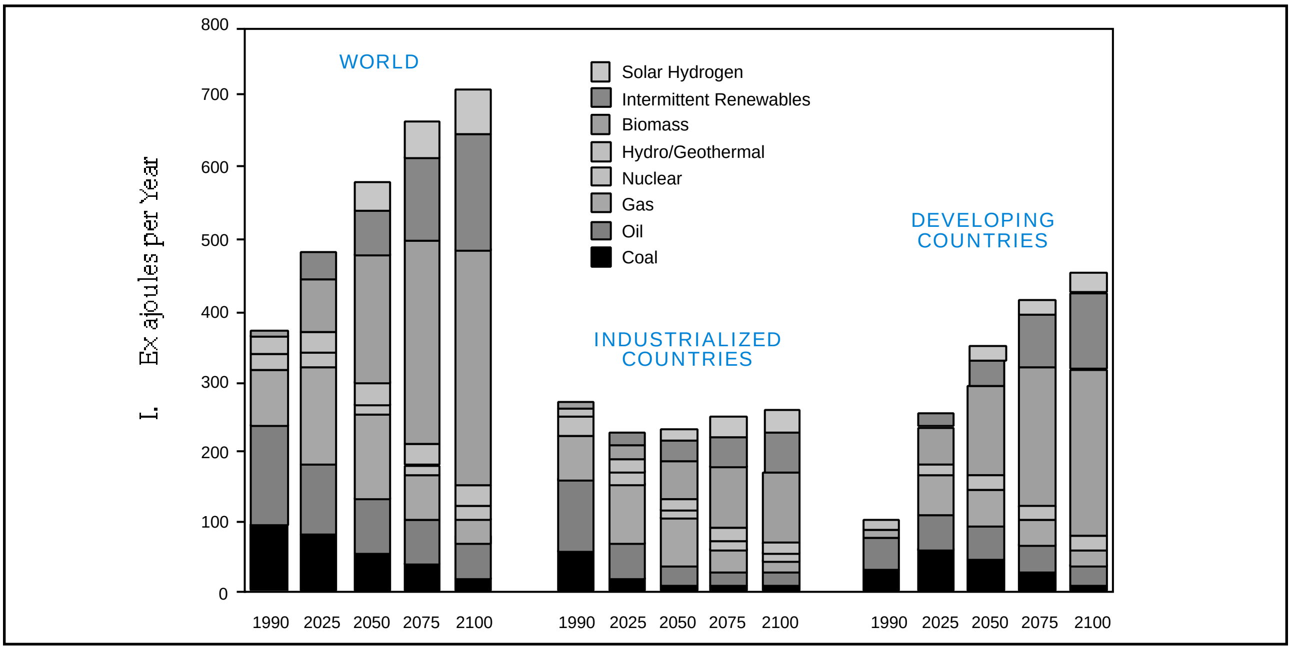
Residues are a particularly important potential biomass energy source in densely populated regions, where much of the land is used for food production and there are large quantities of byproduct residues. For example, in 1996, China generated crop residues in the field (mostly corn stover, rice straw and wheat straw) plus agricultural processing residues (mostly rice husks, corn cobs and bagasse) totaling about 790 million tons. If half of this resource were to be used for generating electricity at an efficiency of 25 per cent (achievable at small scales today), the resulting electricity generation would be about half of the total electricity generated from coal in China in 1996. (China Agricultural Statistical Yearbook, 1996 and China Energy Statistical Yearbook, 1996).

There is also a significant potential for providing biomass for energy by growing crops specifically for that purpose. The IPCC's biomass intensive future energy supply scenario (below) includes 385 million hectares of biomass energy plantations globally in 2050 (equivalent to about one quarter of present planted agricultural area), with three quarters of this area established in developing countries.

Intergovernmental Panel on Climate Change (IPCC)

An Intergovernmental Panel on Climate Change (IPCC) study has explored five energy supply scenarios for satisfying the world's demand for energy while limiting cumulative CO2 emissions between 1990 and 2100 to fewer than 500 Gton (C). In all scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is included to help meet the emissions targets. The figure above shows the results for the IPCC's most biomass-intensive scenario where biomass energy contributes 180 EJ/year to global energy supply by 2050, nearly three times its current contribution. Roughly two-thirds of the global biomass supply in 2050 is assumed to be produced on high-yield energy plantations covering nearly 400 million hectares, or an area equivalent to one-quarter of present planted agricultural area. The other one-third comes from residues produced by agricultural and industrial activities.

Primary commercial energy use by source for the biomass-intensive variant of the IPCC model (IPPC,1996), shown for the world, for industrialized countries, and for developing countries (Sources: Kartha and Larson, 2000)



Such high levels of land use for bioenergy raise the issue of intensified competition with other important land uses, especially food production. But competition between land use for agriculture and for energy production can be minimized if degraded land and surplus agricultural land are targeted for energy crops. Care must be taken however, because land that is considered "surplus" or "degraded" by policy makers may still be occupied and put to productive uses by marginal populations. The process of identifying land for bioenergy production should include a full social impact assessment allowing for participation of local communities. This is discussed further in section 6.3 below.

3.2.4 - Jobs in the commercial biomass sector

Biomass-based industries can be a significant source of jobs in rural areas. However, it should not be assumed that all rural areas in developing countries are characterized by surplus unskilled labor, and therefore automatically provide a pool of workers for labor-intensive bioenergy projects. Employment in rural areas is primarily agricultural and hence highly seasonal. There is also a significantly gendered aspect to labor. In many regions, men of the household leave to seek formal employment in towns and cities, which then places greater demands on women's labor in the home and on the farm. Planners must be aware of competing claims on rural labor before initiating a project, to ensure that labor requirements fit local availability and that unreasonable demands are not placed on women, whose labor often goes unrecognized and unrewarded.

3.2.5- Environmental impacts of medium and large scale biomass utilization

Many bioenergy systems offer flexibility in choice of feedstock as well as the manner in which it is produced, which makes it easier to meet environmental objectives. For example, bioenergy crops can be used to revegetate barren land, reclaim water-logged or saline soils, and stabilize erosion-prone land, most of which would be unsuitable for cash or food crops. Biomass energy feedstock, when properly managed, can both provide habitat and improve biodiversity on previously degraded land.

Erosion and removal of soil nutrients are problems related to the cultivation of annual crops in many regions of the world. Energy crops could be fast-growing trees that are harvested by coppicing in short (4-8 year) rotations. This method leaves the root structures intact. Trees regenerate for multiple rotations, and are replanted every 15-20 years. Energy crops can also be grown from perennial grasses that are harvested every year and replanted every ten years. Compared to annual planting and harvesting of conventional crops, these practices reduce the disturbance of the soil. Where natural forests are being infringed upon for energy or other end uses, bioenergy crops can be used in buffer zones or shelter belts critical for preserving a core of undisturbed forest that acts as a reservoir of biodiversity and a source of non-timber forest products.

Possibly the biggest concern, and perhaps the most limiting factor to the spread of bioenergy crops, is the demand on available water supplies, particularly in arid and semi-arid regions. Impacts on local hydrology always need to be evaluated on a case-by-case basis.

Biomass plantations are frequently criticized because the range of biological species they support is much narrower than natural ecosystems. While there would be a detrimental impact if a virgin forest were to be replaced by a biomass plantation, when a plantation is established on degraded lands or on excess agricultural lands, the restored lands are likely to support a more diverse ecology.

A major environmental concern is, of course, the potential for bioenergy systems to mitigate climate change by the direct displacement of fossil fuels. It is also possible that biomass, either naturally regrown, or managed in plantations, wood lots, or agroforestry systems, can be used as a carbon sink to offset emissions (IPCC, 2000b).

3.3- Scaling up: Conclusion

Utilization of biomass wastes and residues to produce commercial energy services is an initial step toward transforming bioenergy from a predominantly traditional energy source into a renewable source of high-quality fuels and electricity. Rural industries that rely on large amounts of biomass inputs are particularly well placed to initiate this transformation, though it will not proceed without an enabling policy environment, and adequate public and private sector investment.

Progress in scaling up the use of modernized biomass energy can occur only in stages, with different pilot projects focused on overcoming different institutional and commercial barriers. A good example of this strategy comes from the United States Department of Energy's National Renewable Energy Laboratory (NREL) Small Modular Biomass Project (Bain, 2000). See Case Study 1: Modular Biopower for Community-scale Enterprise Development, which relates the experiences of one company that was a successful participant in this program.

4- Biomass energy conversion technologies

Biomass energy has the potential to be 'modernized' worldwide, that is, produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, and electricity. A variety of technologies can convert solid biomass into clean, convenient energy carriers over a range of scales from household / village to large industrial. Some of these technologies are commercially available today, while others are still in the development and demonstration stages. If widely implemented, such technologies can enable biomass energy to play a far more significant role in the future than it does today, especially in developing countries. In addition, modernized biomass energy is projected to play a major role in the future global energy supply.

4.1- Combustion

Direct combustion remains the most common technique for deriving energy from biomass for both heat and electricity. Advanced domestic heaters obtain efficiencies of over 70 per cent with greatly reduced atmospheric emissions. The predominant technology in the world today for electricity generation from biomass, at scales above one megawatt, is direct combustion of biomass in a boiler to produce steam, which is then expanded through a turbine. The typical capacity of existing biomass power plants ranges from 1 to 50 MWe with an average around 20 MWe. Steam cycle plants are often located at industrial sites, where the waste heat from the steam turbine can be recovered and used in industrial processing. Combined heat and power (CHP) systems provide higher efficiencies than systems that only generate power. By utilizing waste heat, combined efficiencies of 80 per cent are possible. There is relatively little CHP capacity installed in developing countries. The most significant installation of such capacity is in sugar refining using bagasse as a fuel, but the potential for CHP exists in many timber and agricultural processing industries worldwide.

An alternative to direct-fired biomass combustion technologies described above, and considered the nearest term low-cost option, is biomass co-combustion with fossil fuels in existing high-efficiency boilers. Effective biomass fuel substitution can be made in the range of 10-15 per cent of the total energy input with minimal plant modifications and no impact on the plant efficiency and operation. This strategy is economical when the biomass fuels are lower cost than the fossil fuels used. For fossil fuel plant capacities greater than 100 MWe, this can mean a substantial amount of displaced fossil fuel, which results in substantial emissions reductions, particularly for coal-fired plants.

4.2- Gasification

Combustible gas can be produced from biomass through a high temperature thermochemical process called gasification, which involves burning biomass without sufficient air for full combustion, but with enough air to convert the solid biomass into a gaseous fuel (Reed and Gaur, 2000). The intended use of the gas and the characteristics of the particular biomass (size, texture, moisture content, etc.) determine the design and operating characteristics of the gasifier and associated equipment. After appropriate treatment, the resulting gases can be burned directly for cooking or heat supply, or used in secondary conversion devices, such as internal combustion engines or gas turbines, for producing electricity or shaft power (where it also has the potential for CHP applications). The systems range from small-scale (5-100 kW), suitable for the cooking or lighting needs of a single family or community, up to large grid connected power or combined heat and power facilities consuming several hundred kilograms of woody biomass per hour and producing 10-100 MW of electricity. Biomass gasification is not yet fully commercialized, though many projects of different scales have been attempted and have yielded valuable lessons (Larson, 2000; Reed and Gaur, 2000).

In direct combustion applications, gas has advantages over solid fuels because it allows for cleaner, more controllable combustion. Models have been implemented in China and India, with producer gas used for industrial processes or distributed for community cooking and space heating (Jain, 2000; Henderick and Williams, 2000).

For electricity production, gas from biomass gasification can be used in modified internal combustion diesel or gasoline engines, where it can replace 70-80 per cent of the diesel or 100 per cent of the gasoline required by the engine. These smaller scale biomass gasifiers, coupled to diesel / gas internal combustion engines, operate in the 10-200 kWe range with efficiencies on the order of 15-25 per cent, and have been made available commercially. However, they have had limited operational success due to gas cleaning requirements, relatively high costs and the need for careful operation, which have so far blocked large-scale applications. In addition, a reliable and technically appropriate fuel supply is a critical issue that requires careful planning, particularly for remote rural applications.

Generally, these smaller gasification / engine systems target isolated areas where grid-connections are either unavailable or unreliable so they can be cost competitive in generating electricity. The United States National Renewable Energy Laboratory (NREL) is funding a small modular biopower project to develop biomass systems that are fuel flexible, efficient, simple to operate, have minimum negative impacts on the environment, and provide power in the 5 kW-5 MW range (Bain, 2000). There is particularly strong interest in the quality-of-life improvements that can be derived from implementing such gasifier / engine technology for electricity generation at the village scale in developing countries. As was mentioned above, Case Study 1 relates the experiences of one company that was a successful participant in this program.

4.3 Anaerobic digestion

Combustible gas can also be produced from biomass through the biological processes of anaerobic digestion. Biogas is the common name for the gas produced either in specifically designed anaerobic digesters or from decomposing municipal waste in landfills. Almost any biomass can be converted to biogas, though woody biomass presents a technical problem because lignin, a major component of wood, is not digestible by bacteria. Animal and human wastes, sewage sludge, crop residues, carbon-laden industrial byproducts, and landfill material have all been used.

Biogas can be burned to provide energy for cooking and space heating, or to generate electricity. Digestion has a low overall electrical efficiency (roughly 10-15 per cent, strongly dependent on the feedstock) and is particularly suited for wet biomass materials. When human or animal wastes are used, the effluent sludge from the digester is a concentrated nitrogen fertilizer, with the pathogens in the original feedstock largely eliminated by the warm temperatures in the digester tank.

Anaerobic digestion of biomass has been demonstrated and applied commercially with success in many situations and countries. In India, biogas production from manure and wastes is applied widely in many villages and is used for cooking and power generation, though not without problems. A mass popularization effort in China in the 1970s led to some 7 million household-scale digesters being installed, using pig manure and human waste as feed material. Many failed to work, however, due to insufficient or improper feed characteristics, or poor construction and repair techniques. Since then, research, development, and dissemination activities have paid greater attention on proper construction, operation, and maintenance of digesters. Several thousand biogas digesters are also operating in other developing countries, most notably South Korea, Brazil, Thailand and Nepal. See Case Study 2: Scaling-up Biogas Technology in Nepal, for a discussion concerning recent biogas dissemination.

4.4- Liquid biofuels

Biofuels are produced in processes that convert solid biomass into liquids, which have the potential to replace petroleum-based fuels used in the transportation sector. However, adapting liquid biofuels to our present day fuel infrastructure and engine technology has proven to be difficult. Soybeans, palm nuts and oilseeds, like rape seed, can produce compounds similar to hydrocarbon petroleum products, and have been used to replace small amounts of diesel. This 'biodiesel' has been marketed in Europe and to a lesser extent in the United States, but it requires substantial subsidies to compete with conventional diesel fuel.

Another family of petroleum-like liquid fuels is a class of synthesized hydrocarbons called Fischer-Tropsch (F-T) liquids. These are produced from a gaseous feedstock, potentially gasified biomass, though more commonly coal-gas or natural gas would be used. F-T liquids can be used as sulphur-free diesel or blended with existing diesel to reduce emissions, which is an environmental advantage. F-T liquids have yet to be produced economically on a large scale, but research and development efforts continue (Larson and Jin, 1999a and b).

Other alternatives to petroleum-based fuels are alcohols produced from biomass, which can replace gasoline or kerosene. The most widely produced today is ethanol, from the fermentation of biomass. The Brazilian Proalcool ethanol program, initiated in 1975, has been successful due to the high productivity of sugarcane, and subsidies. See Case Study 4: Ethanol in Brazil for a more detailed discussion of the Brazilian ethanol experience.

Two other potential transportation biofuels are methanol and hydrogen. They are both produced from biomass feedstock and may be used in either internal combustion engines or in fuel cells, but neither is close to commercialization.

4.5- Bioenergy conversion technologies: Conclusions

Biomass is one of the renewable energy sources that can make a large contribution to the developing world's future energy supply. Latin America, Africa, Asia and, to a lesser extent, Eastern Europe, represent a large potential for biomass production. The forms in which biomass can be used for energy are diverse. Optimal resources, technologies and entire systems will be shaped by local conditions, both physical and socio-economic in nature.

Since the majority of people in developing countries will continue using biomass as their primary energy source well into the next century, it is of critical importance to policy-makers concerned with public health, local environmental degradation, and global environmental change that biomass-based energy truly can be modernized, and that such a transformation can yield multiple socioeconomic and environmental benefits.

Conversion of biomass to energy carriers like electricity and transportation fuels will give biomass a commercial value, and potentially provide income for local rural economies. It will also reduce national dependence on imported fuels, and reduce the environmental and public health impacts of fossil fuel combustion. To make progress, biomass markets and necessary infrastructure must be developed with the realization that the large-scale commoditization of biomass resources can have negative impacts of poor households that rely on biomass for their basic needs. Hence, measures must be taken to ensure that the poor have an opportunity to participate in, and benefit from, the development of biomass markets.

In addition, high efficiency conversion technologies and advanced fuel production systems for methanol, ethanol and hydrogen must be demonstrated and commercialized, and experiences in industrialized and developing countries shared openly. The benefits of modernized bioenergy systems will only be enjoyed globally if efforts are made to gain experience in a wide variety of ecological and socioeconomic venues.

5- Renewable energy technologies: Markets and costs

The development of renewable energy technologies has been driven by fossil fuel markets. Interest in advancing non-fossil fuel energy options surged with the oil 'price shocks' of the 1970s and 1980s, and waned as oil crises subsided. More recently, fossil fuel prices have been relatively low, but there has been a growing awareness of the high external costs of fossil fuel consumption (primarily global climate change and adverse impacts on human and environmental health).

While most of the greenhouse gas emissions from the energy sector currently occur in industrialized countries, this is projected to change by 2035, which is roughly when industrial emissions from developing countries are expected to surpass those of industrialized nations (UNDP et al., 2000). One of the principal ways to reduce greenhouse gas emissions is to make a transition away from conventional fossil fuel-based energy systems.

Technical advances and cost reductions in renewable energy technologies will directly affect the future energy path of developing countries, as will international incentives like the Clean Development Mechanism under the Kyoto Protocol, which will promote technology transfers to developing countries.

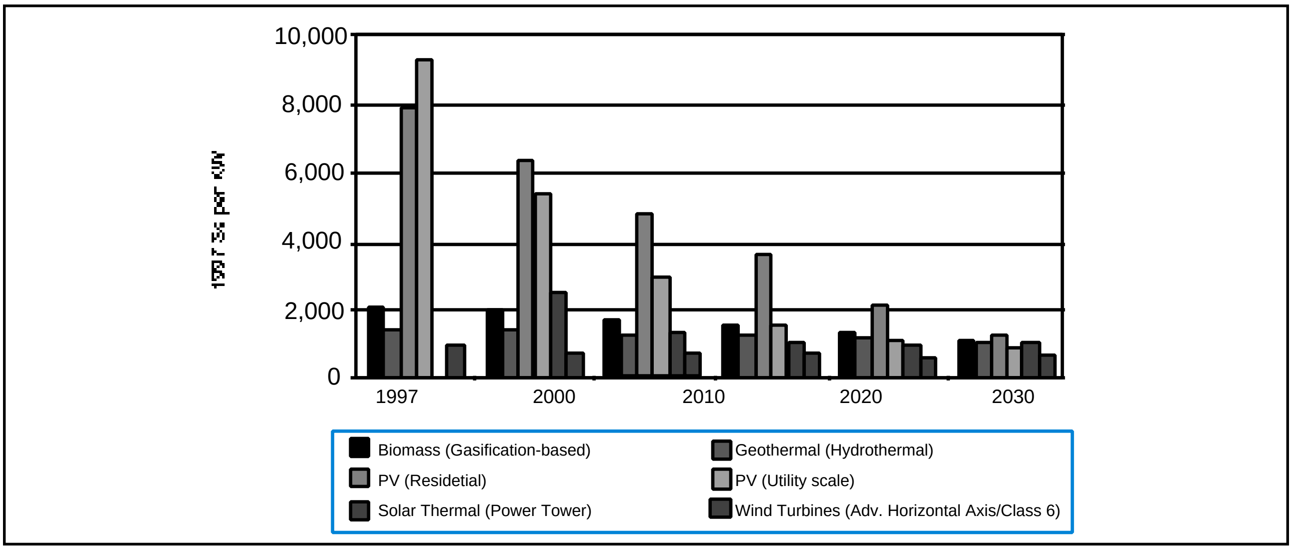
5.1- Recent progress in renewable energy system costs and performance

The American Wind Energy Association (AWEA) estimates that the current levelized costs of wind energy systems range from 4.0 to 6.0 cents per kWh, and that the costs are falling by about 15% with each doubling of installed capacity. Installed capacity has doubled three times during the 1990s and wind energy now costs about one-fifth as much as it did in the mid-1980s (AWEA, 2000). Design and manufacturing advances, along with further economies of scale, are expected to bring the levelized costs of wind power down to 2.5 to 3.5 cents per kWh over the next ten years (U.S. DOE, 1997; Chapman et al., 1998). Wind turbine performance has also increased, and is expected to improve. The United States Department of Energy (DOE) is forecasting a 25-32 per cent improvement in net energy produced per area swept by 2010, from a 1996 baseline, rising to 29-37 per cent in 2020, and 31-40 per cent in 2030 (U.S. DOE, 1997).

Solar energy technologies have also been declining significantly in cost. In Japan, solar photovoltaic (PV) module prices have declined from 26,120 yen per watt in 1974 to 1,200 yen per watt in 1985, and 670 yen per watt in 1995 (in constant Year 1985 yen) (Watanabe, 2000). DOE reports that from 1976 to 1994, PV modules experienced an 18 per cent reduction in cost with each doubling of production, with costs falling from over $30 per watt in 1976 to well under $10 per watt by 1994 (U.S. DOE, 1997). Meanwhile, thin film PV cells tested in laboratories are showing efficiencies of over 17 per cent, compared with about 13 per cent in 1990 and 10 per cent in 1980 (U.S. DOE, 1997).

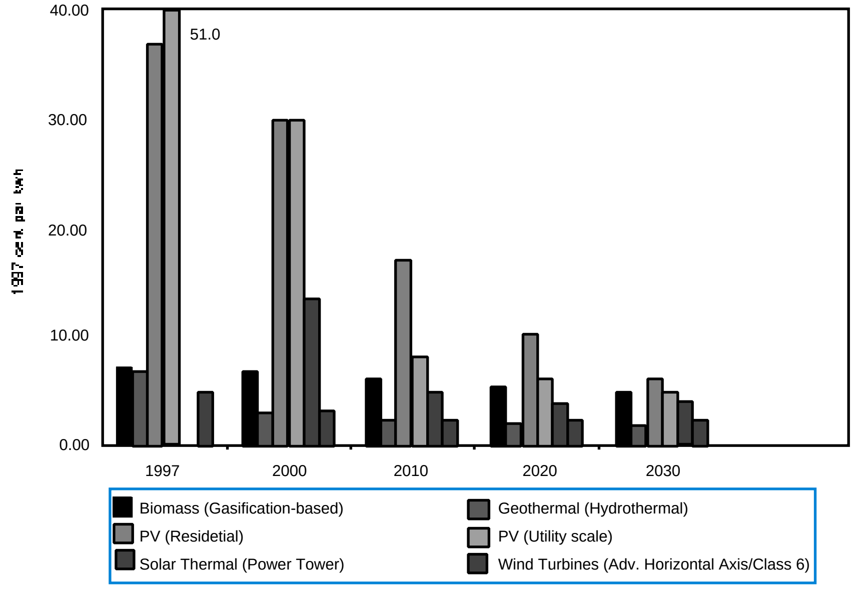
Renewable energy systems based on biomass, geothermal, and solar thermal technologies are also experiencing cost reductions which are forecast to continue. Figure 3 presents forecasts made by the U.S. DOE for the capital costs of these technologies, from 1997 to 2030.

Figure 3 **Capital cost forecasts for renewable energy technologies (Source: U.S. DOE, 1997)**



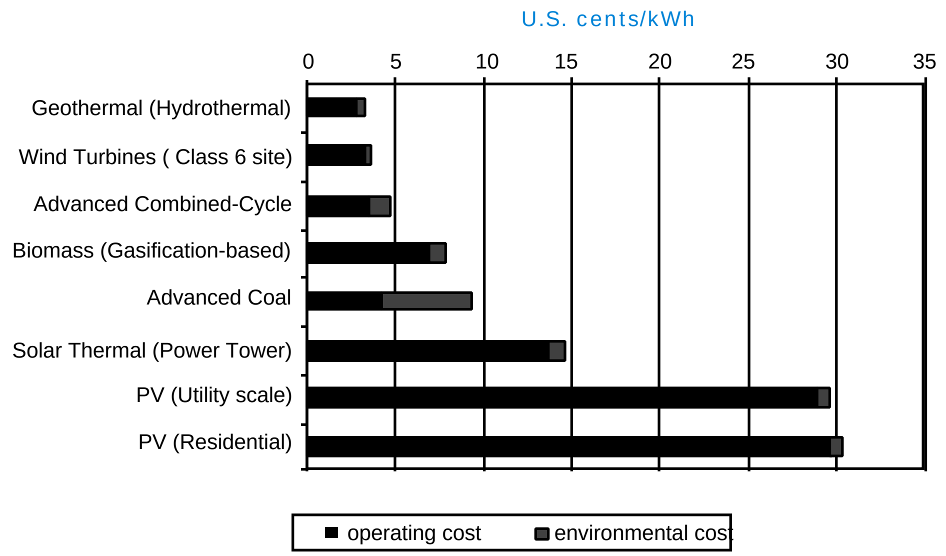
Of course, capital costs are only one component of the total costs of generating electricity, which also include fuel costs, and operation and maintenance costs. In general, renewable energy systems are characterized by low or no fuel costs, although operation and maintenance costs can be considerable But renewable energy systems such as photovoltaics contain far fewer mechanically active parts than comparable fossil fuel combustion systems, and therefore are likely to be less costly to maintain in the long term. Figure 4 presents U.S. DOE projections for the levelized costs of electricity production from these same renewable energy technologies, from 1997 to 2030.

Figure 4 **Levelized cost of electricity forecast for renewable energy technologies (Source: U.S. DOE, 1997)**



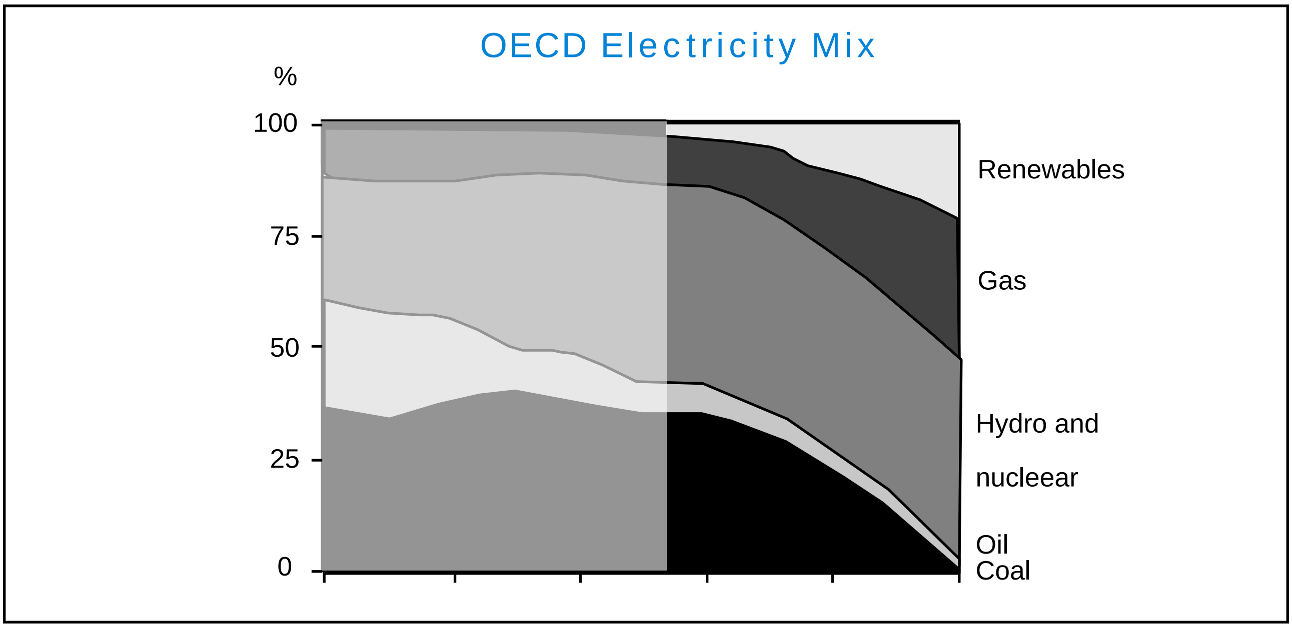
Recent analyses have shown that additional generating capacity from wind and solar energy can be added at low incremental costs relative to additions of fossil fuel-based generation. As shown in Figure 5, geothermal and wind can be competitive with modern combined-cycle power plants. And geothermal, wind, and biomass all have lower total costs than advanced coal-fired plants, once approximate environmental costs are also included.

Figure 5 **Actual electricity costs 2000 (Sources: Ottinger, 1991; U.S. DOE, 1997; U.S. DOE, 2000)**



Shell Petroleum has made one of the highest profile projections of future renewables growth. As shown in Figure 6, Shell projects that renewables could constitute about 15 per cent of the OECD's energy production by 2020, and that renewables and natural gas combined could account for about 50 per cent of total production (Shell, 2000).

Figure 6 **OECD electricity mix (Source: Shell Petroleum, 2000)**



5.2- Lessons learned in developing countries

In developing nations, renewable energy technologies are increasingly used to address energy shortages and to expand the range of services in both rural and urban areas. In Kenya, over 80,000 small (20-100 Wp) solar PV systems have been commercially financed and installed in homes, battery charging stations, and other small enterprises (Kammen, 1999; Duke and Kammen, 1999; Duke et al., 2000). Meanwhile, a government program in Mexico has disseminated over 40,000 such systems. In the Inner Mongolian autonomous region of China, over 130,000 portable windmills provide electricity to about one-third of the non-grid-connected households in this region (IPCC, 2000a).

These examples demonstrate that a combination of sound national and international policies and genuinely competitive markets, the so-called 'level playing field', can be used to generate sustainable markets for clean energy systems. They also show that renewable energy systems can penetrate markets in the developing world, even where resources are scarce, and that growth in the renewables sector need not be limited to applications in the developed world. Just as some developing countries are bypassing construction of telephone wires by leaping directly to cellular-based systems, so too might they avoid building large, centralized power plants and grids, and instead develop decentralized systems.

Despite their recent limited success, renewable energy sources have historically had a difficult time breaking into markets that have been dominated by traditional, large-scale, fossil fuel-based systems. In part, this is because renewable and other new energy technologies are only now being mass produced, and have previously had high capital costs relative to more conventional systems. This is also partly because coal, oil, and gas-powered systems have benefited from a range of subtle subsidies over the years. These include military expenditures to protect oil exploration and production interests overseas, the costs of railway construction that have enabled economical delivery of coal to power plants, and a wide range of smaller subsidies.

Another limitation has been the intermittent nature of some renewable energy sources, such as wind and solar. One solution to this last problem is to develop diversified systems that maximize the contribution of renewable energy sources, but that also use clean natural gas and / or biomass-based power generation to provide base-load power when the sun is not shining and the wind is not blowing.

In essence, however, renewable energy technologies face the same situation confronting any new technology that attempts to dislodge an entrenched technology. For many years, industrialized countries have been 'locked into' a suite of fossil fuel and nuclear-based technologies, and many secondary systems and networks have been designed and constructed accordingly. Just as electric-drive vehicles face an uphill battle to dislodge gasoline-fueled, internal combustion engine vehicles, so, too, do solar, wind, and biomass technologies face obstacles to replace modern coal, oil, and natural gas power plants.

5.3- Leveling the playing field

Renewable energy technologies tend to be characterized by relatively low environmental costs. In an ideal world, this would help them compete with conventional technologies but, of course, many of these environmental costs are 'externalities' that are not priced in the market. Only in certain areas, and for certain pollutants, do these environmental costs enter the picture, and, clearly, further internalization of these costs would encourage the spread of renewables.

When politically possible, the first-best policy is to fully internalize pollution costs (e.g., through pollution taxes set at the marginal social cost of the pollution externality, or tradable emissions permits set at the socially optimal pollution level). The international effort to limit the growth of greenhouse emissions through the Kyoto Protocol may lead to some form of carbon-based tax, and this could prove to be an enormous boon to renewable energy industries. More likely, however, concern about particulate matter emissions from fossil-fuel power plants will lead to expensive mitigation efforts, and this may tip the balance toward cleaner renewable systems.

Targeted government investments and market support programs can promote research and development on renewable energy systems, thereby helping to build demand for cleaner energy technologies, and speed up their commercialization process.

When a new technology is first introduced, it is invariably more expensive than established substitutes. There is, however, a clear tendency for the unit cost of manufactured goods to fall as a function of cumulative production experience, and government support can help to move renewables to a point where they become more cost competitive. However, the costs of poor program design, inefficient implementation, or simply choosing the 'wrong' technologies can easily outweigh cost reduction benefits. Therefore, government market transformation programs should be limited to emergent clean energy technologies with a steep industry experience curve and a high probability of major long-term market penetration once subsidies are removed, and public agencies should invest in a portfolio of new clean energy technologies to reduce overall performance risk through diversification.

5.4- Renewable energy technology markets and costs: Conclusions

Both solar photovoltaics and wind energy are experiencing rapid sales growth, declining capital costs and costs of electricity generated, and continued performance increases. Because of these developments, market opportunity now exists to both innovate and to take advantage of emerging markets, with the additional encouragement of governmental and popular sentiment. The development and use of these sources can enhance diversity in energy supply markets, contribute to securing long term sustainable energy supplies, reduce local and global atmospheric emissions, provide commercially attractive options to meet specific needs for energy services (particularly in developing countries and rural areas), and create new employment opportunities.

Integration of renewable energy supplies and technologies can temper the cyclical nature of fossil fuel markets, and give renewables a foothold from which they can continue to grow and compete. There are many opportunities for creative integration of renewables into energy production systems. These include combined fossil and biomass-fueled turbines, and combinations of intermittent renewable systems and base-load conventional systems with complementary capacity profiles. Strategies such as these, in conjunction with development of off-grid renewable systems in remote areas, are likely to provide continued sales growth for renewable and other clean energy technologies for many years to come.

At present, however, the rates and levels of investment in innovation for renewable and other clean energy technologies are too low. This is because markets undervalue the social costs of energy production, firms cannot typically appropriate the full value of their R&D investments in innovation, and new technologies are always characterized by uncertain performance and thus greater risk compared to their more well-developed rivals. These issues suggest a role for public sector involvement in developing markets for renewable energy technologies through various forms of market transformation programs.

6- Biomass, bioenergy and climate change mitigation

Renewable energy technologies are well suited for climate change mitigation. Biomass-based energy systems are particularly appropriate for applications in developing countries, where climate change may not be given high priority, but where there is an acute need for equitable and efficient provision of modern energy services. Although policy makers and scientists in developing countries are generally quite aware of the need to reduce greenhouse gas emissions, and to take steps to adapt to a changing global climate, most of these nations lack adequate resources to do either. While the consequences of climate change will affect poor countries with disproportionate severity, the world's poorest countries are unable to provide their populations with basic services like clean water, education, health care, and energy. Other nations, partially industrialized or 'in transition', argue that taking measures to reduce emissions now would disrupt the course of national development. They also hold that industrialized countries of 'the West' have been emitting long-lived greenhouse gases for well over a century, and so should bear the brunt of the costs of climate change mitigation.

These circumstances have led to a climate change treaty that requires industrialized countries to reduce their net greenhouse gas emissions by an average of five per cent during the first commitment period (2008-2012), while developing countries have no emission limitations or reduction requirements during the first commitment period. Yet with emissions from developing countries increasing, the five percent reduction in emissions agreed to in the Kyoto Protocol will not be sufficient to “prevent dangerous anthropogenic interference with the climate system”. Therefore, it is critical that developing countries be engaged in the international effort to mitigate climate change. The Kyoto Protocol’s Clean Development Mechanism (CDM) is the principal means for fostering broad engagement of developing countries in climate change mitigation, and can be used as a means of promoting sustainable development as well, by providing access to improved energy services, creating rural employment, and enabling improved land management practices.

6.1- The CDM - an explicit link between climate change mitigation and sustainable development

Article 12 of the Kyoto Protocol introduced the Clean Development Mechanism for the purposes of assisting industrialized countries in achieving compliance with their commitments to reduce greenhouse gas emissions, and of fostering sustainable development in developing countries. Given the dual role of the CDM it is likely that a number of CDM projects will target the energy sector, since the energy sector is simultaneously a major source of greenhouse gas emissions, and an area that is critical for the socioeconomic development of all nations. It is also quite likely that many CDM projects will target land-use and forestry activities. The issues of Land Use, Land Use Change, and Forestry (LULUCF) under the Kyoto Protocol are intimately linked to the themes of biomass, bioenergy, and poverty alleviation in developing countries. Bioenergy systems reduce greenhouse gas emissions through the displacement of fossil fuels, but unlike other renewable energy sources, biomass also removes carbon from the atmosphere, so that any land dedicated to the production of biofuels also acts as a carbon sink though the sink may not be a permanent one (Kartha, 2001).

6.2- Energy projects in the CDM: The critical issues

Energy projects implemented under the CDM must meet several conditions and overcome various barriers that do not arise in clean energy projects implemented within industrialized countries.

In order to qualify for Certified Emission Reductions under the CDM, projects need to address additionality, permanence, and leakage requirements as well as satisfy sustainable development criteria defined by the host country.

The additionality requirement states that emissions from anthropogenic sources must be "reduced below those that would have occurred in the absence of the registered CDM project activity" (FCCC/CP/2001/CRP.11 paragraph 41). In order to determine additionality, a baseline needs to be defined: what would have happened if the project were not undertaken. There are many alternative methodologies for determining a baseline (see IPCC, 2001; Lazarus et al., 2000).

Most biomass projects in the CDM will fall within the range of small projects allowed to choose a standardized baseline based on a regional average or a particular technological package. While we generally consider this a positive outcome, particularly for projects that utilize biomass wastes and residues, we would voice caution in streamlining bioenergy projects that rely on the establishment of new bioenergy plantations. Experience with this type of project is minimal, particularly in sub-Saharan Africa. Bioenergy plantations are extremely land-intensive and even a 'small' 15 megawatt project would require a large amount of land with potentially large ecological and social impacts. We strongly recommend that these types of projects undergo full reviews until sufficient experience is gained to justify streamlining.

Permanence refers to the duration of emissions reductions and leakage is the term used to describe any unintended consequence of project implementation. Both terms are more directly associated with

LULUCF activities, but can apply to bioenergy projects as well. Any forest or plantation is subject to various natural and manmade hazards that could lead to loss of some or all of the carbon it has accumulated over time. In addition, devoting a particular piece of land to forest or plantation for energy or carbon sequestration may lead to leakage by diverting activities previously conducted on that land elsewhere. In energy applications, however, if fossil fuel consumption is displaced by a biofuel, then emissions reductions are permanent. Even temporary substitutions of biofuels for fossil fuels result in permanent reductions of specific quantities of carbon that would otherwise be released. (Kartha, 2001).

While additionality, permanence and leakage are matters that are subject to review by the Executive Board of the CDM, sustainable development criteria are not. Whether or not a project meets the host country's goals for, and definition of, sustainable development, is solely the decision of the host country (FCCC/CP/2001/L.7 section 3.1). Biomass energy projects, as they have been presented in this report, can be associated with numerous positive environmental and social impacts, specifically the improvement of degraded lands, the creation of employment opportunities, and the associated realization of quality of life improvements for poor communities. However, positive impacts like these are not guaranteed and, in many developing countries, national governments do not have a history of supporting local environmental and social justice for poor urban or rural constituencies. Moreover, the effects of biomass-based projects, whether for energy production, carbon-sequestration, or a combination of mitigation measures and alternate uses, can be extremely complex. Decision-making with regard to those projects can be a time-consuming and contentious process, making transaction costs prohibitive and endangering the viability of all but the simplest CDM projects – particularly in countries that do not have a lot of experience in project implementation.

Indicative List of National Sustainability Criteria ensure that AIJ/CDM projects:

✓ limit activities to priority sectors, such as renewable energy or energy efficiency;

✓ protect biological diversity;

✓ deliver local environmental benefits;

✓ contribute to training and enhancing local capacity;

✓ directly or indirectly enhance local employment
✓ purchase local goods and services;

✓ transfer advanced technology or modern production processes;

✓ do not increase the host country's debt burden.

The list is taken from Werksman, et al., 2001, who adapted it from UNFCCC, National Programs for activities implemented jointly under the pilot phase. The latter is available on-line at www.unfccc.de/program/aij/aij_np.html.

6.3- Public participation in project development and implementation

In keeping with the twin goals of climate protection and sustainable development, the CDM should be reserved for locally appropriate projects that involve demonstrated clean energy technologies with a strong emphasis on energy efficiency and renewable energy projects, including sustainable bioenergy projects, while excluding large-scale hydro and coal projects. Furthermore, if CDM projects are to have environmental and social integrity, then the CDM Executive Board should allow public access to project information, meaningful public participation in decision-making, and access to justice, including redress and remedies for poor project implementation. Projects should be guided by public participation and local benefit-sharing policies that are mandatory, credible, and allow for informed input. In this respect, current trends that have project information made available to the public through the internet are troubling because communities that may be adversely affected by project activities generally do not have working knowledge of, or access to, computers. The CDM Executive Board needs to establish rules that allow directly affected local communities as well as the general public to have multiple channels of access to project information in the appropriate language and to have significant input into project design, implementation, and crediting.

6.4- Project management

A registry of well-managed projects is needed to better direct approval of strong CDM projects. This is particularly lacking for bioenergy projects that include best practice land-use management techniques. In addition, projects should be examined holistically, as there can be both positive and negative synergies arising from a group of projects carried out in the same region. CDM projects should be consistent with the biodiversity and desertification conventions as well as with other relevant UN conventions covering the environment, development, human rights, and international labor organization agreements. They should also be in accordance with national policies and priorities of the host countries to ensure their long-term sustainability. Independent third party monitoring and verification of emission reduction credits with the results available to the public, and investor liability, is essential for project success.

6.5- Equity

A number of steps can be taken to ensure that development objectives, and thereby the immediate needs of many poor communities and nations, are not made secondary to carbon issues. First, clear commitments by industrialized nations to invest in biomass energy projects domestically will help to grow the institutional and human capacity for biomass projects, while both building the market and providing important training opportunities for groups and individuals from developing nations. Building domestic industries would also help the international community to encourage industrialized nations not to 'cherry pick', i.e., to use their resources to acquire rights to the least expensive biomass projects around the world in terms of cost per unit of carbon emissions avoided or sequestered. Opting only for the least-cost projects would favor specific countries and hinder the flow of information and technology to least developed countries that arguably need it the most. In contrast, a thriving biomass industry spread evenly throughout the developed nations would provide important opportunities to reduce the cost of new technologies and methods through the learning-by-doing process (Spence 1984; Duke and Kammen, 1999). This, in concert with CDM initiatives, would foster the transfer of biomass and bioenergy technologies.

Second, the CDM can institute clear guidelines that recognize and require multi-disciplinary project teams and review procedures so that the many competing uses of land areas supporting biomass projects are considered. These would include the rights and livelihoods of indigenous and the most marginalized communities, ethnic groups, and women, nature itself, and small-scale as well as larger-scale enterprises. This process would work across socioeconomic levels to promote intra-national and international equity.

Third, projects need to be developed that reward the preservation and sound management of existing forests, as well as new bioenergy-focused tracts of land. Forest systems represent a critical resource for the poorest people and nations of the plant, and sound management is an invaluable resource for local self-determination.

6.6- Technology transfer and capacity building

A key component of any expanded biomass energy and land-use program is access to not only the physical resources, but also, critically, to the knowledge base for sound and profitable biomass and bioenergy management. To accomplish this, a clear and collaborative partnership between researchers, governments and industry in developed and developing nations is needed. Projects specifically focused on the needs of the poorest households and nations remain the greatest need in the bioenergy field. Lessons can be drawn from the UNDP and World Bank's joint effort in climate-change mitigation GEF projects. See for example, Hosier and Sharma (2000), which gives a valuable review of the lessons learned from the Global Environment Facility's biomass-based energy projects.

Unfortunately, there are few examples of successful and sustainable biomass-based land management or energy generation projects, particularly projects effective in addressing poverty alleviation. A database of projects, including a critical analysis of successes and failures, should be developed and widely disseminated in order to facilitate the exchange of information and ideas so critical to the success of innovative projects. The case studies included in the final part of this document provide a preliminary model for such a database.

7- Conclusion

In this report we have explored the links between energy, poverty, and climate change, with an emphasis on energy derived from biomass. Lack of access to clean and efficient energy services – fuels, electricity, and motive power – is a major factor contributing the poverty that is so common in rural areas throughout the developing world. Local environmental factors also limit the ability of the poor to create sustainable livelihoods, while the effects of human-induced climate change will likely impact poor rural populations with disproportionate severity.

The provision of improved energy services based on renewable resources alone will not eradicate poverty in poor communities of the developing world. Nevertheless, providing such access will create an enabling environment that could lead to substantial income generating opportunities as well as improvements in education, public health, and local environmental conditions. In addition, encouraging the provision of energy services for poor communities derived from renewable resources will encourage developing countries to follow a more sustainable energy path fueled by indigenous resources, which will benefit national trade balances as well as the atmosphere.

Keeping in mind that the resources and technologies available in developing countries are highly variable, as are local conditions and needs, it should be obvious that no simple set of policy prescriptions will be applicable in all circumstances. Nevertheless, we conclude with a general set of ideas that project developers and policy makers can utilize, provided that they are suitably adapted to local conditions.

First and foremost, governments, NGOs and the donor community must take a holistic approach to energy projects of all sizes. The development of energy services is linked with many other sectors: agriculture and forestry, finance and lending institutions, education and technical training institutions, to name a few of the most obvious. Energy-related projects have a greater likelihood of success if they are implemented in tandem with other activities in order to ensure that there is sufficient demand for the energy services to be provided, that there is sufficient technical capacity to maintain and improve the energy generation, transmission and distribution infrastructure over time, and that there appropriate mechanisms in place to ensure that the target population is fully informed about, and able to pay for, the services that are being provided.

Secondly, energy project implementation needs to be sensitive to the underlying social relations within the target population. These factors, which cut across lines of gender, ethnicity and class or income level, determine the distribution of power within the community and the household. The distribution of benefits (and costs) from any type of project is going to be determined as much by these relations as by the design and implementation of the project. While this dynamic is widely discussed and accounted for in the literature and documentation published by the development community, it is often overlooked in energy-related projects, which tend to give more weight to technical matters.

Thirdly, current flows of information are inadequate. There are many benefits to be had from sharing lessons, both successes and failures, within and between countries. In recent years, the development community has placed more emphasis on free-market approaches to the provision of "essential" services. While this can lead to improvements in project performance and the efficiency with which services are delivered, it can also impede the flow of information. There are few reasons for private firms to publicize their practices – this is especially true in highly competitive markets. Here the development community needs to assume the role of information clearinghouse and exchange. Further, information should be disseminated in a variety of media. The internet has been an extremely useful tool in making information available to people throughout the world, but we still must recognize that access is limited to a small minority of people in the developing world and that even those who have access may find it difficult to view large reports laden with color graphics – like this one. Other forms of information dissemination like newspaper and radio still reach far more people in developing countries than the internet; project implementers need to take advantage of these more accessible forms of media.

Lastly, while the development community largely discourages the use of subsidies to provide energy services, some well-targeted subsidies are justified. Although costs have come down considerably, renewable energy technologies will continue to have trouble competing with conventional (non-renewable) energy technologies. It is unlikely that the price of fossil fuels will be adjusted to reflect their full social and environmental costs so that subsidies for renewable energy technologies can help to level the playing field. Such subsidies need not distort the cost of providing energy service to the end-user, rather they should be directed upstream at R&D facilities, technical capacity building, information dissemination, consumer education, and the provision of credit on favorable terms.

Financing related to climate change mitigation, like CDM projects and other funds related to the Kyoto Protocol may help in this respect. However, as we stated earlier, the majority of CDM projects are unlikely to be distributed equally among all developing countries. Rather, they will be directed towards a small number of developing countries where emissions reductions are available for the least cost and at the lowest risk. These projects are unlikely to benefit those most in need. In order to provide poor communities with improved energy services, additional funds will still be required.

This is especially true for improved energy services derived from biomass. While there is no single energy technology that will solve the problem of energy poverty, biomass-based energy technologies are associated with an array of benefits, discussed in this paper, which easily justify the type of financing described above. Taken together with other forms of renewable energy technologies – wind, solar, and small, low-impact hydro – biomass-based systems can form part of a secure and sustainable energy infrastructure. Opportunities exist around the world, in both industrialized and developing countries, to build biomass energy industries that also provide income and the means for local control over natural resources. This paper explores a number of technical, social, economic and environmental opportunities that the international community and individual nations and communities can adopt and adapt to build a clean energy future.

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Case Study 1: Modular Biopower for Community-scaleEnterprise Development (Philippines)

Art Lilley, Community Power Corporation

Summary

Conversion of underutilized biomass to high quality heat and power can help the rural poor generate income and reduce emissions of greenhouse gases. Small modular biopower systems hold great promise for community-scale application in countries having large numbers of rural, agricultural communities with access to underutilized biomass resources. A first-of-a-kind small (15kWe)modular biopower system called the BioMax 15, has been developed by Community Power Corporation (CPC) and demonstrated in the Philippines, where it met the electrical energy needs of home owners as well as a small production facility.

Background

For significant income generation activities, or village-wide central power, the rural poor need access to high quality electrical power and thermal energy. In 1998, CPC performed a market assessment for the US Department of Energy that showed that many off-grid communities have ready access to sustainable quantities of biomass residues from either agricultural or forest sources, that could potentially be used for biopower. In fact, most of the residues are underutilized, being left to rot, and generating significant quantities of methane, a significant greenhouse gas. It was also shown that there was a lack of commercially available small biopower equipment that one could purchase for village power and productive use applications. Systems that did exist were too large, were not modular, and did not meet World Bank environmental standards.

Approach

In 1999,with funding support of the US Department of Energy, Shell Renewables and the Sustainable Energy Programme, CPC developed a modular biopower system for community-scale applications in rural, agricultural areas. Based on CPC's prior experience with power systems,

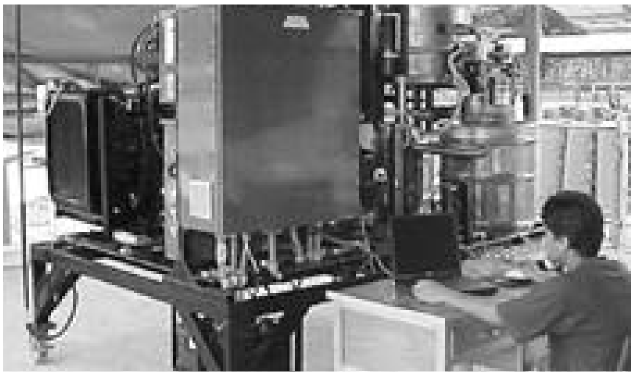
the modular system was designed to be fully automated, mobile, easy to install and relocate, and to produce high quality AC power. It was intended to be competitive against diesel power systems and solar PV/ wind hybrids generating 24-hour power. Unlike solar PV and wind hybrids that require the importation of equipment, the modular biopower system was designed to be manufactured using components that are available locally in most developing countries. Coconut shells were selected as the initial biomass resource, because they are an excellent fuel, and plentiful in the Philippines, where the demonstration project was conducted. Coconut shells have low ash and low moisture, and flow well when crushed into small pieces. The BioMax can also use wood pellets.

Besides providing power to a village, a priority objective was to provide power to a productive enterprise. To further this goal, a new NGO, named Sustainable Rural Enterprise was formed to work with the community cooperative, to develop new coconut-based products, provide marketing assistance, and develop new productive uses of renewable energy.

Impacts

The system was installed in the village of Alaminos, Aklan Province, Philippines in April 2001, where it underwent successful commissioning. In July, the system was handed over to CPC's partner Shell Renewable Philippines Corporation, the Renewable Energy Service Company for the village of Alaminos.

Figure 1 15 kWe BioMax power system fueled by locally available coconut shells



With funding from the Sustainable Energy Programme of the Shell Foundation, a small coconut processing enterprise was developed in the village, using biopower to make coconut-related products such as geotextiles and horticultural plant media. (see figure 2)

Figure 2 Manufacture of geotextiles from coconut husk fibre

About 100 people from the village of Alaminos will be employed in the manufacture of these products.

Lessons Learned

In 1998, CPC had little understanding of biopower technology; however, we understood the village power market and the needs of our customers extremely well. Armed with this knowledge, we were able to specify the requirements for a new generation of small modular biopower systems, and secure the technical expertise needed to develop the system. CPC benefited greatly from the biopower expertise of its collaboration partner, Shell Renewables. Shell's ability to specify key operational and environmental requirements, as well as design a demanding endurance test, resulted in CPC's ability to develop a first-of-a-kind unit that was able to meet all of its field operational objectives. The interest level from the public and private sectors in the biopower system is substantially greater than that for any village power systems that CPC had been involved in previously. The main reason for this interest is that this system is focused on poverty alleviation and local wealth creation. The ability to integrate the biopower system with an enterprise that generates biomass fuel as a waste stream helps to assure sustainability of the fuel supply.

While the Biomax has performed well, a number of improvements have been identified for incorporation in future generations of equipment – primarily to make the system easier to operate, easier to maintain, and lower in cost. Productive use replication projects are being sought to implement these improvements.

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Case Study 2 : Scaling-up Biogas Technology in Nepal

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Summary

Some 80,000 families in Nepal are using methane from biogas digesters for cooking, with around a quarter of the users also using it for lighting. An additional 24,000 families are expected to purchase digesters in the coming year. Plant sizes are in the range of 4m3 to 10m3. The most popular size is 6m3 and costs US$300. Of this, around $100 comes as subsidy support from the Government of Nepal, plus German and Dutch bilateral aid. The users themselves supply the rest, in part through bank loans.

Approximately 48 private companies are certified to construct biogas digesters. The digesters have high reliability, with almost 98% of them working well after three years of operation. Using biogas reduces indoor air pollution, firewood collection, and pressures on forests, shortens cooking times and can also provide significant global climate benefits through lowered emissions of greenhouse gases. In the future, it may be possible to substitute a large part of the government subsidy by selling the greenhouse gas benefits from biogas plants in the developing global carbon market.

Background

The vast majority of rural communities in developing countries will continue to derive the bulk of their energy needs from biomass sources for the foreseeable future. Biogas, largely methane and carbon dioxide, is produced by the anaerobic digestion of animal waste and other biomass. While the technology is well understood and widely used, particularly in South and South East Asia and China, few programs have been able to achieve the rates of use seen in the last decade in Nepal. The technology has been available in Nepal since the mid 1970's, however, it was not until the early 1990's that the number of installations was substantially scaled up by the Biogas Support Programme (BSP).

Approach

Nepal's Biogas Support Programme can be described as subsidy-led while at the same time being demand-driven and market-oriented. Subsidies have been justified by the difference between the high social benefits and the more modest private benefits accruing to users. A progressive structure, which provides lower subsidy amounts to larger plants, has encouraged smaller plants that are affordable to poorer households.

All participating biogas companies have to be certified by BSP and must build plants to one fixed design according to approved standards. Quality control is enforced by carrying out detailed quality checks on randomly selected plants. Ratings, from A to E, are revised each year to encourage companies to improve their performance. This focus on high quality has increased the confidence in the program among users, banks, supplier companies and donors.

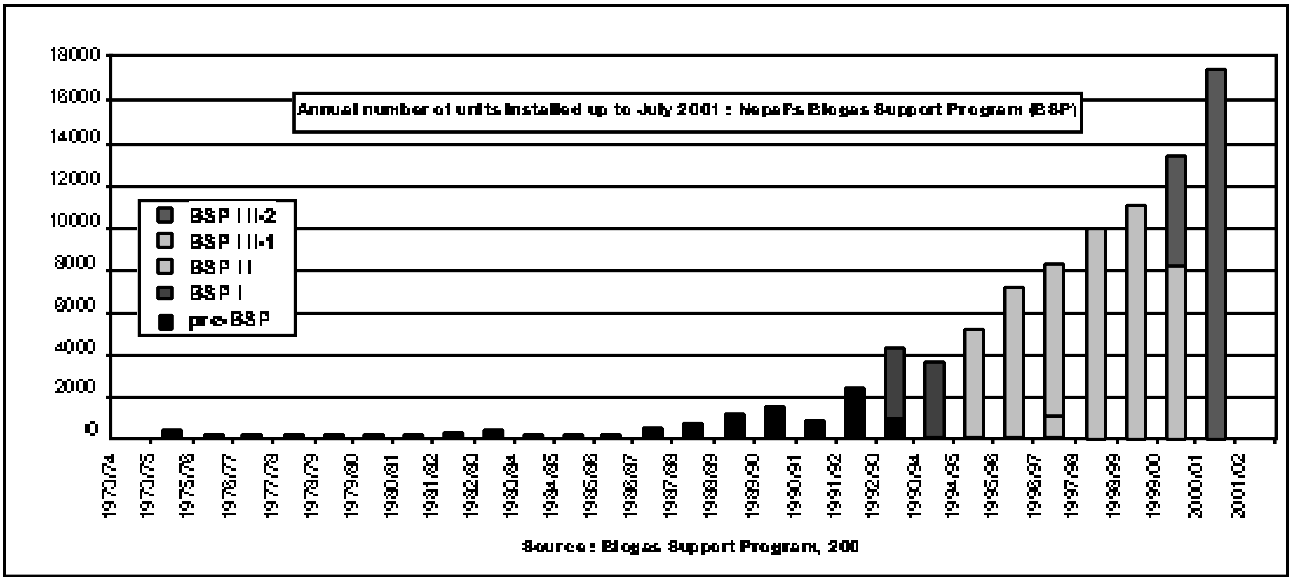
Despite the availability of subsidies, users themselves must invest a substantial amount in cash and labor. Companies must thus market themselves aggressively to generate demand for plants. BSP encouraged the number of participating companies to grow from a single government-related entity in 1991 to 48 separate companies today. The reduction in real prices of installations by 30% in the last ten years demonstrates that there is fierce market competition on the supply side.

Impacts

Biogas plants in Nepal have had positive impacts on a number of fronts. Reduced indoor air pollution has lowered respiratory infection, particularly among children. Firewood collection time has been reduced, as has the time to cook and clean pots. Women have saved an average of 3 hours per day on these chores. Houses using the gas for lighting are saving on kerosene bills. Increased stall-feeding of animals has made more organic fertilizer available to farmers, and almost 45% of the owners of biogas plants have also attached new toilets to them, leading to improved sanitation and hygiene. There is anecdotal evidence of regeneration of forests in areas where there is high penetration of biogas plants, although the exact extent of this has not been documented.

The first attempts are being made to quantify the anticipated climate benefits from biogas plants. Preliminary calculations show that a typical family biogas plant in Nepal saves between 5 and 10 tons of carbon equivalent over its 20-year life, depending on whether all greenhouse gases are included or only those within the Kyoto Protocol. The price per ton of carbon would need to be \$10 to \$20 to cover the subsidy presently provided to biogas plants in Nepal.

Figure 1 **The production of biogas plants up to the end of July 2001 is presented in the attached graph.**



Lessons Learned

The Nepal biogas experience gives a very good example of how a national program can, through a subsidy mechanism, bring commercial companies to the table and, with their participation, obtain high quality installations. Free market conditions, particularly when regulations are weak and when the customer does not have full information regarding the product, often result in competition between suppliers based on price alone, at the expense of product quality. For a program like BSP to succeed, a major prerequisite is that the national program must be independent and free from political interference.

A second lesson is that freezing technology to one approved design makes it easier to control quality while at the same time lowering barriers to market entry. Although such a strategy may not be suitable for a fast-changing sector such as solar PV, this has turned out to be quite effective for biogas.

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Case Study 3: Commercial Production of Charcoal Briquettes from Waste (Kenya)

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Summary

Soaring prices of lumpwood charcoal and regional deforestation associated with traditional charcoal production prompted Chardust Ltd. of Nairobi, Kenya to investigate the production of charcoal substitutes from waste biomass. Chardust's leading product is made from waste products salvaged from charcoal wholesaling sites in Nairobi. In less than a year, sales of the company's "Vendors' Waste Briquettes" have gone from a few bags a week to over 7 tons per day, displacing an equivalent amount of lumpwood charcoal and effectively sparing over 80 tons of indigenous wood per day. The briquetted fuel is cheaper than regular charcoal and burns for much longer. Chardust's customer base is broad, including institutions such as hotels, lodges and schools as well as farmers (for space heating) and domestic consumers.

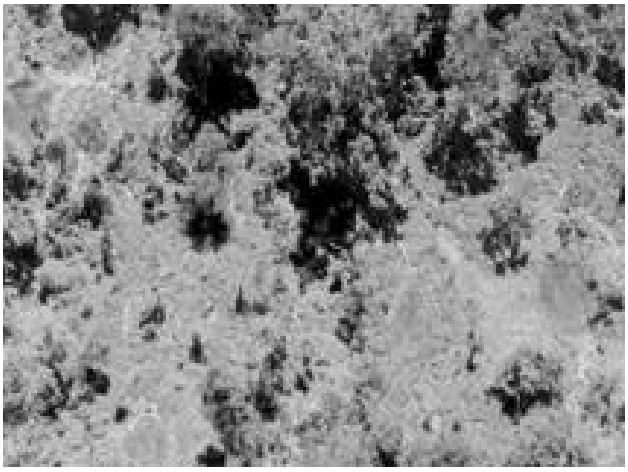
Chardust is also exploring the use of agro-industrial wastes to produce additional types of charcoal briquettes. A recent feasibility study concluded that sawdust, bagasse and coffee husk have practical and commercial potential as raw materials for premium charcoal products.

Briquetting projects in Africa have a poor track record due to an over-emphasis on processing technology or environmental conservation at the expense of market factors. Chardust came to the problem from a new perspective, focusing directly on pricing and performance to under-cut lumpwood charcoal with cheaper and better-performing products.

Background

Over 500,000 tons of charcoal are consumed in Kenya every year, with a retail value in excess of US$40 million. The charcoal trade is a major contributor to environmental degradation, operates largely outside the law and pays no taxes. Demand for charcoal is expected to increase at over 4% per annum for the foreseeable future in East Africa, leading to an intensification of the ongoing process of environmental destruction. For every ton of charcoal consumed, at least 10 tons of standing wood are being felled. Charcoal quality is in decline as the quality of available raw material declines.

Figure 1 Aerial photo showing the impact of charcoal production in Mt. Kenya forest



Government efforts at substitution with kerosene or liquid propane gas have proven financially unworkable. Such fossil fuel alternatives in any case have their own drawbacks associated with unsustainability and foreign exchange dependency. Initiatives to bring charcoal producers and traders under systems of formal management have fallen foul of corruption and influential charcoal 'mafias'. On the production side, improved kiln technologies that could increase wood-charcoal conversion efficiencies have not been adopted due to the quasi-legal and mobile nature of producers who would rather maintain a low profile than install more efficient fixed equipment.

The promotion of fuel-saving stoves is an area where positive impacts have been realized on overall efficiency in the sector, but with adoption of such stoves by consumers now virtually ubiquitous, little that can be done to further improve efficiencies at the point of use. In short, many of the means by which charcoal demand might be reduced, efficiencies improved or substitution encouraged have been tried. They have either failed or have reached the apparent limit of their potential.

Chardust's Approach: Commercial Competition

One opportunity for reducing charcoal demand that has not yet been systematically investigated in Kenya is direct substitution - not with fossil fuels but with nearly identical affordable and environmentally acceptable alternatives that can be produced in-country. Chardust is an alternative energies company that has grasped this opportunity.

Chardust pursues two parallel approaches. The first is to salvage wastes from charcoal wholesalers in the city of Nairobi and use this to fabricate fuel briquettes. The waste is typically 30 years old or more but remains undegraded and is readily salvaged at centralized sites. Chardust uses locally-made machinery to produce cylindrical briquettes 3.2 cm in diameter and 5 cm. in length. These briquettes produce no smoke, sparks or smell when burned. They have a higher ash content than lumpwood charcoal and hence an extended burn. Chardust prices its Vendors' Waste Briquettes (VWB) 30% below regular charcoal in Nairobi and currently sells in excess of 7 tons per day. The operation has also created employment for 23 semi-skilled workers.

Figure 2 An extruder in operation at Chardust's plant

Chardust's second focus is on waste recovery in the agricultural, agro-processing and timber industries. Large amounts of biomass go to waste in this sector but could be converted to charcoal briquettes at an affordable price. Market research and initial production trials on a range of agro-industrial by-products indicate that an injection of lumpwood charcoal substitutes into the urban Kenyan marketplace is currently viable. Chardust has looked into more than 20 different wastes in Kenya and concluded that sawdust, bagasse and coffee husks may have commercial potential due to their bulk availability at centralized locations, few (if any) alternative uses and conduciveness to carbonization and conversion to charcoal briquettes. In conjunction with sawmills, sugar factories and coffee mills, Chardust now intends to produce a range of premium low-ash charcoal products to complement its Vendor's Waste Briquettes.

Figure 3 Waste bagasse at a Kenyan sugar factory

Lessons Learned

With the rapidly rising price of lumpwood charcoal in Kenya's urban centers, Chardust saw that there was a market opportunity to be exploited if it could offer cheaper or better-performing substitutes. This approach is what distinguishes Chardust's operation from that of previous briquetting ventures in Africa, which typically set out to provide technology-driven income-generating opportunities for community groups, salvage urban waste, protect the environment or simply test a recently developed piece of machinery. These top-down approaches tend to be unsustainable as they are not always based on sound commercial sense. Chardust has built its business around market niches that value price and performance. The company's research and development efforts, which respond directly to market forces, have prompted the invention of customized screw extruders, a particulate biomass carbonization system and several types of domestic and institutional water heaters.

Partnership Potentials

Chardust Ltd. is prepared to enter into partnership with suitable businesses or organizations that have similar interests. The company currently re-invests all profits into expansion, so research and development progress is slow (but steady) and governed by available funds. Chardust is currently poised to commercially prove its waste-conversion technology at much larger scales and, by doing so, make a truly significant impact within East Africa.

Figure 4 Dried coffee husks (right) and carbonized coffee husk briquettes (left) produced by Chardust Inc. during a feasibility study of multiple waste-based resources.

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Case Study 4: Ethanol in Brazil

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Summary:

Brazil launched its ethanol program, ProAlcool, in the mid 1970's partially in response to the first oil crisis, but also in an attempt to stabilize sugar prices in the face of a volatile international market. Since its inception, Brazil's production of sugarcane has expanded five-fold to over 300 million tons during the 1998/9 growing season (UNDP et al., 2000). Roughly 65 per cent of this cane is dedicated to the production of ethanol. The industry currently produces nearly 14 billion liters of ethanol per year, which is used either as a blending agent and octane enhancer in gasoline in a 22:78 mixture called gasohol, or in neat, ethanol-only, engines. In total, ethanol displaces roughly 50 per cent of the total demand for gasoline in the country, equivalent to 220,000 barrels per day of gasoline (making Brazil the largest producer and consumer of alternate transportation fuels in the world), and off-setting as much as 13 million tons of carbon emissions while employing hundreds of thousands of people and stimulating the rural economy.

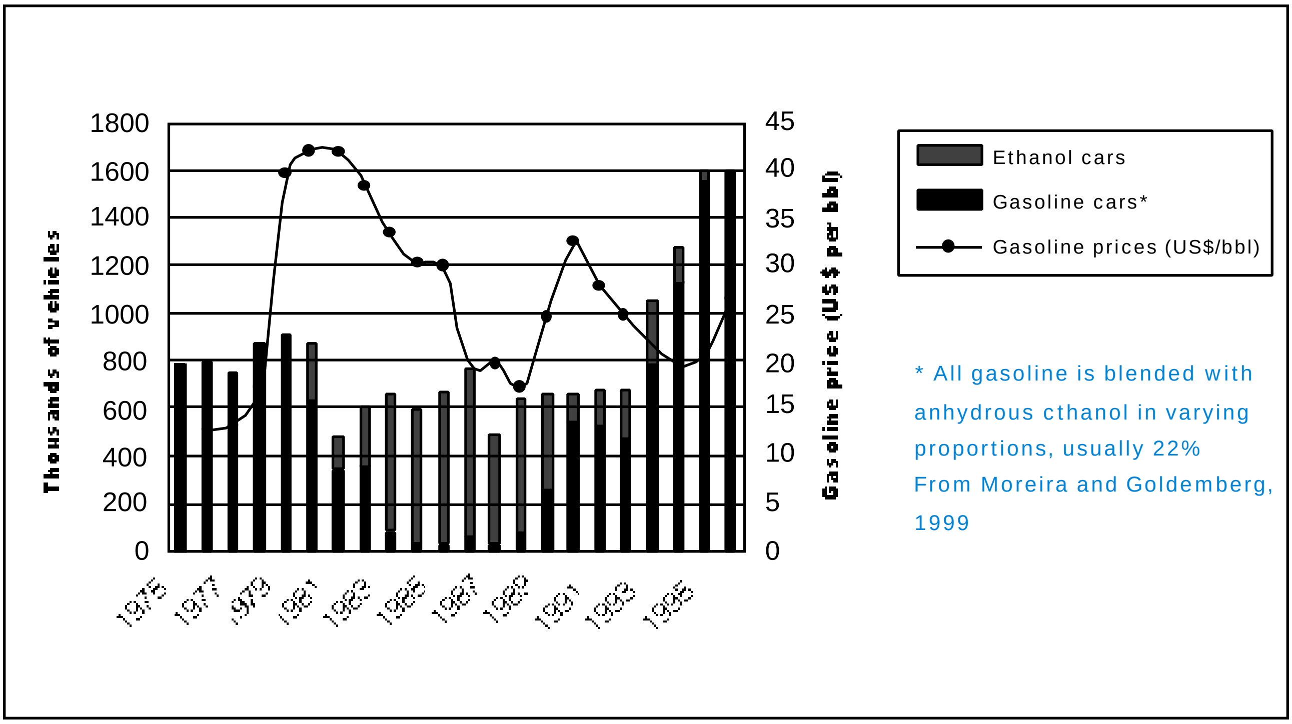
Despite the impressive figures, Brazil's ethanol program is not entirely environmentally benign. Moreover, the future of the ethanol program is by no means clear. It faces considerable uncertainty for a combination of reasons, including the lack of a coherent national energy policy, high sugar prices in the international market favoring sugar production for export over domestic ethanol production, and, of course, lack of incentives to invest in ethanol production as a result of low international oil prices and a failure to fully account for the costs of oil production and consumption.

Background

Brazil began producing ethanol and blending it with gasoline nearly a century ago, but it wasn't until the 1930s that it was mixed in all petrol by federal decree. As a fuel, ethanol can be used in two ways. It can be mixed with gasoline in concentrations that typically range from 10-25 per cent; ethanol that is mixed in this way must be anhydrous, i.e. all of the water is removed, which requires a double distillation process yielding 99.6 per cent pure ethyl alcohol (0.4 per cent water by volume). The second way that ethanol can be used as a fuel is without mixing. So-called neat engines may be used with hydrated ethanol (approximately 4.5 per cent water by volume), which is obtained through a single distillation process.

At the height of Brazil's "ethanolization", in the mid 1980's, 95 per cent of new light vehicle sales were neat ethanol-only automobiles. Sales of ethanol-only vehicles soon declined, partly because of sustained low petroleum prices and increasing world sugar prices, which encouraged sugar production rather than ethanol production. Neat vehicle sales fell to only 1 per cent of total new vehicle sales by 1996, but ethanol consumption has continued a slow increase because of booming sales in conventional cars, which still use a 22 per cent ethanol blend. See Figure 1.

Figure 1 Sales of automobiles in Brazil from 1975 to 1996



Approach

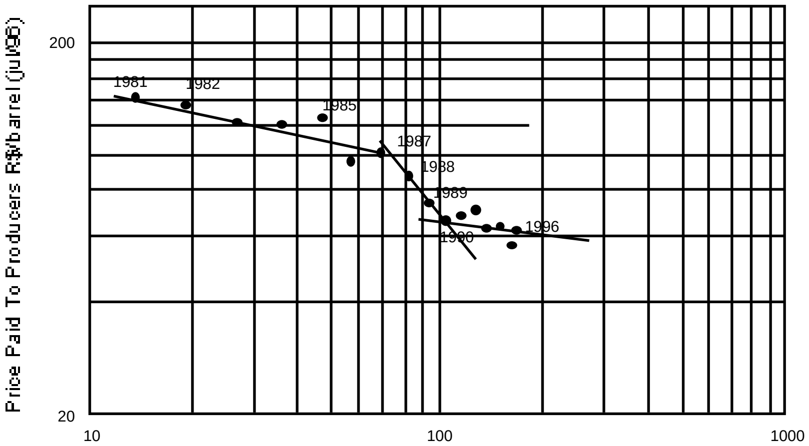
The first decade of the program was characterized by strong government intervention. Initially the Brazilian government used existing sugar mills to produce anhydrous ethanol, eventually moving into autonomous distilleries, which produced hydrous ethanol. To ensure the program's success, a deal was struck between the government and domestic automobile industry to develop and market vehicles with the proper engine modifications so that the ethanol could be used. This met some resistance from manufacturers, but the government assisted with R&D support.

Scaling up sugarcane production was eventually guaranteed because the government secured a commitment from Petrobrás, the state-owned oil company, to purchase a fixed amount of ethanol to blend with their petrol. To meet the projected demand for ethanol, the state offered nearly US$2 billion in low interest loans and initially established a cross-subsidy with petrol so that they could sell ethanol at only 59 per cent of the pump-price of the gasoline, which was set by the government.

This scaling up took place without conflict over land use. Cultivation of sugarcane occurs principally in the south-east and northeast parts of the country. The total area occupied by sugarcane cultivation is about 7.5 per cent of all cultivated land in Brazil, or 0.4 per cent of Brazil's total land area. This is smaller than the land devoted to any one of the major food crops: maize, soybeans, beans, or rice. Despite providing half of the national transportation fuel requirements there has been no significant conflict between ethanol cane, food, or export crops (Moreira and Goldemberg, 1999). One reason for this is that aggressive R&D in both cultivation and processing have led to rapid gains in productivity that have been sustained at over 4 per cent per year since the inception of the project, so that ethanol productivity effectively doubled in twenty years from approximately 2600 liters per cultivated hectare of sugarcane in 1977 to 5100 liters per hectare in 1996. In addition, in roughly the same period of time, the cost of producing a unit volume of ethanol dropped by more than half. Figure 2 shows the experience curve for Brazil's ethanol industry.

Figure 2

Cost Evolution of Ethanol in Brazil



from Moreira and Goldemberg, 1999

Despite the cost reductions, which extended into the 1990's, Brazilian ethanol was not able to compete directly with gasoline. To support the industry, the government continued the cross-subsidy, taxing gasoline. This policy ensured that ethanol producers were paid enough to cover their costs per liter of production and consumers were able to purchase ethanol at 80 to 85 per cent of the pump-price of petrol.

Since the late 1990s there has been a global shift in attitudes toward market-distorting policies, and this has played itself out in the Brazilian ethanol program as well. In some locations, specifically the southeast of Brazil, where the majority of the nation's ethanol is produced, subsidies were reduced, then in 1999 removed altogether (UNDP et al., 2000). The long-term effects of this remain to be seen. The decrease in the number of neat ethanol vehicles has not led to a decrease in ethanol consumption because there has been rapid growth of vehicles using gasohol and in some locations the fraction of ethanol is as high as 26 per cent (UNDP et al., 2000). Figure 1 shows the growth and decline in sales of neat ethanol vehicles. It also shows the price of gasoline on the international market for the same time period. Note that the turning point marking the decline in neat ethanol vehicle sales lags slightly behind the global decline in petroleum prices.

Impacts

The Brazilian ethanol program has passed its 25th year, and there are simply too many impacts to list in a brief case study. Below are some of the more dramatic impacts relating to employment, the environment, and fossil-fuel avoided which were three areas that the national government was most concerned about in initiating the program.

Jobs. The entire sugarcane sector directly employs between 0.8 and 1.0 million people. This is the largest number in the agro-industry sector in terms of formal jobs, with 95 per cent of workers legally employed, and a minimum wage 30 per cent greater than the national minimum wage. Ethanol production also has a relatively low index of seasonal work, contributing to stable employment in sugarcane growing areas (Moreira and Goldemberg, 1999). The ethanol industry also has relatively low investment rates per job created: between US$12,000 and $22,000, compared with US$220,000 in the oil sector, US$91,000 in the automobile industry and US$419,400 in the metallurgical industry (Rosillo-Calle and Cortez, 1998).

Environment. One of the principal negative impacts of large-scale ethanol production is the disposal of stillage, a liquid by-product of the fermentation process. This is a major environmental problem because of its large pollution potential. Air pollution is another environmental issue. Cane harvesting is often preceded by in-field burning of cane leaves and tops, which facilitates the harvest and helps manual harvesters to avoid injuries. This occurs in both ethanol and sugar production. The smoke can have direct health effects on exposed populations and most certainly results in greenhouse gas emissions. Though it is not common, there has been research into harvesting tops and leaves of cane for energy production (Beeharry, 2001) which would incur additional harvesting costs but would likely yield a net gain in energy production, and potentially create additional employment. By reducing consumption of gasoline, the ethanol program has reduced air pollution by cars. Pollutants such as carbon monoxide and hydrocarbons are reduced by about 20 per cent compared with gasoline.

Fossil fuel use avoided (and greenhouse reductions). Ethanol accounts for half of the light-vehicle fuel consumption in Brazil. Since its inception, the ethanol program has displaced the consumption of over 140 million cubic meters of gasoline and saved the country nearly US$40 billion in hard currency that would have been spent on importing the fuel. Use of sugarcane ethanol also mitigates global warming. When one crop is converted to alcohol and burned, the carbon released is sequestered in the subsequent crop. There are small emissions of greenhouse gases in the production process, which uses a fossil fuels for farm machinery, but bagasse provides nearly all of the required thermal, mechanical, and electrical energy needed for production. The production and use of 1 liter of ethanol to replace an energy-equivalent amount of gasoline avoids the emission of about a half a kilogram of carbon dioxide, which is a 90% reduction over gasoline (Rosillo-Calle and Cortez, 1998). In total, ethanol yields a net savings in carbon dioxide emissions of about 13 Mt carbon per year, corresponding to about 20 per cent of the carbon dioxide emissions from fossil fuels in Brazil (UNDP et al., 2000).

Lessons Learned

"The ProAlcool has gone from a highly innovative period to almost technical stagnation. The high governmental intervention of the early years has been replaced by a more conservative attitude towards subsidies and by a lack of clear direction with regard to energy policy" (Rosillo-Calle and Cortez, 1998, p. 124). The same authors contend that the positive environmental aspects of ProAlcool far outweigh its potential damage.

An economic analysis would indicate benefits as well. Consumers pay roughly US$2 billion per year on the cross-subsidy while annual saving for the country in avoided imports is nearly US$5 billion (Moreira and Goldemberg, 1999). We have seen that targeted subsidies and support for R&D yielded huge gains in productivity and substantial cost reductions. In addition, setbacks arose and continue to persist because of the low price of petroleum, which is due in part to the failure to fully account for the environmental and social costs of its production and use. Nevertheless, the project has been able to bring about substantial financial savings, pollution reduction and avoided carbon emissions, while creating jobs and stimulating the rural economy. Future trends toward greater mechanization will bring about further cost reductions and possibly higher productivity, however this must be balanced with the social costs in terms of lost employment.

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Case Study 5: Carbon from Urban Woodfuels in the West African Sahel

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Summary:

This program has two distinct objectives: 1) influencing policy to improve forest management of urban woodfuel use and improve rural and urban well-being; and 2) supporting the emergence of a new generation of policy researchers and analysts and institutions focused on environmental governance issues. The four-phase program is to be executed over a two to three year period.

The charcoal market is most important in Senegal where we propose to base the program. Ideally, however, we would also conduct comparative research of this nature in other countries in the region (The Gambia, Mali and Burkina Faso) where similar issues are emerging as urban woodfuel demand grows.

Background:

Wood is still, by far, the main source of urban and rural household fuel in Africa. As African cities grow through births and in-migration, the demand for commercially harvested woodfuels grows even faster. Wood use also increases disproportionately because urban dwellers consume charcoal produced inefficiently from wood, while the rural population cooks directly over firewood.

Urban woodfuel prices have risen due to greater competition, greater transport distances and transport oligopolies - reducing urban disposable income and increasing insecurity as fuel shortages become more frequent. Growing urban woodfuel demand is also affecting surrounding forests, with broad implications for the rural environment, economy and livelihoods. Woodfuel use also accounts for 10 to 30 per cent of energy based carbon emissions in the Sahel, 20 to 40 per cent coming from urban areas.

Regulation of urban woodfuel production has been the single most-important function of forestry departments in the Sahel since at least 1916. Although efficiency gains from improved cook stoves (designs taken from Kenya) have been largely realized, wood demand is still growing faster than populations. Substitution has been complicated by the high up-front costs of new equipment, cultural preferences for charcoal, and intermittent shortages of substitutes due to foreign exchange constraints. Projects and legal reforms have been targeted at reducing and better managing the harvest.

Substitution with petroleum fuels increases carbon contributions. This has had little effect, however, due to the slow rates of substitution. Sustainable harvesting of wood, however, should sequester as much carbon as is released. But, there is still little understanding of the balance between patterns of wood cutting and regeneration.

Wood-harvesting patterns throughout the region are now changing due to broadening rural access to urban markets. As more local communities become engaged in wood-cutting, they use less intensive production methods than commercial merchants. Further, community-based production regulations also require more measures to ensure regeneration. This new pattern is increasing the potential for regeneration and for sustainable harvest in ways that appear to reduce the urban woodfuel trade's net carbon contribution to the atmosphere. But, older more intensive techniques continue to dominate due to urban demand pressures and powerful transport oligopolies. Fear of urban discontent over rising prices has led politicians to pressure forest services to continue business-as-usual centralized forms of woodfuel harvesting and transport. This project aims to find solutions to this rural-urban tension.

Approach:

Phase I, Constituting the Research Team, involves identifying a research institution and policy researchers. Three or four candidates will be selected through a rigorous review process. These researchers will then constitute a team under the direct guidance of a senior policy analyst and the WRI contact person. This period will also be used to set up a national policy advisory group to provide additional guidance for the program.

Phase II, Assessment, will first involve an analysis of a full range of policies (from constitutional framing, electoral laws, tax codes, and justice codes to forestry codes). This will be followed by grounded field research on Senegal's charcoal commodity chain, following the structure of regulation, the market and market relations from the forest villages where wood is cut and converted to charcoal by surga, to the 'Diallo kerñ' vendors points in Dakar and one secondary city. The analysis will be aimed at understanding the way the commodity chain functions and the effects of the existing policy framework on production, transport, exchange and final sale. This research will explore the rural and urban price effects of current policy structures as well as the spatial distribution of production-with its ecological and social implications. The analysis will include an assessment of the effects of charcoal production and marketing on forest cover change and on carbon emissions. The final product of such the assessment phase will be a thorough mapping of the relations between current policy and the dynamics of production and marketing.

Phase III, Policy Analysis, involves preparation for outreach and advocacy. This period will be used to analyze the data collected, identify opportunities for change and intervention, formulate policy recommendations and strategies, and discuss policy ideas with policy makers, organizations and individuals interested in the range of issues – from environmental management to social justice – that this program aims to influence. In the policy analysis phase, the researchers will analyze how policies and market relations shape ecological, economic and social outcomes. From the analysis, a number of alternative policies – ranging from minimum environmental standards approaches to deregulation and changes in decentralization or fiscal policy – will be considered.

Phase IV, Outreach and Advocacy, will be used to organize a series of national policy dialogues. These dialogues can range from open meetings with all stakeholders to smaller seminars in which findings and policy recommendations are discussed with particular interest groups such as the charcoal magnates, the national forest 'exploiters' union, some marabouts who have interests in the charcoal trade, the forest service, the ministry for environment, the Institute for Environmental Science at the University, associations of forest villagers, particular villages within the charcoal production regions, and members of the national assembly. This phase will also involve following up on any bills being drafted that have implications for the market and encouraging legislators to propose changes where necessary.

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Case Study 6: Sustainable Fuelwood Use through Efficient Cookstoves in Rural Mexico

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Summary

Efficient wood-based cookstoves are being disseminated in the Patzcuaro Region of rural Mexico. The stoves are part of an integrated program that exploits the synergies between health, environmental and energy benefits. It builds on the local knowledge of indigenous women and community organizations, to provide better living conditions at the household level and improved management of forest resources. The program also provides a link between research institutions, NGOs and local communities in a cycle of technology implementation and innovation.

Currently more than 1,000 Lorena-type stoves have been disseminated within the region. A subsidy worth US$10 is provided to users in the form of tubes for the chimney and part of the construction materials. Users provide their own labor as well as the rest of materials. Total stove costs are estimated at US$15. Scaling-up has been initiated, as local municipalities are now providing funds to enlarge the program. In addition to substantial benefits to the users from reduced indoor air pollution and reduction in firewood collection and cooking times, and benefits to the local environment through reduced pressure on forests, efficient cookstoves can also provide significant global climate benefits through lowered carbon dioxide emissions.

Background

Approximately three quarters of total wood use in Mexico is devoted to fuel wood (Masera, 1996). Currently, 27.5 million people cook with fuel wood in the country (Díaz-Jiménez, 2000). Despite increased access to LPG in the last decades, Mexican rural and peri-urban inhabitants continue to rely on fuel wood, in a pattern of "multiple-fuel cooking".

The Patzcuaro Region case study illustrates a new generation of wood-based efficient cookstove dissemination programs that have been launched in different parts of the world with high success rates. Key to their success is a shift from narrow technology-centered approaches to more integrated approaches, centered on understanding local women's priorities and providing capacity building as well as multiple health, environmental, and financial benefits. Efficient cookstoves have been shown to provide reductions of more than 30% in indoor air pollution, a cleaner cooking environment, reductions of 30% in fuel wood consumption and a similar reduction in fuel wood gathering time or fuel purchases.

Approach

The Sustainable Fuelwood-Use Program in the Patzcuaro Region is based on an integrated and participatory strategy that tries to find synergies between environmental and local socio-economic benefits. It draws on local indigenous knowledge and traditions, and seeks to strengthen the abilities and capabilities of local women. To do so, socio-economic and environmental problems associated with fuel wood use are first identified and possible solutions developed by local women themselves. The program was initiated 15 years ago as a collaborative effort between the National University of Mexico (UNAM)-two local NGOs (GIRA and ORCA) and local communities.

Stoves are disseminated in village clusters. Within each village, women are trained by local promoters through two workshops, where the linkages between fuel wood use, health and the environment are emphasized. Users actively participate in their own stove construction and they also help in the construction of other stoves within the village. A strict stove monitoring program provides user feedback and assures the acceptance and adequate performance of the stoves already built. A subsidy policy, in the form of the stove chimney, and specific building materials, implemented three years ago, has been instrumental in increasing the adoption of cookstoves substantially. The subsidy is justified to make up for the difference between higher social benefits (prevention of forest degradation, and reduction in emissions of greenhouse gases) and lower private benefits (reduction in expenditure for fuel wood, savings cooking time, cleaning, and firewood collection, and reduction in respiratory illnesses) accruing to users. The user-centered approach has resulted in dramatic program benefits: stove adoption rates are above 85%; stove construction time has decreased from 2 weeks to 4 hours, and stove duration is 4.8 years, on average.

Figure 1 Efficient Lorena-type cookstove shown during tortilla-making. User adaptations are almost the rule; in these case a cover has been added to the stove to increase durability and cleanliness.

Impacts

The program has had positive socio-economic and environmental impacts. Measured fuel wood consumption and indoor air pollution reductions reach more than 30% in comparison to traditional devices. Firewood collection time has been reduced, as has the time to cook and clean pots.

Participating women and their families are increasingly involved in forest restoration and management programs within their own villages. The forestry options promoted by the NGOs, range from the promotion of agroforestry systems in private lands to the support of common property forest management, and are proving effective to increase the sustainability of fuel wood resources.

These small impacts have led to a multiplier effect, both within the region and at the national level. Locally, the region's municipalities have started to fund the program using the same subsidy incentive and one hundred people, mostly women, have been trained in stove construction and dissemination. In several villages, demand for stoves now surpasses the program's current supply possibilities. One hundred promoters from all over Mexico have been trained by the program, and at least three other regions have started similar programs.

Carbon benefits from the use of stoves have been preliminary estimated at 0.5 tC per stove-year from fuel wood savings, which, for the average duration of the stove means 2.4 tC/stove. Thus, a price of $6.3/tC would cover the present subsidy provided to stoves.

Figure 2 Stove promoter and users chat over an efficient cookstove during tortilla-making.

Lessons Learned

The Sustainable Fuelwood Use Program in Rural Mexico shows how a user-based and integrated approach for efficient cook stove dissemination can result in substantial environmental and socioeconomic benefits. Actively involving local women and relying on their own priorities and traditional knowledge has proven essential for stove adoption. Also essential has been adopting a flexible stove design, based on basic principles and critical dimensions, rather than on a fixed design. The active collaboration between research institutions-local NGO's and users has provided a nurturing field for technology innovation and adaptation. The small in-kind subsidy is essential to get users initially involved in the program, and to speed the dissemination process. Linking fuel wood demand with environmental issues has been important to get users more aware and actively involved in programs to increase the sustainability of fuel wood resources. Government involvement, through this clear and transparent financial support and through a decentralized approach, is essential for project success.

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CASE STUDY 7 : USE OF ENHANCED BOILERS IN THE HAMMAMS IN MOROCCO

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Summary

The hammams or public baths belong to the traditions of Morocco. They constitute, within the low-income strata of the Moroccan society, and especially among women, privileged places for meetings, discussion and exchange of news. There are no less than five thousand hammams in Morocco, mainly within the low-income neighborhoods of the urban centers. Almost all these hammams use wood residues and firewood for the production of hot water.

The consumption of firewood and wood residues by the hammams is estimated at 700,000 tons per year, which represents 3% of the national consumption in conventional energy. The combustion of wood is done in fire rooms using rudimentary and inefficient boilers. Pilot installations of enhanced boilers have enabled firewood savings of 40% to 50% compared with the consumption of a model traditional boiler. The current project consists of generalizing the use of the enhanced boilers tested during the pilot phase to all the hammams of the Kingdom.

Background

The consumption of firewood in Morocco represents 53% of the consumption of biomass; it is estimated at 12 millions tons, 30% of the total energy consumption in Morocco. A comparison between the actual consumption of firewood from the forest and production capacity shows that extractions within the forests represent about 4 times their production capacity, resulting in annual deforestation corresponding to 30,000 hectares. This deficit results in an overexploitation of the forest and compromises its sustainability, with all the resulting negative consequences from the environmental standpoint, in particular weakening of its carbon dioxide sequestering power.

In the cities, it is the hammams and the ovens for bread which are the highest firewood consumers. According to the associations of hammam owners and the studies carried out by the Center for Renewable Energies (CDER), no less than 5,000 hammams distributed over the different urban centers of Morocco consume more 700,000 tons per year of firewood and wood residues.

The low thermal yield of the equipment used for water heating results in considerable waste. Several experiments conducted by the CDER have shown that enhanced boilers enable wood savings somewhere between 40 and 50% over the typical traditional system.

Approach

A pilot project was initiated by the Center for Development of the Renewable Energies and the German cooperation agency (GTZ) in collaboration with the Association of Owners of Hammams of Marrakech (APHM). This first pilot phase led to the development of an enhanced boiler adapted to the specific operating conditions of the hammams, testing of the boiler in some fifteen hammams. The savings achieved were evaluated by monitoring the thermal performance of the pilot hammams before and after the installation of the new boilers. The average thermal yield has gone from 28% to more than 70%.

In order to control the quality of the facilities, reduce the costs and facilitate the manufacturing of the new boilers, a model design plan has been drawn up by the CDER and the GTZ and supplied to the local workshops manufacturing the tanks. Training has been given to local welders regarding the manufacturing and maintenance of the new boilers. Awareness campaigns aimed at the hammam owners and the dissemination of the new boilers have been managed by the APHM.

The CDER plans to expand the use of these boilers to the whole country by equipping the 5,000 hammams in the Kingdom. The large-scale dissemination of these enhanced boilers will be the subject of an agreement between the National Federation of Owners and Operators of Hammams (FNPEH) and the CDER. An appropriate financial package to facilitate the purchase of the new equipment by the owners is under study.

Expected outcomes

Extrapolation of the results of the pilot phase to the 5,000 hammams in the Kingdom leads to an estimated savings - at 50% of the current consumption of the hammams - of 350,000 tons per year of firewood and of wood residues (see table). With 70% of the wood consumption of the hammams coming directly from the forest and an average quantity of biomass on foot estimated at 23 tons of firewood per hectare of forest, the program will contribute to a savings of about 10,000 hectares from clearing, which represents one third of the current loss of Moroccan forest.

By reducing firewood consumption, the program will reduce air pollution (particulate, carbon monoxide, nitrous oxides and sulphur dioxide and greenhouse gas emissions. At the end of the conversion of all the hammams, the reduction will reach 600,000 tons of carbon dioxide emission per year.

HEADING	Model Hammam	Hammam with enhanced boiler
Thermal yield	28% to 42%	78%
Average consumption	140 tons / year	70 tons per year
Savings		50%
Cost of the boiler	2,000 $	4,500$
Time of return on investment		
for the change of boiler		8 months

Despite the excellent economic profitability of the boiler change projects, the owners and the operators remain reluctant to engage in transformation work and in the installation of new boilers. The pilot phase highlighted the need to adopt a global approach, including within the same program the following important aspects:

The involvement of the National Federation and of the local associations of hammam owners and operators in all the phases of the program (design of the boilers, awareness campaigns with the owners, training, etc.).

The establishment of a financial package based on a soft loan and a subsidy (limited to the starting phase of the project) to encourage the owners to purchase the new boilers.

The launch, in collaboration with the FNPEH, of a large-scale campaign to sensitize and inform the owners.

The training and supervision of the manufacturers and installers.

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CASE STUDY 8 : IMPROVEMENT OF COOKING EQUIPMENT UTILIZED IN THE MOROCCAN COUNTRYSIDE

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Summary

Although the use of wood for cooking purposes in the countryside is the main cause of deforestation (about 90% of the energy needs of the rural population, resulting in a deforestation of more than 30,000 hectares per year), the equipment used for cooking food (traditional fire rooms) and for baking of bread (traditional ovens) remain of a rudimentary design.

In order to alleviate pressures on the forest resulting from a non-rational exploitation of wood, and to reduce the consumption of firewood within rural households, the Center for the Development of Renewable Energies (CDER) has launched a pilot project for dissemination of enhanced fire rooms and ovens. Different models of enhanced fire rooms and ovens have been developed and are being disseminated in different regions of the country with the support and close collaboration of local organizations. The prototypes of fire rooms developed under this project are robust, movable, and enable a wood savings of 30 to 40% compared with the traditional fire rooms. (This percentage varies, depending on the

operating mode of the enhanced fire room and of the design of the traditional fire room used before). The CDER is also currently developing, in collaboration with an NGO from Marrakech, a prototype of solar oven whose first launch is scheduled in 2002.

Approach

According to a survey made by the CDER, it has been observed that the correct use of enhanced fire rooms contributes to a significant reduction in the demand for firewood by the households, and consequently to a certain alleviation of the chores of women and young girls in the countryside. These enhanced fire rooms have been widely welcome by housewives, and all the households surveyed are satisfied with the use of these types of fire rooms. The impact of the use of enhanced fire rooms on the reduction of the demand in energy wood of the rural populations can only be maximized by a massive dissemination of this equipment nationwide. To that end, several promotion and outreach activities have been carried out, including demonstration projects in villages, and training and supervision of the manufacturers of enhanced fire rooms and of facilitators for the adoption and use of these technologies. These actions have been undertaken in collaboration with local associations. The following development projects have been carried out:

Dissemination of the enhanced fire rooms and ovens in the Zat Valley in collaboration with

the Association of Friends of the Zat area (about 160 fire rooms installed).

Integrated Development of Tassa - Ouirgane in collaboration with the Regional Direction of

the Water and Forests Authority / Marrakech / The El Haouz Province and the Ouirgane

Association (60 households equipped with enhanced fire rooms).

Thanks to information and awareness building efforts, these new cooking technologies have also been integrated in several local and regional development projects and programs:

- Land reclamation in Ouled Fennane, in collaboration with the Provincial Agriculture Delegation of the city of Khouribga (1,000 enhanced fire rooms and 300 ovens for bread disseminated)

- Land reclamation project in the Doukkala region (joint project between the Regional Agency for Land Reclamation and Agricultural Development and the European Union) : 890 enhanced fire rooms and 10 ovens for bread

- Argan Grove project in Agadir (Water and Forest Authority and GTZ)

- Soil protection and restoration project (GTZ and the Provincial Agricultural Delegation of the city of Khenifra)

- Projects of the NEF Foundation (City of Ouarzazate)

Currently, in Morocco, more than 3,000 enhanced fire rooms and ovens have been disseminated, thus enabling the constitution of an important base of experiences. The studies of the CDER have shown that the dissemination potential is for about:

- 250,000 enhanced fire rooms,

- 120,000 solar ovens,

- 85,000 enhanced ovens for bread.

Through a participatory approach, the CDER plans to achieve a penetration rate of 30% by 2005. This means the dissemination of:

- 80,000 enhanced fire rooms

- 40,000 solar ovens

- 28,000 enhanced ovens for bread.

For the implementation of the program, partnerships are being put in place with some associations in the targeted regions. These are: the Touiza Movement Association in the Province of Azilal: the Green Oasis Association for the conservation of environment in the Province of Guelmim; and the Aoudid Association in the Province of Ouarzazate.

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