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BIOENERGY PRIMER

MODERNISED BIOMASS ENERGY FOR SUSTAINABLE DEVELOPMENT

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United Nations Development Programme

with support from
the Government of Norway

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FOREWORD

There is an unmistakable link between energy and sustainable human development. Energy is not an end in itself, but an essential tool to facilitate social and economic activities. Thus, the lack of available energy services correlates closely with many challenges of sustainable development, such as poverty alleviation, the advancement of women, protection of the environment, and jobs creation. Emphasis on institution-building and enhanced policy dialogue is necessary to create the social, economic, and politically enabling conditions for a transition to a more sustainable future.

Most of those without access to modern energy services belong to the segment of the human population that lives in poverty. Although low energy consumption is not a cause of poverty, the lack of available energy services correlates closely with many poverty indicators. To date, poverty has received scant attention from an energy perspective.

This is particularly remarkable since energy is central to the satisfaction of basic nutrition and health needs, and energy services constitute a sizable share of total household expenditure among the poorest households in developing countries. Policies and programmes that aim to create opportunities for people living in poverty are needed. By making more efficient use of commercial and non-commercial energy and by shifting to higher quality energy carriers, it will be possible to simultaneously improve those people's standard of living, in both the short term and long term.

Biomass energy technologies are a promising option, with a potentially large impact for developing countries, where the current levels of energy services are low. Biomass accounts for about one third of all energy in developing countries as a whole, and nearly 90 percent in some of the least developed countries. Over 2 billion people continue to rely on biomass fuels and traditional technologies for cooking and heating and 1.5-2 billion people have no access to electricity.

Through improved efficiency and increased utilisation of renewable energy sources, energy can become a crucial instrument for achieving UNDP's primary goals. In 1996, the Executive Committee adopted the UNDP Initiative for Sustainable Energy (UNISE) as UNDP's corporate policy on sustainable energy. UNISE is a strategy to place energy within the sustainable human development paradigm. It relates energy to UNDP's thematic areas and programme goals and outlines how energy programmes and projects can become instrumental in achieving sustainable development.

Modernised biomass has great potential to provide improved rural energy services based on agricultural residues/biomass. Widespread use of modernised biomass for cooking and combined heat and power (CHP) generation in rural areas can address multiple social, economic and environmental bottlenecks that now constrain local development. The availability of low-cost biomass power in rural areas could help provide cleaner, more efficient energy services to support local development, promote environmental protection, stem the use of coal as a home fuel, and improve the living conditions of rural people, especially women and children who currently face air pollution associated with indoor burning of agricultural residues.

Under the framework of UNISE, the Bioenergy Primer is designed to help facilitate the practical realisation of sustainable modernised bioenergy activities, including the technical, policy, and institutional aspects. It is driven by the observations that bioenergy is a vastly important part of the world's energy system, and that bioenergy systems, if appropriately designed and implemented, have great promise for contributing to sustainable human development. The Bioenergy Primer can act as a catalyst for strategic policy shifts and breakthrough solutions that will make a difference in the struggle for human development. Collateral activities such as capacity-building, knowledge-networking, policy formulation, the development of regulatory and legal frameworks, and enhanced institutional capacity can promote bioenergy as an important potential contributor to sustainable energy strategies.

The Bioenergy Primer provides guidance to UNDP programme officers, local governments, bilateral and multilateral agencies, and the broader development community. It offers assistance in facilitating projects that demonstrate sustainable, modernised biomass energy systems; developing the appropriate institutional frameworks; and piloting new approaches. With discussion of traditional approaches to biomass as background, the Primer presents promising new biomass technologies, including in-depth analyses of their respective characteristics and their relationship to UNDP's sustainable development objectives. In addition to institutional considerations, the Primer offers case studies from various countries to illustrate operational aspects of bioenergy projects.

Developing countries have considerable potential to use renewable biomass energy to contribute to socio-economic development. The widespread geographic distribution of biomass, combined with its potential to be converted into modern energy carriers and its competitive costs, make it a promising option. The authors make a convincing case for the opportunities available with biomass, and they lay the foundation for programme development in this important area.

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EXECUTIVE SUMMARY

1 ENERGY AND SUSTAINABLE HUMAN DEVELOPMENT

…energy is not an end in itself, but rather a means to achieve the goal of sustainable human development…

Roughly one third of the world's population—more than two billion people—have little or no access to modern energy services. A majority of these people live in poverty. The acute symptoms of this poverty, as well as its chronic causes, are critically linked in many ways to today's patterns of energy production and use. Recognising that existing energy systems are not sustainable, the United Nations Development Programme created the Sustainable Energy and Environment Division, which has initiated a Global Programme in Sustainable Energy. This Primer is one product of the Global Programme.

A fundamental premise of the Global Programme in Sustainable Energy is that *energy is not an end in itself, but rather a means to achieve the goal of sustainable human development.* Sustainable human development requires a focus on improving the access of the poor to assets, goods, and services, including food (and the means to prepare it), water for drinking and irrigation, adequate shelter, health care, sanitation, education, and employment.

Energy can play a critical role, but conventional energy strategies that rely on supply-focused, fossil-intensive, large-scale approaches do not address the needs of the poor. As Reddy, Williams, and Johansson (1997) point out:

> *…Not only is energy one of the determinants of these problems, but actions relating to energy can contribute to their alleviation, if not solution. Implementing sustainable energy strategies is one of the most important levers humankind has for creating a sustainable world. Energy must therefore be an instrument for the achievement of sustainable development…*

Bioenergy—that is, energy that is derived from wood and other plant matter—is an important potential contributor to sustainable energy strategies, particularly when converted to modern energy carriers such as electricity and liquid and gaseous fuels. The purpose of this document is to help countries and communities realise bioenergy's potential. It is based on two premises:

(1) bioenergy is an important part of today's imperfect energy system, and
(2) modernised bioenergy systems, if appropriately designed and implemented, have great promise for contributing to future

sustainable energy systems and thus to sustainable development.

Bioenergy projects can contribute directly to poverty alleviation by helping to meet basic needs, creating opportunities for improved productivity and better livelihoods, and preserving the natural environment on which the poor depend. For instance, bioenergy activities can provide locally produced energy sources to:

- pump water for drinking and irrigation,
- light homes, schools, and health clinics,
- improve communication and access to information,
- provide energy for local enterprises, and
- ease pressure on fuel wood resources.

These are all benefits that directly improve local quality of life, increase productivity, and help relieve the strains of rural poverty.

Biomass production can provide a wide range of additional benefits to the rural poor. Bioenergy feedstocks can be produced in conjunction with other local necessities—food, fodder, fuelwood, construction materials, artisan materials, other agricultural crops, etc. Feedstock production can help restore the environment on which the poor depend for their livelihoods—re-vegetating barren land, protecting watersheds and harvesting rainwater, providing habitat for local species, stabilising slopes or river banks, or reclaiming waterlogged and salinated soils.

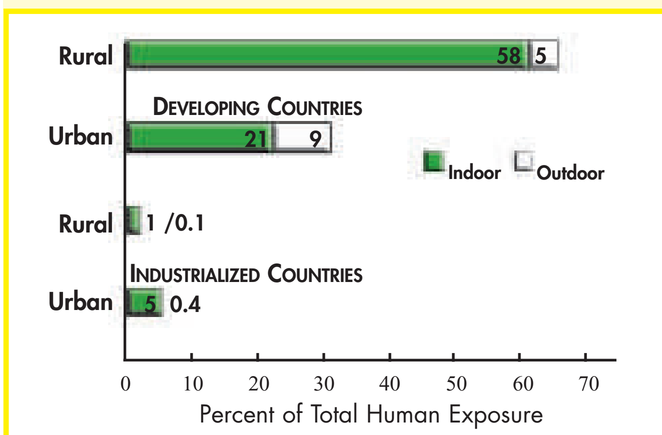
Bioenergy activities also serve as an efficient use for agricultural residues, avoiding the pest, waste, and pollution problems of residue disposal. If designed with the involvement of local communities, a sensitivity toward local environmental constraints, and a clear objective of meeting the identified needs of the poor, bioenergy activities can contribute significantly to the sustainable livelihood of rural populations.

Some 40 to 50 exajoules (EJ = 10^{18} joules) per year of biomass is used for energy today out of some 400 EJ per year of total global energy use. Many have difficulty conceiving of biomass as a modern energy source, given the role that it has played, and continues to play, in most developing countries today. Biomass accounts for an estimated one third of primary energy use in developing countries. Over two billion people cook by direct combustion of biomass, primarily in rural areas. Traditional use of biomass fuels is typically inefficient, relying largely on low-cost sources such as natural forests, which in turn contributes to deforestation.

Biomass fuels as used in developing countries today have been called "the poor man's oil" because direct use by combustion for domestic cooking and heating ranks it at the bottom of the ladder of preferred energy carriers. Biomass might more appropriately be called "the poor woman's oil," since women (and children) in rural areas spend a considerable amount of time collecting daily fuelwood needs and suffer the brunt of indoor air pollution caused by direct combustion of biomass for cooking and heating. An astounding 58 percent of all human exposure to particulate air pollution is estimated to occur indoors in rural areas of developing countries (Fig. ES1).

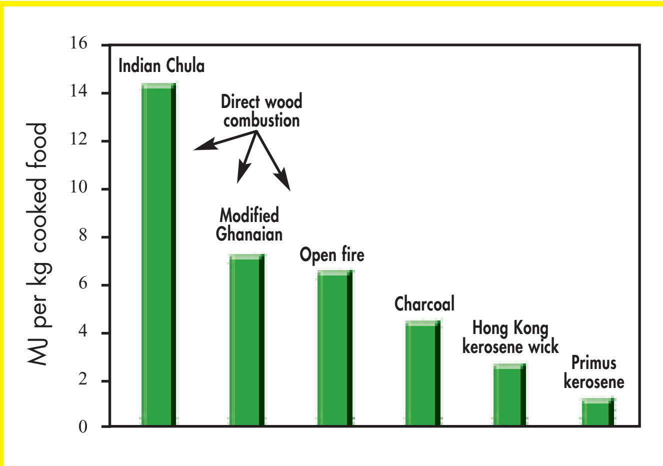
Biomass utilisation in developing countries contrasts sharply with biomass use in industrialised countries. On average, biomass accounts for 3 or 4 percent of total energy use in the latter, although in countries with policies that support biomass use (e.g., Sweden, Finland, and Austria), the biomass contribution reaches 15 to 20 percent. Most biomass in industrialised countries is converted into electricity and process heat in cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities. This both produces a greater variety of

FIG. ES1. APPROXIMATE DISTRIBUTION OF TOTAL HUMAN EXPOSURE TO PARTICULATE AIR POLLUTION



Source: Smith, 1993

FIG. ES2. END-USE ENERGY CONSUMPTION FOR COOKING WITH ALTERNATIVE COOKING FUELS AND STOVES



Source: Dutt and Ravindranath, 1993

energy services derived from biomass, and results in much cleaner and more efficient use of available biomass resources than traditional uses of bioenergy in developing countries.

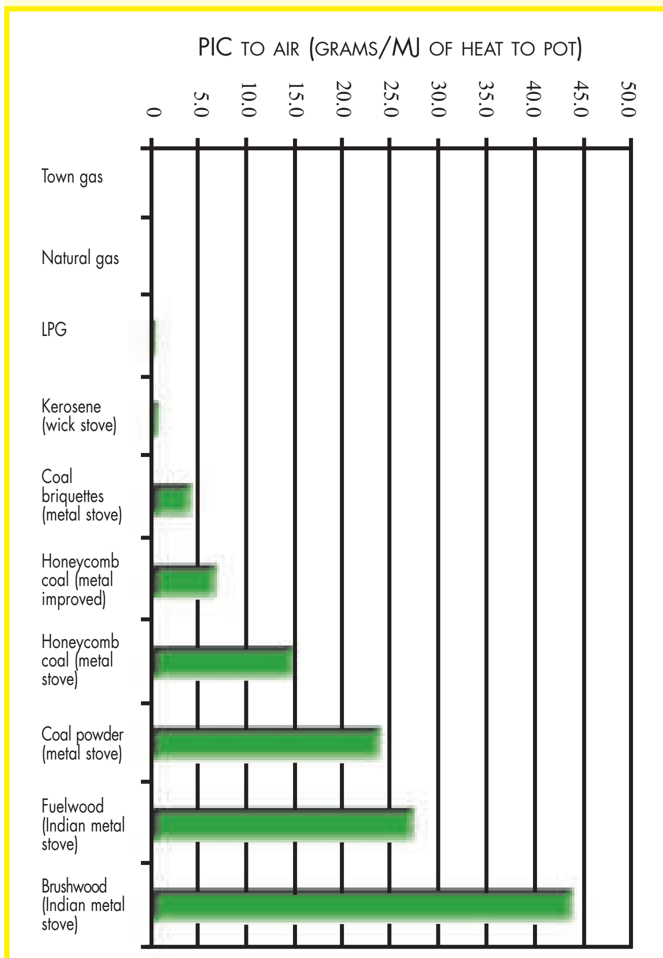
Biomass energy has the potential to be "modernised" worldwide, i.e., produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity. Table ES1 (see page 12) lists a variety of technologies (discussed in chapter 5) which can convert solid biomass into clean, convenient energy carriers. Most of these technologies are commercially available today. If widely implemented, such technologies would enable biomass energy to play a much more significant role in the future than it does today, especially in developing countries.

Household cooking provides an example. Gaseous cooking fuels can be used far more efficiently and conveniently than solid fuels (Fig. ES2), while also emitting far fewer toxic pollutants (Fig. ES3). Thus biomass converted efficiently into fuel gas can meet the cooking energy demands of more households than can burning biomass directly, and it can do so with fewer detrimental health impacts.

Sugarcane is an example of the potential for biomass modernisation on a larger scale. Some eighty developing countries grow and process sugarcane, generating substantial quantities of a fibrous biomass by-product (bagasse) that is used today at most mills as a fuel for combined heat and power (CHP) generation. CHP systems typically generate just enough electricity (a few megawatts at an average-sized facility) and process steam to meet the processing needs of the mill. Because such an abundance of bagasse is generated, however, the CHP systems are designed to be inefficient in order to consume all of the bagasse and thereby avoid disposal problems.

Also, the tops and leaves (sugarcane trash), which are generated in quantities comparable to the bagasse, are typically burned on the fields to facilitate replanting or harvesting. Used as a fuel, cane trash would enable a CHP facility to operate year-round rather than the typical six months during which bagasse is generated. With more efficient CHP systems and year-round operation, substantial amounts of electricity could be generated in excess of the mill's own requirements. Some possibilities with different technologies (discussed in chapter 5) are illustrated in Fig. ES4 (see page 12).

FIG. ES3. MEASURED EMISSIONS (TO ROOM AIR) OF PRODUCTS OF INCOMPLETE COMBUSTION (PIC) FROM FLUE-LESS STOVES IN CHINA



Source: Zhang, 2000, in press

Table ES1. Technologies for Modernised Conversion of Biomass Energy and Energy Services They Can Provide

Technology	Scale	Energy services provided
Biogas	Small	• Electricity (local pumping, milling, lighting, communications,refrigeration,etc. and possible distribution via utility grid) • Cooking • Heating
Producer gas	Small to medium	• Electricity (local pumping, milling, lighting, communications, refrigeration, etc. and possible distribution via utility grid) • Cooking • Heating
Ethanol	Medium to large	• Vehicle transportation • Cooking
Steam turbine	Medium to large	• Electricity (for industrial processing and grid distribution) • Heating process heat
Gas turbine	Medium to large	• Electricity (for industrial processing and grid distribution) • Heating process heat

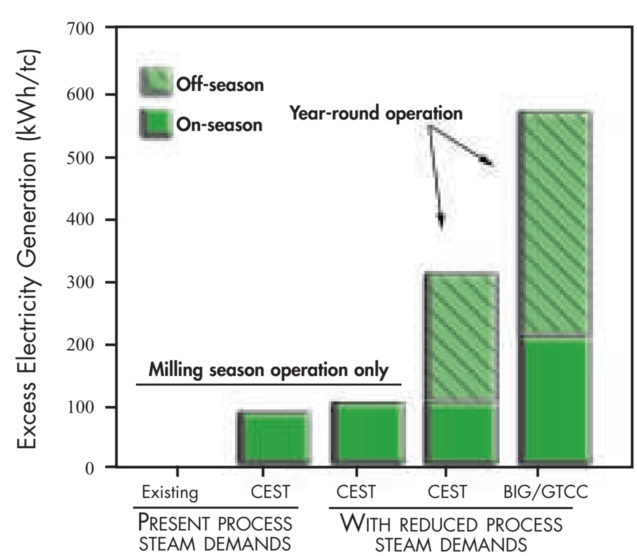
Table ES2 (see page 13) gives some perspective on the contribution of "cane power" to overall electricity supply in the future. For developing countries as a whole, "excess" electricity from cane residues in 2025 could amount to nearly 20 percent of the projected electricity generation from all sources in these countries in 2025 through the adoption of advanced technology (gasifier/gas turbine) that is undergoing commercial demonstration today.

Given such possibilities, a number of international organisations have formulated energy scenarios that envision large contributions from modernised biomass energy in the 21st century. For example, in one scenario developed by the Intergovernmental Panel on Climate Change, biomass energy contributes 180 EJ/year to global energy supply by 2050—satisfying about one third of total global energy demand, and about one half of total energy demand in developing countries. Roughly two thirds of the global biomass supply in 2050 is assumed to be produced on high-yield energy plantations. The other one third comes from residues produced by agricultural and industrial activities.

Such biomass-intensive scenarios raise concerns about local and regional environmental and socioeconomic impacts. Potential negative consequences include depletion of soil nutrients from crop land if agricultural residues are removed; leaching of chemicals applied to intensively-cultivated biomass energy crops; and loss of biodiversity and food supply if land is converted to energy crops.

More than most other types of energy systems, bioenergy systems are inextricably linked to their local environmental and socioeconomic contexts. *If modernised biomass energy*

FIG. ES4. ELECTRICITY GENERATED IN EXCESS OF ON-SITE REQUIREMENTS PER TONNE OF SUGARCANE CRUSHED AT A SUGAR OR ETHANOL FACTORY USING DIFFERENT COGENERATION TECHNOLOGIES



Existing technology is the back-pressure steam turbine with steam pressure about 20 bar. CEST is a condensing extraction steam turbine with steam pressure about 60 bar. BIG/GTCC is a biomass-gasifier/gas turbine combined cycle.

Source: Larson, 1994

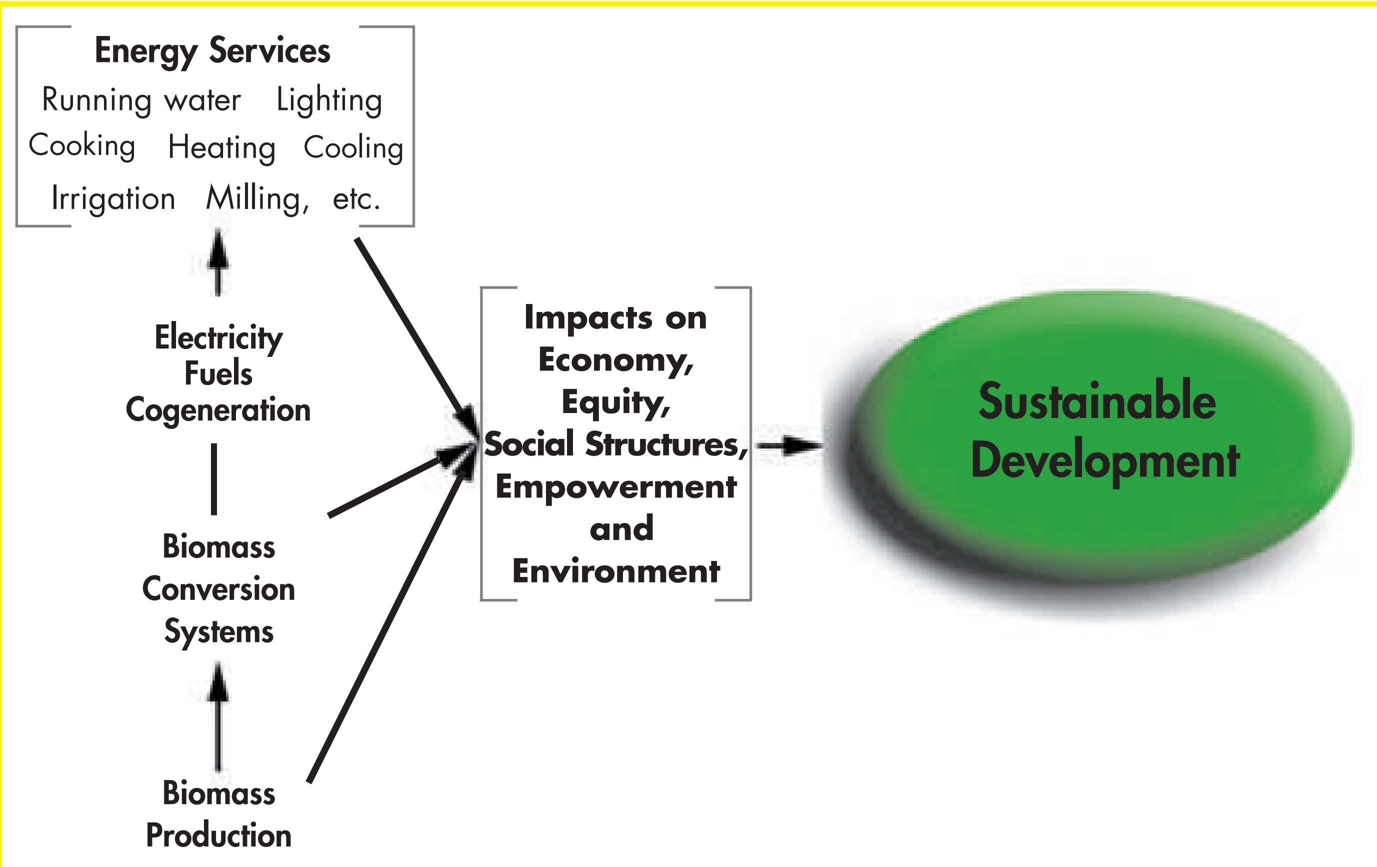
Table ES2. Potential for "Excess" Electricity Generation from Sugarcane Factilities in Developing Countries Using Advanced Technology (Biomass Gasifier-Gas Turbine)

	1995 Cane Production (million tonnes)	2025 Cane Prod@ 2%/yr (million tonnes)	2025 "Excess" Electricity (TWh/year)	2025 Utility Elec. Prod.* (TWh)	2025 Cane Elec./ 2025 Utility Elec.
Brazil	304	550	330	623	0.53
India	260	470	282	883	0.32
China	70	127	76	2085	0.04
Carribean	48	87	52	102	0.51
Indonesia	31	57	34	141	0.24
Other Latin Am.	152	275	165	1063	0.16
Others	233	422	253	2214	0.11
Totals	1098	1988	1192	7112	0.17

*Projected from data for electricity generation in 1995 assuming an annual 3% growth rate.
Note: TWh = billion kWh.

systems are to provide a substantial level of clean, cost-effective, and reliable energy service from locally generated resources in rural areas, then the design and implementation of those systems must take into account environmental and socioeconomic impacts—even at the pilot stage. Fig. ES5 provides a conceptual representation of bioenergy systems, as addressed in this Primer, in the context of sustainable human development. ■

FIG. ES5. CONCEPTUAL REPRESENTATION OF BIOMASS ENERGY SYSTEMS AND LINKAGES TO SUSTAINABLE HUMAN DEVELOPMENT



EXECUTIVE SUMMARY

2 BIOENERGY SOURCES

… in 1996, China generated crop residues in the field ... plus agricultural processing residues ... totaling about 790 million tonnes....if half of this resource were used for generating electricity ... the resulting electricity would be equivalent to half the total electricity generated from coal in China in 1996.

Bioenergy resources take many forms, which can be broadly classified into three categories:

(1) residues and wastes,
(2) purpose-grown energy crops, and
(3) natural vegetation.

This document focuses on the first two categories. The third, natural vegetation, has not been used sustainably on a large scale and thus is not included in this discussion.

Global production of biomass residues, including by-products of food, fiber, and forest production, exceeds 110 EJ/year, perhaps 10 percent of which is used for energy. Residues concentrated at industrial sites (e.g., sugarcane bagasse) are currently the largest commercially used biomass source. Some residues cannot be used for energy: in some cases collection and transport costs are prohibitive; in other cases, agronomic considerations dictate that residues be recycled to the land. In still other cases, there are competing non-energy uses for residues (as fodder, construction material, industrial feedstock, etc.).

Residues are an especially important potential biomass energy source in densely populated regions, where much of the land is used for food production. In fact, biomass residues might play important roles in such regions precisely because the regions produce so much food: crop production can generate large quantities of by-product 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, corncobs, and bagasse) totaling about 790 million tonnes, with a corresponding energy content of about 11 EJ. To put this in perspective, if half of this resource were used for generating electricity at an efficiency of 25 percent (achievable at small scales today), the resulting electricity would be equivalent to half the total electricity generated from coal in China in 1996.

Growing crops specifically for energy has significant potential. The IPCC's biomass-intensive future energy supply scenario includes 385 million hectares of biomass energy plantations globally in 2050 (equivalent to about one quarter of current planted agricultural area), with three quarters of this area established in developing countries. Such levels of land use for bioenergy could intensify competition with other important land uses, especially food production. Competition between land use for agriculture and for energy production can be minimised if degraded lands are targeted for energy. In developing countries in aggregate, hundreds of millions of hectares have been classified as degraded. A wide variety of technical, socioeconomic, political, and other challenges (discussed in chapters 3 and 4) are involved in successfully growing energy crops on degraded lands, but the many successful plantations already established on such land in developing countries demonstrate that these challenges can be overcome.

Energy crops can be produced in two ways: (1) by devoting an area exclusively to production of such crops (energy plantations) or (2) by co-mingling the production of energy and non-energy crops. Since energy crops typically require several years of growth before the first harvest, coproduction in some form has the benefit of providing energy-crop farmers with revenue between harvests of energy crops.

The coproduction approach also helps to meet environmental and socioeconomic criteria for land use. Farm forestry activities in Brazil have been especially successful at involving small farmers in the high-yield production of biomass feedstocks. There is also extensive experience in small-scale fuelwood production in India, China, and elsewhere. ■

EXECUTIVE SUMMARY

3 SOCIOECONOMIC ISSUES

Because potential environmental and socioeconomic impacts are so important, they must be considered from the outset in any bioenergy project, and projects must be designed accordingly.

Biomass energy systems have a wide range of potential socioeconomic and environmental impacts—both positive and negative. Such impacts are often treated as only "secondary" effects in the planning and implementation of energy projects, even though they can greatly influence whether a project is appropriate and sustainable in the local context. Because potential environmental and socioeconomic impacts are so important, they must be considered from the outset in any bioenergy project, and projects must be designed accordingly.

Socioeconomic and environmental issues are discussed in separate chapters in this volume for convenience, but the boundary between these categories is diffuse. Environmental outcomes depend sensitively on how the biomass is produced and used for energy, and the socioeconomic impacts depend on how production and use are integrated with people and institutions.

Compared with other energy projects, bioenergy projects are likely to have large socioeconomic and environmental impacts for two reasons: they are both land intensive and labor intensive. Because bioenergy systems interact extensively with their environmental and socioeconomic surroundings, they will necessarily transform their surroundings; bioenergy strategies are not merely self-contained "energy projects."

This offers both opportunities and challenges. If designed well, bioenergy strategies will contribute to sustainable livelihoods and help address environmental problems such as land degradation or agricultural waste disposal. If not properly executed, however, they can exacerbate social inequities and intensify pressures on local ecosystems. For this reason, a bioenergy activity must be scrutinised and judged along several dimensions: how does it contribute to satisfying basic needs, providing income opportunities, enhancing food security, preserving the local environment, promoting gender equity, and empowering communities. In short, how does it contribute to the broad sustainable development agenda?

In assessing the impacts of a bioenergy activity, the entire bioenergy chain must be considered, including how the biomass is produced and supplied, in addition to downstream activities of conversion to and use of modern energy carriers. By comparison, non-biomass energy projects call for little project-specific upstream assessment; in implementing a conventional energy project, there is little need to revisit the generic upstream details, such as how petroleum is extracted and refined into diesel fuel for a village generator set. Because biomass is a local resource, its production and supply is integral to the bioenergy project and helps to distinguish a "good" bioenergy project from a "bad" one. "Good" strategies are more sustainable, but "bad" strategies might appeal more to investors looking for near-term profit.

Socioeconomic issues are discussed in this document in terms of four broad and linked themes.

Meeting the Basic Needs of the Rural Poor. Bioenergy projects have the potential to provide the rural poor with a range of benefits. However, there is no guarantee that bioenergy activities will go toward satisfying local development needs. Key guidelines to help ensure this include (a) adopt participatory approaches to identifying needs and to designing and implementing projects, (b) treat biomass production and supply as integral parts of the project, and (c) foster local institutional responsibility for the project.

Creating Opportunities for Income Generation. Satisfying the basic needs of the poor will help to relieve the symptoms of poverty, but eliminating the root causes of poverty must involve increasing their purchasing power. Rural energy projects, and bioenergy projects in particular, have great potential to create income opportunities. These opportunities fall into three broad (and over-lapping) categories: direct revenue or employment, general improvement in health and productivity, and expansion of rural enterprises.

Gender Impacts. Women suffer disproportionately to men, for reasons that are intimately linked with current patterns of rural energy use. Gender differences in access to, control over, and reliance on bioresources (for both energy and non-energy

Table ES3. Selected Indicators of Socioeconomic Sustainability

Category	Impact	Quantitative indicators, based on assessment of:
Basic needs	Improved access to basic services.	Number of families with access to energy services (cooking fuel, pumped water, electric lighting, milling, etc.), quality, reliability, accessibility, cost.
Income generating opportunities	Creation or displacement of jobs, livelihoods.	Volume of industry and small-scale enterprise promoted, jobs/$ invested, jobs/ha used, salaries, seasonality, accessibility to local laborers, local recyling of revenue (through wages, local expenditures, taxes), development of markets for local farm and non-farm products.
Gender	Impacts on labor, power, access to resources.	Relative access to outputs of bioenergy project. Decision-making responsibility both within and outside of bioenergy project. Changes to former division of labor. Access to resources relating to bioenergy activities.
Land use competition and land tenure	Changing patterns of land ownership. Altered access to common land resources. Emerging local and macroeconomic competition with other land uses.	Recent ownership patterns and trends (e.g., consolidation or distribution of landholdings, privatization, common enclosures, transferal of land rights/tree rights).Price effects on alternate products. Simultaneous land uses (e.g., multipurpose coproduction of other outputs such as traditional biofuel, fodder, food, artisanal products, etc.)

purposes) mean that women have different needs, opinions, knowledge, and skills than men. A village-level bioenergy project is therefore unlikely to benefit women——or succeed at all——unless it involves women from the beginning. Industrial-scale bioenergy projects may be more gender neutral.

Land Use Competition and Land Tenure. Simultaneously modernising biomass production for energy and biomass production for food could prevent competition for land between these two goals. It is essential to understand local needs for improving agriculture and what resources and expertise would help meet those needs——a challenge lying at the very core of rural development. Even when land-intensive activities do not measurably affect aggregate food production or market prices, they can still seriously erode the food security of displaced rural families. It is important to understand legally recognised land ownership rights, as well as the often subtle nature of traditional land usage rights.

Quantitative indicators of socioeconomic impacts of a project, to the extent that they can be determined, can be helpful in evaluating overall impacts. Table ES3 (see page 17) offers some possible quantitative indicators for assessing impacts in the four thematic areas mentioned. ■

EXECUTIVE SUMMARY

4 ENVIRONMENTAL ISSUES

...key environmental issues associated with producing and harvesting biomass energy feedstocks...soil quality and fertility, biodiversity, energy balances, carbon emissions, hydrological impacts, and chemical loading of soil and ground/surface water.

Modernised bioenergy systems will have environmental impacts associated both with the growing of the biomass and with its conversion to modern energy carriers. This chapter addresses impacts of biomass production; discussion of impacts of conversion processes is included in chapter 5.

Environmental impacts of biomass production must be viewed in comparison to the likely alternative land-use activities. For example, at the local or regional level, the relative impacts of producing bioenergy feedstocks depends not only on how the biomass is produced, but also on how the land would have been used otherwise. Would it have lain barren and degraded? Would annual agricultural crops have been cultivated? Would the natural forest have continued to thrive?

Many bioenergy conversion technologies do not depend on a specific feedstock. They offer flexibility in choice of feedstock and management practices because they put few restrictions on the type of biomass that can be used. In contrast, most agricultural products are subject to rigorous consumer demands in terms of taste, nutritional content, uniformity, transportability, etc. This flexibility makes it easier to meet the challenge of producing biomass energy feedstocks than agricultural products while simultaneously meeting environmental objectives.

For example, bioenergy crops can be used to revegetate barren land, to reclaim waterlogged or salinated soils, and to stabilise erosion-prone land. They can be managed in ways that provide habitat and increase biodiversity relative to degraded land. In general, annual food crops do not offer similar opportunities.

This chapter discusses key environmental issues associated with producing and harvesting biomass energy feedstocks, including soil quality and fertility, biodiversity, energy balances, carbon emissions, hydrological impacts, and chemical loading of soil and ground/surface water. Measures are discussed for minimising negative impacts and for realising positive benefits where possible. Quantitative indicators of the environmental sustainability of a project, to the extent that they can be determined, can be helpful in evaluating overall impacts, e.g., see Table ES 4, page 20. ■

Table ES4. Selected Indicators of Environmental Sustainability

Category	Impact	Quantitative indicators, based on assessment of:
Soil quality and fertility permeability	Nutrient depletion, acidification, organic content loss, soil texture.	Soil analyses. (Soil density, porosity, water-permeability, temperature; heat conductivity, heat capacity; nutrients: phosphorus, potassium, sulfur, nitrogen, magnesium, etc.)
Biodiversity Energy balances	Conversion of genetically rich or poor habitat. Increased use of sustainable, renewable resources.	Biodiversity under alternate/prior land uses. Relative full fuel-cycle consumption of fossil resources.
Carbon balances	Reduction in carbon (and other greenhouse gas) emissions.	Relative fuel fuel-cycle emissions of carbon, including carbon sequestered above and below ground in biomass supply systems
Hydrology/water resources	Water consumption or replacement, quality.	Water table height, surface water availability, seasonality, quality.
Chemical inputs and runoff	Increased or decreased loadings of fertilizers, herbicides, pesticides, COD/BOD	Soil, surface water and ground water analyses.
Land quality	Restoring or degrading of land.	Land quality and productivity under alternate/ prior land uses. Diversity of products and uses provided.
Air quality	Avoided outdoor and indoor pollution from waste combustion, pollution from bioenergy cycle.	Analyses of outdoor and indoor air quality. Investigation of human respiratory health impacts.

EXECUTIVE SUMMARY

5 TECHNOLOGIES TO CONVERT BIOMASS INTO MODERN ENERGY

Most of these technologies are already in commercial use...

This chapter describes a variety of technologies for converting biomass into electricity, gas, or liquid fuels (Table ES1, see page 12). Most of these technologies are already in commercial use, although some more than others. Each technology description—gasification, anaerobic digestion, ethanol, steam turbine, and gas turbine—includes a general discussion of key technical issues that must be addressed in any project involving these technologies. It also includes more detailed technical discussion of basic operating principles, feedstock and other material input requirements, operating and maintenance issues, capital and operating costs, environmental issues,and other factors.

Each technology section also includes two tables. One summarises technical features and principal applications of the technology, and the other provides order of magnitude illustrations of costs. ■

6 IMPLEMENTATION AND REPLICATION

Strong institutions and leadership at international, national, and local levels, as well as the involvement of the private sector, are needed to help surmount practical challenges to widely implementing modernised biomass energy systems.

Pilot bioenergy projects can have a catalytic role by verifying that a technology or process is feasible, providing lessons for subsequent activities, serving an educational role for the public and other actors, etc. A pilot project's impact will be limited, however, unless it is part of a broader vision for widespread replication. This chapter discusses some key institutional and strategic issues regarding the successful implementation and replication of bioenergy projects.

Institutions

Strong institutions and leadership at international, national, and local levels, as well as the involvement of the private sector, are needed to help surmount practical challenges to widely implementing modernised biomass energy systems.

International institutions have important roles to play, including:

(a) helping to launch initiatives that encourage South-North joint ventures aimed at developing, adapting, or transferring technology for converting biomass to modern energy carriers;
(b) facilitating investment and financing for biomass energy modernisation; and
(c) setting policies and programs that support strong national programs (e.g., those aimed at restoring productivity to degraded lands through biomass energy production).

At the national level, coherent policies and regulation regarding biomass energy development are essential to clarify rules and roles of participants. Also, rationalising electricity tariffs and fossil fuel prices, e.g., by lifting subsidies or otherwise more fully reflecting costs (including social and environmental costs) will help to level the playing field for all energy sources. National-level, land-use planning and promulgation of socioeconomic and environmental guidelines for biomass energy projects is also important in order to provide investors and project developers a uniform and consistent set of principles and specific rules for developing biomass energy systems. Generating and providing information and technical assistance relating to biomass resources and technologies are additional important roles for national-level institutions, as is facilitating financing of projects. Strong national-level institutions supporting biomass energy development are needed to establish conditions to enable the emergence of strong local institutions.

Motivated local institutions engaged in the design, implementation, and ongoing management of individual biomass energy modernisation projects are also essential. Local coordinating institutions can provide forums for articulating local needs and concerns, and for building political consensus. Not only does local participation make projects responsive to local needs, but experience has demonstrated that such participation generates a sense of ownership that is a critical ingredient for the success of projects over the long term.

Finally, the private sector has several essential roles to play in expanding biomass energy modernisation, with appropriate public-sector oversight and competitive bidding for projects. Especially important roles for the private sector relate to technology, including manufacturing, marketing, installation, operation, and maintenance. Commercial enterprises can be effective entities for facilitating repeated application of technology by applying accumulated experience and knowledge to new projects. Also, the private sector's inclination toward entrepreneurial risk-taking and its capability for international partnering can facilitate financing, development, and spread of improved technologies.

Strategic Issues

Sound technology, with the potential for economic viability, is an essential element of strategies that seek to modernise biomass energy on a wide scale. Because biomass conversion technologies are typically relatively small, establishing cost-competitiveness is challenging due to the well-known phenomenon where unit costs rise as unit sizes fall. On the other hand, small unit size is a potential advantage in that it facilitates achieving economies of scale in manufacturing and economies of scale in learning through repeated applications. This advantage can be exploited only if there is a sufficient scale of demand for the technology. Critical levels of demand needed to achieve cost reductions through scale economies can be created through regulatory or other mechanisms.

One approach that is drawing increasing attention as a means for encouraging widespread replication of rural energy systems is the granting of concessions to private companies. The key objective with this approach is to encourage the development of a large number of applications and to enable successful bidders to take advantage of equipment and learning cost reductions, as well as administrative and overhead cost reductions, arising from multiple applications in their concession area. Pilot projects involving concession approaches to rural electrification based on renewable energy are being initiated in Argentina, Bolivia, Peru, and the Philippines (see chapter 7).

Access to the electric utility grid is another important consideration in many projects where biomass-based electricity generation is involved. This is important because the economics of any power-generating system depends in large measure on how extensively the installed capacity is utilised, i.e., on the system capacity factor. Often in rural areas, local demands for electricity will not be high enough initially to give economically viable capacity factors for biomass generating systems. To remedy this problem, power might be exported from the rural area to urban demand centers via the utility transmission grid until the size and diversity of local power demands grow. Even where grid extension from urban areas is judged uneconomical for electrifying a rural area, it may nevertheless be economical if the electricity were transmitted from, rather than to, the rural area. When electricity is sent to urban areas from rural areas, transmission lines can be utilised at high capacity factor, making transmission more cost-effective than when electricity flows from urban to rural areas to meet sporadic and low levels of electricity demand. Indeed, rural-to-urban transmission is the configuration under which many remote hydroelectric installations and mine-mouth coal power plants currently provide power to urban centers.

Utilities worldwide have historically been reluctant to purchase power from independent generators, but regulatory measures have been used successfully to overcome this reluctance. For example, in the United States, the 1978 Public Utilities Regulatory Policy Act (PURPA) forced utilities to buy and pay fair prices for purchased electricity. PURPA led to the installation of a substantial amount of new biomass-electric-generating capacity in the United States starting in the 1980s. Total biomass-electric capacity in the United States today is several thousand megawatts. Legislation similar to PURPA is beginning to be enacted in a few developing countries. A law in Brazil that would mandate fair buy-back rates for biomass-generated electricity is currently in the public hearing stage (Bagasse-based electricity generation at sugarcane processing facilities is expected to grow significantly once the law is enacted.). India has in place a fixed purchase price for biomass-generated electricity that has encouraged expansion of biomass generating capacity there. ■

EXECUTIVE SUMMARY

7 CASE STUDIES: BIOMASS PROJECTS IN ACTION

This chapter presents case studies of operating or planned modernised biomass energy projects or programs, especially where widespread replication has occurred or is a goal.

Biogas-Based Electricity and Water Supply in Indian Villages. This ongoing effort in Karnataka, India, to replicate the establishment of sustainable biogas-based Rural Energy and Water Supply Utilities (REWSUs) in several villages builds on more than a decade of experience with one such effort in Pura village.

Sustainable Transformation of Rural Areas in India. This is a proposed effort to establish energy utilities in twenty-four villages in Karnataka, India. The utilities will be based on anaerobic digestion of cattle dung and leaf litter and on producer gas generators fueled from multi-purpose tree plantations established on village common lands.

Projects Using Producer-Gas/IC-Engine Technology. India has developed and successfully commercialised small-scale biomass gasifier-IC engine systems for remote electricity generation. More than 28 MW_e of such technology is currently installed in India, and systems are being introduced in other countries as well.

Rural Energy Concessions: Pilot Programs. Pilot programs built around the sale of concessions to private companies are being initiated in Argentina, Bolivia, Peru, and the Philippines to provide energy services, especially electricity services, to dispersed rural populations. Concessions are potentially powerful mechanisms for achieving widespread implementation of bioenergy systems in rural areas.

Modernising Corn Stover Use in Rural Jilin Province, China. The government of Jilin Province has recently initiated a program to introduce village-scale corn stalk gasifiers to supply cooking fuel to homes, replacing previous direct combustion of stalks for cooking.

Producing Ethanol from Sugarcane in Brazil. Dating to the 1970s, this program is among the largest and most successful large-scale bioenergy modernisation programs anywhere. Considerable technological advances and organisational learning, as well as political support, helped sustain the program for the past twenty years. With the recent lifting of all ethanol price subsidies, the program now appears to be commercially self-sufficient.

Cogeneration of Heat and Power at Sugarcane Processing Facilities. Residues from sugarcane production and processing represent a vastly underutilised energy resource in the eighty developing countries that grow sugarcane. Efficient technologies for combined heat and power production are starting to be introduced, enabling sugarcane processors to supply in-house process energy demands and to export significant quantities of electricity to the local utility grid.

Biomass-Gasifier/Gas Turbine Power Generation in Northeast Brazil. This ongoing project aims to demonstrate the commercial viability of a new technology for electricity generation from planted trees at a scale of 30 to 50 MW_e. Institutional difficulties that slowed the pace of the project have been overcome, and construction is expected to begin in 2000. If the demonstration is successful, a significant expansion in biomass-based power generation is expected in Northeast Brazil and elsewhere.

Farm Forestry in Rural Brazil. Several hundred thousand hectares of small (1 to 50 ha) plots of trees planted by individual farmers (for pulpwood or steel-making charcoal) attest to the success of Brazilian farm forestry programs and provide one model for the production of biomass energy crops.

Social Forestry in India. India's social forestry effort is among the largest in the world, comprising some 14 million hectares of relatively small parcels of land afforested during the 1980s. The diverse projects ranged from centralised efforts to afforest government forestland with monocultures for industrial users to multipurpose agroforestry efforts involving local communities. ■

1 INTRODUCTION: ENERGY AND SUSTAINABLE HUMAN DEVELOPMENT


Credit: Eric Larson

Traditional wood or residue-burning stove in Guangdong Province, China (left) and a modern stove burning producer gas (gasified cornstalks) in Jilin Province, China (right).

Implementing sustainable energy strategies is one of the most important levers humankind has for creating a sustainable world.

Roughly one third of the world's population—more than two billion people—have little or no access to modern energy services. A majority of these people live in poverty. The acute symptoms of this poverty, as well as its chronic causes, are critically linked in many ways to today's patterns of energy production and use. Recognising that existing energy systems are not sustainable, the United Nations Development Programme created the Sustainable Energy and Environment Division, which has initiated a Global Programme in Sustainable Energy.

A fundamental premise of the Global Programme in Sustainable Energy is that *energy is not an end in itself, but rather a means to achieve the goal of sustainable human development*. Sustainable human development requires a focus on improving the access of the poor to assets, goods, and services, including food (and the means to prepare it), water for drinking and irrigation, adequate shelter, health care, sanitation, education, and employment. Energy plays a critical role in determining the ability of the poor to meet these basic needs in two ways.

First, the poor are plagued by a chronic lack of access to energy-related goods and services to meet basic needs. Major energy-related needs include fuel for cooking and heating, power for pumping potable water and irrigation water, electricity for health and education services, etc. Moreover, the kind of income-generating activities that could help break the cycle of poverty often rely on the availability of energy. For example, energy is an important input to agriculture and small-scale enterprises, where it is needed for farm equipment, grain mills and other food processing equipment, kilns, drying equipment, transport, etc. Energy is also needed for industrial and commercial activity in the formal sector. While reliable and adequate energy supplies do not guarantee economic growth and employment generation, their absence typically limits growth. Undoubtedly, the economic growth of many countries has been stifled by physical and institutional inadequacies in their energy systems.

Second, current patterns of energy supply and use are intimately linked with many hardships endured by the poor. The poor are disproportionately victims of the negative impacts that arise from existing patterns of energy supply and use. Traditional biomass fuels, which the poor rely on much more than others, are typically combusted in confined, unventilated spaces, causing severe indoor air quality problems and associated respiratory ailments. In many areas of high fuel demand, the unsustainable harvesting of biomass fuels (sometimes for urban commercial markets) has exacerbated land degradation. Supply and use of modern energy sources also causes negative effects, such as large-scale land appropriation (particularly from hydropower); environmental degradation from fossil fuel extraction and processing; and emission of pollutants that cause smog, lead toxicity, acid deposition, local air quality problems, and worsening climate change impacts due to greenhouse gas emissions. Invariably, adverse environmental impacts of energy use are disproportionately borne by the poor, who are dependent on their immediate environment for their livelihoods. Current energy use patterns also further entrench urban-rural disparities, and perpetuate the inequitable gender relations that preclude women's full participation in society. On the national scale, patterns of energy use are responsible for a crippling drain on foreign exchange resources in many developing countries, and the fiscal strain of government energy subsidies that could otherwise be directed toward more productive investments in sustainable development.

Conventional energy strategies reinforce this unsustainable energy-poverty nexus. Conventional strategies rely on supply-focused, fossil-fuel-intensive, large-scale approaches that do not address the needs of the poor. But alternative approaches are available:

> *…Not only is energy one of the determinants of these problems, but actions relating to energy can contribute to their alleviation, if not solution. Implementing sustainable energy strategies is one of the most important levers humankind has for creating a sustainable world. Energy must therefore be an instrument for the achievement of sustainable development…* (Reddy, Williams, and Johansson, 1997).

1.1. Promoting Sustainable Human Development through Bioenergy

Bioenergy—that is, energy derived from wood and other plant matter—is an important potential contributor to sustainable energy strategies. It appears in both traditional (e.g., fuelwood) and modernised (e.g., electricity, motor fuels) forms. The purpose of this document is to help countries and communities to realise the potential for bioenergy to promote sustainable development. It is based on two premises:

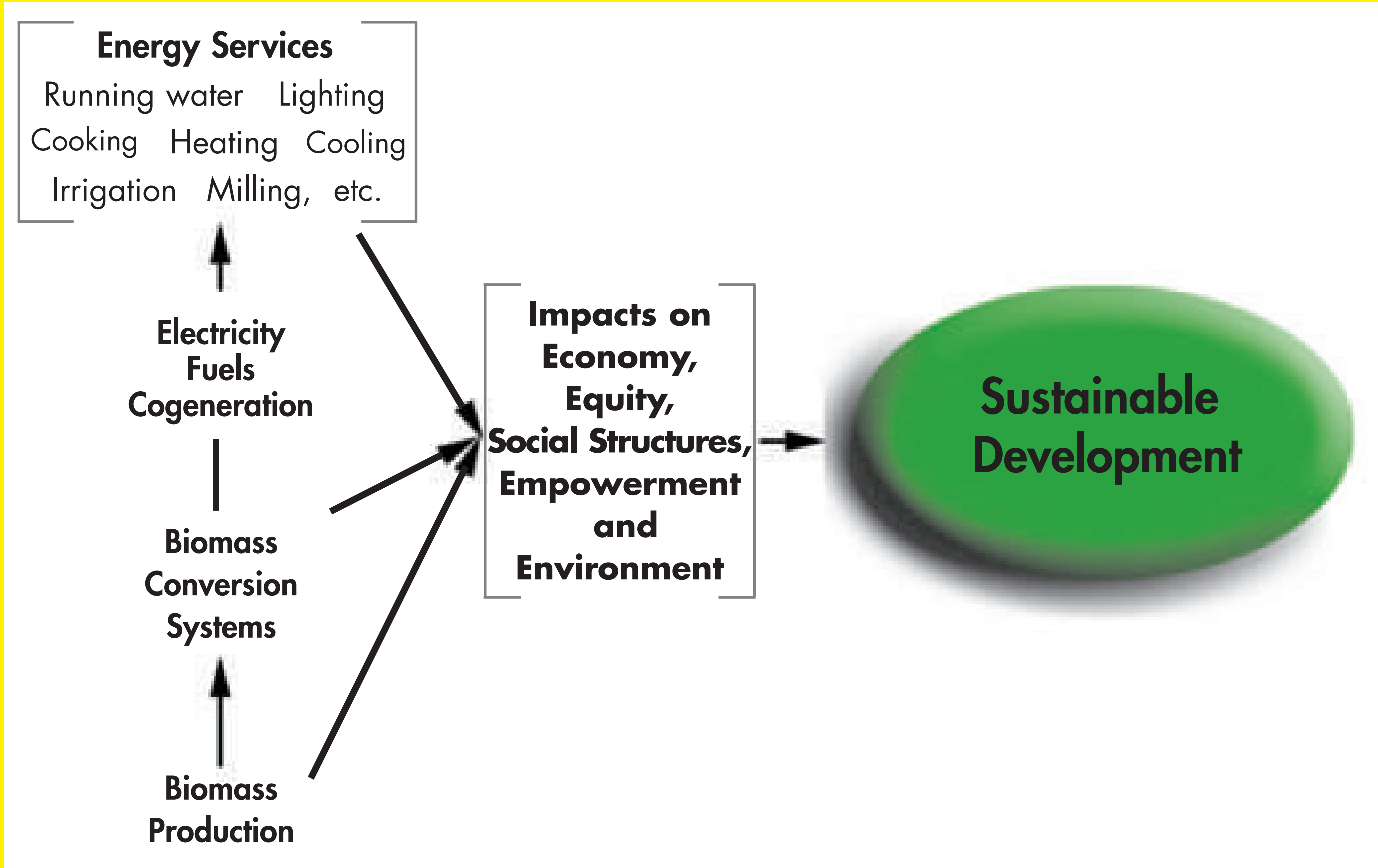
(1) bioenergy is an important part of today's imperfect energy system, and
(2) modernised bioenergy systems, if appropriately designed and implemented, have great promise for contributing to future sustainable development.

Bioenergy projects can contribute directly to poverty alleviation by helping to meet basic needs, creating opportunities for improved productivity and better livelihoods, and preserving the natural environment on which the poor depend. For instance, bioenergy activities can provide locally produced energy sources to:

- pump water for drinking and irrigation;
- light homes, schools and health clinics;
- improve communication and access to information;
- provide energy for local enterprises; and
- ease pressure on fuelwood resources.

Modernised bioenergy systems, if appropriately designed and implemented, have great promise for contributing to future sustainable energy systems and thus to sustainable human development.

FIG. 1.1. CONCEPTUAL REPRESENTATION OF BIOMASS ENERGY SYSTEMS AND LINKAGES TO SUSTAINABLE HUMAN DEVELOPMENT



These are all benefits that directly improve local quality of life, increase productivity, and help relieve the strains of rural poverty.

Biomass production can provide a wide range of additional benefits to the rural poor. Bioenergy feedstocks can be produced in conjunction with other local necessities—food, fodder, fuelwood, construction materials, artisan materials, other agricultural crops, etc. Feedstock production can help restore the environment, on which the poor depend for their livelihoods, by re-vegetating barren land, protecting watersheds and harvesting rainwater, providing habitat for local species, stabilising slopes or river banks, or reclaiming waterlogged and salinated soils.

Bioenergy activities also serve as an efficient use for agricultural residues, avoiding the pest, waste, and pollution problems of residue disposal. If designed with the involvement of local communities, sensitivity toward local environmental constraints, and a clear objective of meeting the identified needs of the poor, bioenergy activities can contribute significantly to the sustainable livelihoods of rural populations.

For modernised biomass energy systems to make such contributions, interactions with environmental and socioeconomic surroundings must be taken into account as the systems are being designed and implemented. Fig. 1.1 gives a conceptual representation of modernised bioenergy systems in the context of sustainable human development. Human development itself shapes the environmental, social, and economic context for biomass systems and hence, their design. The levels of agricultural, industrial, social, political, and economic development in a society all influence that society's desire for, and its ability to supply, modern energy services from biomass.

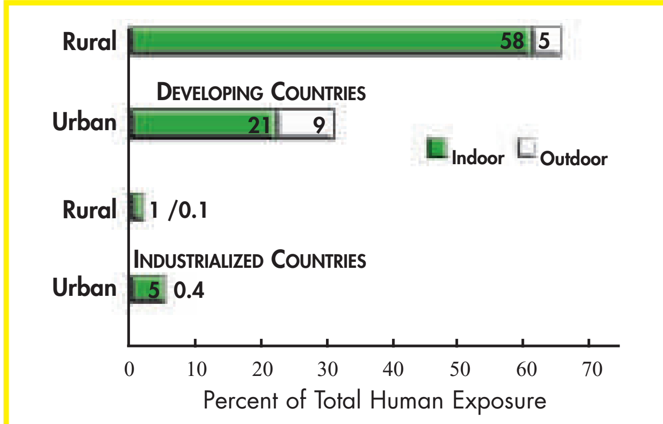
1.2. Biomass Energy Today: Developing and Industrialised Counties

Globally, photosythesis stores energy in biomass at a rate roughly ten times the present rate of global energy use.[1] However, today less than 1.5 percent of this biomass is used for energy—estimated to be between 40 to 50 exajoules (EJ = 10^{18} joules per year (Hall, *et al.,* 1993; Ready, Williams, and Johansson, 1997; Nakicenovic, Grubler, and McDonald, 1998). The precise amount of bioenergy used is uncertain because the majority is used non-commercially in developing countries. For comparison, total global energy use today is around 400 EJ per year.

Many have difficulty conceiving of biomass as a modern energy source given the role that biomass energy has played, and continues to play, in most developing countries today. Biomass accounts for an estimated one-third of primary energy use in developing countries. In many developing countries, the biomass share of primary energy exceeds 70 percent. Over two billion people cook by direct combustion of biomass (WHO, 1997), primarily in rural areas. Traditional use of biomass fuels is typically inefficient, relying largely on low-cost sources such as natural forests, which in turn contributes to deforestation (Reddy, Williams, and Johansson, 1997). The low efficiency of biomass use today means that, even though biomass is consumed globally at a high rate, it produces only a low level of energy services.

Biomass fuels as used in developing countries today have been called "the poor man's oil" because direct use by combustion for domestic cooking and heating ranks it at the bottom of the ladder of preferred energy carriers. Biomass might more appropriately be called "the poor woman's oil," since women (and children) in rural areas spend a considerable amount of time collecting daily fuelwood needs and suffer the brunt of indoor air pollution caused by direct combustion of biomass for cooking and heating. Studies in India have found that the carcinogen benzo(a)pyrene inhaled by some women during cooking is equivalent to smoking twenty packs of cigarettes per day (Smith, Agarwal, and Dave, 1983). An astounding 58 percent of all human exposure to particulate air pollution is estimated to occur indoors in rural areas of developing countries (Fig. 1.2).

FIG. 1.2. APPROXIMATE DISTRIBUTION OF TOTAL HUMAN EXPOSURE TO PARTICULATE AIR POLLUTION



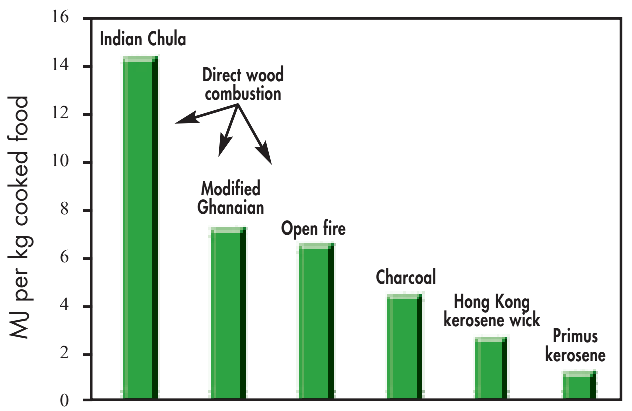
Source: Smith, 1993

Biomass utilisation in developing countries contrasts sharply with biomass use in industrialised countries. On average, biomass accounts for 3 or 4 percent of total energy use in the latter, although in countries with policies that support biomass use (e.g., Sweden, Finland, and Austria), the biomass contribution reaches 15 to 20 percent. Most biomass in industrialised countries is converted into electricity and process heat in cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities. This both produces a greater variety of energy services derived from biomass and results in much cleaner and more efficient use of available biomass resources than traditional uses of bioenergy in developing countries. The United States has some 8000 MW_e of biomass-fueled electricity-generating capacity installed, primarily as combined

Many have difficulty conceiving of biomass as a modern energy source given the role that biomass energy has played, and continues to play, in most developing countries today.

[1] An estimated 220 billion dry tonnes is produced annually by photosynthesis. The higher heating value of a dry tonne of biomass ranges from about 15 GJ (for some crop residues and industrial waste streams) to about 20 GJ (for many woody biomass species). One EJ is 10^9 GJ.

FIG 1.3. END-USE ENERGY CONSUMPTION FOR COOKING WITH ALTERNATIVE COOKING FUELS AND STOVES



Source: Dutt and Ravindranath, 1993

heat and power production systems. Residues of industrial processes and logging are the principal biomass fuels used in industrialised countries.

1.3. Modernising Biomass Energy

Most households in developing countries that use biomass fuels today do so either because it is available at low (or zero) financial cost or because they lack access to or cannot afford higher quality fuels. As incomes rise, preferences tend to shift away from biomass. For example, in the case of cooking, consumer preferences shift with increasing income from dung to crop residues, fuelwood, coal, charcoal, kerosene, liquefied petroleum gas, natural gas, and electricity (Dutt and Ravindranath, 1993). However, it is important to note that although consumers shift away from biomass energy as incomes rise, the shift is associated with the quality of the energy carrier utilised rather than with the primary energy source itself.

If biomass energy were "modernised"—that is, if it were produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity—it might be more widely used, and other benefits, such as reduced indoor air pollution, would accrue. Table 1.1 lists a variety of ways in which solid biomass can be converted into clean, convenient energy carriers. Many of these options are based on existing commercial technologies (see chapter 5). If widely implemented, such technologies would enable biomass energy to play a much more significant role in the future than it does today, especially in developing countries.

Household cooking provides an example. Gaseous cooking fuels can be used far more efficiently and conveniently than solid fuels (Fig. 1.3), while also emitting far fewer toxic pollutants (Fig. 1.4, see page 32). Thus biomass converted efficiently into fuel gas can meet the cooking energy demands of more households than can burning biomass directly, and it can do so with far less detrimental health effect. Biomass can be turned

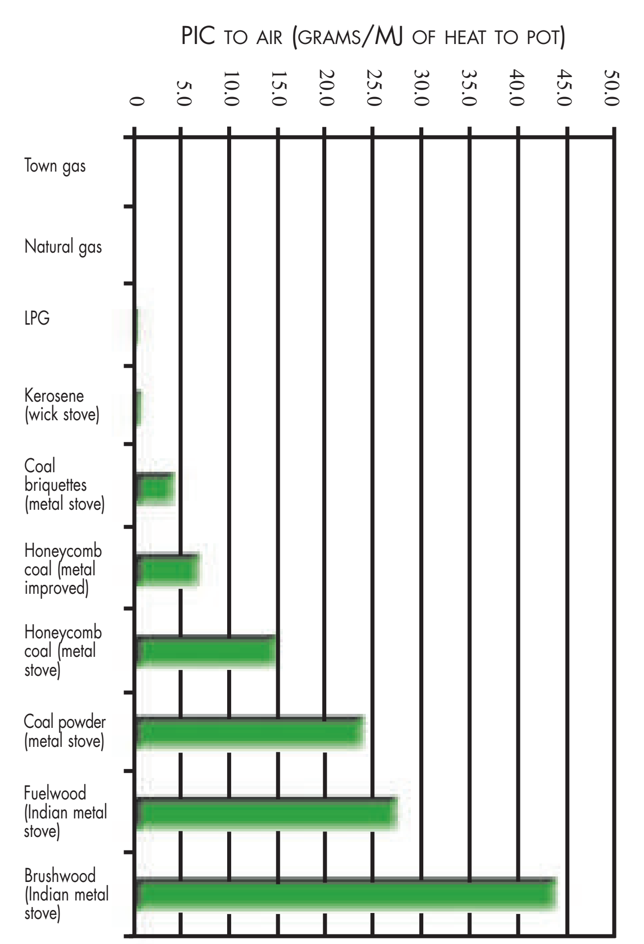
Table 1.1. Technologies for Modernised Conversion of Biomass Energy and Energy Services They Can Provide

Technology	Scale	Energy services provided
Biogas	Small	• Electricity (local pumping, milling, lighting, communications,refrigeration, etc. and possible distribution via utility grid) • Cooking • Heating
Producer gas	Small to medium	• Electricity (local pumping, milling, lighting, communications, refrigeration, etc. and possible distribution via utility grid) • Cooking • Heating
Ethanol	Medium to large	• Vehicle transportation • Cooking
Steam turbine	Medium to large	• Electricity (for industrial processing and grid distribution) • Heating process heat
Gas turbine	Medium to large	• Electricity (for industrial processing and grid distribution) • Heating process heat

into two kinds of gaseous fuel: (1) "producer gas," via a simple high-temperature process, and (2) biogas, via a low temperature anaerobic fermentation process (Table 1.1, see page 31).

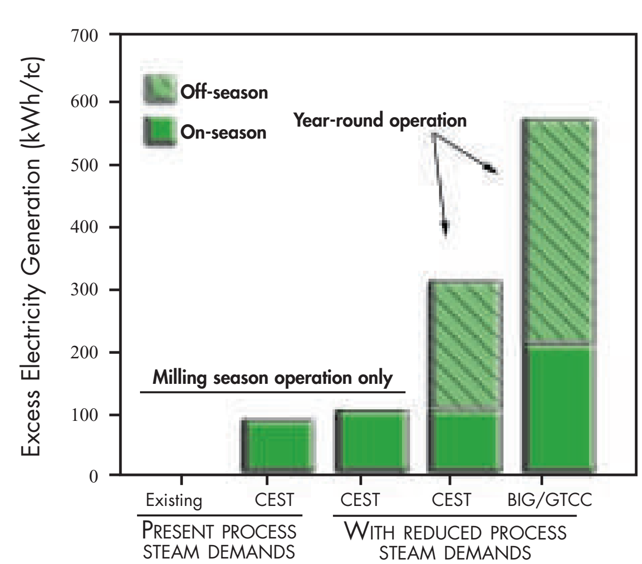
Producer gas generators are being installed today in many villages of Shandong Province, China, to convert corn stalks into cooking gas supplied to homes (Dai, Li, and Overend, 1998). In Shandong, only half as much corn is needed to provide a household's daily cooking need when it is converted to producer gas as when it is burned directly. In India, where many rural homes burn dung directly for cooking, the emphasis is on biogas. In a few villages, dung is first converted into biogas by anaerobic digestion. Because of the high efficiency with which biogas can be used, some 20 percent less cattle dung is needed to meet the same cooking

FIG. 1.4. MEASURED EMISSIONS (TO ROOM AIR) OF PRODUCTS OF INCOMPLETE COMBUSTION (PIC) FROM FLUE-LESS STOVES IN CHINA



Source: Zhang, 2000, in press

FIG. 1.5. ELECTRICITY GENERATED IN EXCESS OF ON-SITE REQUIREMENTS PER TONNE OF SUGARCANE CRUSHED AT A SUGAR OR ETHANOL FACTORY USING DIFFERENT COGENERATION TECHNOLOGIES



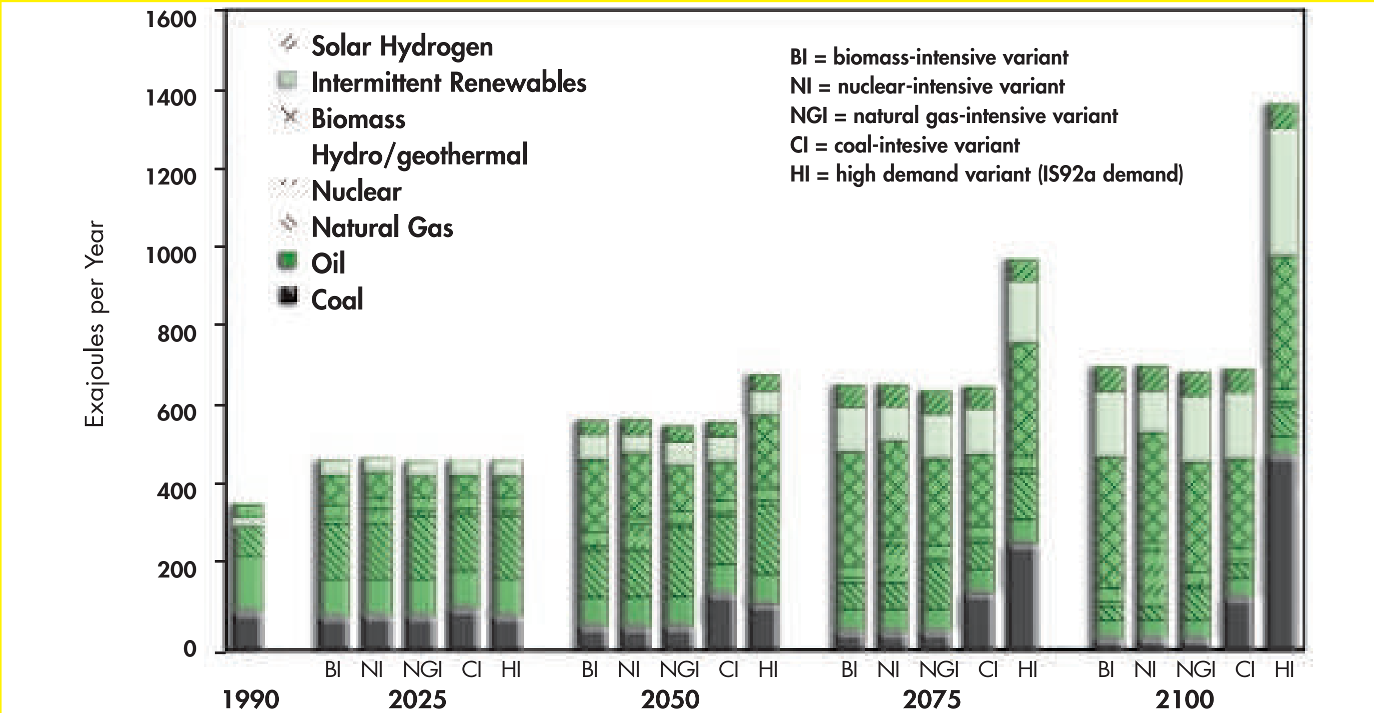
Existing technology is the back-pressure steam turbine with steam pressure about 20 bar. CEST is a condensing extraction steam turbine with steam pressure about 60 bar. BIG/GTCC is a biomass-gasifier/gas turbine combined cycle.

Source: Larson, 1994

needs than when dung is burned directly (Ravindranath and Hall, 1995). Biogas production has the additional advantages that it destroys pathogens in the dung and produces a nutrient-rich fertiliser, as discussed in chapter 5.

Sugarcane is an example of the potential for biomass modernisation on a larger scale. Some eighty developing countries grow and process sugarcane, generating substantial quantities of a fibrous biomass by-product (bagasse) that is used today at most mills as a fuel for combined heat and power (CHP) generation. CHP systems typically generate just enough electricity (a few megawatts at an average-sized facility) and process steam to meet the processing needs of the mill. Because such an abundance of bagasse is generated, however, the CHP systems are designed to be inefficient in order to consume all of the bagasse and thereby avoid disposal problems. With more efficient CHP systems, sugar factories could generate substantial amounts of electricity in excess of their own needs. Fig. 1.5 shows the excess electricity generation possible per tonne of cane (tc) processed with different CHP designs. Most existing sugar mills use low-pressure boilers feeding inefficient steam turbines and generate

FIG. 1.6. GLOBAL PRIMARY ENERGY USE BY SOURCE IN THE LOW-EMISSIONS SUPPLY SYSTEMS *(LESS)* VARIANTS CONSTRUCTED BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



One exajoule is 10^{18} joules.

Source: IPPC, 1996

no excess electricity. However, a few mills now utilise higher-pressure boilers and more efficient steam turbines (condensing-extraction steam turbines, CEST), which result in excess power generation on the order of 100 kWh/tc from bagasse, or 10 to 20 MW_e for typical mill sizes. By making cost-effective changes to the process to reduce steam consumption, a CEST system can export an additional 20 or 30 kWh/tc (middle bar, Fig. 1.5, see page 32).

With bagasse as fuel, a sugarcane processing facility has only limited potential to generate electricity outside of the cane-crushing season, which typically lasts six months. By using a supplemental fuel during the off-season, however, considerably more power could be exported. A potential supplemental fuel is cane trash: the tops and leaves of the sugarcane plant. These are generated in quantities comparable to the bagasse generated (Goldemberg *et al.,* 1993).

Table 1.2. Potential for "Excess" Electricity Generation from Sugarcane Factilities in Developing Countries Using Advanced Technology (Biomass Gasifier-Gas Turbine)

	1995 Cane Production (million tonnes)	2025 Cane Prod@ 2%/yr (million tonnes)	2025 "Excess" Electricity (TWh/year)	2025 Utility Elec. Prod.* (TWh)	2025 Cane Elec./ 2025 Utility Elec.
Brazil	304	550	330	623	0.53
India	260	470	282	883	0.32
China	70	127	76	2085	0.04
Carribean	48	87	52	102	0.51
Indonesia	31	57	34	141	0.24
Other Latin Am.	152	275	165	1063	0.16
Others	233	422	253	2214	0.11
Totals	1098	1988	1192	7112	0.17

*Projected from data for electricity generation in 1995 assuming an annual 3% growth rate.
Note: TWh = billion kWh.

Today, trash is typically burned on the fields to facilitate replanting or harvesting, though the resulting air pollution is motivating some governments to ban this practice. By supplementing bagasse with cane trash during the non-crushing season, a sugar mill using CEST technology could nearly triple exportable electricity production compared to generating only during the crushing season. Adopting biomass-gasifier/gas turbine CHP, an advanced technology that is presently undergoing commercialisation (see chapter 5), a sugar mill could nearly sextuple excess electricity production (Fig. 1.5, see page 32).

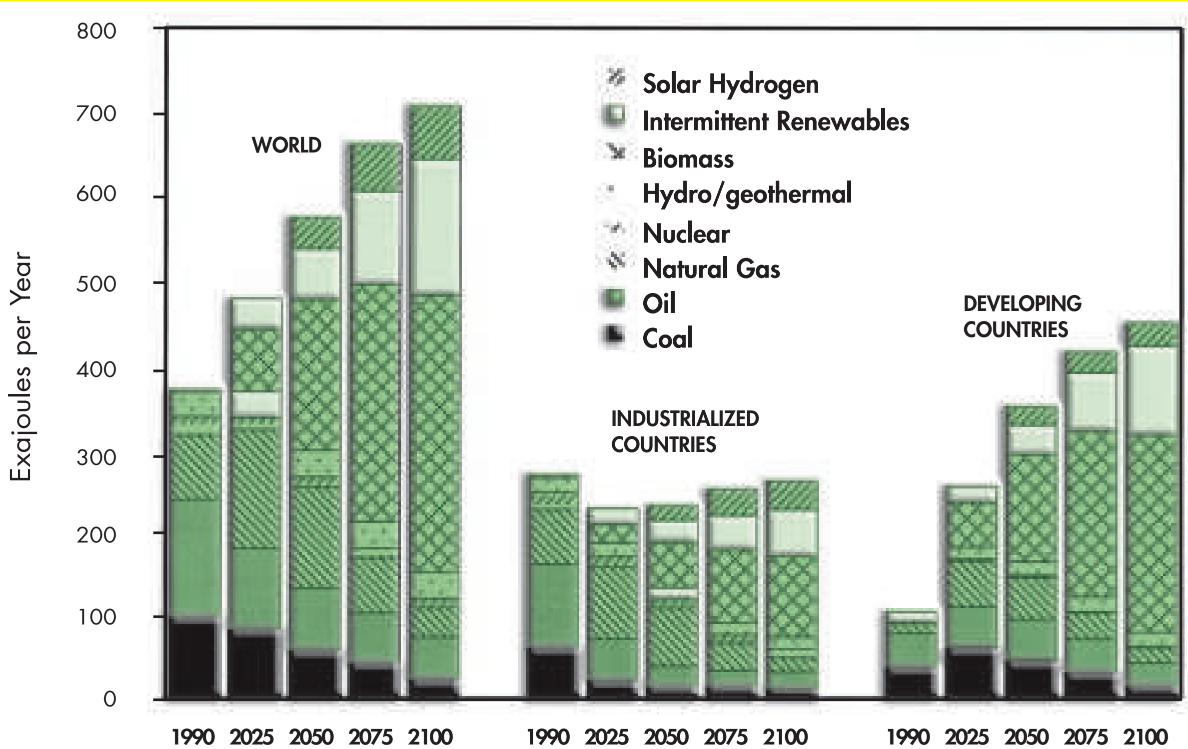
If biomass energy were "modernised"—that is, if it were produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity—it might be more widely used, and other benefits, such as reduced indoor air pollution, would accrue.

Table 1.2 (see page 33) gives some perspective on the potential contribution of "cane power" to overall electricity supply in developing countries. In some eighty developing countries, advanced CHP technology using cane residues could generate up to 40 percent more in 2025 than was produced by all utility generating plants in these countries in 1995. For some countries, e.g., Brazil and some Caribbean nations, the contribution of cane-derived power could be much greater than 40 percent.

1.4. A Long Term Vision of Biomass Energy

Given the possibilities for improving the efficiency of biomass conversion and expanding the energy services that biomass can

FIG. 1.7 PRIMARY COMMERCIAL ENERGY USE BY SOURCE FOR THE BIOMASS-INTENSIVE VARIANT OF THE IPCC LESS CONSTRUCTIONS, SHOWN FOR THE WORLD, FOR INDUSTRIALIZED COUNTRIES, AND FOR DEVELOPING COUNTRIES



Source: IPCC, 1996

provide, a number of international organisations have formulated energy scenarios that envision large contributions from modernised biomass energy in the twenty-first century. For example, the Intergovernmental Panel on Climate Change (IPCC) has explored in detail five alternative energy supply scenarios for satisfying the world's growing demand for energy services in the twenty-first century while limiting cumulative CO_2 emissions between 1990 and 2100 to under 500 billion tonnes of carbon (IPCC, 1996). In all five scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is included to help meet the CO_2 emissions targets (Fig. 1.6, see page 33). (When biomass is grown at the same average rate as it is harvested for energy, it is carbon-neutral: carbon dioxide extracted from the atmosphere during growth is released back to the atmosphere during conversion to energy.)

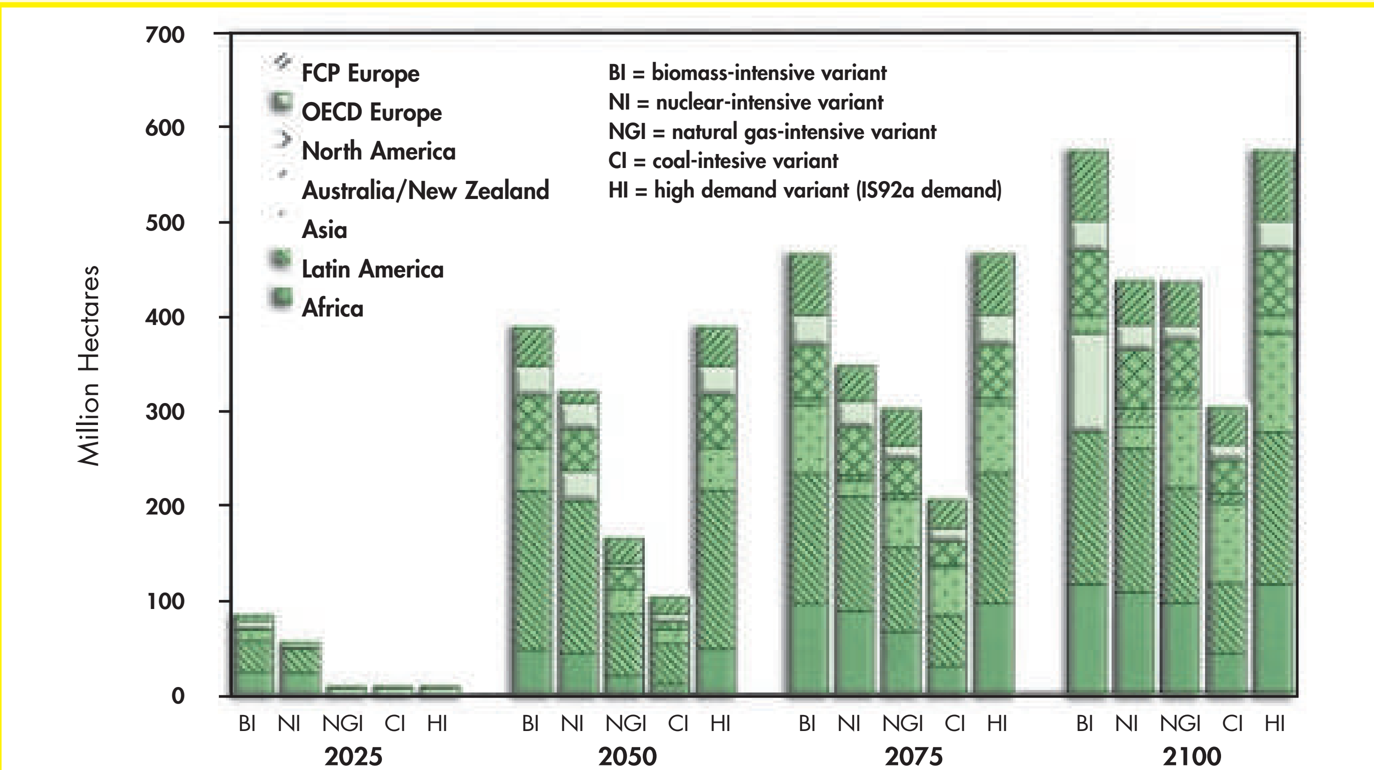
In the most biomass-intensive scenario, biomass energy contributes 180 EJ/year to global energy supply by 2050—satisfying about one third of total global energy demand, and about one half of total energy demand in developing countries (Fig. 1.7, see page 34). Roughly two thirds of the global

In the most biomass-intensive scenario, [modernised] biomass energy contributes...by 2050...about one half of total energy demand in developing countries.

biomass supply in 2050 is assumed to be produced on high-yield energy plantations covering nearly 400 million hectares (Fig. 1.8), 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.

Such large contributions of biomass to energy supply might help address the global environmental threat of climate

FIG. 1.8 LAND AREAS OF BIOMASS ENERGY PLANTATIONS BY REGION FOR ALTERNATIVE *LESS* VARIANTS



Source: IPCC, 1996

change, but biomass-intensive scenarios raise concerns about local and regional environmental and socioeconomic impacts. Potential negative consequences include depletion of soil nutrients from crop land if agricultural residues are removed; leaching of chemicals applied to intensively-cultivated biomass energy crops; and loss of biodiversity and food supply if land is converted to energy crops.

More than most other types of energy systems, bioenergy systems are inextricably linked to their local environmental and socioeconomic contexts. *If modernised biomass energy systems are to provide a substantial level of clean, cost-effective, and reliable energy service from locally generated resources in rural areas, then the design and implementation of those systems must take into account environmental and socioeconomic impacts—even at the pilot stage.*

Thus modernising biomass production implies choosing biomass feedstocks that:

- offer high yields, low costs, and low adverse environmental and social impacts, and
- are suitable for use in modern conversion systems.

While relatively little biomass is grown today specifically for energy, where biomass is grown for specific purposes (e.g., pulpwood) high yields are observed compared to yields from conventional agriculture or forestry (Fig. 1.8,see page 35). Also, substantial amounts of residues are generated as by products of food production and the forestry industry. Some of these residues are put to traditional uses, but substantial quantities go unused.

Modernised biomass conversion implies the production of electricity or fuels, or cogeneration of multiple energy products (especially heat and power), using technologies that offer low unit capital costs and high thermodynamic efficiencies at modest scales (to minimise transportation costs). In both the production and conversion of biomass, continued research and development is needed to expand future options to modernise biomass energy systems.

1.5 A Roadmap for this Primer

This document aims to provide guidance to programme officers in UNDP, local governments, bilateral and multilateral agencies, and elsewhere in facilitating pilot projects that demonstrate sustainable modernised biomass systems. The objective is to encourage wider replication of successful projects.

The table below gives readers help in easily locating information on specific topics. It also serves as an outline of the elements and organisation of the primer. ■

THE ROADMAP

	ISSUES	RELEVANT SECTIONS
What is the potential contribution of biomass?	***Biomass resource characterisation***	• Chapter 2 describes the principal types of bioenergy resources, including their applications, the potential size of the resource, and information that can be used to make initial estimates of the resource availability. • Electricity production for dedicated energy crops (Box 3-1) • Assessment of biomass energy as it relates to land-use competition in India (Section 3.4).
	Biomass energy in a global energy scenario	• IPCC alternative scenarios on the future supply potential of biomass (Section 1.4 and Figures 1.6, 1.7 and 1.8).

	ISSUES	RELEVANT SECTIONS
How is modernised biomass energy relevant to sustainable development?	***Overview***	• Sections 1.1, 1.2, 3.1, 3.2, and Table 3.1 present the overall context for the linkage between bioenergy and socio-economic development.
	Gender impacts	• Section 3.3 examines energy-related roles and needs of women and suggests ways to incorporate gender issues into energy/economic planning.
	Human health impacts	• Sections 3.2 and 4.6 examines how access to energy services can improve the health of people living in poverty.
	Poverty alleviation	• Section 3.2 discusses the approaches for bioenergy projects to create income and increase productivity for people living in poverty.
	Local environmental impacts	• Chapter 4 discusses environmental issues associated with the growing of biomass and its conversion to modern energy carriers. Specifically: - Land degradation (Sections 4.1, 4.3, 4.5, 4.6. and 4.7). - Biodiversity (Section 4.2) - Air and water pollution (Section 4.6) - Water resources (Sections 4.5 and 4.6)
What are the key required institutional issues and policy frameworks?	***Global/regional environmental issues***	• Section 4.4 presents the way in which bioenergy cycles can affect greenhouse gas emissions.
	Land-use competition	• Section 3.5
	Local participation	• Sections 3.2 and 6.1
What are the technology options for producing modern energy carriers from biomass?	***General institutional and policy issues***	• Chapter 6 discusses important institutional and other issues pertaining to implementation and wider replication of bioenergy systems. An example of how policy measures can help focus bioenergy on rural development is found in Box 3-2.
	Case studies	• Sections 7.1, 7.2, 7.4, 7.9 and 7.10.
	Technology descriptions and related environmental impacts	• Chapter 5 describes a variety of technologies for converting biomass into modern energy carriers, such as electricity, gas, and liquid fuels, focusing on those approaches that can be implemented on modest scales in rural areas of developing countries. It includes discussions of technical and cost characteristics intended to inform programme officers in identifying key areas that will affect the success of a particular project. Summary tables are included to highlight technical aspects, applications, and costs.
	Cost analysis	• Tables 5.2, 5.4, 5.6, 5.9 and 5.11.
	Energy services	• Cooking - Sections 5.1, and 5.2 (Case Study 7.5). • Electricity - Sections 5.1, 5.2, 5.4, and 5.5, (Case Studies 7.1, 7.2, 7.3, 7.4, 7.5, 7.7, 7.8, and 7.9). • Heating - Sections 5.1, 5.4, and 5.5, (Case Study 7.7). • Transportation - Section 5.3 (Case Study 7.6).

References for Chapter 1

Cao, J., et al. 1998. "Evaluation on Biomass Energy Resources an Utilisation Technology Prospect in Jilin Province." *Proceedings of Workshop on Small-Scale Power Generation from Biomass* (January 12-13). Changchun, China: Working Group on Energy Strategies and Technologies, China Council for International Cooperation on Environment and Development: 16-25.

Dai, L., J. Li, and R. Overend, eds. 1998. "Biomass Gasification System for Central Gas Supply." Chap. 5 in *Biomass Energy Conversion Technologies in China:* Development and Evaluation. Beijing: China Environmental Science Press.

Dutt, G.S., and N.H. Ravindranath. 1993. "Bioenergy: Direct Applications in Cooking." In *Renewable Energy: Sources for Fuels and Electricity,* edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 654-697.

J. Goldemberg, L.C. Monaco, and I.C. Macedo. 1993. "The Brazilian Fuel-Alcohol Program." In *Renewable Energy,* edited by Johansson et al.: 841-863.

Gu, S., and M. Duan. 1998. "China's Biomass Resources and Its Energy Utilisation." *Proceedings of Workshop on Small-Scale Power Generation from Biomass,* Jan. 12-13. Changchun, China: Working Group on Energy Strategies and Technologies, China Council for International Cooperation on Environment and Development: 1-6.

Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods. 1993. "Biomass for Energy: Supply Prospects." In *Renewable Energy,* edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 593-651.

Intergovernmental Panel on Climate Change (IPCC). 1996. *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses.* Edited by R.T. Watson, M.C. Zinyowera, and R.H. Moss. Chap.19. Cambridge: Cambridge University Press.

Larson, E.D., and R.H. Willams. 1995. "Biomass Plantation Energy Systems and Sustainable Development." In *Energy as an Instrument for Socio-Economic Development,* edited by J. Goldemberg and T. B. Johansson. New York: United Nations Development Programme: 91-106.

——, R.H. Williams, and T.B. Johansson. Forthcoming. "Future Demands on Forests as a Source of Energy." In *Forests in a Full World,* Report of the Scientific Committee contributed to the Report of the World Commission on Forests and Sustainable Development: Yale University Press.

Li, J., J. Bai, and R. Overend, eds. 1998. *Assessment of Biomass Resource Availability in China.* Beijing: China Environmental Science Press.

Nakicenovic, N., A. Grubler, and A. McDonald, eds. 1998. *Global Energy Perspectives.* Joint project of the International Institute for Applied Systems Analysis and the World Energy Council. Cambridge, UK: Cambridge University Press.

Ravindranath, N.H., and D.O. Hall. 1995. *Biomass, Energy and Environment:* A Developing Country Perspective from India. Oxford, UK: Oxford University Press.

Reddy, A.K.N., R.H. Williams, and T.B. Johansson. 1997. *Energy after Rio: Prospects and Challenges.* New York: United Nations Development Programme.

Smith, K.R. 1993. "Fuel Combustion: Air Pollution Exposures and Health in Developing Countries." *Annual Review of Energy and the Environment* 18: 529-566.

——, A.L. Agarwal, and R.M. Dave. 1983. "Air Pollution and Rural Biomass Fuels in Developing Countries: A Pilot Village Study in India and Implications for Research and Policy." *Atmospheric Environment* 17(11).

Sudha, P., and N.H. Ravindranath. 1999. "Land Availability and Biomass Production Potential in India." *Biomass and Bioenergy* 16(3): 207-222.

Taylor, T.B., R.P. Taylor, and S. Weiss. 1982. *Worldwide Data Related to Potentials for Widescale Use of Renewable Energy.* PU/CEES Report No. 132. Princeton, NJ: Center for Energy and Environmental Studies, Princeton University.

World Health Organisation (WHO), 1997. *Health and Environment for Sustainable Development.* Geneva: WHO.`

2 BIOENERGY SOURCES

Bagasse, the fiber residue from milling of sugar cane

…if half of … [China's residue] resource were used for generating electricity …, the resulting electricity would be equivalent to half the total electricity generated from coal in China in 1996.

Bioenergy resources take many forms, which can be broadly classified into three categories:

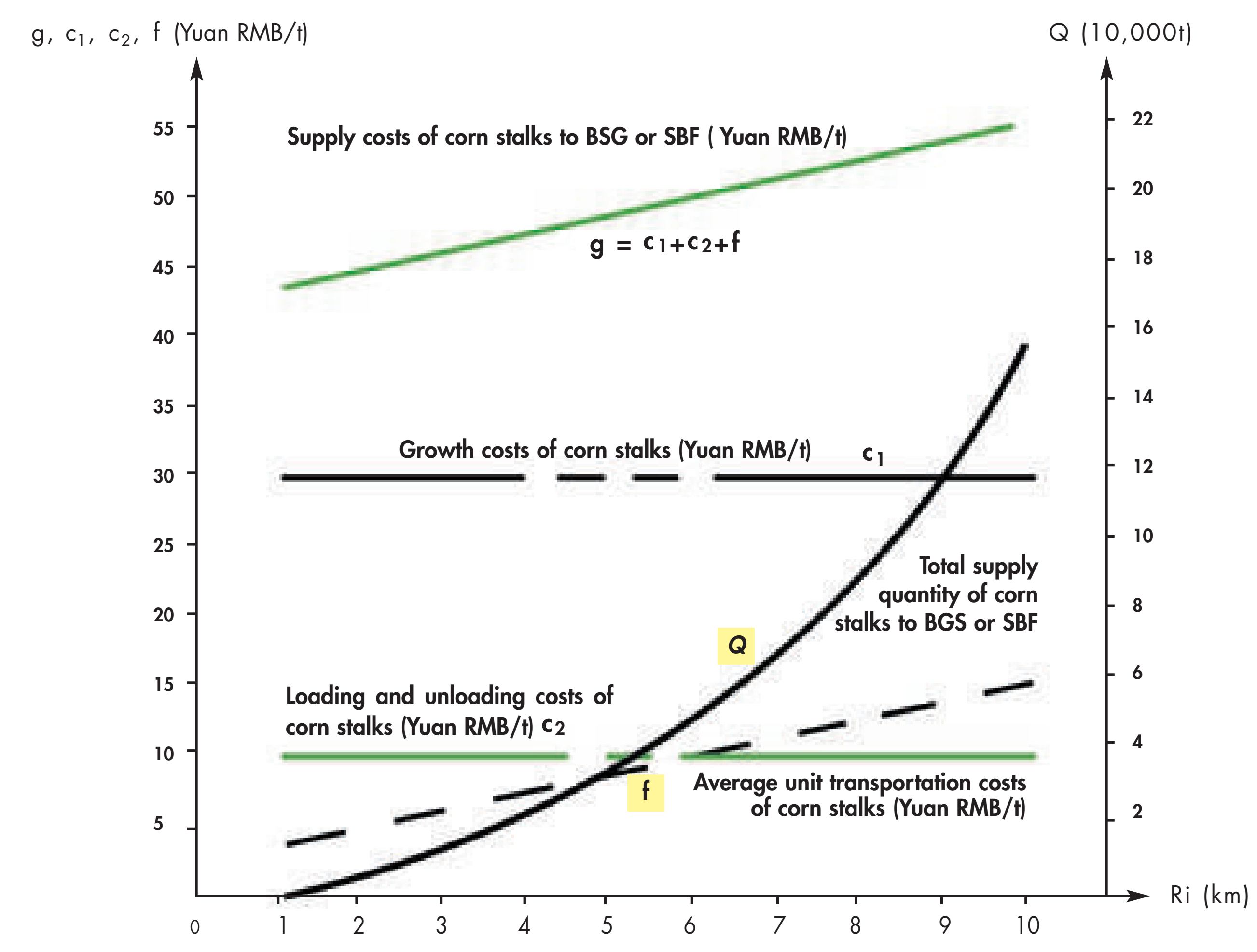
(1) residues and wastes,
(2) purpose-grown energy crops, and
(3) natural vegetation.

This chapter focuses on the first two categories. Natural vegetation might be a sustainable resource in some situations, but it has not been used sustainably on a large scale. For example, in many countries, cutting primary natural forests (for energy, land clearing for agriculture, and other uses) has led to soil erosion, loss of natural habitats, disruption of forest-related sustainable livelihoods, net carbon dioxide emissions to the atmosphere, and other negative impacts. Moreover, although sustainable harvesting of forest growth is possible in theory, ensuring that ecological and socioeconomic constraints are satisfied is difficult in practice. Although there will be situations in which natural vegetation can be used appropriately for energy, general guidelines are difficult to offer for such situations.

2.1. Residues and Wastes

Global production of biomass residues, including by-products of food, fiber, and forest

FIG. 2.1. QUANTITY AND COST OF CORN STALKS IN THE CORN-GROWING REGION OF JILIN PROVINCE, CHINA



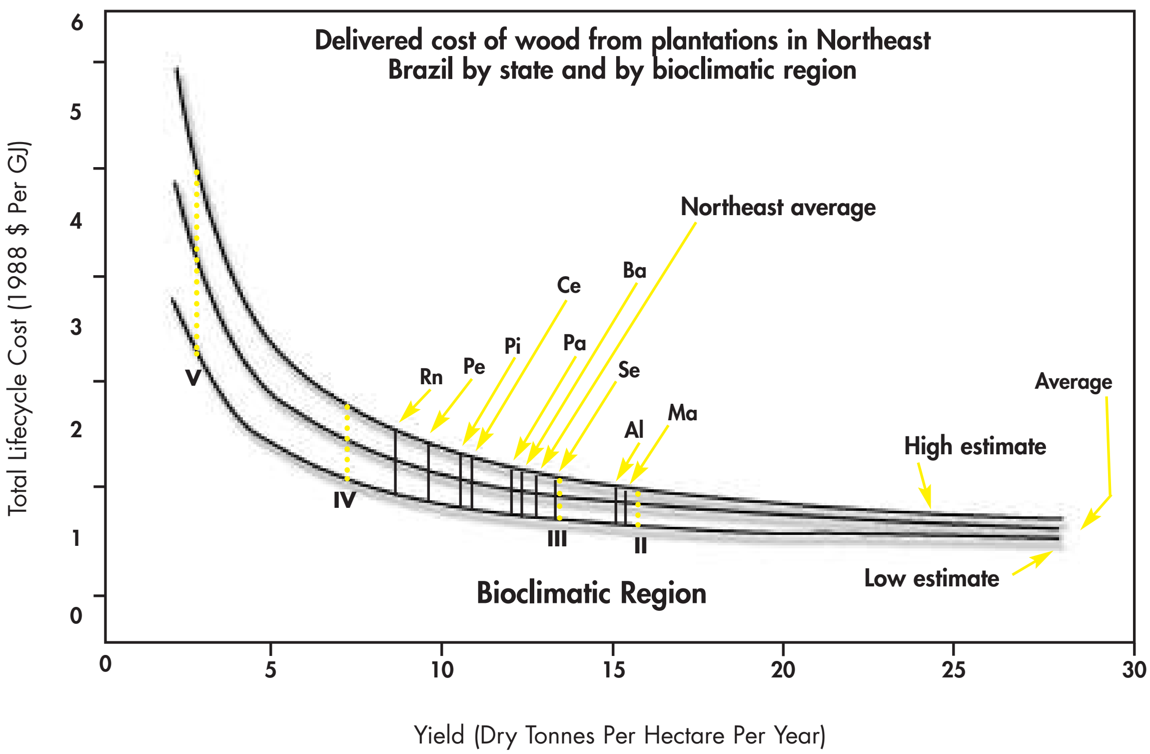
In these data, the growth costs do not include any land rent.

Source: Cai, 1998

production, exceeds 110 EJ/year (Hall *et al.,* 1993), perhaps 10 percent of which is used for energy. Residues concentrated at industrial sites are currently the largest commercially used biomass source. For example bagasse, the fiber remaining after the juice extraction stage in sugarcane processing, provides energy for processing the juice to sugar or alcohol. Some residues cannot be used for energy: in some cases collection and transport costs are prohibitive; in other cases, agronomic considerations dictate that residues be recycled to the land. In still other cases, there are competing non-energy uses for residues (as fodder, construction material, industrial feedstock, etc.). Considering such factors, the IPCC's biomass-intensive energy scenario (see Section 1.4) includes a contribution of 55 EJ/yr from biomass residues to total global commercial energy supply by 2050, or nearly one third of the total biomass supply in that scenario (Williams, 1995).

Residues are an especially important potential biomass energy source in densely populated regions, where much of the land is used for food production. In fact, biomass residues might play important roles in such regions precisely because the regions produce so much food: crop production can generate large quantities of by-product 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, corncobs, and bagasse) totaling about 790

FIG. 2.2 ESTIMATED HIGH, LOW, AND AVERAGE COST OF EUCALYPTUS STEMWOOD GROWN ON INDUSTRIAL PLANTATIONS IN NORTHEAST BRAZIL AS A FUNCTION OF YIELD



These estimates include land rent.

Source: Carpentieri *et al.*, 1992

million tonnes, with a corresponding energy content of about 11 EJ (Gu and Duan, 1998). To put this in perspective, if half of this resource were used for generating electricity at an efficiency of 25 percent (achievable at small scales today), the resulting electricity would be equivalent to half the total electricity generated from coal in China in 1996.

The amount of crop residues available in a given area can be crudely estimated based on "residue ratios," the weight ratio of residue to primary crop (Table 2.1, see page 42). However, to determine actual availability on a project by project basis, two things are needed: measurements of actual residue production, and evaluations of other uses of residues. The cost of producing and transporting residues to a utilisation site must also be considered in any project. Transportation costs are particularly important for projects that require relatively large quantities of residues at a single site. Fig. 2.1 (see page 40) shows the cost of producing and transporting corn stalks in the corn-growing region of Jilin Province. It also shows the quantity of stalks available at a given cost. Ideally, local cost-supply curves would be developed for any project where residue utilisation is being considered.

The growing cost shown in this graph includes only agricultural and labor inputs. It excludes land rent, which is probably an important cost component in most cases.

Table 2.1. Crop Residues: Residue Ratios, Energy Produced, Current Uses

Crop	Residue	Residue ratio[a]	Residue energy (MJ/dry kg)[b]	Typical current residue uses[c]
Barley[d]	straw	2.3	17.0	
Coconut	shell	0.1 kg/nut	20.56	household fuel
Coconut	fibre	0.2 kg/nut	19.24	mattress making, carpets, etc.
Coconut	pith	0.2 kg/nut		
Cotton	stalks	3.0	18.26	household fuel
Mustard Cotton	gin waste	0.1	16.42	fuel in small industry
Groundnut	shells	0.3		fuel in industry
Groundnut	haulms	2.0		household fuel
Maize	cobs	0.3	18.77	cattle feed
Maize	stalks	1.5	17.65	cattle feed, household fuel
Millet	straw	1.2		household fuel
seed	stalks	1.8		household fuel
Other seeds	straws	2.0		household fuel
Pulses	straws	1.3		household fuel
Rapeseed	stalks	1.8		household fuel
Rice	straw	1.5	16.28	cattle feed, roof thatching, field burned
Rice	husk	0.25	16.14	fuel in small industry, ash used for cement production
Soybeans[e]	stalks	1.5	15.91	
Sugarcane	bagasse	0.15	17.33	fuel at sugar factories, feedstock for paper production
Sugarcane	tops/leaves	0.15		cattle feed, field burned
Tobacco	stalks	5.0		heat supply for tobacco processing, household fuel
Tubers[e]	straw	0.5	14.24	
Wheat	straw	1.5	17.51	cattle feed
Wood products[f]	waste wood	0.5	20.0	

(a) Unless otherwise noted, the residue ratio is expressed as kilograms of dry residue per kg of crop produced, where the crop production is given in conventional units, e.g. kg of rice grain or kg of clean fresh sugarcane stalks. The ratios given here are illustrative only: for a given residue, the residue ratio will vary with the agricultural practice (species selected, cultivation practices, etc.). Unless otherwise noted, the ratios given here are from Biomass Power Division (1998).

(b) Unless otherwise noted, these are higher heating values as reported by Jenkins (1989). The lower heating values are about 5 percent lower. The higher and lower heating values differ by the latent heat of evaporation of water formed during complete combustion of the residue.

(c) The use to which residues are put varies greatly from one region of a country to another and from country to country. The uses listed here are illustrative only. They are typical uses in parts of India.

(d) Source: Taylor, Taylor, and Weis (1982).

(e) Estimate for China as given by Li, Bai, and Overend (1998). Tubers includes crops such as cassava, yams, and potatoes.

(f) Wood products refers to lumber or finished wood products such as furniture. The residue ratio is given as a broad average by Hall et al. (1993). The ratio will vary considerably depending on the specific product.

Corn stalks stored along field edges for use as domestic fuel for cooking and heating in a village in Jilin Province, China.

Animal manure is another agricultural by-product that can be used in anaerobic digesters to produce biogas. The availability of this resource depends both on the condition of the livestock producing it and on how much of the animal's manure is actually collected. In some cases, estimates of manure availability used for project planning purposes have been far in excess of actual availability, which has led to project failures. Table 2.2 (see page 44) gives several estimates of manure production in India and China.

2.2. Purpose-Grown Energy Crops

Growing crops specifically for energy has significant potential. Energy crops can be produced in two ways: (1) by devoting an area exclusively to production of such crops (energy plantations), or (2) by co-mingling the production of energy and non-energy crops. Coproduction can occur either on adjacent pieces of land (farm forestry), on the same piece of land (agroforestry), or even using different parts of the plant for energy and non-energy purposes. Since energy crops typically require several years of growth before the first harvest, coproduction in some form has the benefit of providing energy-crop farmers with revenue between harvests of energy crops.

Energy Plantations

The IPCC's biomass-intensive energy supply scenario (see Section 1.4) includes 385 million hectares of dedicated biomass energy plantations globally in 2050, with three quarters of this area established in developing countries. In comparison, crop-land and forests/woodlands globally today occupy approximately 1.5 and 4.1 billion hectares, respectively; and there are an estimated 100 million hectares of commercial tree plantations worldwide (Bazett, 1993), most of which are dedicated to industrial products other than energy. To meet the IPCC's 2050 projection of area devoted to energy plantations, about 5 million hectares per year will need to be established between now and 2050. In comparison, industrial tree plantations on official government forest land in tropical regions were established at an average rate of 2.6 million hectares per year between 1981 and 1990 (FRA Project, 1992). Thus the global average planting rate required to reach the IPCC's projected biomass supply levels for 2050 appears achievable.

Are land resources sufficient to support the level of energy crop production envisioned by the IPCC? The answer to this question is country-specific, but competition between land use for agriculture and for energy production can be minimised if degraded lands are targeted for energy (Johansson *et al.*, 1993; Hall *et al.*, 1993; Williams, 1994; Ravindranath and Hall, 1995; Sudha and Ravindranath, 1999). Planting tree or perennial-grass energy crops is more likely to improve such lands than planting annual row crops such as soy or maize.

In developing countries in aggregate, Grainger (1988 and 1990) and Oldeman *et al.* (1991) estimate that more than 2 billion hectares of land are "degraded." Grainger further estimates that some 621 million hectares of this land could be reforested. Houghton (1990) estimates that previously forested area suitable for reforestation amounts to 500 million hectares.

The environmental outcome [of growing biomass for energy] depends sensitively on how the biomass is produced and the socioeconomic impact depends on how production is integrated with people and institutions.

A wide variety of technical, socioeconomic, political, and

Table 2.2. Animal Manure Yield Estimates in China and India

India[a]	kg fresh weight/ day/animal
National government estimates	
Orissa state, bullocks	10.6
Orissa state, buffaloes	12.7
Karnataka state, bullocks	11.6
Karnataka state, buffaloes	10.1
Uttar Pradesh state, bullocks	13.2
Uttar Pradesh state, buffaloes	10.2
Measurements of dung collected at cattle sheds	
Ungra village (south), bullocks	5.78
Ungra village (south), buffaloes	5.78
Sirsi village (south-west), bullocks	3.90
Sirsi village (south-west), buffaloes	10.40
BNPura (east), bullocks	3.65
BNPura (east), buffaloes	4.57
Uttar Pradesh villages (north), bullocks	5.5 - 6.4
Uttar Pradesh villages (north), buffaloes	8.1 - 8.9
China[b] (national estimate of collectable manure)	
Cattle	12
Pigs	3.6
Chickens	0.02

(a) *Source:* Ravindranath and Hall, 1995
(b) *Source:* Li, Bai, and Overend, 1998

other challenges are involved in successfully growing energy crops on degraded lands, but the many successful plantations already established on such land in developing countries demonstrate that these challenges can be overcome (Hall *et al.*, 1993).

One question often asked is whether the energy inputs required to establish and maintain energy plantations are larger than the net biomass energy they produce. Based on extensive trials on short-rotation intensively cultivated crops in the United States (such as switchgrass and hybrid poplar), the biomass energy output is 10 to 15 times greater than all required fossil fuel inputs (including energy embodied in fertilisers, herbicides, and pesticides and fuel for machinery) (Hall *et a*l.*,* 1993).

Where perenial energy crops are grown with less chemical inputs and using less mechanistion and/or where yields are higher than in the United States, as in many tropical regions of developing countries, the energy output to input ratio would be still higher. Unlike the case for perenial crops (especially wood crops), net energy balances for some annual row-crop biomass energy sources are not favorable, eg., ethanol from corn (Wyman *et al.,* 1993).

A key factor determining the cost of producing energy crops is the biomass output per hectare (Fig. 2.2, see page 41). Yield varies geatly depending on precipitation, soil quality, length of growing season, plant species and spacing, intensity of chemical inputs, and other factors. Very high yields are achievable when rainfall is adequate (>1500 mm/year), the growing season is long, fertilisation is used, and species are bred for high yield. Eucalyptus plantations (for pulpwood production) located along the northeast Atlantic coast of Brazil have these characteristics, with average yields in excess of 20 dry tonnes per hectare per year of stem wood, and growth in the highest yielding stands approaching 50 dt/ha/yr. At the other extreme are yields from unmanaged, unfertilised stands of unimproved species established on poor-quality soil in semi-arid areas. Eucalyptus plantations established in such areas of India yield 3 to 7 dt/ha/yr (Sudha and Ravindranath, 1999). Table 2.3 (see page 45) shows various yield estimates for eucalyptus production in Brazil and India.

There is no doubt that biomass can be grown for energy in

Table 2.3. Yield Estimates for Energy Plantations Growing Eucalyptus in India and Northeast Brazil (dry metric tonnes per hectare per year)

India[a]	No genetic improvement, no fertilizer	Genetically improved planting stock, no fertilizer	Genetically improved planting stock, fertilizer used
Dry semi-arid (75-119 growing days, soil & terrain very suitable, suitable, or maginally suitable)	3 - 7	4 - 10	6 -12
Moist semi-arid (120-179 growing days, soil & terrain very suitable or suitable.)	4 - 8.5	7 - 16	9 - 21
Sub-humid (180-269 growing days, soil & terrain very suitable or suitable)	5 - 10	10 - 22	12 - 30
Humid (>270 growing days, soil & terrain very suitable or suitable)	13 - 17	17 - 25	30 - 35
Northeast Brazil[b]			
Bioclimatic region 1: 1500-2300 mm/yr precipitation			21
Bioclimatic region 2: 1000 - 1700 mm/yr precipitation			16
Bioclimatic region 3: 700 - 1300 mm/yr precipitation			13
Bioclimatic region 4: 500 - 1000 mm/yr precipitation			7
Bioclimatic region 5: 250 - 600 mm/yr precipitation			3

(a) *Source:* Sudha and Ravindranath, 1999
(b) *Source:* Carpentieri, *et al.,* 1993

ways that are socially and environmentally undesirable. However, it can also be grown in ways that both improve the land and have better socioeconomic impacts than current land use. The environmental outcome depends sensitively on how the biomass is produced and the socioeconomic impact depends on how production is integrated with people and institutions. Chapters 3 and 4 discuss these issues in detail.

Farm Forestry

Many countries, including India (Ravindranath and Hall, (1995) and China (RWEDP, 1998), have considerable experience in small-scale fuelwood production.

Farm forestry activities in Brazil have been especially successful in involving small farmers in high-yield production of biomass feedstocks (Larson et al., 1994). In a typical program in Brazil, a forestry company provides the material inputs and technical know-how to establish trees on part of a farmer's land (1 to 50 hectares of trees per farm). The company contracts with the farmer to buy some or all of the first harvest for an agreed price that incorporates repayment for the initial inputs and services. The inputs include saplings (usually some species of eucalyptus), fertilisers (applied at planting), herbicides (applied at some point after planting), and pesticides. The company samples the farmer's soil and provides fertilisers and species "tuned" to that farmer's soil.

The integration of trees with other agricultural activities, which has been carried out by farmers for millennia, is now attracting the attention of researchers that can bring modern methods to bear on improving the overall performance of agricultural systems.

Because of the sophisticated material inputs and the careful tending provided by the farmer, biomass yields reported from small-farm planting in Brazil are not much below those reported for large-scale (thousands of contiguous hectares) industrial plantations owned and operated by forestry companies. Moreover, yields are likely to increase as both farmers and their contracting companies learn improved methods and approaches (farm forestry programs in Brazil started only in the 1980s). Limited data for Brazil suggest that already the delivered costs for biomass from farm-forests and from large-scale plantations are comparable.

Several hundred thousand hectares of farm forests have been established in Brazil since the mid-1980s, with encouragement from the private sector, from federal, state, and local governments, and from farmers. The overall result of the small-farm forestry programs has been minimal changes in land ownership and use patterns, while local wood supplies at reasonable costs have increased, and farmers (including formerly subsistence farmers) have gained a revenue source (see section 7.9).

Agroforestry

One way of producing purpose-grown biomass feedstocks is through multi-purpose cropping systems that simultaneously meet many needs of local communities. Agroforestry is a term for a wide range of such multi-purpose systems. Agroforestry refers to "a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic, and environmental benefits for land users at all levels" (ICRAF, 1999).

In agroforestry, trees are integrated with agricultural activities to provide a diverse set of products and functions, including food, fuelwood, fodder, mulch, construction and artisan materials, medicinals and cosmetics, oils and resins, as well as energy feedstocks. The integration of trees with other agricultural activities, which has been carried out by farmers for millennia, is now attracting the attention of researchers that can bring modern methods to bear on improving the overall performance of agricultural systems.

Agroforestry can be either simultaneous or sequential. In simultaneous agroforestry, trees are grown concurrently with other crops and spaced to minimise competition for light, water, and nutrients. Simultaneous agroforestry can involve,

Credit: Eric Larson

Harvesting a commercial eucalyptus plantation in the state of Espirito Santo, Brazil.

for example, planting live hedges and fences, shade or grazing trees, and trees for wind breaks or water contours, or inter-cropping trees and crops in alternate rows (or other mutually beneficial patterns). In sequential agroforestry, trees and other crops are grown in turn (Shifting agriculture is a form of sequential agriculture and, indeed, the most extensive farming system in the humid tropics.).

Trees can interact with other crops in beneficial ways. Trees with deep root systems can bring moisture and nutrients into the surface layers, making them accessible to shallow-rooted crops. Trees can also directly provide nutrients—for example, leguminous species replenish soil nitrogen. Tree roots and litter can replenish organic matter, help create a vital microfauna community, and improve soil structure. Certain tree/crop combinations are beneficial because trees provide shade to protect young crops against too much light and water loss. Trees can reduce wind and water erosion, and be used with contouring to channel water toward certain areas. ■

References for Chapter 2

Bazett, M. 1993. "The Need for Industrial Wood Plantations." *Tree Plantation Review.* Study No. 3, Non-Traditional Business Group. Shell Center, London: Shell International Petroleum Co.

Cao, *et al.* 1998. "Evaluation on Biomass Energy Resources and Utilisation Technology Prospect in Jilin Province." In *Proceedings of Workshop on Small-Scale Power Generation from Biomass* (January 12-13). Changchun, China: Working Group on Energy Strategies and Technologies, China Council for International Cooperation on Environment and Development: 16-25.

Carpentieri, A.E., E.D. Larson, and J. Woods. 1992. "Prospects for Sustainable, Utility-Scale, Biomass-Based Electricity Supply in Northeast Brazil." PU/CEES Report 270. Princeton, New Jersey: Center for Energy and Environmental Studies, Princeton University.

——, E.D. Larson, and J. Woods. 1993. "Future Biomass-based Electricity Supply in Northeast Brazil." *Biomass and Bioenergy* 4(3): 149-173.

Food and Agriculture Organisation (FAO). Forest Resources Assessment Project (FRA Project). 1992. *The Forest Resources of the Tropical Zone by Main Ecological Region*. Rome.

Government of India. Ministry of Non-Conventional EnergySources, Biomass Power Division. 1998. *Biomass Power Generation in India* (November). New Delhi.

Grainger, A. 1988. "Estimating Areas of Degraded Tropical Lands Requiring Replenishment of Forest Cover." *International Tree Crops Journal* 5: 31-61.

——. 1990. "Modeling the Impact of Alternative Afforestation *Strategies to Reduce Carbon Emissions." Proceedings of the Intergovernmental Panel on Climate Change Conference on Tropical Forestry Response Options to Climate Change, Report* No. 20P-2003.Washington, DC: Office of Policy Analysis, US Environmental Protection Agency.

Gu, S., and M. Duan. 1998. "China's Biomass Resources and Its Energy Utilisation." In *Proceedings of Workshop on Small-Scale Power Generation from Biomass:* 1-6.

Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods. 1993. "Biomass for Energy: Supply Prospects." In *Renewable Energy:* Sources for Fuels and Electricity, edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 593-651.

Houghton, R.A. 1990. "The Future Role of Tropical Forests in Affecting the Carbon Dioxide Concentration of the Atmosphere." *Ambio* 19(4): 204-209.

International Center for Research in Agroforestry (ICRAF). 1999. "Agroforesty Facts."www.cgiar.org/icraf/ag_facts/ag_y facts.htm

Jenkins, B.M. 1989. "Physical Properties of Biomass." In *Biomass Handbook,* edited by O. Kitani and C.W. Hall. New York: Gordon and Breach Science Publishers: 860-891.

Johansson, T.B., H. Kelly, A.K.N. Reddy, and R.H. Williams. 1993. "Renewable Fuels and Electricity for a Growing World Economy: Defining and Achieving the Potential." Chap. 1 (1-71), and "A Renewables-Intensive Global Energy Scenario." Appendix to Chap. 1 (1071-1142). In *Renewable Energy,* edited by Johansson, *et al.*

Larson, E.D., L.C.E. Rodriguez, and T.R. de Azevedo. 1994. "Farm Forestry in Brazil." Presented at BioResources '94: Biomass Resources: A Means to Sustainable Development (October 3-7). Bangalore, India. Available from E. Larson, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ.

Li, J., J. Bai, and R. Overend, eds. 1998. *Assessment of Biomass Resource Availability in China.* Beijing: China Environmental Science Press.

Oldeman, L.R., *et al.* 1991. *World Map of the Status of Human*

Induced Soil Degradation (April). International Soil Reference and Information Center and United Nations Environment Programme.

Ravindranath, N.H., and D.O. Hall. 1995. *Biomass, Energy, and Environment: A Developing Country Perspective from India.* Oxford, UK: Oxford University Press.

Regional Wood Energy Development Programme in Asia (RWEDP). 1998. "Wood Energy in China." *Wood Energy News* 13(3) (December). Bangkok, Thailand: Food and Agriculture Organisation (FAO), Regional Office for Asia and the Pacific.

Sudha, P., and N.H. Ravindranath. 1999. "Land Availability and Biomass Production Potential in India." *Biomass and Bioenergy* 16(3): 207-222.

Taylor, T.B., R.P. Taylor, and S. Weiss. 1982. *Worldwide Data Related to Potentials for Widescale Use of Renewable Energy.* PU/CEES Report No. 132. Princeton, NJ: Center for Energy and Environmental Studies, Princeton University.

Williams, R.H. 1994. "Roles for Biomass Energy in Sustainable Development." Chap. 14 in *Industrial Ecology and Global Change.* Cambridge University Press: 199-225.

——. 1995. *Variants of a Low CO2-Emitting Energy Supply System (LESS) for the World.* Prepared for the IPCC Second Assessment Report, Working Group IIa, Energy Supply Mitigation Options. Report No. PNL-10851. Richland, WA: Pacific Northwest Laboratories.

Wyman, C.E., R.L. Bain, N.D. Hinman, and D.J. Stevens. 1993. Ethanol and Methanol from Cellulosic Biomass." In *Renewable Energy,* edited by Johansson et al.: 866-923.

3 SOCIOECONOMIC ISSUES

Credit: Roger Taylor and DOE/NREL

Women selling traditional fuel (charcoal) in an outdoor market in a rural village in Ghana.

Bioenergy systems, with their high land and labor intensities, interact fully with their environmental and socioeconomic surroundings, whether intended or not. They will necessarily transform their surroundings.

Biomass energy systems can have a wide range of potential socioeconomic and environmental impacts—both positive and negative. Such impacts are often treated as only "secondary" effects in the planning and implementation of energy projects, even though they can greatly influence whether a project is appropriate and sustainable in the local context. Because potential environmental and socioeconomic impacts are so important, the strategy promoted in this Primer is that such impacts must be considered from the outset in any bioenergy project, and that projects must be designed accordingly.

Compared with other energy projects, bioenergy projects are likely to have large socioeconomic and environmental impacts for two reasons. First, bioenergy is land intensive—producing a given amount of energy requires a large amount of land for capturing sunlight and turning it into biomass feedstock. Second, bioenergy is labor intensive—acquiring biomass feedstock involves a large amount of typically low-skilled labor, particularly as practiced in developing countries. The land requirements of bioenergy can be illustrated with two simple calculations, one showing how much electricity a hectare of land can yield, and the other showing how much modern transport fuel a hectare of land can yield. The labor intensity of bioenergy can also be illustrated with a simple example (see Box 3.1, page 50).

Box 3-1. Land and Labor Costs of Producing Energy

How much electricity could be produced from a hectare of energy crops?

Based on field trials with Eucalyptus, a fairly arid region (receiving 900 millimeters of rain per year) could produce about 15 dry tonnes of harvestable wood per hectare using modern plantation techniques. This wood could then be used to fuel a small power generator—for example, a small-scale biomass gasifier coupled with a diesel generator—to produce electricity at 22% efficiency. This combination of biomass productivity and conversion efficiency is enough to continuously generate roughly 2 kilowatts of electric power from each hectare committed to biomass. 2 kW is enough to satisfy the average power requirements of, say, four standard irrigation pumps used daily for three hours.

Other non-fossil energy sources will generally be less land-intensive. Solar installations yield on the order of 100 kilowatts per hectare. Wind turbines can provide megawatts per hectare, without greatly affecting the suitability of the underlying land resource for many uses including grazing and agriculture. Fossil energy sources also require land—strip mines or subsurface mines for extracting coal, or wells for extracting oil and gas. Compared to biomass feedstocks, producing these fuels requires less land per unit of energy provided, although the required land would be heavily impacted.

How much vehicle fuel could be produced from a hectare of energy crops?

Alternatively, consider devoting a hectare to raising sugarcane for ethanol production. At a yield of 65 tonnes of cane stems per hectare, and an ethanol conversion efficiency of 75 liters per tonne of cane, roughly 5000 liters of ethanol can be produced each year. This would almost satisfy the annual fuel needs of 4 standard passenger cars (each consuming 12 liters of ethanol per 100 kilometers and traveling 12,000 km per year—roughly the global average values for efficiency and annual travel).

How much labor goes into producing transport fuel?

A typical ethanol distillery in the center of Brazil (producing 20 million liters of ethanol per year) draws directly upon the full-time labor of 150 industrial workers and 455 agricultural workers. (In the northeast of Brazil, where sugarcane crop yields are lower, close to 1800 agricultural workers would be needed.) This means that roughly 140 liters of ethanol are produced per workday. Per unit of energy, this is far more employment than is generated in the extraction and refining of petroleum to vehicle fuels. This could be welcome while unemployment is high and labor costs are low, but problematic as a country becomes more affluent and wages rise.

Bioenergy systems, with their high land and labor intensities, interact fully with their environmental and socioeconomic surroundings, whether intended or not. They will necessarily transform their surroundings. A key lesson emerges from this observation: bioenergy strategies are not merely self-contained "energy projects."

This offers both opportunities and challenges. If designed well, bioenergy strategies will contribute to sustainable livelihoods and help address environmental problems such as land degradation or agricultural waste disposal. If not properly executed, however, they can exacerbate social inequities and intensify pressures on local ecosystems. For this reason, a bioenergy activity must be scrutinised and judged along several dimensions: how does it contribute to satisfying basic needs, providing income opportunities, enhancing food security, preserving the local environment, promoting gender equity, empowering communities? How does it contribute to the broad sustainable development agenda?

In assessing the impacts of a bioenergy activity, the entire bioenergy chain is implicated. One must scrutinise the unique and project-specific details of how the biomass feedstock is produced and supplied, in addition to the more generic downstream issue of how it is converted to energy. By comparison, non-biomass energy projects call for little project-specific upstream assessment. In implementing a conventional energy project, there is little need to revisit the generic upstream details of the project: how the petroleum is extracted and refined into diesel fuel for use in a village generator set, how the coal is mined and burned in a distant power plant to feed an expanding electrical grid, or how wind turbines and solar cells are designed and manufactured before being integrated into a remote power system. In contrast, because biomass is a local resource, its production and supply is integral to the bioenergy project and, in large part, distinguishes "good" bioenergy strategies from "bad." "Good" strategies are more sustainable, but "bad" strategies might appeal more to investors looking for near-term profitability.

Impacts occur at a number of levels—farm, community, watershed, national, and global. One must consider not only the immediate effects of a single project, but also the cumulative effects of several discrete projects. Some types of impacts might be negligible or difficult to discern as the result of a single project, but become important cumulatively. For example, the impacts on food prices, biodiversity, or urban migration rates can probably be measured only as the combined result of many bioenergy activities.

These multidisciplinary issues are discussed in this chapter and the next. Although the discussion is divided into "socioeconomic" and "environmental" issues for convenience, the boundary between these categories is admittedly diffuse; there are in fact many crosscutting aspects, which are also discussed.

Bioenergy projects can provide a wide range of energy services—including many that address local development needs among the poor in rural communities... For the development practitioner and the bioenergy planner, the challenge is to identify bioenergy strategies that will truly help satisfy local needs.

The remainder of this chapter discusses socioeconomic issues in terms of four broad themes: provision of basic services, income-generating opportunities, gender implications, and land issues. This somewhat simple categorisation is intended to provide some organisation without obscuring the links among the themes. For these four themes, we outline the major issues and highlight opportunities for designing bioenergy projects that promote sustainable development goals.

3.1. Meeting the Basic Needs of the Rural Poor

Bioenergy projects can provide a wide range of energy services—including many that address local development needs among the poor in rural communities. For example, projects help meet basic needs when they provide energy to pump water for drinking and irrigation, or to light homes, schools, and health clinics. Such projects can also improve communication and access to information, give local enterprises access to energy, and ease pressure on fuelwood resources. These are benefits that can directly improve local quality of life, increase productivity, and help relieve the strains of rural poverty. On the other hand, bioenergy programs that generate electricity or fuels consumed primarily in urban-industrial centers do not directly address local needs—although they may, as discussed below, have rural employment benefits.

Similarly, biomass can be produced in ways that provide a wide range of benefits. Bioenergy feedstocks can be produced in conjunction with other local necessities—food, fodder, fuelwood, construction materials, artisan materials, etc. They can help restore the environment on which the poor depend for their livelihoods—revegetating barren land, protecting watersheds and harvesting rainwater, providing habitat for local species, stabilising slopes or river banks, or reclaiming waterlogged and salinated soils. They can also serve as an efficient use for agricultural residues, avoiding the pest, waste, and pollution problems of residue disposal. On the other hand, biomass production could be aimed solely at energy production, with land managed to maximise the yields of energy crops. While this might appeal to the consumers of bioenergy feedstocks, it does not address other local needs. Whether a multiple or a single-product approach is most appropriate depends on the local context. In either case, bioenergy projects should be designed with a clear understanding of how they affect the provision of basic needs.

There is no guarantee that bioenergy activities will help meet local development needs. Indeed, the history of energy planning suggests the contrary. Energy planning has historically adhered to a strictly supply-side approach, in which the perennial shortfall of energy services is addressed by pumping up energy supplies. This is unlikely to help alleviate poverty. As articulated in *Energy for a Sustainable World* (Goldemberg, *et al.*, 1988):

> *If the focus of energy planning is merely on the supply of energy, without scrutinising the structure of demand, the end-uses of energy and the*

beneficiaries of the energy supply, then whether energy ever reaches the poor to perform the services they need will be largely a matter of chance. Conventional supply-oriented energy strategies are unlikely to make a dent in the poverty of the majorities in developing countries. In fact, such policies may even accentuate inequalities. This is because, in a situation of inequality, the pattern of demand is skewed, with the energy demands of the affluent exerting far greater influence over the nature of energy supply than the needs of the poor. And when energy supply is shaped by such skewed demand patterns, it reinforces privilege and aggravates poverty, leading to an even worse skewing of the pattern of demand. Only if energy is deployed as an essential component of a programme to satisfy the basic needs of the population, with special emphasis on the needs of poverty-stricken sectors, is it likely that there will be an improvement in the conditions of the poor as a consequence of actions relating to energy planning. [p.33]

For the development practitioner and the bioenergy planner, the challenge is to identify bioenergy strategies that will truly help satisfy local needs. There is no question that alleviating poverty means providing greater access to energy services. In the specific context of a given rural site, however, what exactly should be done? The following guidelines are recommended to help figure this out.

Adopt participatory approaches to identify needs and to design and implement projects. Participation is one of the most effective ways to ensure that bioenergy projects help fulfill local needs. Community workers, academics, and NGOs have pioneered and promoted participatory methods, which are gradually being adopted within the broader development organisation community. Participatory approaches lead to projects that address the articulated needs of local people, rather than needs as perceived by well-meaning outsiders. The rural poor rarely express their needs in terms of energy, per se, but rather as concrete concerns in their unique contexts: such as the endemic prevalence of diarrhea among infants, the prohibitively high cost of kerosene, and the lack of paying work.

"Participatory" must be appropriately defined. If the intended beneficiaries are the poor—especially women, whose involvement is repeatedly demonstrated to be crucial—then projects need their participation. Too often, the visible and prominent community members are easily accessed, while the disenfranchised—almost by definition—are unrepresented. Their participation, therefore, is elusive and must be deliberately sought. A forum will be more successful in eliciting their participation if it targets the poor, is unthreatening, and perhaps comes with a minor incentive, such as a meal. In many cases, women can only effectively voice their opinions and discuss their concerns in separate women-only forums (Kanetkar and Varalakshmi, 1994; FAO, 1999).

Participatory approaches should underlie every stage of the bioenergy project: data collection, project design, implementation, continued operation, and ongoing evaluation. (See UNDP, *Participatory Assessment,* 1998; World Bank, *Participation Sourcebook,* 1995; and Husain, C*ommunity Participation,* 1992.)

Treat the production and supply of biomass as an integral part of the project. The entire bioenergy chain affects the local community. The existing flows of biomass resources within the community should be clearly understood, based on data and observations obtained with the assistance of local people. There is almost never enough reliable information regarding local biomass resources and their patterns of production and use. Only after carrying out a thorough biomass resource assessment is it possible to consider options for supplying a bioenergy project.

A biomass supply option must start with the articulated needs of the local community. Rarely will a community desire biomass solely for energy. Rural communities depend on local biomass resources for innumerable purposes, and their fortunes rise and fall with the availability of those resources. The amount and type of *food* locally available, and the *fuel* to prepare it, determine whether families are hungry or fed. The availability of *fodder* determines whether livestock—the single most valuable asset in many rural cultures—thrive and are productive. Homes need poles and thatch; rural entrepreneurs use an uncatalogued range of plant materials. The very health of the rural environment itself depends on a secure and diverse base of biomass.

A bioenergy project must be sensitive to these other biomass uses, and be developed accordingly. Unfortunately, this too often has not been the case. For example, an early initiative to popularise family biogas plants in India targeted only families with enough cattle to support a dung-fueled digester. Poor families did not own enough cattle, and in fact had previously depended on free dung for fuel and fertiliser. Once the digesters appeared, dung suddenly became valuable and could no longer be collected for free. The poor families ultimately had to rely on inferior, and less sustainable, sources of fuel. Where the poor use residues for fuel, bioenergy projects can make scarce a resource that was previously abundant and free. (In contrast, community biogas installations in Karnataka, India, provide digester sludge—a superior fertiliser—to all community members. See section 7.1.)

Tree planting activities in India and elsewhere in the 1980s provide another example. Often, these initiatives were justified on the basis of satisfying the rural need for fuelwood, and common land was given over to plantations and planted with quick-growing species such as eucalyptus. In many cases, however, the harvested wood went instead toward satisfying urban demand for fuel and construction poles; while the rural poor who had previously relied on the common lands for resources were left without their traditional source of fuelwood. Moreover, since eucalyptus leaves are not edible, eucalyptus plantations no longer provided fodder for livestock that formerly grazed on common land. Where the poor rely on common property for their sustenance, bioenergy projects that appropriate such land can deprive the poor of a vital common resource.

When considering a biomass supply option, therefore, it is essential to anticipate whether it will compete with existing uses—for the biomass itself, or the land on which it is grown. That is not to say that biomass and land resources are off limits unless they are utterly unutilised. Indeed, virtually no resource in rural areas of developing countries can truly be called unutilised. Rather, it means that *preexisting uses should be identified and satisfied through other means or integrated into the proposed bioenergy system.*

Foster a local institution to take responsibility for the project. Projects are more likely to satisfy local needs over the long term if a local institution is intimately involved. A local institution should be constituted through transparent, public meetings, and include ample representation of the rural poor. Their mandate should be to contribute to the design, implementation, and ongoing management of the project. Such institutions enhance a project's sustainability, and can contribute to the broader aim of fostering democratisation and effective governance at the community level. The "Village Development Society" formed to manage the community biogas digesters in Karnataka, India, is an example (section 7.1). Local institutions fill a number of roles (these are discussed more fully in chapter 6):

- The local institution can serve as the primary forum for local community participation. It is a well-defined point of contact and can provide constancy over time.
- The local institution can be charged with the responsibility and authority for successfullymanaging the project. This can endow the community with a sense of equity in the project and accountability for its success. Experience has demonstrated this to be a necessary ingredient for project success.
- By providing a transparent decision-making process and an open source of information, the local institution can minimise opportunities for abuses of office or corruption.
- When a project calls for cooperative action, the local institution can coordinate or mobilise the community. It can resolve disputes between community members.
- The local institution can be given official legal authority over common resources in cases where the bioenergy feedstock relies on common resources.

3.2. Creating Opportunities for Income Generation

Satisfying the basic needs of the poor will help to relieve the symptoms of poverty, but eliminating the root causes of poverty must involve increasing their purchasing power. Rural energy projects, and bioenergy projects in particular, have great potential to create income opportunities. These opportunities fall into three broad (and overlapping) categories.

Direct revenue or employment. Bioenergy projects offer direct opportunities for generating income. Many farmers would welcome the opportunity to sell residues or purpose-grown wood to long-term, steady consumers. Producing biomass provides a new source of revenue and helps farmers to diversify. This reduces their vulnerability to crop failures or declining crop prices, especially if the biomass is derived from a tree—a secure standing asset that can be harvested as the demand arises. Tree planting has additional rewards in terms of improved agricultural productivity and environmental benefits (For an example of contract farming, see section 7.9). Bioenergy projects benefit rural wage laborers as well, by offering employment raising biomass or working at the bioenergy facility. Sometimes, participants in bioenergy activities learn skills they can transfer to other profitable activities.

However, the rural poor do not benefit automatically from these income opportunities. Farmers need to be able to negotiate fair terms of trade, and workers need to have basic protections as wage laborers.

Typically, poor rural farmers operate in a buyer's market. With imperfect information about market prices, poor access to transport, and complete reliance on a single regional buyer, local farmers are rarely able to command the market price their product deserves. Small farmers invariably earn lower profit margins than medium and large farmers, primarily because of unequal exchange relations.

Farmers' cooperatives can help to remedy these inequities. Cooperatives exploit the economies of scale that are otherwise available only to larger farmers. They inform small farmers about market conditions and technical advances. They enable large investments of capital and labor that would otherwise be unfeasible for individual farmers. Cooperatives can spread project risk and, perhaps most importantly, they endow small farmers with greater bargaining power. Where there is only a single buyer, as in a contract-farming situation, cooperatives can make the difference between a profitable, low-risk undertaking and debt-ridden foreclosure.

…[E]nergy services can directly increase productivity by increasing the physical capacity, the skills, and the time available to carry out productive work. When the poor can invest this increased productive capacity in income-generating activities, they generally are able and willing to pay for the enabling energy services.

For rural laborers, a job's attractiveness depends on a variety of factors: wage rates, seasonal variability, job security, length of workday, job safety, availability of medical care, ability to air grievances, etc. Sometimes laws exist to ensure minimum job standards—but these laws are seldom enforced consistently. Indeed, agricultural and forestry enterprises have a poor track record of respecting basic labor rights. Bioenergy projects, if they are to contribute to equitable rural development, should only offer employment that honors basic labor rights. Ensuring that employers respect basic labor rights is not an easy task, but it is unquestionably easier when workers are allowed to organise and bargain collectively. They are then better equipped to identify, articulate, negotiate, and secure acceptable labor conditions.

Farmer and worker organisations benefit greatly from collaboration with supportive NGOs, which can lend assistance by:

- providing legal, strategic, and technical advice,
- facilitating contact with other farmer and worker organisations,
- monitoring local exchange and employment conditions,
- initiating and mediating dialogues between

employers/buyers and workers/farmers,

- introducing a recognition of gender issues,
- advocating for the farmers and workers in legal and bureaucratic forums, and
- publicising issues and attracting outside support.

As part of the participatory process, bioenergy planners can encourage the formation of local farmer and worker organisations and facilitate the participation of NGO advocates (Lipton, 1996).

General improvement in health and productivity. The energy services provided by bioenergy projects increase the general productivity of the rural poor in three ways.

First, expanded energy services can improve the general health conditions of the poor. Energy for pumping can supply potable ground water, thus reducing the reliance of the poor on surface waters, which are frequently the medium through which disease vectors are spread. Replacing wood with cleaner cooking fuels improves indoor air quality and helps reduce the pandemic levels of respiratory disease in rural areas. It can also improve nutrition in areas where fuelwood scarcity has changed consumption patterns and degraded the diet, e.g., by forcing a shift to quick-cooking cereals instead of more nutritious coarse grains and pulses, or by altogether reducing the proportion of cooked food in the diet. Indeed, the very availability of food will be improved if biomass feedstock is coproduced with additional food crops or fodder (which allows livestock to become more productive and provide greater yields of dairy products and meat). Finally, the availability of electric power for lighting and refrigeration can improve the quality and availability of medical services.

Second, energy services can improve educational opportunities and access to information, for example by electrifying educational facilities and increasing the availability of information sources such as radio, television, and telephone.

Third, energy services can free up time for productive activities by relieving some of the unending drudgery that characterises the daily lives of poor families—gathering fuelwood, hauling water, milling grain, and other laborious tasks. Currently, the poor must rely predominantly on their own labor (or on animal power) to meet these energy needs; much time and physical effort is invariably spent on these unrewarding subsistence activities. Water can be obtained in negligible time with an electric pump, whereas fetching water manually can consume one half to three hours per household per day or more. An electric pump uses only about 5 percent as much energy and, at $0.10 per kilowatt-hour, costs a fraction of a cent. A comparable amount of electricity would complete a one- to two- hour job pounding millet by hand (OTA, 1991).

Thus energy services can directly increase productivity by increasing the physical capacity, the skills, and the time available to carry out productive work. When the poor can invest this increased productive capacity in income-generating activities, they generally are able and willing to pay for the enabling energy services. A key constraint is access to these services. As discussed, bioenergy activities can be designed and implemented to maximise the potential for these services to reach the poor, but the second constraint—access to income-generating opportunities—must also be overcome.

Expansion of rural enterprises. Access to energy services can help the poor to remedy two pervasive problems that keep them in poverty: their low productivity, and their limited range of productive options. Many rural enterprises become viable only once there is access to a reliable modern energy source—mechanical power, electricity, process heat, transport fuel.

These modern forms of energy can provide critical energy services for rural agriculture and non-farm enterprises. Just as electric motors dramatically reduce the amount of effort demanded by simple household chores, they enable people to carry out activities at a commercial scale that would otherwise be simply infeasible—for example, milling a large amount of grain or irrigating an entire field. When household electric lighting replaces inferior light sources such as kerosene lamps, candles, or cooking fires, it adds productive hours to the day, since traditional light sources are barely adequate for fine work or reading. Efficient sources of process heat enable farmers to process agricultural output, increasing their revenues by turning an agricultural product into a value-added, marketable good. And increased availability of transport services provides better access to raw materials and markets.

For too long, policymakers and international agencies have neglected small rural enterprises. With perhaps only one or two workers, rural enterprises are typically part of the informal sector and are easily overlooked in official economic and labor statistics—especially in the case of women entrepreneurs, who frequently operate out of the home and are usually marginal, smaller producers. But it is now increasingly recognised that small enterprises play a vital role in rural economies. They provide a primary or secondary income for 30 to 50 percent of rural households, and contribute 30 to 40 percent of total rural family incomes—considerably more than farm wage labor. In several lines of activity, small rural enterprises are actually more economically efficient than their large-scale, urban counterparts (Liedholm, 1998; FAO, 1998).

However, rural enterprise will not be spurred automatically, with the mere arrival of modern energy. Bioenergy projects should explicitly seek to establish links with income opportunities. A bioenergy project in Hosahalli, India, provides an especially good example. In this village, a small-scale biomass gasifier and diesel generator provides electric power for household lighting, a village flourmill, and pumping of potable water and irrigation water. The irrigated cropland includes a plot on which the villagers grow mulberry, which produces enough woody stalks as a residue to fuel the gasifier. The primary crop is the mulberry leaves that are fed to silkworms, yielding silk cocoons that are then sold. This covers the cost of the bioenergy system and generates a profit for the villagers. Similarly, a biogas digester installation in Karnataka (section 7.1) provides irrigation water to a high-value crop that yields extra revenue for the community-managed biogas system.

As in this example, rural enterprises are often linked to the production steps upstream and downstream of farm activities: providing and preparing agricultural inputs such as fertiliser, selling and servicing farm equipment such as bullock carts, handling and processing agricultural products, and transporting and marketing finished goods. Certain bioenergy feedstock production and supply chains, if appropriately designed, can offer multiple opportunities for income generation. The co-production of value-added products is economically promising, as is already evident in many examples (e.g., silkworm rearing in Hosahalli).

Bioenergy planners need to create the enabling conditions that make rural enterprises viable. Rural entrepreneurs typically identify the lack of credit and capital as their greatest impediment. Most developing countries have two distinct capital markets: the formal and the informal. The formal capital market consists of banks and other government regulated sources of credit, offering loans at official interest rates that range from 10 to 20 percent. This source of capital is primarily available to a limited commercial clientele, and even subsidised credit programs frequently do not benefit poor households. On the other hand, the informal capital market is more widely accessible to the poor, but at interest rates that are set at exorbitant levels by moneylenders, often exceeding 100 percent. In addition to this lack of a reasonable source of credit, poor families lack a secure option for accumulating savings that provides both liquidity and returns.

Thus for the poor it is extremely difficult to acquire or accumulate financial assets. But in recent years, innovative microfinance initiatives, such as the well-known Grameen Bank in Bangladesh, have definitively shown that poor families are creditworthy and that they make investments that are highly remunerative—indeed life-transforming. The Bank Rakyat Indonesia, also involved in local banking, has demonstrated furthermore that local microfinance can be a self-sustaining, unsubsidised, commercial undertaking, *without* levying the exorbitant rates found on the informal credit market. With supportive policies, this model appears poised to expand into other poor communities, particularly those with unexploited opportunities for productive investment (Robinson, 1998; Zeller and Sharma, 1996; Lipton, 1996). Bioenergy activities could serve as an effective platform for this expansion, bringing together enterprise-enabling energy services with access to investment capital.

In many cases, however, the key obstacle facing rural enterprise is not credit but inadequate upstream and downstream linkages.[1] Remote enterprises can find it difficult to procure raw materials at reasonable prices on a reliable basis, or to reach prospective sources of demand for their

[1] In such cases, easy credit could undermine rural enterprises by overcapitalising them.

products. Often, this results from inadequate physical infrastructure such as roads. Integrating these rural areas more fully into the wider economy opens up opportunities for small enterprises. This integration should be undertaken carefully, however, as it could hurt rural enterprises as well as help them—poor transportation infrastructure and other high transaction costs sometimes protect rural enterprises from urban competition and imports (FAO, 1998). No less important than physical infrastructure is social infrastructure—healthy workers with productive skills, management expertise, access to market information, and the resources to negotiate fair terms of trade.

Rural bioenergy activities can foster the growth of physical and social infrastructure. Where developing bioenergy is profitable for the private sector, rural bioenergy facilities can provide a much-needed tax base to finance development-supporting investments. In the case of larger, capital-intensive facilities such as ethanol distilleries or grid-feeding electric power facilities, substantial tax revenues can be raised. If tax policies are structured to reinvest taxes locally, rather than diverting them to the urban sector, tax revenues can fund roads, schools, health care facilities, etc., in rural areas. These and other infrastructure improvements that promote economic activity, along with the availability of competitively priced power, can attract energy-consuming activities to rural area (Box 3-2).

Box 3-2. Taxing Rural Industries: The Potential

There are a variety of approaches that could be considered for taxing rural industries to pay for infrastructure development. Without passing judgment on the relative merits of one tax instrument over another, consider the following zillustration of the potential revenue base that might be generated from a taxation strategy.

In the United States, property taxes on businesses and homes are levied to support much local infrastructure building. A property tax levied on a rapidly growing, capital-intensive industry, such as the electric power industry could provide an enormous tax revenue base. To illustrate this, suppose that a 1.5 percent property tax were levied on biomass electricity-generating facilities (A 1.5 percent per year tax on the installed capital cost is a typical rate for investor-owned power plants in the United States). Such a tax applied to a multi-megawatt biomass power plant would account for a minor part of the total cost of generating electricity, but the tax revenues would be substantial over the lifetime of the facility.

Consider the implications for a particular developing country, say India. In the mid-1980s, only about one sixth of electricity generated was provided to rural areas of India even though nearly three fourths of the population is rural. Suppose that a concerted effort were made on the part of policymakers to accelerate rural industrialisation, and assume that:

- for the country as a whole electrical generating capacity increases by 5 GW each year, (i.e., 5 percent annual growth over the present installed capacity of approximately 100 GW),
- one third of all new electrical generating capacity is sited in rural areas,
- the average installed cost for new biomass generating capacity is $1300/kW$_e$, and
- rural power facilities are owned privately and taxed at an annual property tax rate of 1.5 percent of the installed capital cost during their presumed operating lifetime of 30 years.

Then new rural generating stations built in one year would result in lifetime tax revenues of approximately $1 billion:

$$(5{,}000{,}000\ \text{kW}) * (1/3) * (\$1300/\text{kW}_e) * (1.5\%/\text{year}) * (30\ \text{years}) = \sim \$1\ \text{billion}.$$

This revenue could grow to be an important source of funds for rural areas, if it were reinvested in rural economies to build infrastructure and provide basic services.

Source: Larson and Wilson,1995

Although the focus here is on rural enterprise, access to energy resources benefits farming as well. Agricultural productivity can be greatly increased. The availability of a reliable supply of irrigation water is a main factor enabling farmers to plant more than one crop during the year. This increases not only the amount of food produced per hectare, but also the amount of agricultural employment per hectare. The amount of arable land under irrigation—now less than a third of all agricultural lands—will probably have to expand to keep pace with food demands. On the large amount of land that cannot be irrigated by gravity-flow techniques, irrigation will rely on the use of motorised pump sets, which can be powered by biomass-derived gas or electricity. Better access to energy services can also improve the efficiency with which food reaches consumers. Food losses are high in developing countries in part because the means of processing, storing, and transporting agricultural produce are inadequate.

Growing incomes, expanding enterprises, and improving agriculture in rural areas generates a self-reinforcing momentum. As incomes increase, capital for investment becomes more available and demand for locally produced goods and services grows—fueling further opportunities for income-generating activities. Increasing the purchasing power of lower-income households is the most effective means of stimulating this self-reinforcing phenomenon. Households with higher incomes tend to spend more of their earnings on goods from the urban manufacturing sector or on imports, whereas poorer households tend to purchase services and goods generated within the local rural enterprise sector (FAO, 1998; Liedholm, 1998). The development goals of bioenergy projects will benefit from targeting efforts at poorer households, helping them to meet their basic needs, accumulate productive assets, and become a source of demand in the incipient local economies.

Bioenergy planners must bear in mind that a diffusion of energy-services and an increase in mechanisation do not always benefit rural development. In some situations, labor scarcity is indeed a problem and labour-saving innovations are welcome—for example, at key points in the seasonal agricultural cycle when lack of labor constrains agricultural productivity. But in *most* rural areas at most times of the year, severe unemployment or underemployment prevails. Energy services will support development only to the extent that they expand employment opportunities.

Historically, mechanisation has often conflicted with employment. From the displacement of English farm laborers by threshing machines (which culminated in an agrarian uprising in 1830 that was "the greatest machine-breaking episode of English history" (Hobsbawm and Rude, 1968) up to today, this process of displacement is frequently rationalised on the grounds of improved economic efficiency. Its impacts on poor laborers are deemed a regrettable but unavoidable consequence of modernisation. Too often, however, the displacement of labor cannot even be rationalised on the grounds of economic efficiency. In many economies, overvalued exchange rates, direct capital incentives, and subsidised credit have introduced market distortions that induce excessive substitution of capital for labor. Bioenergy planners should be aware that such external economic factors might increase the possibility that a bioenergy project will displace laborers.

One well-studied example of the effects of mechanisation is the introduction of small rice-milling machines, which spare rural households the laborious task of hand-pounding rice. Frequently, however, this hand pounding was done by hired women, usually from a village's poorest families with little or no land on which to produce their own rice. In rice-growing regions throughout the world, the introduction of mechanised rice milling led to the rapid loss of employment for millions of poor women, while jobs as rice mill operators generally went to men (Batliwala and Reddy, 1996). This has been documented, for example, in Bangladesh (OTA, 1991) and Indonesia (Timmer, 1998; Reddy, Williams, Johansson, 1997). Whether the net economic impact of this innovation was positive or negative has been debated (Collier *et al.,* 1998; Timmer, 1998), but the point is that severe social dislocation can, and often does, result.

If they are to avoid such impacts, bioenergy projects must target energy services in ways that *increase* opportunities for productive activity, not *displace* them. Bioenergy planners should try to anticipate where workers might be displaced, design projects to minimise this possibility, monitor to see whether this is happening, and if so, implement steps to soften or offset the impacts. Such steps include, for example, temporary material assistance, alternative employment opportunities, and the training and resources that will enable displaced workers to take advantage of those opportunities. Particular attention should be directed toward women and girls; they are especially likely to be displaced, their displacement is more likely to go unredressed, and their access to alternative employment opportunities is more likely to be constrained.

A bioenergy project is unlikely to benefit women—or succeed at all—unless it involves women from the beginning. Indeed, more likely than not, women will be the main local collaborators in successful bioenergy activities.

3.3. Gender Impacts

> *Poverty has a woman's face. Of the approximately 1.3 billion people living in poverty, 70% are women. Increasing poverty among women has been linked to their unequal situation in the labour market, their unequal treatment under social welfare systems, their lack of access to health and education services, and their lack of status and power in the family.*
> (Reddy, Williams, Johansson, 1997)

Despite the obvious disparities between men and women, development interventions have stubbornly maintained a unitary "family approach," assuming that the welfare of the head of the family, who is assumed to be a man, will percolate down to the women and children. This trickle-down theory, applied at the household level, has proven as ineffectual as when applied at the national level. Increasingly, however, the development community is gaining an appreciation for the distinct positions held by men and women and the significance of gender roles for development. This growing awareness involves recognition that women and men have different interests, different needs, different roles, and different degrees of access and control to productive resources. These affect how a household functions, how it responds to environmental and social stresses, and its prospects for escaping poverty (Kelkar, 1995; Obaidullah Khan, 1995; Osterveen, 1995; Skutsch, 1995).

Women's energy-related needs. In energy policy, this recognition is urgently needed. Women suffer in ways that are intimately linked with current patterns of rural energy use. They invariably do more work than men, despite the fact that they eat more poorly and get less sleep. Women, who are responsible for almost all household labor, are burdened with the arduous tasks of gathering fuelwood and hauling water—tasks that are growing more difficult as wood and water resources diminish. Consequently, women are especially vulnerable to environmental scarcity.

By some estimates, the proportion of rural women affected by fuelwood scarcity is 60 percent in Africa, nearly 80 percent in Asia, and nearly 40 percent in Latin America, and gathering fuelwood can consume 1 to 5 hours of these women's day (UNDP, 1995). The proportion of rural women affected by water scarcity has been estimated at 55 percent in Africa, 32 percent in Asia, and 45 percent in Latin America, and the median time for collecting water during the dry season is 1.6 hours (World's Women, 1995). Processing food—for example, grinding grain in a mortar and pestle—and cooking food are additional major daily responsibilities women have that require excessive time and energy (Reddy, Williams, and Johansson, 1997).

These labor-intensive activities take their toll in several ways. If acquiring wood and water become yet more time-consuming due to scarcity, they will put ever-growing burdens on rural women, who already face several conflicting demands on their time. These tedious and unrelenting daily chores constrain women's ability to devote time to income-generating activities, household food production, and family welfare in general. In some areas of Nepal, for example, deforestation is now so severe that a women might spend an entire day collecting fuelwood, whereas a generation ago it took her mother an hour or two. These Nepalese women therefore have less time for tasks related to food production and preparation, and child nutrition has declined as a direct result. Children, especially girls, are also adversely affected, and sometimes must sacrifice schooling so they can help their mothers obtain fuelwood (Conway, 1997; Agarwal, 1986).

Women also contend with health problems caused by their strenuous physical labors. They routinely suffer neck, back, and reproductive problems from carrying heavy loads. Women who gather wood for sale sometimes carry headloads of 40 to 60 kg—nearly their own body weight. Women and girls, because they are almost exclusively responsible for cooking, also disproportionately endure indoor air pollution and suffer its chronic, noxious effects (Reddy *et al.*, 1997). Each of these taxing responsibilities—wood collecting, water hauling, food processing, and food cooking (among others)—can be eased with bioenergy-related services. Thus bioenergy projects must take gender into account if they are to address the abiding problems of rural poverty effectively.

Integrating gender issues into energy. Taking gender into account requires a conscious shift in attention.

> *Women's survival tasks, with the exception of cooking, have been largely invisible in the energy literature: an electric pump that transports water uses energy, but a woman carrying water does not. A water mill grinding grain falls within the energy sector, but a woman doing the same task with mortar and pestle does not. Trucks transporting crops are consuming fossil fuels, but women headloading crops walk outside the energy balance.*
>
> *Not only are such non-marketed goods and services not considered within the scope of the energy sector, they are not usually included in the national accounts that measure Gross National Product. Thus a misleading picture of the real economic importance of informal production as well as of the actual value of substitutes is provided by national accounts. This can induce policy makers to invest in large infrastructure projects rather than informal household production. Such neglect of informal sector activities can be to the detriment of the national economy in general, and of rural and urban poor populations, especially women, in particular.* (Cecelski, 1995, p.565)

Acknowledging these areas as legitimate concerns for energy policy is a first step toward addressing them. Of course, merely throwing an energy technology at a problem will not solve it, and it certainly does not constitute a gender approach to energy. Women must not be seen merely as beneficiaries of targeted welfare improvements, but also as agents of judgement and change in their own right—no less, and perhaps more so, than men. That will require understanding their distinct circumstance in rural society. Women's circumstances differ considerably from one location to the next and, even within a given village, women of different classes, castes, or ethnicities can have greatly differing circumstances. Despite all the generalisations made in this brief discussion of gender and energy, conditions vary dramatically from one situation to the next, which is why local women's input is vital.

Participation of women. A bioenergy project is unlikely to benefit women—or succeed at all—unless it involves women from the beginning. Indeed, more likely than not, women will be the *main* local collaborators in successful bioenergy activities. They are, in fact, indispensable to many local development organisations and movements. Owing to the considerable gender differences in access to, control over, and reliance on, bioresources (both for energy and non-energy purposes), women will have different needs, opinions, knowledge, and skills than men.

As the primary gatherers of biomass and water, and the primary users of household energy, women have expertise in local biomass resources, including their properties as fuels and fuel-saving techniques. "Women can differentiate between those species which provide quick high heat, those which provide long-lasting low heat, and those which smoke." They understand the costs and benefits of different end-use devices such as cookstoves, are the chief repositories of knowledge concerning the use and management of trees and other biomass resources, and can be invaluable contributors to technical innovation. "When it comes to the management of fuelwood species, successive generations of older women have trained younger women in the art of lopping or pollarding." They influence household decisions about energy use, and pass on their knowledge and attitudes to succeeding generations (Kelkar, 1995; Cecelski, 1995).

It can be especially challenging to elicit the participation of women. Women are frequently excluded from public decision-making forums or, if not excluded, their active participation and initiative may be discouraged by attitudes about appropriate female conduct. Women face a "glass ceiling" in village committees and farmers organisations, just as in the corporate world (Obaidullah Khan, 1995). In many situations, local women can freely interact only with female project implementers or extension workers, and can only effectively voice their opinions and their concerns in women-only forums (Varalakshmi, 1993; FAO, 1999).

Access and control. Especially with bioenergy projects, it is imperative to recognise that women and men have different degrees of access and control to environmental resources. In most rural societies, women are deeply involved with obtaining resources from the surroundings—food, fuelwood, dung, fodder, artisan materials, water, etc.—but their access is limited and they rarely have true control over the resource. They can harvest, but often cannot *sell*. They tend crops, but often are excluded from decisions about *which* crops are planted. They can cultivate land, but often are prohibited from *owning* land (Kelkar, 1995).

This lack of control is one of the conditions that make women particularly vulnerable to adverse impacts from bioenergy projects. Often, common lands are appropriated to grow biomass feedstock. Women, however, are especially dependent on common property resources because of their limited control over private resources. In northern India, for example, nearly half the income of poor women depends on resources from common land, compared to only one eighth of poor men's incomes (Reddy, Williams, and Johansson, 1997).

The loss of access to common land can have devastating impacts on their livelihoods, since women rely on common lands not only for fuel but also for food (fruits, oils, nuts, herbs, honey, etc.), fodder, construction materials, artisan materials, medicinal plants, resins, gums, etc. However, traditional use-rights to common lands—especially women's use-rights—are often disregarded and overridden by official legal agreements. Moreover, because their activity frequently is part of the informal economy, it may be overlooked by outsiders.

Thus bioenergy planners must carefully document existing patterns of resource use, and make sure that the proposed use of land or resources for bioenergy does not conflict with current uses—conflicts which are especially likely to affect women. Since common lands often fulfill such a diversity of needs, their use for energy production must be scrutinised with local participation during the early planning phases of a project. Where local communities rely on common lands for multiple purposes, the cultivation of energy crops should be carefully integrated with other competing needs. By the same token, women, by virtue of their dependence on the common resources, are often uniquely qualified to manage common land resources.

Engaging in income-generating activities. Although it is widely acknowledged that women benefit greatly when they secure an independent source of income, women face many barriers to participating in the income-generating opportunities of rural development projects. Women have difficulty accessing credit, because they often lack title to land, livestock, or other property needed as collateral for loans. In some regions, women are treated as legal minors, and are not permitted to engage in financial contracts involving the purchase, sale, or mortgaging of assets. They may be restricted from interacting with the community, which limits their ability to benefit from extension services or to acquire inputs, market finished goods, or organise with other women. They are constrained further by the chronic load of subsistence activities—fuel and water collecting, food production and preparation, childrearing—for which women are responsible but are not remunerated. Additional work, even if it could provide much-needed income, is sometimes impossible unless subsistence activities are more equitably shared. Bioenergy planners must be familiar with such constraints if projects are to effectively benefit women.

Benefiting from energy end-use technologies. The introduction of energy end-use technologies can affect women in complex ways, many of which are positive. For example, community water systems powered by biogas spare women the drudgery of hauling water (section 7.1). Women have also benefited from some projects that introduced small-scale mills to villages. In the Gambia, a sorghum mill saved women 1 to 1.5 hours of milling daily, which was invested in increased food production or more time for household work (Barret and Browne, 1993). In these cases, energy end-use technologies relieved women of unremunerative work and generated time for other activities.

But the introduction of new technologies can also worsen women's situation. There is a pervasive cultural sense that machines are the domain of men. When machines are introduced, women's work all too often becomes men's work, and women laborers are displaced by male operators. This bias applies to animal energy as well as mechanical energy. If a given task is "assisted by animal power involving the use of bullocks, men take charge of it; and if the operation requires continuous bending or sitting postures and is back-breaking and strenuous, then women do it" (Batliwala and Reddy, 1996; p.3).

This cultural bias is aggravated when innovation, education, and dissemination are targeted at larger farmers or entrepreneurs, as often happens. Less visible to government or development institutions, and unable to invest in capital, women are overlooked in favor of men and their private enterprises. In Ghana, for example, a feasibility study of improved kilns for making charcoal from sawmill residues "found that small-scale itinerant producers (mostly women) were unlikely to be able to secure land tenure for fixed kilns, to invest in the new equipment or to purchase the now more valuable residues." In Nigeria, "the introduction of modern power-driven palm-oil mills resulted in women demonstrating against them because the women lost valuable by-products and income to their husbands" (Cecelski, 1995; p.568). The displacement of women by the introduction of small grain mills, discussed earlier, is a well-known and widespread example of how women laborers are displaced by mechanical equipment.

Cases where this bias toward men has been successfully overturned provide lessons for future projects. "Women have been trained very successfully to repair and maintain drinking water pumps and installations in many countries. Experience with women in maintenance roles indicates that while some costs may be higher (due to their need for more training and restrictions on travel that can reduce the number of pumps they maintain), their effectiveness in regular and preventive maintenance is better than men's, and costs of repair campaigns are lower" (Van Wijk-Sijbesma and Bolt, 1992, quoted in Cecelski, 1995; p.570).

Expanding women's capacities and empowering women. A bioenergy project that accounts for gender will inevitably meet the *immediate* needs of rural women more effectively. However, as articulated in the FAO's Policy Statement on Gender and Wood Energy, such an approach has the potential to "assist in meeting the *strategic* needs of women also, particularly with regard to establishing women's rights in the sharing of both responsibilities and benefits" (RWEDP, 1995; p.15). Indeed, this broader approach can tackle not only the *symptoms* but also the *cause* of gender disparities.

Bioenergy projects offer multiple opportunities to forward this wider agenda. They can provide innovative fora that allow women to share, articulate, and act on their concerns; enhance women's access to productive resources; offer the independence that comes with personal income; and promote literacy, numeracy, technical skills and other knowledge and information.

3.4. Land Use Competition and Land Tenure

High yields and efficient conversion and use of biomass energy can minimise the amount of land required for biomass energy production. But biomass is still a land-intensive energy resource, and in many countries there is justified concern whether bioenergy diverts land from production of food and other essential needs. This concern would be especially relevant if biomass energy became a major contributor to national energy supplies, or if particular regions had large concentrations of bioenergy activities.

Simultaneously modernising biomass production for energy and biomass production for food could prevent such competition for land. These "two modernisations" could be pursued synergistically. The availability of modern energy carriers (especially electricity) derived from biomass would spur rural enterprises and generate the income needed to pay for the capital investments and inputs required for modernising agriculture (Larson and Williams, 1995). In turn, higher yield agriculture would provide larger quantities of biomass residues that can be used for energy. This synergistic process would yield considerable local benefits if agriculture were modernised in ways that are locally appropriate and sustainable.

If agriculture is modernised and intensified, more land would potentially become available for biomass energy. Consider a recent food-versus-fuel assessment for India (Ravindranath and Hall, 1995; Sudha and Ravindranath, 1999)—a country widely considered to have little spare land. The total area under crops in India was roughly the same in 1990 (around 125 million hectares) as in 1970, despite population growth averaging about 2.4 percent per year during this time, and cultivable non-cropland has remained stable at about 40 million hectares. Ravindranath and Hall note that the average yield of India's most important crop, rice, is only about half the Asian average, one third of the yield in China and Japan, and one fifth the Korean yield. They also note that in some states of India (Tamil Nadu and Punjab), the rice yield is double the Indian average.

Bioenergy planners should be clear about what the biomass requirements are in a bioenergy project, and from where the biomass will be obtained. If there is potential for competition with other land uses, such competition should be addressed, perhaps by exploring ways to enhance the production and/or accessibility of the other products.

The authors conclude from these data, along with an analysis of the barriers to raising crop yields and cropping intensities (i.e., cultivation of at least two crops per year through irrigation), that the prospects are good for doubling or tripling average annual yields in India—thus doubling or tripling food production without increasing cropped area. This would leave substantial amounts of land for other uses. Ravindranath and Hall propose using degraded lands for biomass energy production. India has an estimated 60 to 70 million hectares of uncultivated degraded land, out of a total land area of about 300 million hectares. To illustrate the potential, if 60 million hectares could be used to grow biomass for energy (at fairly high yields of 10 dry tons/ha) on a sustainable basis, it would yield as much as 12 EJ per year. For comparison, total commercial energy use in India in the mid-1990s was about 20 EJ per year.

This suggests that with a concerted parallel effort to modernise agriculture, production of food need not compete with production of biomass for energy. It is essential, therefore, to understand local needs for improving agriculture and what resources and expertise would help meet those needs. It is important to recognise that modernising agriculture is a notoriously daunting challenge lying at the very core of rural development.

Not surprisingly, the historic record provides few examples of large land-intensive undertakings that successfully minimised competition with staple food production by supporting investments in agricultural modernisation. In contrast, such undertakings often present severe competition for land, frequently to the detriment of local populations. In Brazil, for example,

> *As a result of the Ethanol Programme, large sugarcane plantations [were] established in regions where previously many small farms existed. As a result, the subsistence crops of small farms—corn, vegetables, black beans, etc.—are being eliminated, leading to the import of food from distant regions. This has had the negative social consequence of forcing an exodus of small farmers and field laborers to cities where it is difficult for them to get jobs, or of making them seasonal laborers for the large plantations where sugarcane cultivation occupies only six to seven months in a year. It has had a negative effect on income distribution by concentrating resources in the hands of a few entrepreneurs.* (Goldemberg *et al.*, 1988; p. 250)

Similarly, social forestry initiatives in certain Indian states have displaced staple food crops and led to a rapid rise in food prices (Pasztor and Kristoferson, 1990). Pulpwood plantations

Table 3.1. Selected Indicators of Socioeconomic Sustainability

Category	Impact	Quantitative indicators, based on assessment of:
Basic needs	Improved access to basic services.	Families with access to energy services (cooking fuel, pumped water, electric lighting, milling, etc.), quality, reliability, accessibility, cost.
Income generating opportunities	Creation or displacement of jobs, livelihoods.	Volume of industry and small-scale enterprise promoted, jobs/$ invested, jobs/ha used, salaries, seasonality, accessibility to local laborers, local recyling of revenue (through wages, local expenditures, taxes), development of markets for local farm and non-farm products.
Gender	Impacts on labor, power, access to resources.	Relative access to outputs of bioenergy project. Decision-making responsibility both within and outside of bioenergy project. Changes to former division of labor. Access to resources relating to bioenergy activities.
Land use competition and land tenure.	Changing patterns of land . ownership. Altered access to common land resources Emerging local and macroeconomic competition with other land uses	Recent ownership patterns and trends (e.g., consolidation or distribution of landholdings, privatization, common enclosures, transferal of land rights/tree rights).Price effects on alternate products. Simultaneous land uses (e.g., multipurpose coproduction of other outputs such as traditional biofuel, fodder, food, artisanal products, etc.).

in many countries have led to the displacement of farmers and a decline in production of other agriculture and forest products (Carrere and Lohmann, 1996; WRM, 1999).

Even when land-intensive activities do not measurably affect aggregate food production or market prices, they can still seriously erode the food security of displaced rural families. The ousting of tenant farmers, the reoccupation of land by absentee landowners, and the outright appropriation and consolidation of land, have all been routine responses to rising land values. Common lands, which are often managed in accordance with traditional usage rights that are not legally documented, are particularly susceptible to appropriation.

Bioenergy planners should be clear about what the biomass requirements are in a bioenergy project, and from where the biomass will be obtained. If there is potential for competition with other land uses, such competition should be addressed, perhaps by exploring ways to enhance the production and/or accessibility of the other products. For example, in the case of food, parallel efforts to sustainably modernise food production might be necessary to preserve the food security of a community. Furthermore, it is important to understand legally recognised land ownership rights, as well as the often-subtle nature of traditional land usage rights.

3.5. Socioeconomic Indicators for Evaluating a Project

Quantitative indicators of socioeconomic impacts of a project, to the extent that they can be determined, can be helpful in evaluating overall impacts. Table 3.1 offers some possible quantitative indicators for assessing impacts in the four thematic areas discussed in this chapter. ■

References for Chapter 3

See combined references for chapters 3 and 4 on page 79.

4 ENVIRONMENTAL ISSUES

Aerial view of commercial eucalyptus stands separated by natural vegetation strips in the state of Bahia, Brazil.

An underlying theme is that biomass must be produced in a manner that is sensitive to local ecological conditions.

Bioenergy systems can have a wide range of potential impacts. These impacts have to be viewed in comparison to the likely alternative land-use activities. That is, the relative impact of producing bioenergy feedstocks depends not only on how the biomass is produced, but also on how the land might have been used otherwise. Would it have lain barren and degraded? Would annual agricultural crops have been cultivated? Would natural forest have continued to thrive?

Many bioenergy conversion technologies do not depend on a specific feedstock. They offer flexibility in choice of feedstock and management practices because they put few restrictions on the type of biomass that can be used. In contrast, most agricultural products are subject to rigorous consumer demands in terms of taste, nutritional content, uniformity, transportability, etc. This flexibility makes it easier to meet the challenge of producing biomass feedstocks than agricultural products while simultaneously meeting environmental objectives.

An underlying theme is that biomass must be produced in a manner that is sensitive to local ecological conditions. To the extent possible, crop types should be favored that match native ecosystem types, for example, by selecting perennial grasses in prairie or savanna regions, and trees in woodland regions. Indigenous species should be favored over exotic species. Non-indigenous crops are generally unsuitable as habitat for native insect species, with the result that fewer birds and other predator species find the planted area to be a productive feeding ground. Moreover, native species are better adapted to local stress conditions, so they reduce the risk of catastrophic failure due to pestilence, disease, or drought.

In addition, a bioenergy crop must not be an invasive species, that is, capable of escaping the cultivated area and thriving uncontrollably at the expense of other indigenous species. Some species commonly used in plantations have reproduced widely beyond the plantation and become pests to the local vegetation—for example, *Pinus patula* and *Acacia melanoxylon* in South Africa, *Pinus pinaster* in Uruguay, and Eucalyptus in various regions. Similarly, monoculture must be avoided, since widespread planting of a single crop can function as an incubation medium for pests or disease, which can then spread into natural habitat. This has occurred in India, where a fungal disease spread from the exotic pines on plantations to native pines, and in Kenya and Malawi, where aphids spread from exotic cypress to native species.

Crops must not only be suitable for the broad ecological region, but must be tailored to the ecological characteristics of the specific cropping site as well. Susceptibility to erosion depends on slope, soil type, wind patterns, animal and human traffic—all of which determine what crops are appropriate. Soil quality, nutrient status, and water availability determine what crops can thrive sustainably. Whether a given biomass cropping systems can contribute to biodiversity depends in part on the other local species and the types of habitat they require.

4.1. Soil Quality and Fertility

Soil Nutrient Content and Fertility

Plants, and ecosystems more broadly, depend on the soil as a reserve of nutrients for healthy functioning. The major nutrients (macronutrients) are phosphorous, potassium, nitrogen, calcium, magnesium, and sulfur. Micronutrients, needed only in minute quantities, include iron, copper, chlorine, manganese, boron, zinc, and molybdenum.

Dissolved nutrients are taken up through the roots of plants, incorporated into plant biomass, returned to the soil in the form of organic matter when plants die or shed, and are mineralised (broken down once more into soluble forms) by microorganisms in the soil. The nitrogen cycle involves an important additional sub-cycle, through which nitrogen is exchanged between the atmosphere and the soils through the action of highly specialised microorganisms. These cycles dominate the flow of nutrients, although there is some additional gain of nutrients through rainwater and the weathering of minerals, and some loss of nutrients that dissolve into groundwater or surface water. In undisturbed systems, these gains and losses strike a balance.

Impacts. As with any land-intensive human activity, bioenergy feedstock production can dramatically affect these naturally balanced nutrient cycles. The most direct way that bioenergy systems affect soil nutrient cycles is by removing nutrients when biomass feedstock is harvested from the field, interrupting the natural process by which decomposing plant matter would replenish soil nutrients. Especially in the case of rapid-growth bioenergy crops and complete removal of agricultural residues, there is a concern about depletion of nutrients and decline in soil fertility. Moreover, exposure of soils after harvesting can increase decomposition rates at a time when no vegetation is present to take up nutrients, leading to increased leaching. The soil's fertility can also decline if the community of microorganisms responsible for nutrient cycling is adversely affected, or if chemical or physical changes in the soil cause nutrients to be leached or converted into compounds that are less usable to plants. Leaching is accelerated in acidic soils and in warm, humid climates, which favor more rapid decomposition.

Plants, and ecosystems more broadly, depend on the soil as a reserve of nutrients for healthy functioning… As with any land-intensive human activity, bioenergy feedstock production can dramatically affect these naturally balanced nutrient cycles.

Responses. In many cases, the risk of nutrient depletion can be reduced by allowing the most nutrient-rich parts of the plant—e.g., small branches, twigs, and leaves—to decompose on the field. In some cases, the harvest can be timed for the part of the growing cycle when the above-ground living biomass has relatively low nutrient content. Table 4.1(see page 67) shows for a particular Eucalyptus

Table 4.1. Nutrient Content of *Eucalyptus* Saligna Plantation

	Percent of tree's total content of nutrient				
Component	**Nitrogen**	**Phosporous**	**Potassium**	**Calcium**	**Magnesium**
Trunk	12	49	24	8	14
Bark	8	9	15	27	30
Branches	17	14	26	34	17
Leaves	63	28	35	31	39
Total Tree	100	100	100	100	100

Source: Carerre and Lohman, 1996

species, that harvesting the trunk and bark (which accounts for most of the biomass), while leaving the branches and leaves, allows much of the nutrient content to return to the soil. As discussed below, this practice can have beneficial effects on soil quality, erosion control, weed control, and biodiversity, but it also has potential risks in terms of presenting a fire hazard, encouraging the growth of pests and diseases, and in some cases contaminating the soil. Compared to natural forests, leaf litter and other detritus in pine and eucalyptus stands are decomposed by soil flora and fauna more slowly and contribute less readily to the reservoir of available nutrients. This is because of changes in physical conditions (pH, temperature, humidity) that make decomposition proceed more slowly, and the presence of compounds (tannin, lignin, oils, waxes) that are difficult to metabolise or toxic to microorganisms.

In some bioenergy systems, the feedstock's nutrient content can potentially be recovered from the conversion facility in the form of ash or sludge and then converted into a form that can be applied to the field rather than put in a landfill, with its potential environmental problems. However, the nutritive value of the ash or sludge may be less than optimal: e.g., nitrogen released during combustion will be absent from ash, and certain other nutrients may not be in a bioavailable form. If chemical or organic fertilisers are needed, it could introduce other potential problems (See below for a further discussion of the use of fertilisers).

The use of nitrogen-fixing species as a biomass feedstock can eliminate or reduce the need for nitrogen fertiliser. Nitrogen-fixing species support on their roots specific bacteria that convert bio-unavailable nitrogen in the soil into bioavailable forms. Periodic soil analyses can help diagnose and correct nutrient deficiencies.

Organic Content of Soil

Although organic matter is a small percentage of the total soil mass (typically only 1 to 6 percent), it plays a fundamental role. Soil organic matter serves as the soil's nutrient reservoir—it is the raw material from which microorganisms release the soluble nutrients needed by plants. It also serves as a storage site for inorganic nutrients, which bind to the large surface areas of organic matter particles. Organic matter is therefore largely responsible for preserving the fertility of soils by preventing leaching and making nutrients available for plant use. Thus soils can quickly become barren as organic content declines.

Organic matter is also a main determinant of soil texture and structure, increasing the porosity and decreasing the density of soil, thereby allowing water and air to reach roots and opening the soil to root growth. Loose soil structure also increases the water-holding capacity of soils, which is especially important in regions with low or highly variable rainfall.

Impacts. Soil organic matter is generated when plant matter above and below ground (i.e., leaves, twigs, roots, etc.) dies and decays. The main threat to organic matter is the excessive removal of plant matter from the land. Whereas soil nutrient deficiencies can often be prevented through the addition of fertiliser, organic matter deficiencies can only be addressed through careful management of plant matter.[1] Intensive harvesting of quick-growing energy crops and removal of residues from agricultural and forestry activities can rapidly

[1] Plant matter might also be the only viable source of some micronutrients that are not generally available in chemical fertilisers.

diminish soil organic content. Conversely, careful crop management can help renew the organic content of degraded soils.

Responses. As discussed above in the case of soil nutrients, it is important to ensure that sufficient plant matter remains on the land. For some agricultural conditions, empirically based methods can be used to estimate the amount of agricultural residues that should remain on the field after a harvest. Similarly, estimates are available of the rate at which residues can be safely extracted from forests that are logged for timber and pulpwood. To be useful, such estimates must account for type of plant, field characteristics, weather, agricultural/ forestry practices, and other site specific characteristics (These issues are discussed further below as they pertain to soil erosion.).

Soil Texture

Soil texture refers to physical characteristics such as soil density, porosity, and permeability. It is important for two main reasons. First, these characteristics determine how easily roots can grow and penetrate into the soil, which is necessary if plants are to have adequate access to water and nutrients. Second, soil texture largely determines how the soil interacts with water. Rainwater penetrates soil that is porous and permeable, providing a ready source of water for plants as well as recharging groundwater reserves.

Impacts. Soil texture can be adversely affected by over-removal of organic matter (as mentioned above), and by compaction of the soil by livestock or agricultural machinery. As soil is compacted, it loses its ability to absorb water. During rainy periods, more water will be lost in runoff, and less will penetrate the soil—increasing erosion rates and decreasing the availability of ground water and soil water for plants. An extreme degree of compaction results in the formation of a "hardpan" below the depth at which the soil is worked by plowing. Hardpan prevents the penetration of roots deep into the soil and allows water to pool below the surface and create anaerobic conditions.

Responses. Maintaining good soil texture requires two key measures. First, to ensure that soil has adequate organic matter content, sufficient plant material must be recycled into the soil, rather than harvested. Second, management practices must be used that prevent excessive compaction of soil by livestock or machinery. This can be done in several ways that include: selecting coppicing species that provide several harvests for each planting; timing activities so that operations are conducted when soil is firm but not arid or sodden; limiting heavy machinery operations (by relying more on manual labor, which may be recommended for employment reasons as well); limiting pasturing to sustainable levels; and limiting repeated crossings that form ruts, etc.

Increased Vulnerability to Erosion vs. Improved Soil Stabilisation

Erosion can be an acute problem; for example, when deforestation causes sudden flooding that washes away soils and leaves the land barren and scarred by gullies. But more prevalent worldwide is chronic erosion—the long-term and inexorable degrading of land as topsoil is gradually lost and productivity slowly drops off. Such soil loss can be difficult to perceive as an immediate threat. Even the unacceptably high erosion rate of 20 tonnes/ha/yr is merely 0.2 cm/yr of soil loss.[2] In the short term, declines in productivity are often masked by increased levels of chemical inputs and changes in crop management practices, but unabated erosion will ultimately cause fertile land to become barren.

In addition to the on-site damage resulting from soil erosion, off-site impacts of erosion can also be severe, as soil is washed away and deposited downstream. Suspended particles and sediment can adversely affect the health of freshwater ecosystems by reducing water clarity, damaging bottom habitat, increasing nutrient loading, and decreasing oxygen availability. Siltation has severely reduced the lifetime and limited the capacity of many irrigation and hydroelectric reservoirs, waterways, and harbors.

Impacts. Relative to healthy natural ecosystems, bioenergy feedstock systems, like most agricultural practices, may increase erosion. On the other hand, bioenergy production on degraded or erosion-prone land can stabilise soils and help reduce erosion. The most disruptive stage is the initial clearing

[2] As defined by the U.S. Department of Agriculture Soil Conservation Service.

of land and crop establishment. At this stage, the protective covering of plants and litter is removed and soils are directly exposed. Rainfall dislodges soil particles and surface runoff carries soil away once the soil's water-holding capacity is saturated. Harvesting and exporting the biomass feedstock is somewhat less disruptive, and the intermediate stages (tending, pruning, treating, etc.) generally present little threat of erosion. The construction and maintenance of access roads can also exacerbate runoff and erosion.

The actual rate of erosion depends on several factors, including the intensity of rainfall and wind, the water-holding capacity of the soil and other soil characteristics, local topography, and the type and quantity of plants and plant litter on the land. An empirically based Universal Soil Loss Equation can be used to estimate rates of soil loss based on these. Bioenergy planners can apply the equation to estimate how much erosion will occur under alternative bioenergy production systems, *providing that the data on which the estimate is based are reliable.*

Responses. The single most important strategy for limiting erosion is to recognise the fragility of marginal lands and to avoid cultivating them, or to cultivate them with careful management regimes that are specially tailored to prevent or reverse erosion. Lands that are highly sloped, semi-arid, subject to forceful water flows, or already degraded, are especially susceptible to erosion. Increasingly, however, political, economic and social pressures are forcing farmers to work marginal lands and degraded lands. In cases where cultivating vulnerable lands is unavoidable, or is being undertaken with the intent of stabilising soils, the following measures can help to limit erosion.

The most effective mitigation measure is to maintain a continuous, dense cover of living plants and/or plant litter. This has several beneficial effects. Plant cover absorbs the impact of water on the soil, which reduces the loosening and dislodging of soil particles. Plant matter also increases infiltration of water into the soil, which reduces the amount and speed of runoff while also increasing the availability of water. Plant cover also prevents the soil from drying out by providing shelter against the wind and sun, and reduces the loss of soil to the wind. Finally, a steady cover of plants and plant litter helps to rebuild soil by cycling organic matter into the soil. Crop residues and discarded material from thinning and weeding can contribute to soil litter. Farmers practicing mixed cropping, inter-cropping, or agroforestry can manage crops so that the soil is exposed rarely or never. If the soil must be exposed for some periods, these should not coincide with excessively rainy or dry seasons.

A second class of measures involves limiting and managing water runoff. Runoff flows through channels such as natural depressions, hillside gullies, drainage ditches, access roads, etc. Lining such channels with stones or planting them with soil-stabilising perennials such as grasses can often reduce runoff. Contour cropping, rather than cropping along the grade, can be facilitated with easily disseminated technologies such as a simple wooden "A-frame" level. Terracing, earthen ridges, and basins for collecting sediment, all help to reduce the amount and rate of runoff. However, mechanical measures such as these can be expensive, labor intensive, and require continued maintenance, and should be used with careful planning. Channels on small holdings should be designed in coordination with neighbors, since discharged water must inevitably pass onto their lands. In general, measures that increase infiltration of rainwater (see below) are preferable to measures that divert and channel rainwater.

A third set of measures entail limiting activities that disturb the soil and increase its susceptibility to water and wind erosion. Minimum tillage practices reduce the severity of soil disruption. Since impacts are proportional to the frequency of disturbance, it helps to minimise the need for replanting, harvesting, and other disruptive activities. This is one reason why annual crops generally cause much greater impacts than perennials (such as many grasses, for instance) or tree crops. Especially appealing are trees that can re-grow from coppice shoots, allowing several rotations to be harvested without needing to remove the stumps and replant the field.

4.2. Biodiversity

Bioenergy feedstock production systems affect biodiversity on several levels. From the microfauna within the soils, to the plants and animals in the field, to the large vertebrates whose habitat extends far beyond the planted area, the agronomic choices of the farmer have wide-ranging impacts.

Soil Biodiversity

Bacteria, fungi, worms, insects, and other members of the underground biota are a fundamental component of the soil. These species break down organic material and provide nutrients to plants, and they condition the soil by improving aeration and drainage. Some plants rely directly on symbiotic relationships with microfauna. Certain fungi (mycorrhizae—"fungus root") enable nutrient uptake by roots in exchange for food. The most well known symbiotic partners are nitrogen-fixing bacteria, which are uniquely responsible for providing the terrestrial biosphere with otherwise inaccessible nitrogen from the atmosphere.

Generally, enhanced biodiversity within the managed area is best accomplished by making the area as similar to a natural healthy ecosystem as possible. A cropping system with a high degree of inter-species and intra-species variation … will support a more biodiverse community of insects, birds, and other guest species.

Impacts and Responses. The health of the soil is now understood to depend critically on the diversity and healthy functioning of its resident fauna. Generally, soil biodiversity will be adequate when organic matter is abundant, soil moisture and acidity conditions are proper, and the above-ground cropping system itself is diverse. Soil fauna suffers from frequent tillage and frequent or excessive application of chemical inputs, especially broad-spectrum pesticides and herbicides, which can claim a range of unintended victims (See below regarding use of chemical inputs).

Biodiversity of Crops and Guest Species

The bioenergy feedstock production system itself can have either high or low biodiversity. Production can be based on a genetically impoverished monoclonal plantation, or it can be a varied agroforestry endeavor using several species—plant and livestock—that fill multiple ecological niches. Diversity within the cropping system is valuable in itself, and it furthermore fosters diversity within the ecosystems to which it is linked.

Impacts and Responses. Generally, enhanced biodiversity within the managed area is best accomplished by making the area as similar to a natural healthy ecosystem as possible. A cropping system with a high degree of inter-species and intra-species variation (including varied sizes, shapes, ages, and ecological functions) will support a more biodiverse community of insects, birds, and other guest species. Large and small debris, such as standing and fallen dead wood and litter, serve as main microhabitats for insects, fungi, and epiphytes, which in turn support other animals. Wood debris also introduces structural diversity, providing concealment, food storage, lookout perches, etc.

Crops can be made more welcoming to wildlife by providing protective or otherwise hospitable perimeters. Shelterbelts, windbreaks, and fencerows provide habitat for birds and predatory insects. In some cases, it is appropriate to provide supplemental artificial nesting structures.

Harvesting and other major agronomic activities should be timed and carried out in ways that interfere minimally with the species that share the managed area, especially during their nesting periods and other key lifecycle activities. The populations of native animal species, including microfauna, can require several years to recover after a major disruption. It can also take several undisturbed years for bird populations to begin to reproduce successfully. For perennials, harvesting cycles should be coordinated to leave stands with a continuous range of ages for habitat.

Even single-species industrial plantations can increase biodiversity compared to degraded, nonproductive land. Measures such as those discussed above can be implemented to further enhance biodiversity. In Brazil, for example, environmental regulations now require 25 percent of the plantation area to be left in natural vegetation to help preserve biodiversity and provide other ecosystem services. Forestry companies support this requirement because they have found that the natural areas support predators that keep down pest populations in nearby plantation stands.

At present, however, most industrial plantations are not designed with significant elements of biodiversity in mind. Instead their goal is to produce a uniform product (usually pulpwood), quickly and intensively, by growing very large stands of same-aged monoculture (sometimes monoclonal) trees. Other species are viewed as competition, and are eliminated mechanically and chemically. Some plantation species produce substances with allelopathic effects, discouraging the growth of other species. Fallen and standing dead trees, despite their microhabitat value, are seen merely as economic loss to be removed because they are a potential source of disease and insect infestation, a fire hazard, and an impediment. Better management practices are needed to prevent these problems and promote biodiversity.

Biodiversity of Contiguous Natural Habitats

Bioenergy feedstock production significantly influences surrounding ecosystems, enhancing or suppressing its biodiversity. However, adverse side effects can be limited by preserving especially important or vulnerable habitat types. This requires first defining which habitats need protection most—due to their especially valuable biodiversity, the presence of specific threatened species, their importance for migration or reproduction, or other valuable or unique features.

Impacts and Responses. Riparian areas are especially important—both for their habitat and for the protection they provide to waterways. Riparian areas tend to be rich in the basic resources of food, water, and protective cover. They generally display greater structural and plant diversity, and microclimates appropriate for a range of species. The riparian flora protect the waterways by stabilising the banks, filtering sediment and agricultural chemicals from runoff, moderating stream temperatures, supplying woody debris for aquatic habitats, and providing food. Although bioenergy crops are not preferable to healthy natural riparian ecosystems, they can be a considerable improvement over annual row crops or degraded stretches along riparian zones.

Not only the total amount but also the distribution of natural habitat is important. Small fragmented parcels of natural habitat support less biodiversity than a single unified parcel of the same area. If it is too small, a parcel can be entirely dominated by the ecological features of its boundary and lose its characteristic interior features. In approximate terms, the number of different species supported by an area drops in half as the area is decreased by a factor of ten. Moreover, the intra-species genetic diversity declines because of the smaller number of individuals, increasing the community's vulnerability to a single catastrophic event.

Bioenergy production—to the extent that it offers an environment that is more biodiverse and more similar to a natural habitat than other agricultural options—can be sited to fill gaps in remaining fragments of natural habitat and buffer their boundaries to reduce edge effects. Bioenergy crops can also serve as corridors between natural habitat for the benefit of migrating or wide-ranging wildlife. There currently are few field data on how such corridors should be effectively designed, and how to avoid adverse effects. For example, strips intended as corridors for woodland species could in fact become barriers for grassland species.

To the extent that managed agricultural systems are hospitable to species from adjacent natural systems, they must not become net ecological sinks rather than sources. Examples of such adverse effects include luring prey into areas where they are more susceptible to predation, or providing seemingly attractive habitat that is harvested at a vulnerable period in the species lifecycle—such as during the nesting or birthing season.

4.3. Energy Balances

Although biomass is usually called a "renewable" source of energy, this term is used somewhat loosely, as biomass production typically requires the use of fossil fuels. How much fossil fuel is used depends on the particular form of biomass and varies dramatically among biomass options. Usually, the degree of fossil fuel consumption is measured in terms of an energy ratio: the energy of the biomass produced divided by the energy of the fossil fuel consumed.[3] To be accurate, the amount of fossil fuel consumed should include all inputs

[3] Some studies report the "net energy ratio" (the amount of bioenergy produced minus the amount of fossil fuel consumed, divided by the amount of fossil fuel consumed). Numerically, the net energy ratio simply equals the energy ratio minus one.

into the biomass feedstock:

- fuels consumed by farm machinery in land preparation, planting, tending, and harvesting;
- fossil feedstocks used to produce chemical inputs such as herbicides, pesticides, and especially fertilisers, which are energy intensive;
- energy used for irrigation, if any;
- fuels consumed during transport, storage, and processing of the biomass; and
- the energy required to manufacture and transport equipment and machinery (which is often neglected because it is a relatively minor contribution—a few percent of the energy content of the biomass for transport distances within 200 km (Borjesson, 1996a,b).

Although biomass is usually called a "renewable" source of energy, this term is used somewhat loosely, as biomass production typically requires the use of fossil fuels. How much fossil fuel is used depends on the particular form of biomass and varies dramatically among biomass options.

A single quantitative measure such as the energy ratio can be a misleading comparison among biomass options, however, because it does not reflect the non-energy agricultural outputs, which can be as important as the energy outputs in terms of their economic, social, or environmental value. Nonetheless, for comparing bioenergy cycles that provide comparable outputs, such quantitative measures reasonably reflect the relative reliance on fossil fuels.

Many agricultural or forestry residues can be considered essentially renewable, because negligible fossil fuel is consumed in addition to what is required to produce the primary crop. For purpose-grown crops, energy ratios are generally higher for perennial crops than for annual crops, which are more energy intensive because they involve greater use of machinery and a higher level of chemical inputs. Nevertheless, some annual crops are preferable for other reasons, e.g., less land might be needed per unit of energy produced as a result of higher yields, or a particular agricultural activity may have strong political support. For example, production of corn-based ethanol in the United States has an energy ratio about one (Wyman *et al.*, 1993), but enjoys strong political support in the form of subsidies to producers.

For many perennial energy crops, energy ratios for feedstock production are high enough to make them attractive energy options. For example, some crops (poplar, sorghum, and switchgrass) grown in a temperate climate have energy ratios of 12 to 16 (Turhollow and Perlack, 1991). In tropical climates with good rainfall, these ratios could be considerably higher, due to both higher yields and less energy-intensive (i.e., more labor-intensive) agricultural practices (Ravindranath and Hall, 1995).

4.4. Carbon Emissions

Bioenergy cycles can affect carbon emissions in two main ways: (1) they can provide energy that displaces fossil fuel energy, and (2) they can change the amount of carbon sequestered on land. The net carbon benefit depends on what would have happened otherwise; the amount and type of fossil fuel that would have otherwise been consumed; and the land-use that would have prevailed if biomass were not grown and harvested for energy. Since this counterfactual situation is speculative, it is impossible to calculate the carbon benefit of a given bioenergy cycle with certainty. However, carbon benefits can be estimated using some illustrative assumptions.

Fossil Fuel Displacement

The carbon benefit of displacing fossil-fuel consumption depends on the bioenergy cycle considered. For electricity generation, the carbon emissions depend on how efficient the generation technology is and how much fossil fuel was used to produce the biomass. Table 4.2 (see page 73) gives some approximate values for the carbon emissions of selected technologies. It assumes that the biomass feedstock is carbon-neutral—that is, the carbon released during combustion balances the carbon extracted from the atmosphere during growth, and there is no net change in carbon on the land. Production and transport of either biomass or fossil fuel would give rise to some additional carbon emissions, but these are minor and are considered comparable (Borjesson, 1996b).

Table 4.2. Approximate Carbon Emissions from Sample Biomass and Conventional Technologies

Fuel and Technology	Generation Efficiency	Grams of CO_2 per kWh
diesel generator	20 %	1320
coal steam cycle	33 %	1000
natural gas combined cycle	45 %	410
biogas digester and diesel generator (with 15% diesel pilot fuel)	18 %	220
biomass steam cycle (biomass energy ratio[a]= 12)	22 %	100
biomass gasifier and gas turbine (biomass energy ratio[a] = 12)	35 %	60

(a) The energy of the biomass produced divided by the energy of the fossil fuel consumed to produce the biomass.

Land Changes

In fact, there will be some change in the amount of carbon sequestered on land. This change is highly dependent on the particular details of the land in question and the proposed biomass feedstock system. Three cases are considered here.

In the first case, natural forest is cleared in unsustainable ways to provide fuel for a bioenergy facility, leaving a denuded site that does not regenerate. In this case, the carbon emissions from the bioenergy cycle are comparable to or greater than carbon emissions from a fossil-fuel cycle generating an equivalent amount of energy. There is no justification for this fuel cycle from a greenhouse gas perspective, nor from any other environmental perspective. Unfortunately, this is a frequently used model for production of non-energy biomass, and could be the most cost-effective strategy for a bioenergy project from the standpoint of an investor guided solely by short-term profits.[4] Measures might be required to prevent this from happening.

In the second case, natural forest is cleared and replanted with an energy plantation harvested sustainably to supply a bioenergy facility with biomass continuously. The carbon formerly sequestered in the natural forest will be released. The amount of carbon released depends on the type of forest, but a rough figure is 300 tonnes of carbon per hectare (tC/ha) (Brown, Cabarle, Livernash, 1997). As biomass feedstock is grown and harvested in cycles, carbon will be sequestered on the land, partly compensating for the carbon released when the natural forest was cut down. Averaged over a growth cycle, a typical amount of carbon sequestered on the plantation land might be 30 tC/ha.[5] The natural forest therefore sequesters 270 tC/ha more than the energy crop. If the biomass is used to displace fossil fuels, thereby reducing carbon emissions, this 270 tC/ha difference will eventually be compensated over a period of roughly 45 years.[6] Thus, depending on the precise stocks of carbon involved, there might be a case based on carbon benefits for clearing natural forest to plant energy plantations. However, it is not a very compelling case, even without taking into account the loss of ecosystem services that would accompany clearing of natural forest. Environmental and social considerations such as preserving habitat, protecting watersheds, etc., might more than outweigh the carbon benefits.

In the third case, unproductive land, such as degraded land

[4] A 100 MW power plant with a thirty-year lifetime would require about 50 thousand hectares of land (assuming a 35 percent efficiency and a one-time yield of 250 dry tonnes of harvested fuel per hectare), roughly the amount of land within a 13-kilometer radius of the plant. Alternatively, producing biomass on an energy plantation with a yield of 15 dt/ha/yr would call for roughly 30 thousand hectares of land, roughly the amount of land within a 10-kilometer radius of the plant. From a strictly financial perspective, the choice between these options would depend on a number of factors, including relative cost of land versus the cost of managing a plantation, and the expected future plans for the land.

[5] This assumes a 7.5 tC/ha/yr growth rate and an eight-year harvest cycle. (In this rough approximation, carbon in soils and litter is assumed unchanged relative to the natural forest.)

[6] This assumes that a tonne of fossil fuel carbon is displaced by 1.25 tonnes of biofuel carbon. (The factor 1.25 accounts for differences in power conversion efficiency and fuel carbon content, and also the fossil fuels inputs consumed for biomass production.) Then it will take 45 years [(270 tC/ha * 1.25) / (7.5 tC/ha/yr) = 45] to make up for the initial release of carbon from the natural forest. This is a worst case scenario, in that it assumes that the original natural forest biomass is not used, like the purpose-grown biomass, to displace fossil fuels or other non-renewable resources. If some fraction of the biomass is suitable for use as fuel, the carbon benefits of this case will improve, and the breakeven time will be less than the 45-year worst-case situation.

that would benefit from revegetation, is converted to bioenergy crop plantation. The degraded land probably sequestered considerably less carbon than the plantation, including the increase in carbon sequestered in the soil and other below-ground biomass. In this case, the change in land use will have carbon benefits over and above the benefits resulting from displacing fossil fuels, as well as other ecosystem benefits.

Bioenergy cycles can affect carbon emissions in two main ways: [by] displac[ing] fossil fuel energy, and chang[ing] the amount of carbon sequestered on land.

4.5. Hydrology

Agricultural activities influence a region's hydrology in four main ways:

(1) Plant foliage intercepts some of the rainfall that would otherwise reach the ground.
(2) When rainfall reaches the ground, it either infiltrates the soil or flows over the soil as surface runoff. Dense plant litter and porous soil increase the amount of infiltration and reduce the amount of surface runoff. Conversely, when plant litter is sparse and soil has been compacted from agricultural activities, infiltration is impeded and surface runoff increases.
(3) Growing plants absorb water through their roots and transpire it through their leaves, reducing the amount of water that recharges the groundwater supply.
(4) Crops sometimes draw upon groundwater, either directly (when their roots are sufficiently deep and the water table is sufficiently shallow—as in wetlands) or indirectly through irrigation.

Through these four mechanisms, cultivating and harvesting biomass for energy can affect the hydrological health of a region, either positively or negatively. A barren, degraded site will invariably be subject to rapid runoff and limited infiltration, minimising the rate at which groundwater is replenished. Revegetating such an area with bioenergy crops such as trees or grasses can help reduce runoff (and thereby limit soil erosion), recharge groundwater, and sustain spring-fed streams. Bioenergy crops can also be integrated into systems for harvesting surface water. Plants suitable for fuel and fodder can be planted to stabilise catchments, fortify earthen barriers and channels, and line artificial ponds. Such water harvesting techniques, combining traditional and modern technology, have been used with considerable success (Agarwal, 1997). Energy crops can also help address waterlogging problems in poorly drained or flood-prone zones.

On the other hand, fast-growing crops can consume water at excessive rates. Water transports nutrients from the roots up into the above-ground tissue, and rapidly transpires through the leaves during photosynthesis. Plants require from 300 to 1,000 tonnes of water per tonne of dry biomass (Hall *et al.*, 1993), or 450-1500 mm per hectare per year (assuming a yield of 15 dry tonnes/ha/yr). Crops optimised for rapid growth are generally water-hungry and can be expected to consume more water than natural flora. One study noted that tree plantations "use larger quantities of water than shorter vegetation types such as scrub, herbs, and grass" and concluded that "afforestation tended to deplete substantially both the total

Revegetating [barren] areas with bioenergy crops such as trees or grasses can help reduce runoff (and thereby limit soil erosion), recharge groundwater, and sustain spring-fed streams.

Table 4.3. Typical Fertlizer and Herbicde Application Rates and Soil Erosion Rates for Selected Food and Energy Crop Production Systems in the United States

Cropping System	N-P-K application rates (kg/ha/year)	Herbicide application rate (kg/ha/year)	Soil erosion rates (tonnes/ha/yr)
Annual crops			
Corn	135-60-80	3.06	21.8[a]
Soybeans	20[b]-45-70	1.83	40.9[a]
Perennial energy crops			
Herbaceous	50[c] -60-60	0.25	0.2
Short-rotation woody	0[c]-15-15	0.39	2.0

Source: Hohenstein and Wright, 1994

(a) Based on data collected in the early 1980s. New tillage practices used today may lower these values.

(b) The nitrogen input is inherently low for soybeans, a nitrogen-fixing crop.

(c) Not including nitrogen-fixing species.

annual water yield and the base flow in the dry season" of the affected watershed. It cautioned that "the indiscriminate planting of trees may seriously affect the viability of the springs and wetlands in many catchments" (Le Roux, 1990).

Quick growing tree crops have been observed to adversely affect water supplies—lowering the water table, reducing stream yields, and making wells less reliable. Tree plantations in many different agro-ecological regions, including sites in Chile, India, Brazil, New Zealand, Thailand, South Africa, and Spain, have caused such impacts—one of the reasons why local agricultural communities have often opposed the introduction of tree plantations (Carrere and Lohmann, 1996). Harvesting residues, cultivating tree crops without undergrowth, and planting species that do not generate adequate amounts or types of litter, are all practices that can reduce the ability of rainfall to infiltrate soil and replenish ground water supplies, exacerbating problems of water overconsumption.

Bioenergy planners should carefully assess the potential impacts throughout a watershed of crop cultivation and harvesting, including both groundwater and surface water impacts. Species should be selected for bioenergy crops that are suited to local conditions, helping to avoid excessive water consumption and to maintain hydrological health.

4.6. Chemical Loading of Soil and Ground/Surface Water

An important potential impact from bioenergy feedstock production is the introduction of agricultural inputs into the environment. Inputs such as fertilisers and pesticides (including herbicides, fungicides, insecticides, and nematicides) are likely to be used for growing perennial bioenergy feedstocks, although to a lesser extent than for annual row crops (Table 4.3). Fertilisers can lead to nutrient overloading of surface waters and accelerate the growth of algae, while inhibiting the growth of other aquatic species. Persistent toxins in pesticides can bio-accumulate and poison wildlife, workers, and communities, with human impacts ranging from cancer to immune disorders to hormone disruption. Resistance to these same chemicals can appear in pests, making them all the more difficult to control. Globally, at least 450 species of insects and mites, 100 species of plant pathogens, and 48 species of weeds have become resistant to one or more pesticide products. (See Thrupp, 1996, as a main reference for the material in this section.)

As they have come to recognise the environmental and health impacts of agricultural chemicals, farmers and agronomists have developed a range of management practices to minimise the need for such inputs. These practices should be applied to bioenergy crops, even though they already have lower chemical input requirements. One example is integrated pest management (IPM), which relies less on chemical inputs and more on nature's species diversity, adaptability, and nutrient cycling capability (Thrupp, 1996). Farmers in many places are demonstrating that IPM is an ecological and cost-effective alternative to conventional chemical-intensive practices for a wide array of crops and regions—contrary to the expectations of some conventional farmers and researchers. In many cases, IPM has proven to be more profitable, although farmers sometimes bear the costs of a transition period of one or two years (Thrupp, 1996).

Farmers in many places are demonstrating that [integrated pest management] IPM is an ecological and cost-effective alternative to conventional chemical-intensive practices for a wide array of crops and regions—contrary to the expectations of some conventional farmers and researchers.

Several steps can be taken to reduce reliance on fertilisers. Using nitrogen-fixing species and using green manure (including crop residues and compost) can maintain or enhance soil fertility without the use of fertilisers. Rotation of crops can slow or prevent the depletion of nutrients, as well as the spread of diseases and pests. Intercropping (growing two or more crops simultaneously), cover crops (crops that cover and protect the soil during periods when it would otherwise be bare), crop residue management, and changes in tillage practices can improve soil quality and enhance nutrient availability.

Similarly, many options are available for eliminating or reducing the use of pesticides. Where labor is readily available, farmers can employ labor-intensive methods of applying inputs and controlling weeds that use inputs more efficiently than methods typically used in highly mechanised agriculture. Very effective non-chemical traps have been developed for many insects. For example, a program in Kenya reduced tsetse flies populations by more than 95 percent with non-chemical traps, greatly reducing the incidence of trypanosomiasis infections in cattle (Ssennyonga, 1996). Steps can be taken to increase the diversity of beneficial insects and to restore the natural predator-prey interactions in crops. For example, if some portion of the land is set aside and preserved in its natural state, it can function as a habitat for predators that reduce the need for pesticides on adjacent cropland. Traditional plant breeding can also be used to develop more pest-resistant strains.

Bioenergy crops can also help mitigate the impacts of chemical use from agricultural cropland. Well-planned siting of bioenergy crops can help to filter agricultural chemicals in runoff from annual row crops.

A number of policy changes can help encourage use of IPM approaches. Such policy measures include:

- removing incentives and subsidies for pesticides, including credit policies tied to chemicals,
- tightening and enforcing regulations on pesticide import and use,
- providing public funds and political support to IPM programs or educational processes, and
- involving stakeholders, farmers groups, and NGOs in policy decisions concerning plant protection, pesticide laws, and production issues.

4.7. Restoring Degraded Land

Tremendous benefit could result from integrating biomass production with restoration of degraded lands. Optimal restoration strategies are extremely site-specific and depend on a large number of factors.

These include the availability of water and light, susceptibility to wind and water erosion, soil characteristics (fertility, organic content, pH, soil type, temperature, salinity, water-logging), altitude and climate, susceptibility to pests and overgrazing, and concurrent land uses (such as grazing, fuelwood harvesting, and shifting agriculture).

Farmers have experimented with and adapted many land-restoration strategies. Box 4-1 (see page 78) presents some of the many options available, but no specific recommendations are given here, since specific strategies vary dramatically from situation to situation. Table 4.4 provides some examples of tree species that are well-suited to particular types of adverse situations.

If the degraded land is currently meeting a need for grazing, fuelwood gathering, shifting agriculture, etc., then restoring the degraded land should involve finding suitable alternatives that are identified and designed in a participatory manner.

In selecting approaches, it is critical to understand the pre-existing uses of the land. If the degraded land is currently meeting a need for grazing, fuelwood gathering, shifting agriculture, etc., then restoring the degraded land should involve finding suitable alternatives that are identified and designed in a participatory manner. This is the only way successfully to undertake a land-restoration project that will involve and benefit the local communities.

4.8. Environmental Indicators for Evaluating a Project

To the extent that they can be measured, quantitative indicators are helpful in evaluating overall impacts. Table 4.5 (see page 78) offers some possible quantitative indicators. These indicators relate to many of the impacts that are discussed in the preceding sections. Most of them are relatively straightforward, and should be measured at intended project sites, estimated for prospective project designs, and then regularly measured for ongoing projects. ■

Table 4.4. Selected Species Tolerant to Specific Conditions

species / conditions	Acacia aurinculiformis	A. mearnsii	A. saligna	A. senegal	Albizia lebbek	Azadirachta indica	Casuarina equisetifolia	Casuarina sequisetifolia	Cupressus arizonica	Eucalyptus brockwayi	E. camaldulensis	E. globulus	E. gomphocephala	E. intertexta	E. microtheca	E. occidentalis	E. salmonophloia	Gmelina arborea	Leucaena Leucocephala	Parkinsonis aculeata	P. articulata	Pinus halepensis	Prosopis juliflora	P. tamarugo	Schinus molle	Tamarix articulata	Zizyphus mauritiana
arid lands			✔	✔					✔	✔	✔			✔	✔	✔	✔			✔	✔		✔	✔	✔	✔	✔
heavy soils	✔	✔	✔	✔	✔	✔					✔	✔			✔	✔		✔	✔				✔	✔			
impeded drainage	✔														✔									✔			
alkaline soils	✔		✔				✔				✔		✔		✔	✔			✔	✔		✔	✔	✔			
saline soils			✔					✔			✔		✔			✔				✔			✔	✔			

Source: Ramsay, 1985

Table 4.5. Selected Indicators of Environmental Sustainability

Category	Impact	Quantitative indicators, based on assessment of:
Soil quality and fertility permeability	Nutrient depletion, acidification, organic content loss, soil texture.	Soil analyses. (Soil density, porosity, water-permeability, temperature; heat conductivity, heat capacity; nutrients: phosphorus, potassium, sulfur, nitrogen, magnesium, etc.)
Biodiversity Energy balances	Conversion of genetically rich or poor habitat. Increased use of sustainable, renewable resources.	Biodiversity under alternate/prior land uses. Relative full fuel-cycle consumption of fossil resources.
Carbon balances	Reduction in carbon (and other greenhouse gas) emissions.	Relative fuel fuel-cycle emissions of carbon, including carbon sequestered above and below ground in biomass supply systems
Hydrology/water resources	Water consumption or replacement, quality.	Water table height, surface water availability, seasonality, quality.
Chemical inputs and runoff	Increased or decreased loadings of fertilizers, herbicides, pesticides, COD/BOD	Soil, surface water and ground water analyses.
Land quality	Restoring or degrading of land.	Land quality and productivity under alternate/ prior land uses. Diversity of products and uses provided.
Air quality	Avoided outdoor and indoor pollution from waste combustion, pollution from bioenergy cycle.	Analyses of outdoor and indoor air quality. Investigation of human respiratory health impacts.

Box 4-1. Restoring Degraded Land and Establishing Bioenergy Crops: Sample Strategies

Soil temperature: Supply mulch and use cover crops to provide shade. Plant during relatively cool periods (temperatures in excess of 30ºC can cook plant roots).

Soil fertility: Supply mulch and use cover crops that build soil organic matter and help to recycle nutrients. Use leguminous species, manure, or, if necessary, chemical fertilisers (phosphates are often necessary). In some cases, it will be possible to make existing nutrients available by adjusting the soil pH.

Retaining water: Supply mulch and use cover crops to retain soil moisture. Plant in depressions to retain accumulated water and aid water infiltration near the plants. Create contours, channels, and other physical structures to harvest water and direct it to areas of plant growth.

Draining water: Use plants with high water demands (such as many Eucalyptus species). Use physical measures to drain land.

Erosion: Reduce ground-level wind speeds and water flow rates using mulch and cover crops. Stabilise soils using crops with appropriately deep, extensive, and quickly growing roots (for example, Casuarina has been used to stabilise sand dunes). Create wind breaks and water barriers by using physical structures (contours, bunds, etc.) and crops (hedgerows, etc.).

Browsing: Remove or greatly reduce browsing pressure, using fences, predators, guards. Grow species that are unpalatable or otherwise resistant to grazing, while providing alternate sources of fodder if necessary. Otherwise grazing can easily devastate a young colony of plants.

References for Chapters 3 and 4

Agarwal, B., 1986. *Cold Hearths and Barren Slopes.* Riverdale, MD: Riverdale Company.

Agarwal, A., 1997. "The Rise and Fall of Traditional Water Harvesting Systems in India." *Down to Earth* 5(20) (March 15).

Barret, H., and A.Brown. 1993. "The Impact of Labour-Saving Devices on the Lives of Rural African Women: Grain Mills in the Gambia." *In Different Places, Different Voices: Gender and Development in Africa, Asia, and Latin America,* edited by J.H. Momsen and V. Kinnaird. New York: Routledge.

Batliwala, S., and A.K.N. Reddy. 1996. *Energy for Women & Women for Energy: Engendering Energy and Empowering Women.* Prepared for meeting of ENERGIA: Women and Energy Network (June 4-5, 1996). Netherlands: University Twente.

Bewinga, E.E., and G. van der Bijl. 1996. *Sustainability of Energy Crops in Europe.* Utrecht: Centre for Agriculture and Environment.

Borjesson, P. 1996a. "Energy Analysis of Biomass Production and Transportation." *Biomass and Bioenergy* 2: 305-318.

——. 1996b. "Emissions of CO2 from Biomass Production and Transportation in Agriculture and Forestry." *Energy Conversion and Management* 37: 1235-1240.

Brown, P., B. Cabarle, and R. Livernash. 1997. *Carbon Counts: Estimating Climate Change Mitigation in Forestry Projects.* Washington, DC: World Resources Institute.

Carrere, R., and L. Lohmann. 1996. *Pulping the South: Industrial Tree Plantations and the World Paper Economy. London:* Zed Books.

Cecelski, E.W. 1995. "From Rio to Beijing: Engendering the Energy Debate." *Energy Policy* 23(6): 561-575.

Chambers, R., and G. Conway. 1992. *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century.* Sussex, UK: Institute for Development Studies.

Collier, W.L., J. Colter, Sinarhadi, R.d'A. Shaw. 1998. Comment on Timmer (1998). In *International Agricultural Development*, edited by C.K. Eicher and J.M. Staatz. Baltimore: Johns Hopkins University Press.

Conway, G. 1997. *The Doubly Green Revolution: Food for All in the 21st Century.* London: Penguin Books.

Cook, James, Jan Beyea, and Kathleen Keeler. 1991. "Potential Impacts of Biomass Production in the United States on Biological Diversity." *Annual Review of Energy and the Environment 16:* 401-431.

——, and Jan Beyea. n.d. "An Analysis of the Environmental Impacts of Energy Crops in the USA: Methodologies, Conclusions and Recommendations." www.panix.com/-jimcook/data/ec-workshop.html

Food and Agriculture Organisation (FAO). 1998. *The State of Food and Agriculture: Rural Non-Farm Income in Developing Countries.* Rome: FAO.

——. 1999. *Wood Energy and Gender.* www.rwedp.org/i_gender.html

Ford Foundation. 1998. *Forestry for Sustainable Rural Development. New York:* Ford Foundation.

Goldemberg, J., and T.B. Johansson., eds. 1995. *Energy as an Instrument for Socio-Economic Development.* New York: United Nations Development Programme (UNDP).

——, T.B. Johansson, A.K.N. Reddy, and R.H. Williams. 1988. *Energy for a Sustainable World.* New Delhi: Wiley Eastern.

Hobsbawm, E., and G. Rude. 1968. *Captain Swing: A Social History of the Great English Agricultural Uprising of 1830.* New York: Norton and Company.

Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods. 1993. "Biomass for Energy: Supply Prospects." In *Renewable Energy: Sources for Fuels and Electricity,* edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 593-651.

Hall, David, and Jeremy Woods. 1994. *Bioenergy for Development: Technical and Environmental Dimensions.* Rome: Food and Agriculture Organisation (FAO).

Hohenstein, W.G., and L.L. Wright. 1994. "Biomass Energy Production in the United States: An Overview." *Biomass and Bioenergy* 6: 161-173.

Howes, Mick, and Pandula Endagama. 1995. *Farmers, Forests, and Fuel: Towards a New Biomass Energy Strategy in Sri Lanka.* London: Intermediate Technology Publications.

Husain, Tariq. 1992. *Community Participation: The First Principle.* Karachi, Pakistan: IUCN-The World Conservation Union.

Kanetkar, R.S., and V. Varalaksmi. 1994. *Women in Godam — Haryana: A Gender and Caste Based Study on Conservation of Forest Resources.* TERI Joint Forest Management Series, no. 13. Delhi: Tata Energy Research Institute.

Kelkar, G. 1995. "Gender Analysis Tools." *Wood Energy News*

10(2). Issued by the Rural Wood Energy Development Program. Bangkok: Food and Agriculture Organisation (FAO).

Larson, E.D. 1993. "Technologies for Fuels and Electricity Production from Biomass." *Annual Review of Energy and the Environment* 18: 567-630.

——, and R.H. Williams. 1995. "Biomass Plantation Energy Systems and Sustainable Development." In *Energy as an Instrument for Socio-Economic Development,* edited by Goldemberg and Johansson.

Le Roux, S.D. 1990. "Impact of Afforestation on Agricultural Resources of Natal." In *The Physical, Social and Economic Impacts of Large-Scale Afforestation in Natal/Kwazulu.* Proceedings of the Forestry Impact Workshop. Pietermaritzburg: University of Natal, Institute of Natural Resources. Quoted in Carrere and Lohman,1996.

Liedholm, C. 1998. "Micro and Small Enterprises and the Rural Poor." In *International Agricultural Development,* edited by C.K. Eicher and J.M. Staatz. Baltimore: Johns Hopkins University Press.

Lipton, M. 1996. *Successes in Anti-Poverty.* Issues in Development. Discussion Paper, no. 8. Geneva: International Labor Organisation.

Miller, A., I. Mintzer, and S. Hoagland. 1986. *Growing Power: Bioenergy for Development and Industry.* Washington, DC: World Resources Institute.

National Biofuels Roundtable (NBF). 1994. *Principles and Guidelines for the Development of Biomass Energy Systems: A Report from the National Biofuels Roundtable (May 1994).* Draft Final Report.

Obaidullah Khan, A.Z.M. 1995. Opening address in *Gender and Wood Energy in Asia.* Report of the Regional Expert Consultation on Gender and Wood Energy in Asia. RWEDP Report, no. 22. Bangkok: Rural Wood Energy Development Program (RWEDP), Food and Agriculture Organisation (FAO).

Latin American Energy Organisation (OLADE) and Inter-American Development Bank (IDB). 1994. *Guide for Assessing the Environmental Impact of Biomass Developments for Energy Purposes.* Quito: IDB.

Oak Ridge National Laboratory (ORNL). 1982. *Biomass Energy Systems and the Environment.* New York: Pergamon Press.

——, and Resources for the Future (RFF). 1998. *Estimating Externalities of Biomass Fuel Cycles,* Report no. 7 on the *External Costs and Benefits of Fuel Cycles: A Study by the U.S. Department of Energy and the Commission of the European Communities.* Oak Ridge: ORNL.

Osterveen, H. 1995. "Development in Gender?" *Wood Energy News* 10(2).

Office of Technology Assessment (OTA) of the Congress of the United States. 1991. *Energy in Developing Countries.* OTA-E-486. Washington, DC: Government Printing Office.

——. 1993. *Potential Environmental Impacts of Bioenergy Crop Production – Background Paper.* OTA-BP-E-118. Washington, DC: Government Printing Office.

Pasztor, Janos, and Lars Kristoferson. 1990. *Bioenergy and the Environment.* Boulder, CO: Westview Press.

Ramsay, William. 1985. *Bioenergy and Economic Development.* Energy Policy Series 1(1). Boulder, CO: Westview Press.

Ravindranath, N.H., and D.O. Hall. 1995. *Biomass, Energy, and Environment: A Developing Country Perspective from India.* Oxford, UK: Oxford University Press.

Reddy, A.K.N., R.H. Williams, and T.B. Johansson. 1997. *Energy After Rio: Prospects and Challenges.* New York: United Nations Development Programme (UNDP).

Robinson, M.S. 1998. "Microfinance: The Paradigm Shift from Credit Delivery to Sustainable Financial Intermediation." In *International Agricultural Development,* edited by Eicher and Staatz.

Rural Wood Energy Development Program (RWEDP). 1995. *Policy Statement on Gender and Wood Energy.* In *Gender and Wood Energy in Asia.* Report of the Regional Expert Consultation on Gender and Wood Energy in Asia. RWEDP report no. 22. Bangkok: Food and Agriculture Organisation (FAO).

Sargent, C., and S. Bass, eds. 1992. *Plantation Politics: Forest Plantations in Development.* London: Earthscan.

Skutsch, M. 1995. "Placing Gender." In RWEDP, *Gender and Wood Energy in Asia.*

Shell and World Wildlife Fund (WWF). 1992. "Tree plantation review." London and Godalming: Shell and WWF.

Smil, Vaclav. 1983. *Biomass Energies: Resources, Links, Constraints.* New York: Plenum Press.

Ssennyonga, J.W. 1996. "Kenya: Community-Based Tsetse Control." In Thrupp (1996).

Sudha, P. and N.H. Ravindranath. 1999. "Land Availability and Biomass Production Potential in India." *Biomass and Bioenergy* 16(3): 207-222.

Thrupp, Lori Ann, 1996. *New Partnerships for Sustainable Agriculture.* Washington, DC: World Resources Institute.

Timmer, C.P. 1998. "Choice of Technique in Rice Milling on Java." In *International Agricultural Development,* edited by Eicher and Staatz.

Turhollow, A.H., and R.D. Perlack. 1991. "Emissions of CO2 from Energy Crop Production." *Biomass and Bioenergy* 1:129-135. Cited in Hall *et al.,* 1993.

United Nations Development Programme (UNDP). 1995. *Human Development Report* (HDR). New York: Oxford University Press.

——. 1996. *UNDP Initiative for Sustainable Development.* New York: UNDP.

——. 1997. "Promoting Sustainable Livelihoods: A Briefing Not Submitted to the Executive Committee." New York: UNDP.

——. 1998. *Participatory Assessment, Planning and Implementation for Sustainable Livelihoods – Users Manual.* Draft. New York: UNDP.

United Nations Industrial Development Organisation (UNIDO). 1995. *Development and Utilisation of Biomass Energy Resources in Developing Countries.* Proceedings of a symposium in Vienna (December 11-14). Vienna: UNIDO.

Van Wijk-Sijbesma, C., and E. Bolt. 1992. *Women, Water, Sanitation: Annual Abstract Journal.* International Reference Centre for Community Water Supply and Sanitation (IRC). The Hague and PROWWESS/UNDP. UNDP – World Bank Water and Sanitation Program. Cited in Cecelski, 1995.

Varalakshmi, v., 1993. *Women as Partners in the Regeneration of Haryana Shivaliks.* TERI Joint Forest Management Series, no. 1. Delhi: Tata Energy Research Institute.

World's Women. 1995. *Trends and Statistics.* New York: United Nations.

World Bank. 1995. *Participation Sourcebook.* Washington, DC: World Bank.

——. 1996. *Rural Energy and Development: Improving Energy Supplies for Two Billion People.* Washington, DC: World Bank.

——. 1998. *Fuel for Thought: A New Environmental Strategy for the Energy Sector.* Washington, DC: World Bank.

World Rainforest Movement (WRM). 1999. *Tree Plantations: Impacts and Struggles.* Montevideo, Uruguay: WRM.

Wyman, C.E., R.L. Bain, N.D. Hinman, and D.J. Stevens. 1993. "Ethanol and Methanol from Cellulosic Biomass." In *Renewable Energy,* edited by Johansson *et al.*: 866-923.

Zeller, M., and M. Sharma. 1996. *Rural Financial Services for Poverty Alleviation: The Role of Public Policy.* Washington, DC: International Food Policy Research Institute.

5 TECHNOLOGIES TO CONVERT BIOMASS INTO MODERN ENERGY

Credit: Eric Larson

Anaerobic cattle dung digester producing biogas in the village of Pura, Karnataka State, India.

....a number of gasifier and gas cleanup system designs have been developed that largely eliminate tar production and other technical problems.... a growing number of companies worldwide now offer systems with warranties and performance guarantees.

This chapter describes a variety of technologies for converting biomass into electricity, gas, or liquid fuels. Most of these technologies are already in commercial use, although some more than others. Each technology description—gasification, anaerobic digestion, ethanol, steam turbine, and gas turbine—includes an overview to give the general reader an understanding of key technical issues that must be addressed in any actual project involving these technologies. It also includes a more detailed technical description for the interested reader consisting of basic operating principles, feedstock and other material input requirements, operating and maintenance issues, capital and operating costs, environmental issues, and other factors, as well as a section-by-section bibliography (at the end of the chapter).

Each technology section also includes tables that summarise technical features and principal applications of the technology and that provide order-of-magnitude illustrations of costs. Case studies of projects involving some of the technologies are included in chapter 7.

5.1. Gasification

Combustible gas can be produced from biomass through high temperature (thermochemical) or low temperature (biological) processes. After appropriate treatment, the resulting gases can be burned directly for cooking or heat supply, or they can be used in secondary conversion devices such as internal combustion engines for producing electricity or shaft work. The term gasification commonly refers to high-temperature conversion. (The term anaerobic digestion commonly refers to low-temperature biological conversion; the resulting product is biogas.)

Overview

Producer gas is one of several names for the product gas resulting from gasification. The name derives from the first "gas producers" that were developed in the 1800s for gasifying biomass. Producer gas consists primarily of carbon monoxide, hydrogen, carbon dioxide, and nitrogen, and has a heating value of 4 to 6 MJ/Nm^3, or 10 to 15 percent of the heating value of natural gas, hence its French name "poor gas" *(gaz pauvre)*.[1]

Producer gas can also be made from coal. Coal-derived gas was widely used in Europe and the United States until the mid-1900s for urban domestic cooking and heating. This "town gas" is still used in many urban areas of developing countries, including India and China. "Suction gas" from wood-charcoal was a prominent civilian fuel in Europe during World War II, when it was used to run several hundred thousand vehicles (Engine suction is used to draw the required combustion air into the gasifier). The development of inexpensive and more convenient petroleum fuels and natural gas pipeline systems after the war led European countries and the United States to abandon producer gas for vehicles and household use.

After the first oil price shock in 1973, crash attempts were made to resurrect and install gasifier/engine systems for electricity generation, especially in remote areas of developing countries. However, most of these systems encountered technical problems arising from the condensation of tars on downstream equipment,[2] and by the end of the 1980s, gasifier/engine technology was abandoned again.

Research has continued, however, and a number of gasifier and gas cleanup system designs have been developed that largely eliminate tar production and other technical problems. Transferring these research findings into commercial products is an ongoing process. Interest in gasification is reviving, and there is growing recognition that gasifier/engine technology in village-scale electricity generation offers potential environmental and quality-of-life improvements. Unlike in earlier gasification efforts, a growing number of companies worldwide now offer systems with warranties and performance guarantees.

The Technology

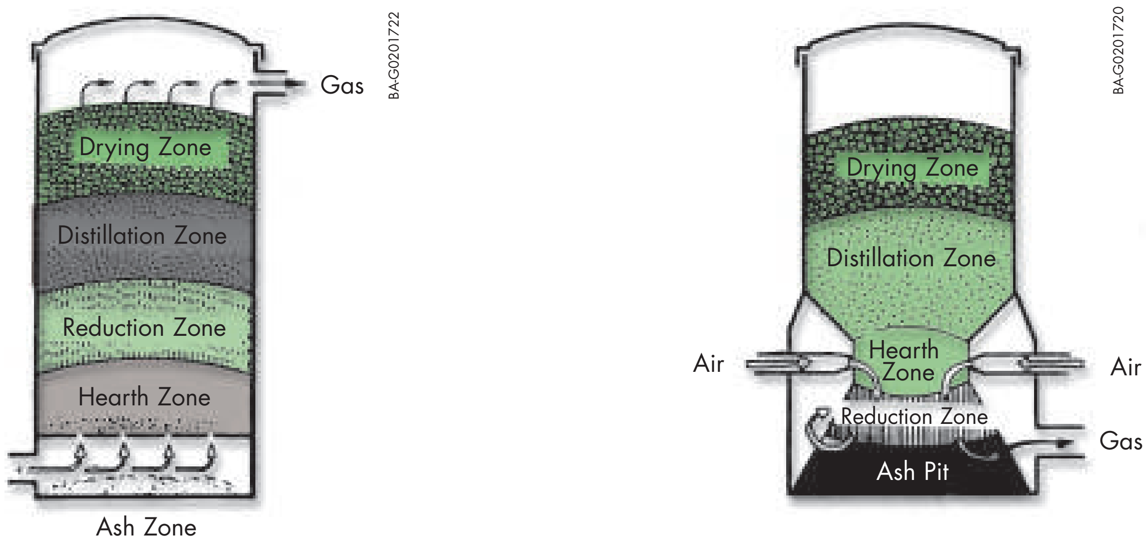
Thermochemical gasification involves, in essence, burning biomass without sufficient air for full combustion, but with enough air to convert the solid biomass into a gaseous fuel. The intended use of the gas and the characteristics of the particular biomass (size, texture, moisture content, etc.) determine the design and operating characteristics of the gasifier and associated equipment. Typically, a gasifier supplier will specify the characteristics of the biomass required for satisfactory performance. For small-scale applications, defined here to range from about 5 kg/hour up to about 500 kg/hour of biomass input, two basic gasifier designs are used: updraft or downdraft fixed-bed gasifiers.

In an *updraft fixed-bed gasifier* (Fig. 5.1, see page 85) air is injected at the bottom and biomass enters at the top and moves down by gravity as it is gasified. The entering biomass undergoes drying followed by partial gasification and finally combustion of the ungasified solid fraction. Updraft gasifiers have high energy efficiencies due to the efficient counter-current heat exchange between the rising gases and descending biomass. However, the product gases from updraft gasifiers have an unacceptably high concentration of tars and oils. Tars and oils must be filtered or flushed out of the gas to produce the clean, cool gas that is required for many applications, such as generating electricity or shaft power with an engine. Removing the tars and oils penalizes overall efficiency, since they constitute an important fraction of the

[1] One Nm^3 (normal cubic meter) is one cubic meter at standard temperature and pressure.

[2] Such problems were not found in gasifier-engine systems used during World War II, because the fuel for most of these was charcoal, not raw biomass. Charcoal produces much less tar because the process of converting raw biomass into charcoal removes most of the compounds in the biomass with tar-forming potential. However, a substantial fraction of the energy content of the original raw biomass is lost in the process of converting it to charcoal, particularly with traditional charcoal production technologies. These energy losses are unacceptable from a resource supply standpoint, and thus beginning in the 1970s efforts focussed on gasifying raw biomass. (Similar concerns with over-utilisation of the biomass supply during World War II led Sweden to ban charcoal use in gasifiers toward the end of the war.)

FIG. 5.1 AND 5.2. BASIC DESIGN OF AN UPDRAFT FIXED-BED GASIFIER (LEFT) AND A DOWNDRAFT FIXED-BED GASIFIER (RIGHT).



energy content of the gasified biomass. Thus, in practical operations, the use of updraft gasifiers has been limited to direct heating applications where no gas cleaning and cooling is required (e.g., for producing a fuel that is burned in a "close-coupled" boiler or kiln).

Downdraft fixed-bed gasifiers produce significantly less tar. In this kind of gasifier (Fig. 5.2), the product gas is drawn out from below, through the combustion zone. All the initial gasification products are forced to pass through the hot zone at and below the combustion region, where almost all the initial tar produced is broken down into lighter gases without sacrificing their energy content. The gas leaves the reactor at a higher temperature than from an updraft gasifier. With tar production minimised, gas cooling and cleaning can be done with acceptably small energy losses.

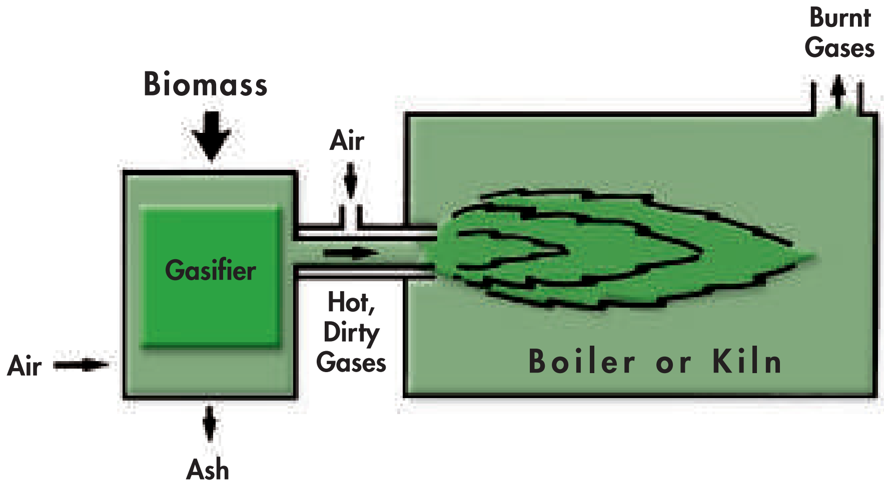
The gasifier itself is only one piece of equipment in a system. The additional equipment needed varies with the application.

Direct heating. A successful recent application of producer gas has been to replace fuel oil in industrial boilers, furnaces, and kilns (Fig. 5.3, see page 86). Producer gas has generally been successful in direct heating applications because the gasifier can be closely coupled to the gas burner, thereby eliminating tar condensation and associated problems.

Cooking. Producer gas from biomass can be used as a household or service-sector cooking fuel. Such applications require gas storage and piping systems, as well as burners. Some gas cleanup is required after gasification to avoid downstream buildup of contaminants. A growing number of projects today involve cooking applications, especially in China. Cooking with producer gas offers several advantages over traditional direct biomass burning, including more efficient overall use of the primary biomass resource, reduced indoor smoke and particulate levels leading to improved respiratory health, and reduced fuel collecting time. An important safety concern with producer gas cooking is the toxicity of the carbon monoxide component of the gas. Educating users about this safety issue is important.

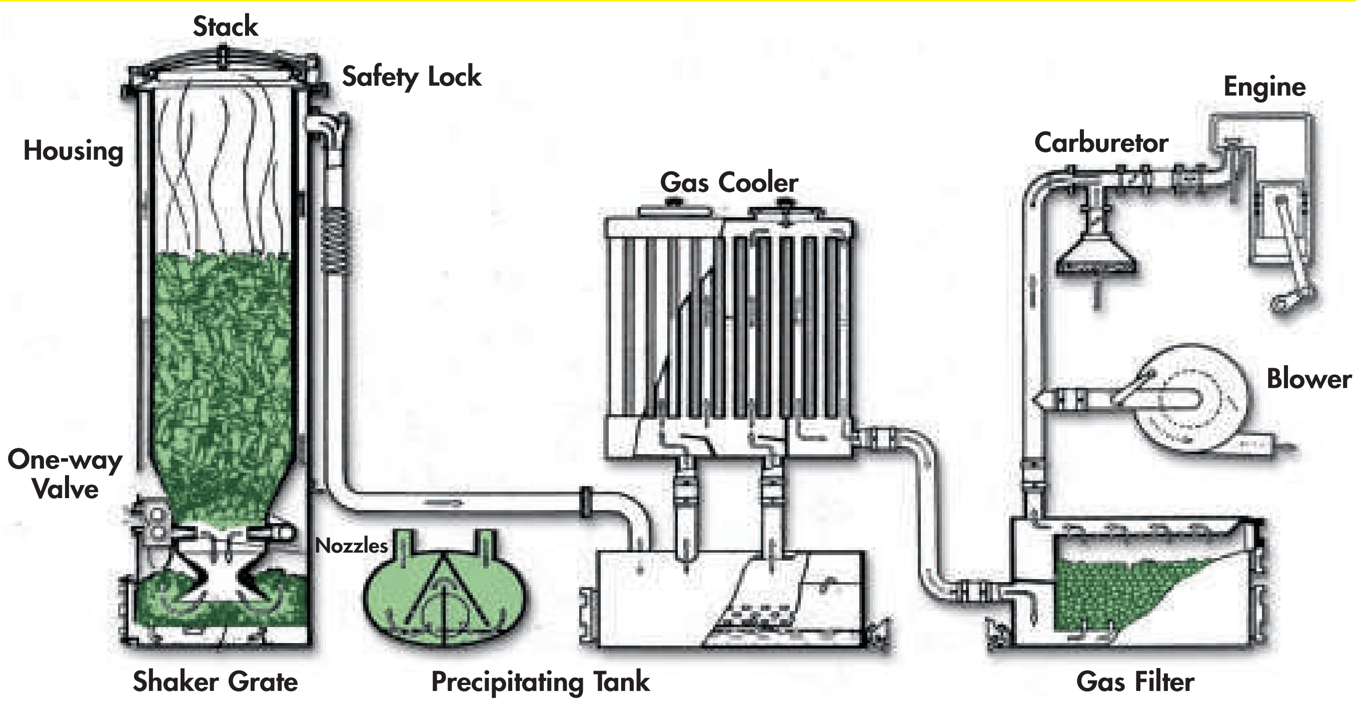
Electricity or shaft power generation. Producer gas can be used to fuel internal combustion engines—either diesel (compression-ignition) or gasoline (spark-ignition) engines. Diesel engines are favored because of their higher efficiency, greater durability and reliability, simpler maintenance, and because diesel fuel (as a backup) is more readily available than

FIG. 5.3. SCHEMATIC REPRESENTATION OF A DIRECT-HEAT PRODUCER GAS SYSTEM



gasoline in most developing countries. Using a gasifier's output in an engine requires cleaning it more thoroughly than in other applications to avoid contaminant deposition and erosion or corrosion damage to the engine. It also requires cooling the output to increase its density to enable a large enough charge to enter the engine cylinders (Fig. 5.4). Properly designed and operated, the best commercial gasifiers available today produce so little tar that a direct-contact water quench followed by a filtration system for particulate removal provides sufficient cleaning. Careful design of the scrubber and filter are critical to ensuring adequate gas cooling and cleaning, as well as ease of maintenance and operation of the cooling/filter system. Clean, cool producer gas can replace 60 to 70 percent of an engine's diesel fuel requirements; some

FIG. 5.4. BASIC LAYOUT OF A BIOMASS GASIFIER INTERNAL COMBUSTION ENGINE SYSTEM



Source: National Research Council, 1983 diesel fuel is needed to assist ignition. Commercial diesel engines require only minor modifications to the air intake system so that engine suction draws both air and fuel gas simultaneously. Decreasing air flow with a control valve permits the fuel-air ratio to be adjusted.

Combined heat and power generation. Combined heat and power (CHP) provides a more efficient means for using biomass than power generation alone. In a CHP system, the waste heat produced by an engine-generator (i.e., heat in engine cooling water and in exhaust gas) is recovered to provide heat, for example, for an industrial process or for heating homes or domestic hot water.

Table 5.1 summarises the characteristics of producer gas systems.

Table 5.1. Technology Summary: Biomass Gasification

Energy services	**Electricity**	**Shaft power**	**Cooking gas**[a]	**Heat**[a]
Range of output	5 to 500 kW_e	5 to 500 kW	10 to 1200 Nm^3/hr	10,000-1.2 million kcal/hour
Range of biomass input[b]	~5 to ~500 kg/hour		~ 3 to ~300 kg/hour	
Technical Parameters				
Basic equipment	Gasifier, gas cleanup, diesel engine		Gasifier, gas cleanup, gas distribution, stove	Gasifier & furnace; or Gasifier, gas cleanup, furnace
Fuel inputs	Per kWh: 1-1.4 kg biomass + ~ 0.1liter diesel (gives 60-70% diesel replacement)		0.4 to 0.6 kg biomass per 1000 kcal	
Energy outputs	~ 1 kWh per (kg biomass + 0.1 liter diesel)		1500 - 2500 kcal/kg biomass	
Acceptable biomass	Wood chips, corn cobs, rice hulls, cotton stalks, coconut shells, palm nut shells, soy husks, saw dust, biomass briquettes			
Biomass requirements	Sized (10-150 mm, depending on gasifier design), dried (~5-20% moisture)			
Useful byproducts	Waste heat, mineral ash	Waste heat, mineral ash	Mineral ash	Mineral ash
Key to good performance	Good gas cleanup (esp. tars), high capacity utilization			High capacity utilization
Special safety concerns	Leakage of (poisonous) carbon monoxide, exposure to (carcinogenic) tars			
Technology availability	From several multinationals and (in some countries) from domestic companies			
Difficulty of maintenance	Diesel engine maintenance		Low	Low
Key cost factors	Capital, diesel fuel, operating labor		Capital, operating labor	
Other attributes	Can operate exclusively on diesel fuel, if necessary		–	can burn gas in existing oil-fired boilers or furnaces
Environmental and Socioeconomic Parameters				
Environmental strengths	Reduced air pollutant emissions compared to diesel-fueled engine		Reduced particulate emissions compared to direct burning of solid fuel.	
Environmental concerns	Waste-water cleanup, clean combustion			clean combustion
Direct job creation	Modest (excluding biomass collection work)			
Operator skill required	Low to modest			

(a) Typical gas energy content is 4 to 5 MJ/Nm^3. Typical gas composition (volume%) is 20% CO, 10% CO_2, 18% H_2, 2% CH_4, 50% N_2.
(b) Assuming an average input-biomass energy content of 17.5 MJ per kilogram.

Table 5.2. Illustrative Costs for Gasification Systems (1998 US$)

Gas supply to homes for cooking from central village gasifier system with capacity ~ 60 Nm^3/hr gas[a]		
Total capital investment for gas production		$14,000
Total capital investment for gas storage tank		$15,000
Total capital investment for piping system for gas distribution		$15,000
Biomass consumption (17.5 MJ/kg biomass)		25 kg/hour
Operating labor		2 operators per shift
Maintenance/spare parts (assuming ~2% of capital cost/year)		$300/yr
Cost of delivered gas[b] (assuming 50% capacity utilization)		$ 0.069/Nm^3
of which	gas production system capital charges	$ 0.009
	gas distribution capital charges	$ 0.019
	biomass fuel charges (assuming $0.10/kg biomass)	$ 0.004
	operating labor (assuming $1/hr per operator)	$ 0.035
	maintenance	$ 0.001
Electricity production gasifier/diesel engine system with capacity ~ 100 kW_e		
Capital investment (including equipment and installation)		$75,000
Biomass consumption		100 kg/hour
Diesel consumption		10 liters/hr
Operating labor		2 operators per shift
Maintenance/spare parts (assuming 1% of capital cost/year)		$750/yr
Cost of electricity generation[c] (assuming 50% capacity utilization)		$ 0.084/kWh
of which	gas production system capital charges	$ 0.027
	biomass fuel charges (assuming $10/tonne biomass)	$ 0.010
	diesel fuel charges (assuming $0.25/liter)	$ 0.025
	operating labor (assuming $2/hr per operator)	$ 0.020
	maintenance	$ 0.002

(a) Assumed gas energy content of 4.5 MJ/Nm^3.

(b) For 50% capacity utilization (4380 hours per year operation), gas production is about 250,000 Nm^3/year--enough cooking fuel for ~100 households (based on estimate of 6 Nm^3/household/day for Jilin Province, China). With operator compensation of $1 per hour per operator; a biomass price of $10/tonne; and an annual capital charge rate of 16%, corresponding to an assumed equipment life of 10 years and a 10% discount rate, the cost of delivered gas is:
[(14,000+15,000+15,000)*0.16 + (25*0.01 + 1*2)*4380 + 300]/250000 = $0.0688/$Nm^3$

(c) For 50% capacity utilization (4380 hours per year operation), electricity production is 438,000 kWh/year. With operator compensation of $1 per hour per operator; a biomass price of $10/tonne; a diesel fuel price of $0.25/liter; and an annual capital charge rate of 16%, corresponding to an assumed equipment life of 10 years and a 10% discount rate, the electricity generating cost is:
[75,000*0.16 + (100*0.01 + 10*0.25 + 1*2)*4380 + 750]/438000 = $0.084/kWh

Costs

The cost of delivering fuel gas, electricity, or shaft power with a gasification-based system varies with the characteristics and requirements of a specific application. Capital investment is an important cost factor in all cases, especially where the capacity utilisation rate is relatively low, as it often is in village applications. Operator costs are also important. When electricity is produced using a dual-fuel (producer gas + diesel) engine, the cost of the diesel fuel generally is an important cost component as well.

Table 5.2 illustrates the costs of biomass gasification systems. While the electricity costs shown are generally higher than the cost of electricity generation from a new central-station coal or nuclear facility, gasifier-engine generators generally operate at sites where grid electricity is unreliable or unavailable. Thus an appropriate comparison is with the costs of central-station power generation, including costs to extend the transmission and distribution system, or, alternatively, with pure diesel-based generation. With a sufficiently high capacity utilisation, the gasifier-engine-generated electricity is easily competitive with the latter option, and it is likely to be competitive with the former under many conditions as well.

In a village cooking application, the direct financial cost to the user of cooking with producer gas may be higher than cooking with traditional technology such as a three-stone fire using "free" fuelwood. In some cases, villagers can afford and are willing to pay the higher cost because the system provides ancillary benefits such as lower in-home pollution and reduced effort gathering fuelwood. For villagers unable to afford the higher cost, creative financing programs are required—often with public-sector involvement.

Technology-Related Environmental Concerns

At a biomass gasification facility, environmental emissions of potential concern are primarily liquid effluents from the gas cleanup system. Tar-contaminated liquid effluent contains carcinogenic compounds such as phenols and thus requires appropriate treatment before discharging to the environment.

Leakage of poisonous and odorless carbon monoxide, at the conversion facility and at points of gas use (e.g., cooking stoves) is an additional danger. Other gaseous pollutant emissions are small in comparison to emissions from direct combustion of solid fuels. The solid residue from gasification of most biomass types is an inert inorganic material that has some by-product value, for example, as a mineral fertiliser or as a construction material (as is the case with rice husk ash).

5.2. Anaerobic Digestion

Anaerobic digestion is the low-temperature or biological process through which combustible gas can be produced from biomass. The gas produced by anaerobic (that is, without air) digestion is call biogas. Like gas produced through gasification, it can, after appropriate treatment, be burned directly for cooking or heating, or it can be used in secondary conversion devices such as internal combustion engines for producing electricity or shaft work.

Background

Biogas generally is 60 percent methane and 40 percent carbon dioxide. Almost any biomass except lignin (a major component of wood) can be converted to biogas: animal and human wastes, sewage sludge, crop residues, carbon-laden industrial-processing by-products, and landfill material have all been widely used. High-moisture feedstocks are especially well suited for anaerobic digestion.

Compared with other biomass energy conversion technologies, anaerobic digestion has important, direct non-energy benefits: it produces concentrated nitrogen fertiliser and neutralises environmental waste. The effluent sludge from a digester has a high fertiliser value. For example, the slurry from a cattle-dung digester contains essentially the same amount of nitrogen as the input dung, but in a form that is more readily usable by plants. Furthermore, dried digester effluent contains about twice the nitrogen of dried cattle dung, because more nitrogen is lost from dung than from digester effluent during drying. Digestion also provides for environmental neutralisation of wastes by reducing or eliminating pathogens and/or by reducing the high chemical or oxygen demand (COD) or biological oxygen demand (BOD) of feed materials.[3] Significant declines in parasite infections, enteritis, and bacillary dysentery have been noted in some developing-country regions following installation of small-scale digesters.

Small-scale digesters have been used extensively in India and China. Over 1.85 million cattle-dung digesters were installed in India by the mid-1990s, but about one third of these were not operating in early 2000 for a variety of reasons, primarily insufficient dung supply and difficulties with the organisation of dung deliveries. Some seven million household-scale digesters were installed in China as the result of a mass popularisation effort in the 1970s. These digesters used pig manure and human waste as feed material. However, many failed to work due to insufficient or improper chemical compositions of the feed or poor construction and repair techniques. According to estimates, some 3 to 4.5 million digesters were operating in the early 1980s. Since then, research, development, and dissemination activities have focussed greater attention on proper construction, operation, and maintenance of digesters, and, according to one estimate,

[3] COD is the amount of oxygen required to chemically oxidize the organic matter in a waste stream. BOD is the amount of oxygen required to biologically (aerobically) degrade the organic matter in a waste stream.

some 5 million household digesters were in working condition in China in the mid-1990s. In addition, China has some 500 large-scale digesters operating at large pig farms and other agro-industrial sites, and some 24,000 digesters at urban sewage treatment plants.

Several thousand biogas digesters are operating in other developing countries, most notably South Korea, Brazil, Thailand, and Nepal. An estimated 5,000 digesters are installed in industrialised countries, primarily at large livestock processing facilities (stockyards) and municipal sewage treatment plants. An increasing number of digesters are located at food processing plants and other industrial facilities. Most industrial and municipal digesters are used predominantly for the environmental benefits they provide, rather than for their fuel production.

The Technology

In an anaerobic digester, organic matter is degraded by three kinds of bacteria: fermentative bacteria, acetogens, and methanogens. The first two break down complex organic compounds into simpler intermediates, which are then converted to methane and carbon dioxide by the methanogens. Minerals are concentrated in the effluent slurry. Operation of a digester relies on a dynamic equilibrium among the three bacterial groups. This balance, and hence the quality and quantity of gas produced, is strongly affected by temperature. Most digesters operate in the mesophilic temperature regime (with a peak in microbe activity at around 35°C). Some operate in the thermophilic regime (with a peak in microbe activity around 55°C). Up to the temperature of peak microbial activity, higher operating temperatures produce greater metabolic activity within either regime. The pH and the composition (particularly the carbon-nitrogen ratio) and rate of loading of the feedstock also affect the bacterial balance.

The basic distinguishing characteristic of different digester technologies is the relationship between the average time influent feed remains in the reactor (called hydraulic retention time, HRT) and the average time solids remain in the reactor (solids retention time, SRT). Since the anaerobic bacteria act relatively slowly, long SRTs are needed to achieve reasonable conversion of biomass to gas. On the other hand, short HRTs are desired to improve economics by increasing the rate of reactor throughput. The simplest digester designs that are widely used for small-scale applications in developing countries, so-called unmixed tanks, have long SRTs (on the order of weeks) and equally long HRTs. For more dilute feed streams, e.g., many industrial waste streams, such designs are uneconomical in most cases. So-called retained-biomass reactors have been developed for larger-scale uses to provide long SRTs with short HRTs.

Unmixed-tank digesters. The two most common unmixed-tank designs are the floating-cover digester and the fixed-dome digester.

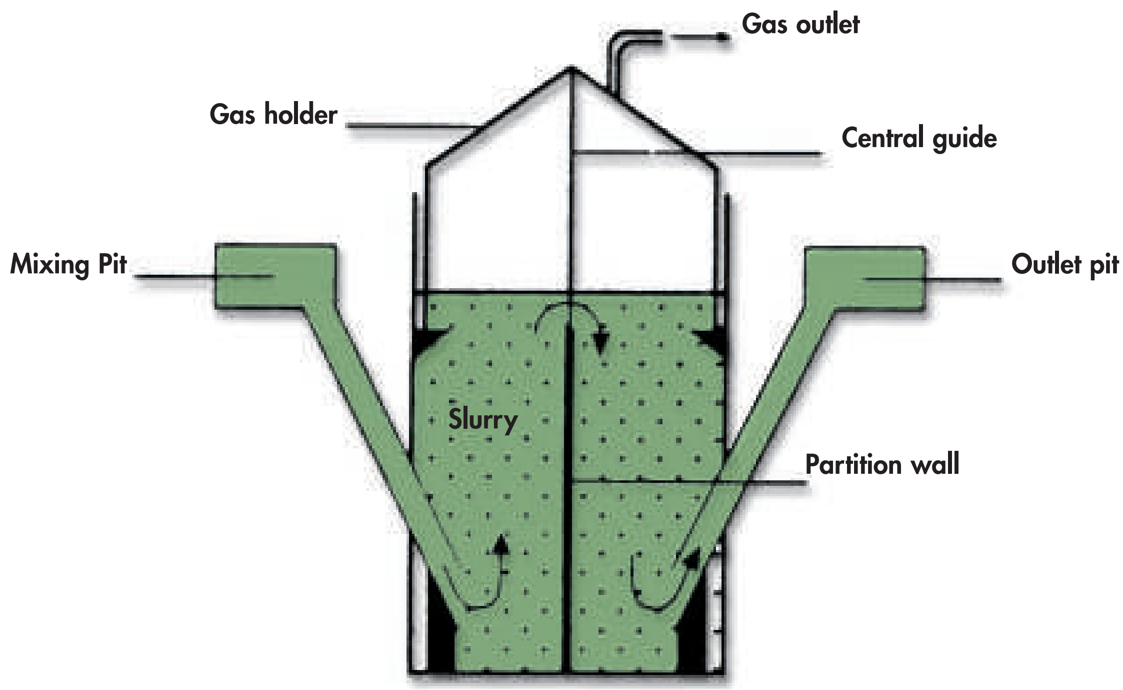
...anaerobic digestion has important, direct non-energy benefits: it produces concentrated nitrogen fertiliser and neutralises environmental waste.

The predominant design in India is the floating-cover digester (Fig. 5.5, see page 91), which was introduced commercially in 1962 by the Khadi and Village Industries Commission (KVIC). With this design, a gas holder floats on a central guide and provides constant pressurisation of the produced gas. The reactor walls generally are brick or concrete, and the cover is made of mild steel. The digester is fed semi-continuously, with input slurry displacing an equivalent amount of effluent sludge. In India, the predominant feed for digesters is a mix of cattle dung and water.

The fixed-dome design (Fig. 5.6, see page 91) originated in the 1930s in China. Biogas collects under a fixed brick or concrete dome, displacing effluent sludge as the gas pressure builds. The dome geometry is used to withstand higher pressures than are generated in the floating cover design. A shortcoming of the fixed-cover units, even in small sizes, has been the difficulty of constructing a leak-proof dome. Some improved versions of the fixed-dome design have been introduced, including "plug flow" digesters and/or storage of gas in variable-volume "bags."

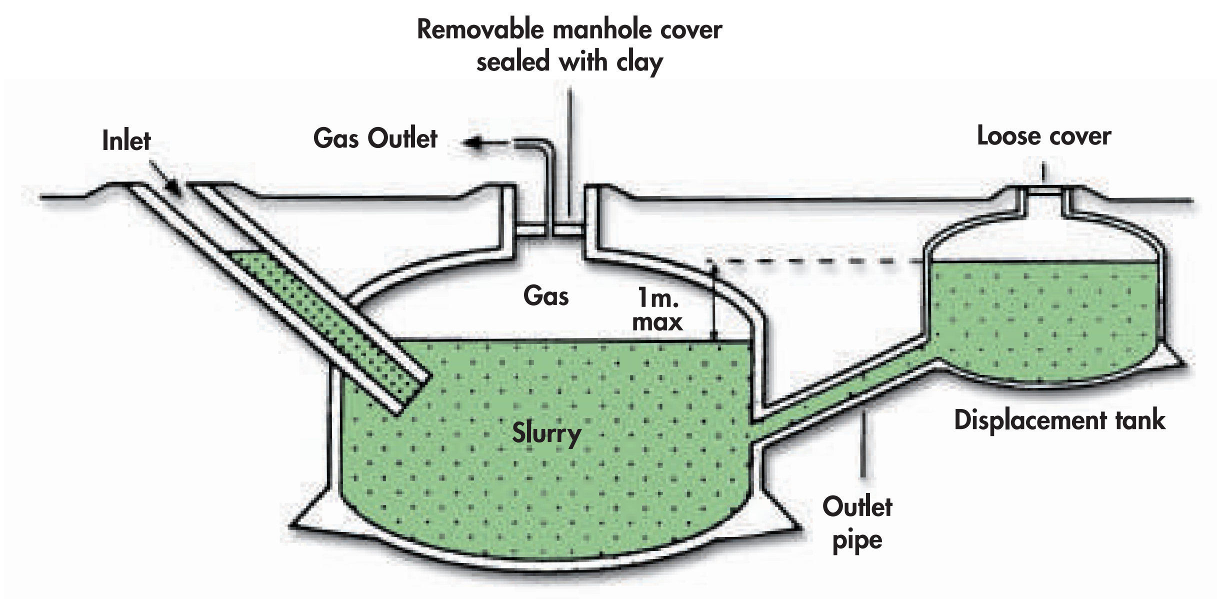
For any digester, the gas production rate is expressed in terms

FIG. 5.5. BASIC DESIGN OF A FLOATING-COVER BIOGAS DIGESTER OF THE TYPE COMMONLY FOUND IN INDIA



Source: Gunnerson and Stuckey (1986).

FIG. 5.6. BASIC DESIGN OF A FIXED-DOME BIOGAS DIGESTER OF THE TYPE COMMONLY FOUND IN CHINA



Source: Gunnerson and Stuckey (1986).

of daily volumetric gas production per unit of digester volume. A typical value for floating or fixed-cover reactors is 0.2 Nm^3/m^3/day at an ambient temperature of 18 to 20°C. This value reflects a balance between higher gas production rates (which would result from higher feeding rates) and lower gas yields and pathogen destruction (which would result from shorter residence times). Some innovative floating-cover designs, which increase the slurry surface area within a fixed reactor volume, achieve higher outputs with reduced capital costs and satisfactory yields. Gas production of up to 0.5 Nm^3/m^3/day has been achieved in such designs.

The concentration of solids in a floating-cover or fixed-dome digester fed with human or animal manure is relatively low. Solid-phase biomass, such as weeds, leaves, agricultural residues, and the like, fed to such "slurry" digesters tend to float and thereby hinder fermentation. Such feed materials are thus not well suited to slurry-based fermentation. Some simple digesters that can accommodate solid-phase feed materials (e.g., horizontal "plug-flow" reactors) are being developed at the Indian Institute of Science (Bangalore) and elsewhere.

Retained-biomass digesters. Retained-biomass digester designs have been developed primarily for use with very diluted industrial or municipal waste streams. These technologies are more complex and use more exotic construction materials than unmixed-tank designs. Capital investment requirements are consequently more substantial. Retained-biomass digesters are widely used in industrialised countries and are increasingly being adopted for industrial and urban-municipal applications in developing countries.

Retained-biomass-digester designs include the anaerobic contact reactor, the anaerobic filter reactor, and the upflow anaerobic sludge blanket (UASB) reactor; of these, the UASB is the most widely used. Solids in the feed material are allowed to settle so that a granular sludge blanket forms at the bottom of the reactor. A gas-solid-liquid separating device is used to enable solids to remain in the blanket for a long period, while HRTs can be very short (hours). China has some 24,000 retained-biomass digesters installed for urban sewage treatment.

Biogas cooking or electricity systems. Systems for cooking or for generating electricity from biogas generally include a sludge de-watering system to increase the solids concentration of the nutrient-rich effluent. In India, screening placed over sand beds has been employed effectively. The liquid filtrate, containing the required anaerobic microorganisms, is recovered and mixed with the fresh input dung. The de-watered sludge is used as a fertiliser.

To distribute biogas for cooking, piping is required, with provision made for removing water that may condense out of the gas in the pipes. In addition, biogas burners are required at cooking points. For electricity generation, spark or compression ignition engines can be fueled with biogas. Diesel (compression ignition) engines are favored because they are more efficient, durable, reliable, and easier to maintain, and because diesel fuel (as a backup) is more readily available than gasoline in most developing countries. A disadvantage of the diesel engine is that it requires continuous use of some diesel fuel (typically around 15 percent of rated diesel fuel consumption). Spark ignition engines can be operated on pure biogas.

Table 5.3 (see page 93) summarises the characteristics of anaerobic digestion systems.

Costs

Costs of biogas from household and community-scale unmixed-tank digesters in developing countries have been widely reported. Because floating-cover and fixed-dome designs are relatively standardised, reported capital costs are reasonably consistent. At the individual household scale, fixed-dome designs are 40 to 50 percent less capital-intensive than floating-cover designs, primarily because they do not require a steel cover. However, fixed-dome designs historically have been more prone to malfunction as a result of cracking of ceramic or brick containment surfaces.

The cost of delivering fuel gas, electricity, or shaft power with a biogas system varies with the characteristics and requirements of a specific application. However, capital investment is an important cost factor in all cases, especially where the capacity utilisation rate is relatively low, as it often is in village applications. Operator costs are also important. When electricity is produced using a dual-fuel (producer gas + diesel) engine, the cost of the diesel fuel is also an important cost component. Table 5.4 (see page 94) shows the expected

Table 5.3. Technology Summary: Biogas from Anaerobic Fermentation

Scale of application	Household or Village		Industry or Municipality	
Energy services	Electricity or shaft power	Cooking gas[a]	Electricity	Fuel gas
Range of output	3-10 kW_e	2 to 100 Nm^3/day	500 - 15,000 kW_e	10-200 1000Nm^3/day
Scale of services provided	Village	Home or village	Industrial facility or electric utility grid	
Technical Parameters				
Basic equipment	Digester, diesel engine, sludge filter/drier	Digester, sludge filter/drier, gas storage/ distribution, burner/stove	Digester, gas cleanup, gas engine, sludge filter/drier	Digester, gas cleanup, storage, distribution sludge filter/drier
Typical biomass inputs	Fresh animal or human manure, crop straws leaves, grasses		Sewage sludge, food-processing or food wastes, distillery effluents, animal manure	
Typical gas production	0.2-0.5 Nm^3/day per m^3 digester volume		4-8 Nm^3/day per m^3	
Inputs per unit output[b]	~14 kg fresh dung + 0.06 liters diesel fuel per kWh	~ 30 kg fresh dung[c] + 30 liters water per Nm^3 biogas	Varies with feedstock	
Gas required for cooking	–	~ 0.2 Nm^3/capita/day[d]	–	
Useful byproducts	Nitrogen fertilizer Pathogen destruction		Reduction of COD, BOD Fertilizer/irrigations	
Key to good performance	C:N ~20:1 Water:solids ~85:1 Internal temperature ~35°C		Temperature ~55°C	
Special safety concerns	Avoid build up of biogas in enclosed spaces (explosion or asphyxiation risk)			
Technology availability	Designs widely available, can be built with mostly local materials.		Sold/made by companies in many countries	
Difficulty of maintenance	diesel engine maintenance	Low	Moderate	Moderate
Failure modes	Inadequate feed supply; social or organization problems (e.g., dung collection); lack of skilled labor for repairing structural damage (especially cracking of fixed-dome units)		–	
Key cost factors	Capital, diesel fuel, operating labor		Capital	
Notes	Land area required for installation of digesters and sludge filtering			
Environmental and Socioeconomic Parameters				
Environmental strengths	pathogen destruction effluent fertilizer value		COD, BOD reduction Clean burning fuel gas	
	Less air pollution than diesel-fuel engine	Clean-burn cooking fuel	–	
Environmental concerns	Incomplete pathogen destruction		Insufficient COD, BOD reduction	
Direct job creation	Modest (excluding biomass collection work)			
Operator skill required	Low to modest			

(a) Typical gas energy content is 23 MJ/Nm^3. Typical gas composition (volume%) is 40% CO_2, and 60% CH_4. with trace amounts of other compounds.
(b) Typical for Indian cattle dung digesters.
(c) Fresh dung contains ~15% dry solids.
(d) Estimate for rural Indian or rural Chinese households.

costs of installing and operating a floating-cover biogas electricity-generating system.

Large-scale industrial digesters (retained-biomass designs) have much lower costs per unit of gas production (although they typically require greater capital investment) than small unmixed-tank digesters because throughput rates are much higher. A recent estimate for the total cost of methane from a UASB digester (300,000 GJ/year capacity or larger) with a typical industrial feedstock is less than $2/GJ (less than $0.07 per liter of diesel equivalent) under European conditions and about $1/GJ under Brazilian conditions—making this technology highly competitive with many fossil-fuel alternatives.

Technology-Related Environmental Concerns

Biogas is often, and appropriately, touted for its positive environmental attributes, which include pathogen destruction and production of a natural, nutrient-rich fertiliser. If pathogen destruction is an objective (as it has been in China) sufficiently long residence times (both SRT and HRT) are required in the digester. (With longer residence times, gas yields per unit volume of digester are necessarily lower than when shorter residence times can be used.)

Some precautions are needed in using biogas, particularly for household cooking. Biogas is not toxic, but an accumulation of gas in a closed living space presents explosion and asphyxiation risks. In practice, safety has not been a problem in the vast majority of cases where biogas has been used.

5.3. Ethanol from Sugarcane

Ethanol is a clean-burning alcohol fuel that is traditionally

Table 5.4. Illustrative Costs for a Floating-Cover Biogas-Electricity System

Indian village biogas-electricity generation: 5 kW_e installed capacity (all costs are in 1996 Indian Rupees)		
Generating hours per day	**5**	**16.4**
Annual net electricity generation[a] (kWh/yr)	**9035**	**30000**
Total installed capital cost (Rs/kW_e)	**50852**	**63547**
Installed capital cost for biogas plant (Rs/kW_e)	34372	
Installed capital cost for dual-fuel engine and generator[b] (Rs/kW_e)	16480	29175
Number of operators	**1**	**2**
Operator wages (Rs/yr)	**12600**	**25200**
Annual maintenance cost (Rs/yr)	**3115**	**6120**
Annual fuel costs (Rs/yr)	**8934**	**29400**
Dung (Rs. 0.02/kg and 14 kg/kWh)	2555	8400
Diesel fuel (Rs. 12.5/liter and 0.056 liters/kWh)	6388	21000
Levelized cost of electricity generation (Rs/kWh)	**6.31**	**3.38**
Capital charges[c]	3.59	1.35
Operating labor	1.39	0.84
Maintenance	0.34	0.20
Dung	0.28	0.28
Diesel fuel	0.71	0.71

(a) One percent of gross electricity generation is consumed on site during plant operation.

(b) Includes present value of the cost of replacement engines needed over a 25 year operating lifetime (at 12% discount rate).

(c) For a 25-year plant life and a 12% discount rate, the capital charge rate is 12.75% per year.

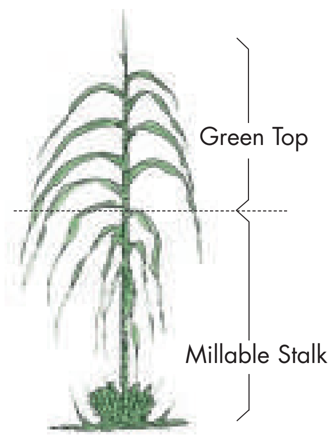
Source: Shivakumar, Rajan, and Reddy, 1998 made from biomass. Two varieties of ethanol are produced from biomass today: anhydrous ethanol (100 percent ethanol) and hydrous ethanol (containing about 5 percent water). Anhydrous ethanol can be blended with gasoline for use in standard gasoline-fueled engines, up to a maximum ethanol content of about 25 percent. Hydrous ethanol cannot be blended with gasoline, but can be used alone as a fuel (neat fuel) in internal combustion engines specifically designed for ethanol.

Ethanol can be produced from a variety of biomass crops, including starch-laden crops like corn, sugar-laden crops like sugarcane, or lignocellulosic feedstocks like wood or grasses. Because sugarcane is grown in over 80 developing countries, and because it is the least costly method of producing ethanol from biomass today, the discussion here focuses on ethanol production from sugarcane. With further technological developments, the economics of ethanol production from other crops might improve.[4]

With the exception of Brazil, most countries that produce fuel ethanol from sugarcane (Zimbabwe, Malawi, Kenya, and others) make anhydrous ethanol for blending. Production quantities in these countries are limited due both to oil-price fluctuations that affect the economics of ethanol relative to gasoline and to the limited size of the potential market for anhydrous ethanol (25 percent of gasoline consumption).

Brazil produces some 16 billion liters per year of ethanol from sugarcane, making it by far the largest ethanol producer in the world. It reached this position by launching a national ethanol program in 1975 in the wake of the first oil-price shock and during a period of depressed world sugar prices. Ethanol production grew an average of about 25 percent per year from 1976 to 1989. By the mid-1980s, ethanol consumption exceeded gasoline consumption on a volume basis, and more than 90 percent of new cars sold in Brazil used ethanol. High volumes of ethanol are still produced today, but new ethanol car sales are dramatically reduced from the mid-1980s levels, and the ethanol program is undergoing a critical re-evaluation driven in part by the economic impact of unprecedentedly low world oil prices.

FIG. 5.7. A TYPICAL SUGARCANE PLANT



Fibrous biomass accounts for about two-thirds of the energy contained in the above-ground portion of the plant.

Source: Alexander, 1985

Because of Brazil's extensive experience with ethanol production, much of the material in this section is based on Brazilian practices.

The Technology

Sugarcane consists of a main stalk, a green top, and a significant amount of leaves (Fig. 5.7). In most cane-processing operations worldwide, only the stalk (without the tops and leaves) is delivered to the mill for processing. The length of the harvesting season ranges from a low of about three months in Thailand to a more typical six months in Brazil, or longer. In most regions of the world, tops and leaves are burned on the field, typically before harvesting to promote pest control and facilitate harvesting (its tough exterior enables the stalk to survive field burning with minimal damage).

Ethanol production at an autonomous distillery. The majority of Brazil's production is hydrous alcohol, produced

[4] The United States produces substantial quantities of ethanol from corn, currently about 3 billion liters per year for use in a 10 percent blend with gasoline. However, the high cost of corn makes ethanol uneconomic today (and for the foreseeable future) without the large subsidy ($0.14/liter) paid by the government to producers. The high cost of starch crops like corn has motivated efforts in the United States to find ways to make ethanol from lower-cost lignocellulosic biomass, such as wood or grasses. These feedstocks are less costly largely because they do not compete for food uses, but their indigestibility makes them more difficult (and to date more costly) to convert to ethanol. "Acid hydrolysis" processes, in which acids are used to break down lignocellulosic biomass into fermentable compounds, have been used in a few commercial applications since the 1930s, but low energy efficiencies and high capital costs make such processes uneconomical now and for the foreseeable future. "Enzymatic hydrolysis" processes, wherein enzymes are used in place of acids, are promising, but they are still at an early stage of technological development.

either in distilleries annexed to sugar mills or in autonomous distilleries. At an autonomous ethanol distillery, raw sugarcane is washed, chopped, and crushed in rolling mills to separate the sugar-laden juice from the fiber in the cane, called bagasse. The juice, which contains over 90 percent of the sucrose in the cane, is filtered, heated, and in some cases concentrated, after which it is fermented. Beer, the fermented mixture, contains water and ethanol in about a 10:1 ratio. Distillation concentrates the mixture to 95 percent ethanol.[5] Stillage, a potassium-rich liquid, is drained from the bottom of the distillation columns. Typical yields of hydrous alcohol in Brazil fall between 70 and 80 liters per tonne of cane processed.

Bagasse accounts for about 30 percent of the weight of fresh cane and over half the cane's energy content. In a typical Brazilian distillery, all of the bagasse is burned to generate steam used in steam-turbine cogeneration systems to meet onsite process heat and electricity needs. A few distilleries with some excess bagasse are beginning to use it to generate additional electricity for sale to the local electric utility. However, the potential for economically exporting large amounts of electricity from alcohol distilleries is significant—largely due to new process technologies that reduce on-site energy needs and new cogeneration technologies that increase the ratio of electricity to heat produced using bagasse (discussed below).

Stillage contains about 6 percent of the energy in the cane. In Brazil, nearly all stillage is treated in closed circuit, anaerobic lagoons or digesters before being released in order to reduce high COD and BOD levels. In many areas, the treated stillage is used for fertilising and irrigating sugarcane crops.

The ratio of output-to-input energy in ethanol production[6] (including the agricultural phase) is very favorable (unlike the case for ethanol production from corn). Autonomous distilleries in the state of Sao Paulo (where 70 percent of Brazil's ethanol is produced) have an average output/input ratio of 6, and the most efficient mills have ratios of 8. Ratios in Northeast Brazil, the other major producing region of the country, are generally higher, since agricultural operations are less mechanised.

These ratios consider ethanol as the only energy output. Distilleries that generate significant amounts of excess electricity for export to the grid would have higher ratios, since a large proportion of the sugarcane's energy is stored in its bagasse. Energy ratios would be still higher if the sugarcane plant's tops and leaves were also used, since they contain energy amounts comparable to the amount in the bagasse. There currently is little use of tops and leaves for energy, but energy applications are being explored in a number of countries, including Brazil, Cuba, India, Thailand, and others.

Brazil produces some 16 billion liters per year of ethanol from sugarcane, making it by far the largest ethanol producer in the world.

Table 5.5 (see page 97) summarises the characteristics of ethanol production at autonomous distilleries, based on data for Sao Paulo state, Brazil.

Ethanol production at an annexed distillery. At an annexed distillery, the fermentation feedstock is typically molasses produced as a minor by-product of the adjacent sugar factory. The molasses is diluted to 18 to 20 percent sugar, and then converted to ethanol as in an autonomous distillery. Some Brazilian factories are designed to use either molasses or a mixture of molasses and raw cane juice as the fermentation feedstock.

The energy analysis of an annexed distillery is complicated by the multiple outputs produced. One detailed analysis for a facility in Zimbabwe indicated an output/input ratio of about 2. This much lower value than for ethanol produced in autonomous distilleries results largely from the use of a substantial amount of coal to produce steam and electricity to meet the distillery's energy needs during the non-cane

[5] Additional distillation steps are needed to produce anhydrous ethanol.

[6] Not including the energy content of sugarcane in the inputs.

Table 5.5. Technology Summary: Fuel Ethanol from Sugarcane at a Typical Autonomous Distillery, Sao Paulo State, Brazil

Scale of application	Medium-to-large industrial
Energy services	Clean liquid transportation fuel
Typical unit capacity	120,000 liters per day (standard Brazilian distillery unit)
Technical Parameters	
Basic equipment	Sugarcane juice extraction, fermentation, distillation
Typical sugarcane inputs	1500 to 1700 tonnes per day
Ethanol production	70 to 80 liters per tonne of sugarcane ~ 6000 liters per hectare
Byproduct electricity[a]	0 to 250 kWh per tonne of sugarcane (or 0 to 15 MW for a mill processing 1500 tonnes of cane per day)
Process electricity use	20 to 30 kWh per tonne of sugarcane
Technology availability	Packaged distilleries commercially available, especially from Brazilian companies
Key cost factors	Sugarcane feedstock; capital investment
Notes	Financially uncompetitive with gasoline when crude oil pricel is lower than $25-$30/barrel. Economic competitiveness depends on valuation of employment, foreign exchange savings, pollution reductions, and other societal benefits.
Environmental and Socioeconomic Parameters	
Environmental strengths	Reduced urban air pollution from vehicles; highly favorable energy output:input ratio.
Environmental concerns	Groundwater contamination by stillage; burning of cane fields; soil degradation
Total direct jobs created	2200 to 7000 per million tonnes of cane processed per year
Agricultural jobs[b]	1600 to 6400 per million tonnes of cane processed per year
Distillery jobs	600 per million tonnes of cane
Skill level required	30% managerial and highly-skilled; 10% medium-skilled; 60% unskilled
Seasonality index[c]	1.3 to > 2

(a) Most distilleries burn bagasse, the fiber extracted from the cane stalk, to generate steam used for process heating and for generating electricity by driving a steam turbine. The most efficient steam-based combined heat and power (CHP) system at a typical distillery can produce about 120 kWh per tonne of cane from bagasse. A CHP system at a distillery that uses an additional fuel, e.g., cane tops and leaves or coal, during the off-season (when no ethanol is being made) will be able to produce a maximum amount of electricity per tonne of sugarcane processed about double this level.

(b) The lower estimate is for Sao Paulo State, Brazil, where a high degree of agricultural mechanization leads to fewer (but higher paying) jobs. The upper estimate is for Northeast Brazil, where there is much less mechanization.

(c) The seasonality index is the ratio of labor requirements for agricultural operations during the sugarcane harvesting season to those required during the non-harvesting season. The lower estimate is for Sao Paulo State, Brazil, as of a few years ago. The seasonality index has been falling steadily there throughout the 1980s and 1990s as a result of several factors (Macedo, 1995). The upper figure is a lower bound estimate for the Northeast region of Brazil (and may be representative for most sugarcane producing regions in other countries). Employment in sugarcane production in such regions is still highly seasonal.

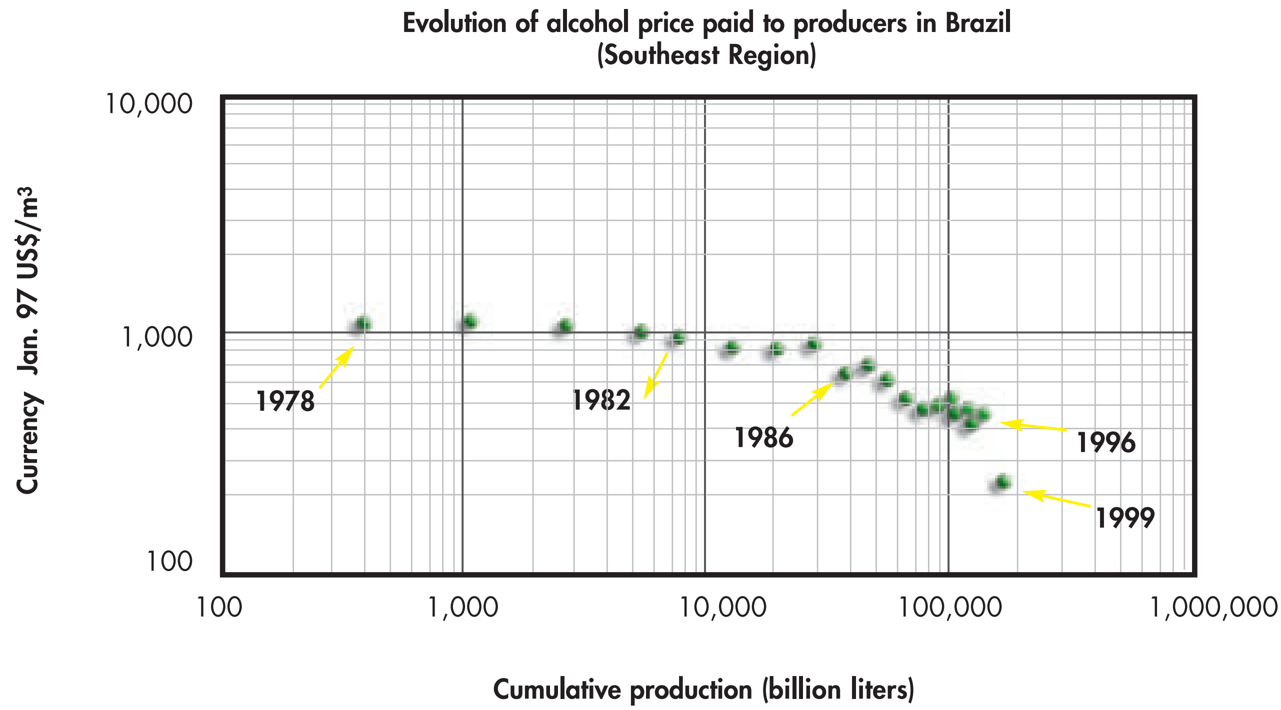
harvesting season, when purchased molasses is used as the fermentation feedstock. Using available cane tops and leaves in place of coal during the off-harvest season would raise the energy output/input ratio to about 4.

Costs

The average cost of anhydrous ethanol production in Sao Paulo state, Brazil, in the early 1990s was $0.23 to $0.25 per liter in 1989 US$, or about $0.29 to $0.32 per liter in 1998 US$ (Table 5.6, see page 99).[7] This is about half the average cost in Brazil a decade earlier. Production costs declined during that period partly as a result of increased efficiency of distilleries (increased liters of ethanol per tonne of cane), but more importantly, as a result of increased land productivity (tonnes of

[7] Costs for hydrous ethanol are about 7 to 10 percent less.

FIG. 5.8. EVOLUTION OF ETHANOL PRICES PAID TO PRODUCERS IN THE SOUTHEAST REGION OF BRAZIL



Source: J. Goldemberg, personal communication, August 1999

cane per hectare). Average costs have continued to fall since the early 1990s. As a result, even with the complete lifting of subsidies on ethanol in early 1999 that led to a major drop in ethanol prices (Fig. 5.8) ethanol production is expected to be competitive because of cost reductions that have already been achieved.

Table 5.6 (see page 99) shows that the cost of the sugarcane feedstock accounts for over half of the per liter cost of producing ethanol in Sao Paulo. Brazilian cane costs are among the lowest in the world because of the large scale of production, the relatively low cost of labor, and the emphasis placed on cane varieties and cultivation practices to maximise yield. In other countries with higher cane costs, ethanol would be more costly to produce.

A promising strategy for improving the competitiveness of cane ethanol is to make more energy-efficient use of the bagasse and cane trash (tops and leaves). By reducing distillery energy demands and adopting more efficient biomass cogeneration technology, on-site energy demands can be met while producing a surplus of electricity for export to the national grid. The tops and leaves of the cane could be collected and used in the non-milling season to allow year-round electricity generation, and the electricity revenues could be credited against ethanol costs. Such strategies are increasingly being considered by both ethanol and sugar producers (see the discussion below on steam turbine combined heat and power).

Technology-Related Environmental Concerns

Producing sugarcane, converting it to ethanol, and using it in vehicles, all present environmental challenges, including how to maintain soil productivity and how to prevent water contamination and air pollution. These issues are discussed here in the context of Brazil, which has the most experience in addressing them.

Maintaining soil productivity is a concern with a monoculture such as sugarcane. Surprisingly, in the case of Brazil, sugarcane yields per hectare have been increasing over time, rather than falling as would be expected if soil degradation were occurring. The increased productivity has been attributed

Table 5.6. Illustrative Costs for Anhydrous Ethanol Production in Brazil, 1990 (1989 US$)

Autonomous distillery in Sao Paulo State, Brazil, with production capacity of 240,000 liters/day of ethanol		
	Average[a]	Higher Average[a]
Number of employees[b]	**1125 - 3825**	
Sugarcane production/harvesting (varies with mechanization level)	900 - 3600	
Sugarcane conversion at distillery	225	
Specific ethanol production, liters per tonne of sugarcane	**74**	**77**
Approximate Installed distillery capital cost (1989$ per liter/day)	**77.5**	
Total cost of production, 1989$ per liter	0.229	0.251
Fixed charges		
Capital charges[c]	0.051	0.053
Other	0.011	0.013
Interest on working capital + commercial costs	0.022	0.029
Variable costs		
Sugarcane	0.127	0.134
Labor	0.006	0.007
Maintenance	0.004	0.006
Chemicals	0.002	0.002
Energy	0.002	0.003
Other variable costs	0.004	0.004

(a) Costs shown are based on a survey of 50 distilleries in Sao Paulo state Brazil. "Average" refers to the sample average. "Higher average" refers to the average of the mills operating above the sample average.

(b) Extrapolated from labor estimates for a 120 m^3/day ethanol distillery, with agricultural labor assumed to scale linearly with ethanol production, and distillery labor assumed be 50% greater with double the production capacity.

(c) Assuming a 25-year plant life, a 12% discount rate, and a 150 day operating season.

Source: Goldemberg, Monaco, and Macedo, 1993

to improved soil preparation techniques, the development of superior cane varieties, and the recycling to land of nutrients from distilleries (in the form of stillage). As a result, in Sao Paulo state, topsoil loss per hectare of sugarcane is far below that for most other major monoculture crops.

Water quality issues arise with two liquid-waste streams generated at a distillery: run-off of cane-wash water and leaching of stillage. Historically, these liquid streams both have been dumped directly on the ground. With increasing recognition of the potential environmental damage this practice causes, the large majority of mills in Sao Paulo state now recirculate cane-wash water and/or discharge it to aeration lagoons to be neutralised before being released to the environment. Stillage, which is rich in potassium, is distributed back onto cane fields in controlled amounts that have been found through extensive studies to avoid groundwater contamination. Where groundwater is closer to the surface, the level of stillage applied per hectare is lower. Application levels of under 400 m^3/hectare-year generally have been found to be safe in Sao Paulo state, but a limit of 200 m^3 is the actual recommended rate to avoid over-fertilisation of cane plants.

Stillage is also a suitable feedstock for biogas production. Biogas from stillage could be a substantial energy resource (with up to 25 percent of the energy in the alcohol), while the digestion process would reduce COD and BOD to low enough levels in the digester effluent for it to be safely returned to the soil. Biogas trials have been undertaken at some Brazilian mills.

A major air pollution concern is open-field burning of cane tops and leaves before and/or after harvest to facilitate cutting and/or replanting. Cane burning is starting to be banned by law in some countries, including parts of Brazil. Such bans are forcing sugarcane growers to find alternative uses for cane tops and leaves. Energy applications are getting increased attention.

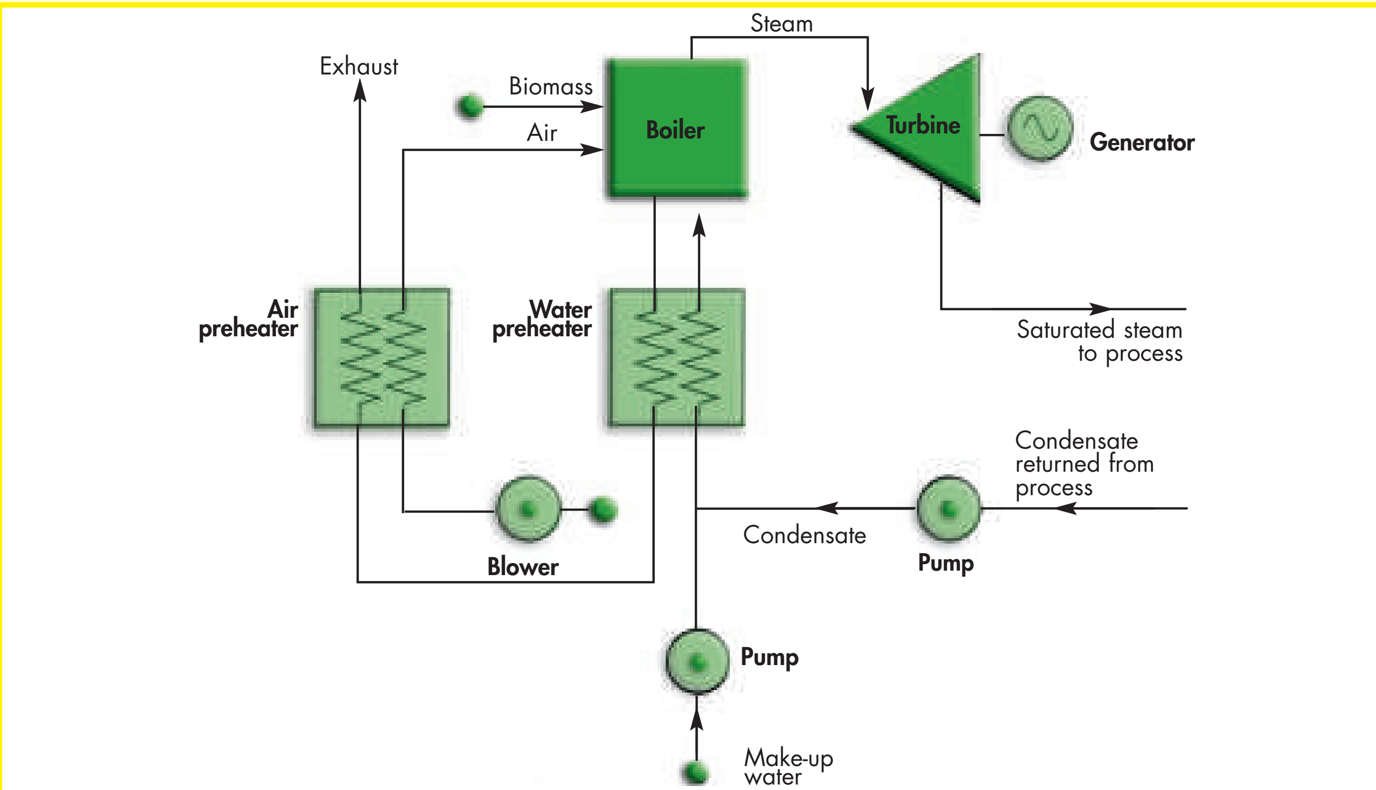
5.4 . Steam Turbine Combined Heat and Power

The predominant technology in all parts of the world today for generating megawatt (MW) levels of electricity from biomass is the steam-Rankine cycle, which consists of direct combustion of biomass in a boiler to raise steam, which is then expanded through a turbine. The steam-Rankine technology is a mature technology, having been introduced into commercial use about 100 years ago. Most steam cycle plants are located at industrial sites, where the waste heat from the steam turbine is recovered and used for meeting industrial-process heat needs. Such combined heat and power (CHP), or cogeneration, systems provide greater levels of energy services per unit of biomass consumed than systems that generate power only.

In the United States, the installed biomass-electric generating capacity exceeds 8000 MW, with the majority of this capacity located at pulp and paper mills, where biomass fuels are available as by-products of processing. In California, a substantial number of biomass power plants use agricultural processing wastes as fuel. Biomass power-generating capacity grew rapidly in the United States in the 1980s, largely as the result of incentives provided by the Public Utilities Regulatory Policies Act of 1978 (PURPA). PURPA required utilities to purchase electricity from cogenerators and other qualifying independent power producers at a price equal to the utilities' avoided costs. A significant number of biomass power plants are also found in Scandinavia, especially Sweden.

Compared to the installed steam-Rankine power-generating capacity in OECD countries, there is relatively little capacity installed in developing countries. The most

FIG. 5.9. SCHEMATIC DIAGRAM OF A BIOMASS-FIRED STEAM-RANKINE CYCLE FOR COMBINED HEAT AND POWER PRODUCTION USING A BACK-PRESSURE STEAM TURBINE



Source: Williams and Larson, 1993

significant installation of steam-Rankine capacity in developing countries is at factories making sugar and/or ethanol from sugarcane. Over 80 developing countries grow and process sugarcane. Each factory (except those using very low-technology sugar-refining technologies, such as open-vat boiling) typically includes a steam-Rankine CHP system fueled by bagasse, the fiber residue that remains after juice extraction from sugarcane.

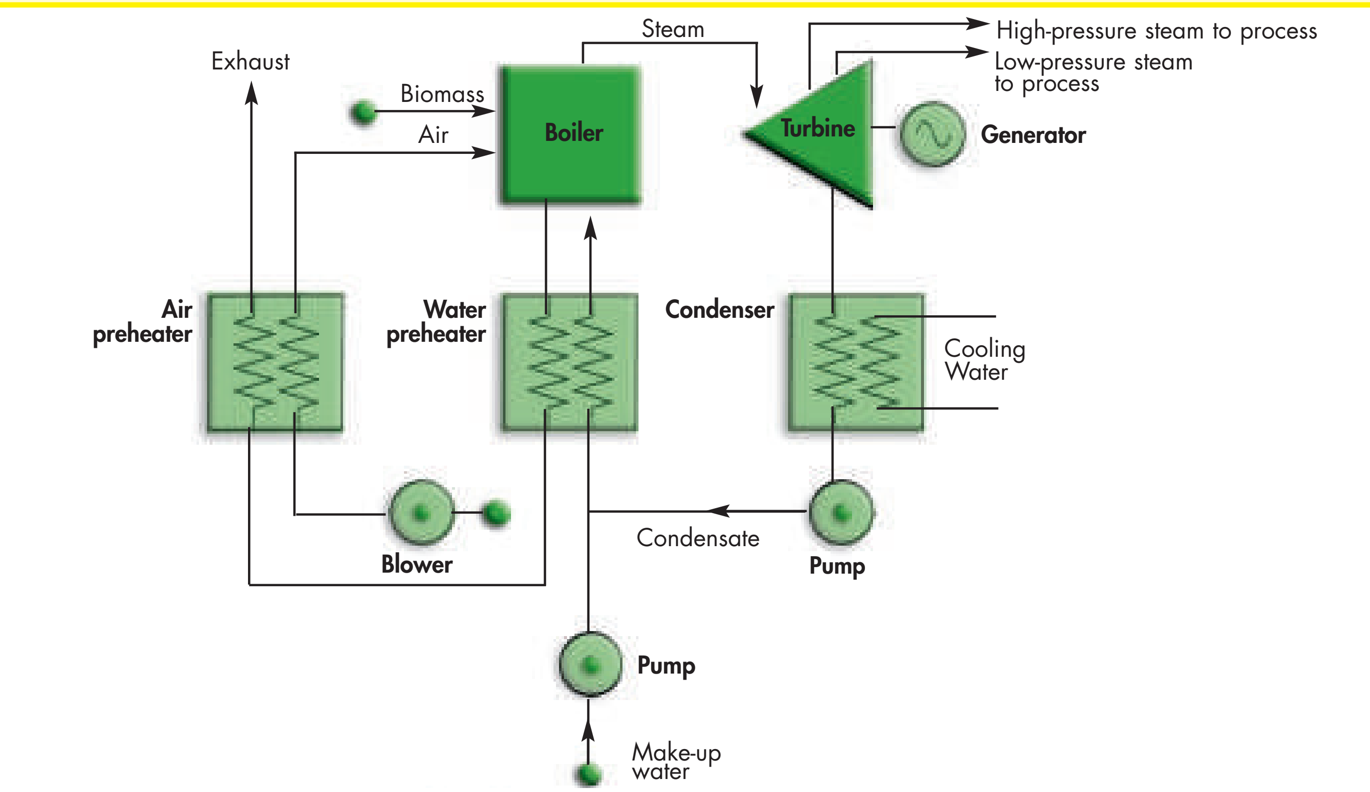
The Technology

The steam-Rankine cycle involves boiling pressurised water, with the resulting steam expanding to drive a turbine-generator, and then condensing back to water for partial or full recycling to the boiler. A heat exchanger is used in some cases to recover heat from flue gases to preheat combustion air, and a de-aerator must be used to remove dissolved oxygen from water before it enters the boiler. Drying of the biomass is not usually required before combustion, but will improve overall efficiency if waste heat is utilised for drying.

Steam turbines are designed as either "back-pressure" or "condensing" turbines. CHP applications typically employ back-pressure turbines, wherein steam expands to a pressure that is still substantially above ambient pressure (Fig. 5.9, see page 100). It leaves the turbine still as a vapor and is sent to satisfy industrial heating needs, where it condenses back to water. It is then partially or fully returned to the boiler.

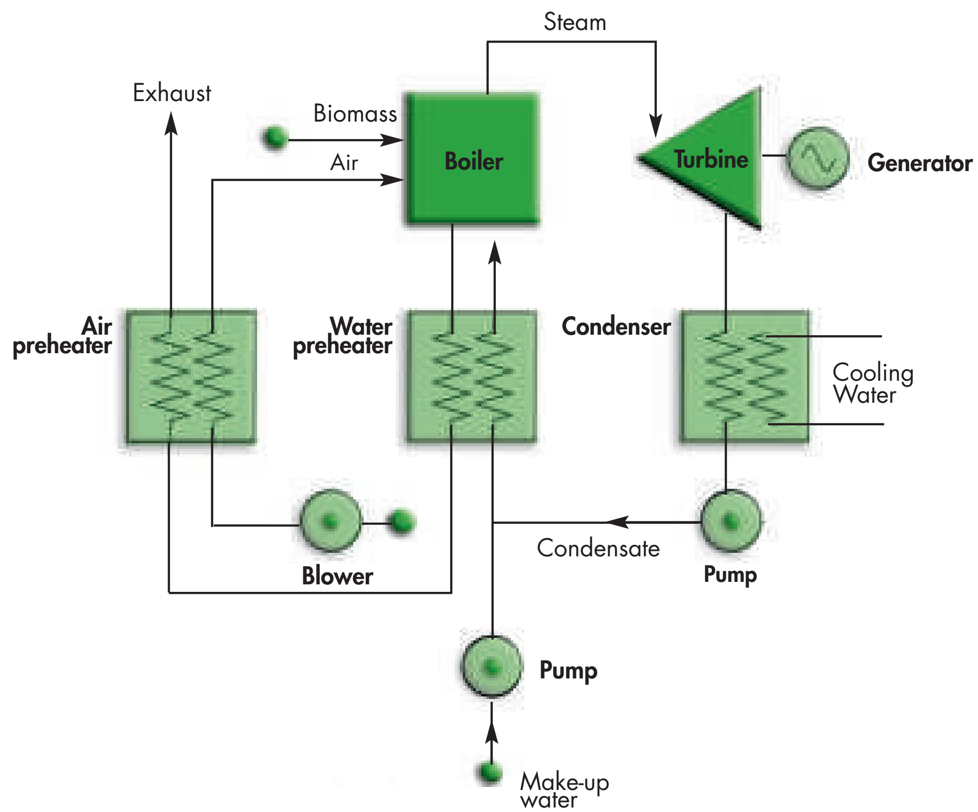
Alternatively, if process steam demands can be met using only a portion of the available steam, a condensing-extraction steam turbine (CEST) might be used. This design includes the capability for some steam to be extracted at one or more points along the expansion path for meeting process needs (Fig. 5.10). Steam that is not extracted continues to expand to sub-atmospheric pressures, thereby increasing the amount of electricity generated per unit of steam compared to the back-pressure turbine. The non-extracted steam is converted back to liquid water in a condenser that utilises ambient air and/or a cold water source as the coolant. Where there is no demand for process heat, a purely condensing steam turbine

FIG. 5.10. SCHEMATIC DIAGRAM OF A BIOMASS-FIRED STEAM-RANKINE CYCLE FOR COMBINED HEAT AND POWER PRODUCTION USING A CONDENSING-EXTRACTION STEAM TURBINE



Source: Williams and Larson, 1993

FIG. 5.11. SCHEMATIC DIAGRAM OF A BIOMASS-FIRED STEAM-RANKINE CYCLE FOR DEDICATED POWER GENERATION USING A CONDENSING-EXTRACTION STEAM TURBINE



Source: Williams and Larson, 1993

generally is employed to maximize electricity production (Fig.5.11).

The steam-Rankine cycle uses different boiler designs, depending on the scale of the facility and the characteristics of the fuel being used. These include the oldest designs for small-scale systems, manually-fed, brick-lined "Dutch ovens" in which the biomass burns in a pile ("pile burners"). The most commonly found boilers in OECD countries are more sophisticated, using stoker feeding onto stationary or moving grates. Others use suspension burning, wherein a dry pulverised fuel (e.g., sawdust) burns while free-falling. Still others use fluidised-bed combustion, wherein the combustion air enters as jets from below to "fluidise" the burning biomass fuel particles and the sand that makes up the bed. The commercial introduction of fluidised-bed technologies started in earnest in the late 1970s/early 1980s. These boilers all have the capability, to greater or lesser extent, to burn different fuels or mixtures of fuels.

The initial pressure and temperature of the steam, together with the pressure to which it is expanded, determine the amount of electricity that can be generated per kilogram of steam. In general, the higher the peak pressure and temperature of the steam, the more efficient, sophisticated, and costly the cycle. Biomass-fired steam-Rankine plants operate with far more modest steam conditions than are used in large, modern electric-utility coal-fired steam-Rankine systems.

In the mid-1990s, a survey of some 100 biomass plants in California found that most of these operate with a steam pressure and temperature of about 60 bar and 480°C. In comparison, large coal-fired plants generally operate at 100 to 240 bar and 510°C to 537°C. Biomass plants in California that generate power only (no cogenerated heat) operate with efficiencies of 14 to 18 percent, compared to 35 percent for a modern coal plant. The best biomass plants today have efficiencies of 20 to 25 percent. Biomass steam-Rankine plants operating in developing countries tend to use milder

Table 5.7. Technology Summary: Steam Turbine Combined Heat and Power (CHP)

Scale of application	Medium-to-large industrial
Energy services	Electricity and process heat/steam
Typical electrical capacity	1 to 50 MW_e
Typical heat to power ratio [a]	5
Technical Parameters	
Basic equipment	Boiler, steam turbine, dearator, pumps
Typical steam conditions [b]	20 to 80 bar; 400-500°C
Biomass fuels	Any/all (boiler design varies with fuel)
Typical biomass rate [c]	1 to 2 dry kg/kWh; 6575 to 13150 dry tonnes/year per installed MW_e
Technology availability	Boilers and turbines manufactured in most large developing countries
Key cost factors	Capital investment (especially at smaller scales), fuel cost
Technical concerns	Deposition on boiler tubes with high-ash biomass (with low ash softening temp.); Boiler feedwater purity (at minimum, demineralization and dearation are required)
Environmental and Socieconomic Parameters	
Environmental strengths	Efficient use of biomass with CHP; multi-fuel capability
Environmental issues	Particulate emissions, thermal pollution; ash disposal
Total direct jobs	Two per MW_e at 10 MW_e; One per MW_e at 30 MW_e (California experience)
Managerial/highly skilled	20%
Moderate skill level	75%
Low skill level	5%

(a) This varies significantly with the amount of process steam produced. The number shown is typical for a back-pressure steam turbine. With a fully condensing steam turbine, no process heat is produced.

(b) Steam pressures can be as low as 20 bar, as is found at many sugar factories in developing countries, or as high as 100 or 120 bar, as is found at many large coal-fired thermal power plants.

(c) These figures assume an input biomass with a moisture content of 50% and energy content of 18 GJ per dry tonne. Also, assumed overall conversion efficiencies to electricity are 10% (which might be representative of a system using 20-bar steam in a back-pressure turbine) to 20% (which might be representative of a system using a fully-condensing turbine with a steam pressure of 60 bar). For the biomass rate per MW_e, a 75% capacity factor is assumed, i.e., the annual electricity production per installed kW_e is 6575 kWh.

steam conditions than those in California. For example, back-pressure steam turbine systems in the majority of sugar factories operate with steam pressures of 20 bar or less. Power plants in developing countries have considerably lower efficiencies than those found in California.

Low efficiencies, together with relatively high capital costs, explain the reliance of existing biomass power plants on low-, zero-, or negative-cost biomass (primarily residues of agro- and forest-product-industry operations). Many regions of the world still have significant untapped supplies of low-cost biomass feedstocks for which the economics of steam-Rankine systems are probably reasonable. Sugarcane processing industries present major opportunities for steam-Rankine-based CHP generation from biomass.

Table 5.7 summarises the characteristics of steam-Rankine cycle combined heat and power.

Biomass CHP at Sugarcane-Processing Facilities

Brazil, China, India, Indonesia, and over 70 other developing countries grow sugarcane. The production of sugar or ethanol from sugarcane generates a fibrous biomass by-product (bagasse) that is used as a fuel for combined heat and power generation to supply the sugarcane processing facility with its process energy requirements. Raw bagasse (with 50 percent moisture content) typically accounts for 25 to 30 percent of the weight of cane stalks delivered to a mill. The amount of sugarcane tops and leaves (cane trash) potentially available as additional biomass fuel is comparable to the amount of bagasse generated. Cane trash traditionally has been burned on the fields to facilitate replanting or harvesting, though the resulting air pollution has motivated some governments to ban this practice.

Historically, sugar factories have exported little electricity because most bagasse-fired CHP systems have low efficiency. However, sugar factories produce such large quantities of bagasse and trash that they could be major electricity exporters. With conventionally generated electricity supply unable to keep pace with electricity demand in many developing countries, there is growing interest in excess electricity generated at sugar factories.

...sugar factories produce such large quantities of bagasse and trash (from sugarcane) that they could be major electricity exporters.

Most existing sugar mills use low-pressure (~20 bar) boilers feeding back-pressure steam turbines. These systems are designed to be inefficient, so that they consume all available bagasse while generating just the amount of electricity (about 20 kWh per tonne of sugarcane crushed) and steam needed to operate the mill. A few mills are now beginning to utilise higher-pressure boilers (40 to 60 bar) and condensing-extraction steam turbines. Because of their higher efficiency, such systems can meet process electricity and heat needs and also generate an additional amount of electricity (80 to 100 kWh per tonne of sugarcane crushed) that can be exported from the mill. (Cost-effective changes to reduce process steam demand could make another 20 to 30 kWh per tonne of cane available for export.)

An undesirable characteristic of such plants is that they generate power only during the cane crushing season, which lasts three to nine months, depending on the country. In some installations, for example in Mauritius, coal is used as a supplemental fuel to extend the length of the power-generating season. Alternatively, some of the vast quantity of cane trash that goes uncollected today could be used to extend the power generating season, so that total exportable power generated from biomass per tonne of cane crushed could reach 200 to 300 kWh per tonne. Efforts to develop cane trash collection and utilisation systems are ongoing today in Brazil, Cuba, India, Thailand, and elsewhere. If the sugar industries in such countries were to implement efficient steam-Rankine technology on a widespread basis and sell excess electricity to the national grid, the contribution of cane-derived power to meeting national electricity needs could be substantial (Table 5.8). Most such generating plants would be located in rural areas.

Costs

The costs of steam-Rankine systems vary widely depending on the type of turbine, type of boiler, the pressure and temperature of the steam, and other factors. An important characteristic of

Table 5.8. Potential for Electricity Generation from Sugarcane in Developing Countries (in excess of sugar or ethanol factory demands) Using Commercially-Established Technology (CEST)

	1995 Cane Production (million tonnes)	2025 Cane Prod. @ 2%/yr (million tonnes)	2025 "Excess" Electricity (TWh/year)	2025 Utility Elec. Prod.* (TWh)	2025 Cane Elec./2025 Utility Elec.
Brazil	304	550	165	623	0.27
India	260	470	141	883	0.16
China	70	127	38	2085	0.02
Carribean	48	87	26	102	0.26
Indonesia	31	57	17	141	0.12
Other Latin Am.	152	275	83	1063	0.08
Others	233	422	127	2214	0.06
TOTALS	1098	1988	591	7112	0.08

* Projected from data for electricity generation in 1995 assuming an annual 3% growth rate.
Note: TWh = billion kWh.

Table 5.9. Illustrative Costs for a Biomass Steam-Turbine CHP Plant (1998 US$)

Combined process heat and power production at an industrial site	
Technical Characteristics	
Process design	Extraction/condensing turbine (60 bar steam)
Average electricity generation[a]	10 MW_e
Heat to power ratio	5:1
Annual electricity production[b]	78,894 MWh
Annual heat production	394,470 MWh_{th}
Annual biomass consumption (dry matter)[c]	157,788 tonnes per year
Annual biomass charged to power consumption[d]	45,082 tonnes per year
Cost Characteristics	
Installed capital costs per unit of maximum capacity	$2000 per kW_e maximum capacity[e]
Annual fixed non-labor costs (~2% of initial capital cost)	$40 per year per kW_e maximum capacity[e]
Annual fixed labor costs (USA wage rates)	$50 per year per kW_e maximum capacity[e]
Variable costs	$0.0025 per kWh
Total cost of electricity production	**$0.104 per kWh**
Capital charges[f]	0.066
Fixed non-labor operating costs	0.010
Fixed labor costs	0.013
Variable costs	0.0025
Biomass cost charged to power production[g]	0.012

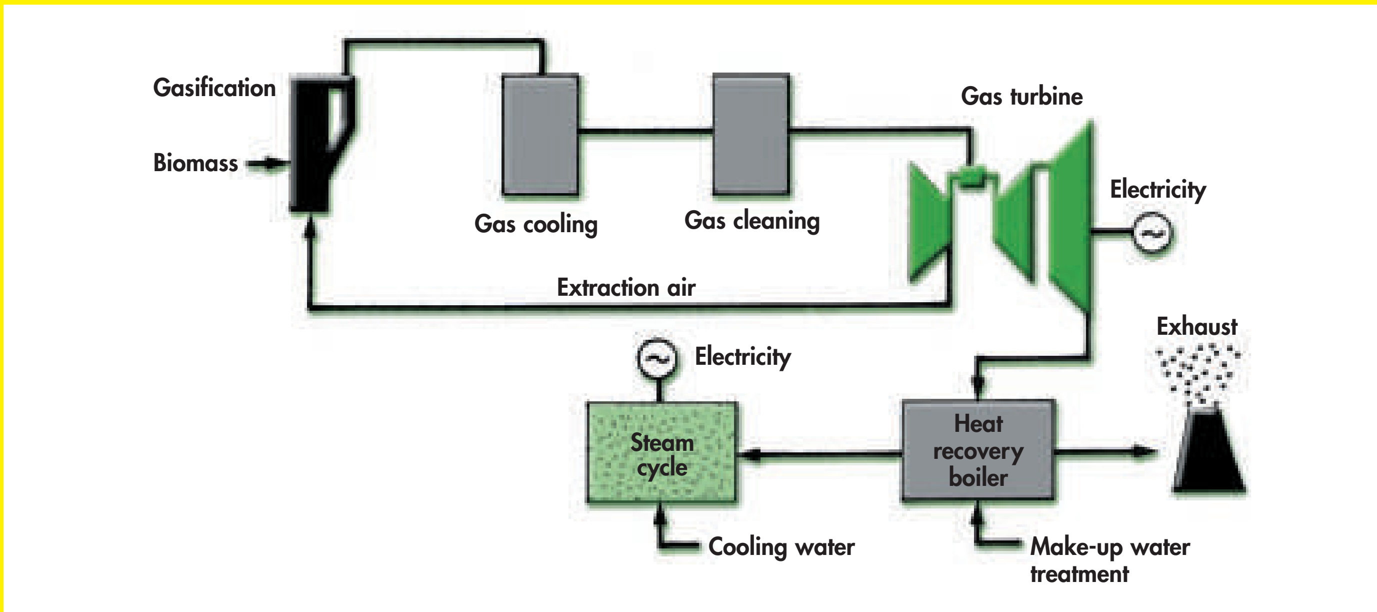
(a) If all steam were expanded without extracting any for process use, the electricity generation would be about 21 MW_e.
(b) Assuming operation 90% of the time at full capacity, i.e., a capacity factor of 0.9.
(c) Assuming an average electricity generating efficiency of 10% with biomass containing 18 GJ per dry tonne. The biomass has 50% moisture content delivered to the power plant.
(d) This is the amount of biomass actually consumed less the amount of biomass that would be consumed in a dedicated biomass boiler (assumed to have a 70% steam generating efficiency) to raise the same amount of process steam as that generated by the cogeneration system.
(e) The installed cost is given per kW_e of maximum generating capability (21 MW_e in this case--see note a).
(f) Assuming a capital charge rate of 0.1252 (10% discount rate, 25 year lifetime, and 1.5%/year property tax and insurance).
(g) The price of biomass to the powerplant is assumed to be $18 per dry tonne ($1/GJ). Only the "biomass charged to power generation" is included in the biomass charges. (The cost for the balance of the biomass is assumed to be offset by the value of the steam delivered from the CHP plant to the industrial process.)

steam turbines and boilers is that their capital costs (per unit of capacity) are scale-sensitive (This is the main reason coal and nuclear steam-electric plants are built big—500 to 1000 MW_e). Moreover, biomass steam-Rankine systems are constrained to relatively small scales (because long-distance transport of biomass fuels is costly). As a result, biomass steam-Rankine systems generally are designed to reduce capital costs at the expense of efficiency. For example, biomass-fired systems are typically designed with relatively low steam pressures and temperatures, which enables lower grade steels to be used in boiler tubes. Also, less air or water preheating might be used in order to eliminate heat exchangers. However, even with such cost-reducing measures, capital costs for small-scale systems are still substantial and lead to relatively high electricity-generating costs compared to conventional fossil-energy power plants, as illustrated in Table 5.9.

Technology-Related Environmental Concerns

Biomass steam-Rankine systems pose a number of environmental issues, including the potential for particulate emissions to the air. Flue-gas-filtration systems are required to minimise these. Ambient-temperature air or water is used to cool the condenser in biomass steam cycles. If the reservoir of water or air available for cooling is not sufficiently large, thermal pollution may result. Ash generated during combustion contains much of the inorganic minerals found in the original biomass. Ideally, the ash would be returned to the soil. In many cases, it is sent to a landfill.

FIG. 5.12. SCHEMATIC DIAGRAM OF ONE POSSIBLE CONFIGURATION OF A BIOMASS-GASIFIER/GAS TURBINE COMBINED CYCLE. IN THIS CASE, THE BIOMASS GASIFIER IS PRESSURIZED AND AIR-BLOWN.



Source: Carpentieri *et al.*, 1993

5.5. Gas Turbine Combined Cycle CHP

Gas turbines fueled by gasified biomass are of interest for power or combined heat and power generation in the range of 5 to 100 MW_e. The biomass-gasifier/gas turbine (BIG/GT) technology is not commercially employed today, but a brief discussion of the technology is included here because intense worldwide interest in its commercialisation is likely to lead to the technology being available within a few years.

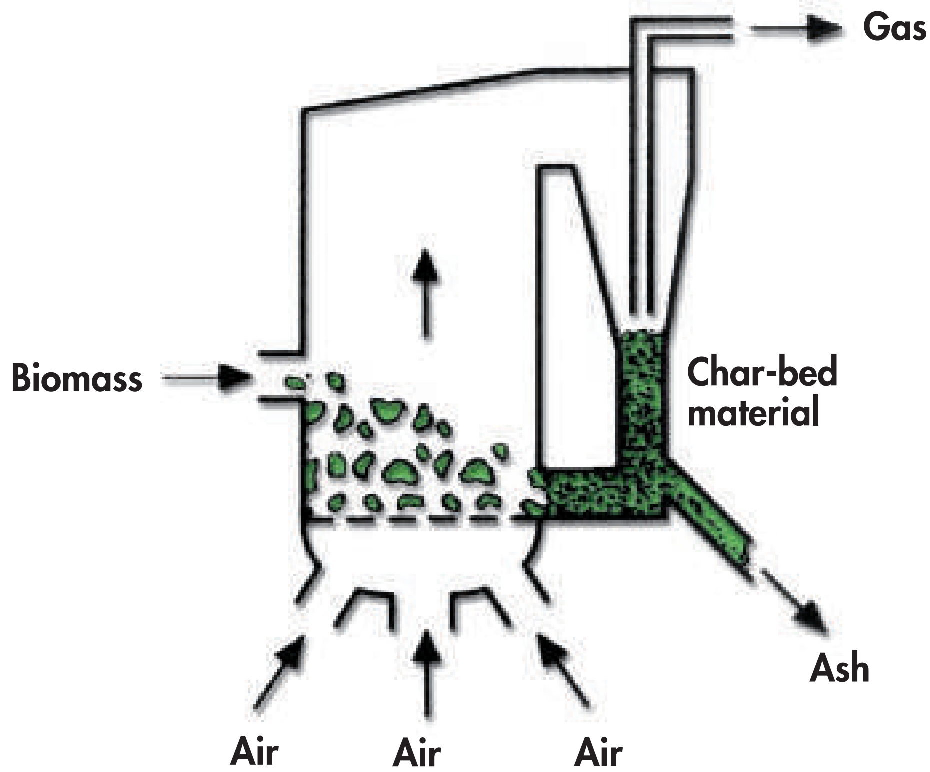
The steam-Rankine cycle (Section 5.4) is the predominant commercial technology used today with biomass fuel in the 5 to 100 MW output range. In approximate terms, the BIG/GT technology will make electricity generation two or more times as efficient as the steam cycle, and the capital cost per installed kW for commercially mature BIG/GT units is expected to be lower than for comparably-sized steam cycles. Thus the overall economics of biomass-based power generation are expected to be considerably better with a BIG/GT system than with a steam-Rankine system, especially in situations where biomass fuel is relatively expensive.

BIG/GT technology is expected to be commercially ready within a few years, based on the substantial demonstration and commercialisation efforts ongoing worldwide today. The most advanced demonstration projects are in Sweden, the United Kingdom, and Brazil. At Varnamo, Sweden, a BIG/GT system has operated for several thousand hours on forest residues, generating 6 MW of electricity and 9 MW of heat for the local-district heating system. At Yorkshire, England, construction of a BIG/GT facility that will generate about 8 MW of electricity from short-rotation biomass plantations was completed in early 2000. At a site in the state of Bahia, Brazil, construction of a 32 MW BIG/GT power plant using plantation-grown eucalyptus for fuel is scheduled to begin in 2000. The facility will also test the use of sugarcane bagasse as a fuel. The Brazil demonstration project is supported by a grant from the Global Environment Facility.

The Technology

A BIG/GT system involves sizing and drying of the feedstock, followed by thermochemical gasification to produce a combustible gas, cooling and cleaning of the gas, and combustion in a gas turbine (Fig. 5.12, see page 106). Steam is raised using the hot exhaust of the gas turbine to drive a steam turbine that generates additional power and/or delivers lower pressure steam for heating purposes. The cascading of a gas turbine and a steam turbine in this manner is commonly called a combined cycle.

FIG. 5.13. SCHEMATIC DIAGRAM OF A GENERIC AIR-BLOWN CIRCULATING FLUIDISED-BED GASIFIER. SEVERAL VARIANTS OF THE BASIC FLUIDISED-BED DESIGN ARE UNDER COMMERCIAL DEVELOPMENT.



A variety of biomass gasifier designs have been proposed for BIG/GT systems. The designs that are furthest advanced toward commercialisation in BIG/GT applications involve fluidised beds, in which the gasifying agent is air and gasification occurs in a bed of inert material such as sand (Fig. 5.13). A number of large (> 30 MW biomass input) atmospheric-pressure, "air-blown," fluidised-bed gasifiers are operating commercially today. The UK and Brazil projects mentioned above will use this gasification technology. The Swedish project utilises a high-pressure, air-blown fluidised-bed.

Another generic class of biomass gasifiers, which could be used for BIG/GT applications, is the indirectly-heated design. These provide heat for gasification without subjecting the biomass to an oxygen-containing gasification agent, e.g., by heating through a heat exchanger. The resulting gas is not diluted with nitrogen and hence has a higher energy content per unit volume than gas from an air-blown gasifier, which is advantageous when using it in a gas turbine.

BIG/GT technology is expected to be commercially ready within a few years.

Adequate cleaning of the gasified biomass is critical to ensure that the gas turbine will operate satisfactorily on the gas. (Gas turbines were originally designed for clean fuels such as natural gas or distillate fuel.) The concentration of particulates, alkali metal compounds (potassium, sodium, etc.), and condensable tars must all be very low. Particulates cause turbine blade erosion. Alkali metal vapors corrode turbine blades. Condensation of tars (heavy organic molecules) can cause operating problems, including constricted piping or clogged valves and filters. Ceramic or sintered-metal filters operating

Table 5.10. Technology Summary: Gas Turbine Combined Cycle Heat and Power Production

Scale of application	Medium-to-large industrial
Energy services	Electricity and process heat or steam
Typical electric capacity	5 to 100 MW_e
Typical heat to power ratio	1
Technical Parameters	
Basic equipment	Gasifier, gas cleanup, gas turbine, heat recovery boiler, steam turbine cycle
Maximum pressures	Fuel gas to turbine, 30 to 40 atmospheres; steam cycle, 60 to 80 atmospheres
Biomass fuels	Any/all (gasifier design varies with fuel)
Typical biomass rate[a]	0.50 to 0.67 dry kg per kWh_e generated; 3288 to 4405 dry tonnes/year per installed MW_e
Technology availability	Technology is not commercially-mature; commercial demonstrations are in progress
Key cost factors	Capital investment; fuel cost
Technical concerns	Biomass feeding (especially to high pressure gasifier), gas cleanup for gas turbine
Environmental and Socieconomic Parameters	
Environmental Strengths	Near-zero air pollutants; lower biomass per kWh than steam-rankine
Environmental Concerns	Thermal pollution (from steam cycle cooling); ash desposal; waste water treatment
Total direct jobs[b]	Two per MW_e at 10 MW_e; One per MW_e at 30 MW_e
Managerial/highly skilled	20 %
Moderate skill level	75%
Low skill level	5%

(a) These figures assume an input biomass with a moisture content of 50% and energy content of 18 GJ per dry tonne. Also, assumed overall conversion efficiency to electricity is 30 to 40%. For the biomass rate per MW_e, a 75% capacity factor is assumed, i.e., the annual electricity production per installed kW_e is 6575 kWh.

(b) In the absence of sufficient operating experience with the biomass-gas turbine technology, labor requirements are assumed to be the same as with steam-rankine cycle technology.[o]

at elevated temperatures are being developed for use with pressurised gasifiers. With atmospheric-pressure gasifiers, wet scrubbing systems are proposed. Wet scrubbing entails some thermodynamic penalty compared to filtering at elevated temperature, and requires treatment of the scrubber water, but there is less uncertainty about the cleaning effectiveness of such systems.

Table 5.10 summarises the expected characteristics of commercial BIG/GT systems.

Projected Costs

The commercialisation of BIG/GT technology is being pursued in large part because of promising long-term economics. Higher efficiency and lower unit capital cost at the modest scales required with biomass mean that BIG/GT systems can be expected to produce electricity at considerably lower cost than steam-Rankine systems. Because BIG/GT technology is not yet commercial, however, there is some uncertainty in capital cost projection. Expectations are that the capital cost for a fully mature 30-MW_e BIG/GT system will be in the range of \$1500/kW_e. At this capital cost level, electricity could be generated at competitive costs under a variety of biomass-fuel price scenarios, including those using low-cost residues or higher-cost biomass from dedicated plantations (Table 5.11, see page 109).

While the economics of BIG/GT power generation appear attractive enough that plantation-biomass is a feasible fuel, initial BIG/GT applications are likely to be at industrial sites

Table 5.11. Projected Costs for a Biomass-Gasifier/Gas Tubine Combined Cycle Generating Only Electricity (no cogeneration of heat) (1998 US$)

Plant dedicated to power production only (no process heat production)		
Technical Characteristics		
Process design	Gasifier, gas cleanup, gas turbine, heat recovery steam generator, steam turbine	
Average electricity generation	30 MW_e	
Annual electricity production[a]	236,682 MWh	
Annual biomass consumption (dry matter)[b]	135,247 tonnes per year	
Cost Characteristics		
Installed capital costs per unit of maximum capacity	$1500 per kW_e installed capacity	
Annual fixed non-labor costs (~2% of initial capital cost)[c]	$30 per year per kW_e installed capacity	
Annual fixed labor costs (USA wage rates)[d]	$33 per year per kW_e installed capacity	
Variable costs[c]	$0.0025 per kWh	
Total cost of electricity production	**$0.045**	**$0.055**
Capital charges[e]	0.024	0.024
Fixed non-labor operating costs	0.004	0.004
Fixed labor costs	0.004	0.004
Variable costs	0.0025	0.0025
Biomass cost[f]	0.010	0.021

(a) Assuming operation 90% of the time at full capacity, i.e., a capacity factor of 0.9.

(b) Assuming an average electricity generating efficiency of 35% with biomass containing 18 GJ per dry tonne. The biomass has 50% moisture content delivered to the power plant.

(c) Assumed to be the same as for a biomass steam-Rankine cycle (see Table 5.9).

(d) Assumed labor cost (per kW_e) is two thirds of that for the steam cycle in Table 5.9 (due to higher efficiency with BIG/GT).

(e) Assuming a capital charge rate of 0.1252 (10% discount rate, 25-year lifetime, and 1.5%/year property tax and insurance).

(f) The price of biomass to the powerplant is assumed to be $18 per dry tonne ($1/GJ) in left column and $36/t ($2/GJ) in right column

where biomass processing residues are readily available today, such as at cane sugar processing mills and mills in the forest products industry. Biomass-fired steam-turbine cogeneration systems are already used in these industries to meet on-site steam and electricity needs (see above). With much higher electrical efficiencies, BIG/GTs could produce two to three times as much electricity from the same biomass resource. ■

References for Chapter 5

SECTION 5.1.

Bernardo, F.P., and G.U. Kilayko. 1990. "Promoting Rural Energy Technology: The Case of Gasifiers in the Philippines." *World Development* 18(4): 565-574.

Foley, G., and G. Barnard. 1982. *Biomass Gasification in Developing Countries*. Earthscan Technical Report no. 1. London.

Food and Agriculture Organisation (FAO). 1999. Regional Office for Asia and the Pacific. "Rural Energy in the Asia-Pacific Region: Combustion and Gasification of Biomass." *RAP Bulletin*, 1998-99. Bangkok: FAO.

Larson, E.D. 1993. "Technology for Electricity and Fuels from Biomass." *Annual Review of Energy and the Environment* 18: 567-630.

———. 1998. "Small-Scale Gasification-Based Biomass Power Generation." In *Proceedings of the Workshop on Small-Scale Power Generation from Biomass* (January 12-13). Changchun, China:

Working Group on Energy Strategies and Technologies, China Council for International Cooperation on Environment and Development: 26-45.

Mukunda, H.S., S. Dasapa, and U. Shrinivasa. 1993. "Open-Top Wood Gasifiers." In *Renewable Energy: Sources for Fuels and Electricity*, edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 699-728.

——, S. Dasappa, J. Paul, N.K.S. Rajan, and U. Shrinivasa. 1994a. "Gasifiers and Combustors for Biomass—Technology and Field Studies." *Energy for Sustainable Development* I(3) (September): 27-38.

——, J. Paul, S. Dasappa, U. Shrinivasa, and H. Sharan. 1994b. "Results of an Indo-Swiss Programme for Qualification and Testing of a 300-kW IISc-Dasag Gasifier." *Energy for Sustainable Development* I(4) (November): 46-49.

National Research Council. 1983. *Producer Gas: Another Fuel for Motor Transport.* Washington, DC: National Academy Press.

Reed, T.B., and A. Das. 1988. *Handbook of Biomass Downdraft Gasifier Engine Systems.* Golden, Colorado: Solar Energy Research Institute.

Solar Energy Research Institute. 1979. *Generator Gas: The Swedish Experience from 1939-1945.* SERI/SP-33-140. Golden, Colorado: Solar Energy Research Institute. (Translation from Swedish of GENGAS. Prepared by Swedish Academy of Engineering, Stockholm, 1950).

Stassen, H.E.M. 1995. *Small-Scale Biomass Gasifiers for Heat and Power: A Global Review.* Energy Series, World Bank Technical Paper No. 296. Washington, DC: World Bank.

——, and H.A.M. Knoef. 1995. "UNDP/World Bank Small-Scale Gasifier Monitoring Programme – Final Findings." *Energy for Sustainable Development* II(1) (May): 41-48.

SECTION 5.2.

Bhatia, R. 1990. "Diffusion of Renewable Energy Technologies in Developing Countries: A Case Study of Biogas Engines in India." *World Development* 18(4): 575-590.

Chanakya, H.N., N.K. Ganguli, V. Anand, and K.S. Jagadish. 1996. "Performance Characteristics of a Solid-Phase Biogas Fermentor." *Energy for Sustainable Development* III(4) (November): 28-42.

Crook, M., trans. and A. van Buren, ed. 1983. *A Chinese Biogas Manual.* London: Intermediate Technology Publications, Ltd.

Dai, L., J. Li, and R. Overend, eds. 1998. *Biomass Energy Conversion Technologies in China: Development and Evaluation.* China Environmental Science Press.

Daxiong, Q., G. Shuhua, L. Baofen, W. Gehua, and A. Barnett. 1990. "Diffusion and Innovation in the Chinese Biogas Program." *World Development* 18(4): 555-563.

Food and Agriculture Organisation (FAO). Regional Office for Asia and the Pacific. 1995. "Medium and Large Scale Biogas Systems in the Asia-Pacific Region." *Special issue of Rural Energy, the RAP Bulletin.* Bangkok: FAO.

Gunnerson, C.G., and D.C. Stuckey. 1986. *Anaerobic Digestion: Principles and Practices for Biogas Systems.* Technical Paper no. 49. Washington, DC: World Bank.

Jagadish, K.S., H.N. Chanakya, P. Rajabapaiah, and V. Anand. 1998. "Plug Flow Digesters for Biogas Generation from Leaf Biomass." *Biomass and Bioenergy* 14(5/6): 415-423.

Larson, E.D. 1991. *A Developing-Country-Oriented Overview of Technologies and Costs for Converting Biomass Feedstocks into Gases, Liquids, and Electricity,* PU/CEES Report No. 266 (November). Princeton, NJ: Center for Energy and Environmental Studies (CEES), Princeton University.

——. 1993. "Technology for Electricity and Fuels from Biomass." *Annual Review of Energy and the Environment* 18: 567-630.

Lettinga G., and A.C. van Haandel. 1993. "Anaerobic Digestion for Energy Production and Environmental Protection." *In Renewable Energy: Sources for Fuels and Electricity,* edited by Johansson et al.: 816-839.

Lichtman, R., A. Ellegard, S. Lal, and N. Sharma. 1996. "The Improved Biogas Systems Project: Results and Future Work." *Energy for Sustainable Development* III(4) (November): 28-42.

Office of Technology Assessment (OTA) of the U.S. Congress. 1992. *Fueling Development: Energy Technologies for Developing Countries.* OTA-E-516. Washington, DC: Government Printing Office.

Rajabapaiah, P., S. Jayakumar, and A.K.N. Reddy. 1993. "Biogas Electricity: The Pura Village Case Study." In *Renewable Energy,* edited by Johansson *et al.*: 787-815.

Ravindranath, N.H. and D.O. Hall. 1995. *Biomass, Energy, and Environment: A Developing Country Perspective from India.* Oxford, UK: Oxford University Press.

Santerre, M.T., and K.R. Smith. 1982. "Measures of Appropriateness: The Resource Requirements of Anaerobic Digestion (Biogas) Systems." *World Development* 10(3): 239-261.

Shivakumar, A.R., S.C. Rajan, and A.K.N. Reddy. 1998. *Phase I Implementation of Rural Energy and Water Supply Utilities* (July). Final Report to Rockefeller Foundation from the International Energy Initiative. Bangalore, India.

Tomar, S.S. 1995. "Status of Biogas Plants in India–an Overview." *Energy for Sustainable Development* I(5) (January): 53-56.

SECTION 5.3.

Alexander, A.G. 1985. *The Energy Cane Alternative.* Amsterdam: Elsevier: 509 pages.

Geller, H. 1988. "Ethanol from Sugarcane in Brazil." *Annual Review of Energy* 10: 135-164.

Goldemberg, J. 1998. "Leapfrog Energy Technologies." *Energy Policy* 26(10): 729-741.

——, L.C. Monaco, and I.C. Macedo. 1993. "The Brazilian Fuel Alcohol Program." In *Renewable Energy,* edited by Johansson et al.: 841-863.

Larson, E.D. 1993. "Technology for Electricity and Fuels from Biomass."

Macedo, I.C. 1995. "Converting Biomass to Liquid Fuels: Making Ethanol from Sugar Cane in Brazil." In *Energy as an Instrument for Socio-Economic Development,* edited by J. Goldemberg and T.B. Johansson. New York: United Nations Development Programme: 107-112.

Rosenschein, A.D., and D.O. Hall. 1992. "Energy Analysis of Ethanol Production from Sugarcane in Zimbabwe." *Biomass and Bioenergy* 1(4): 241-246.

Rosillo-Calle, F. and L.A.B. Cortez. 1998. "Towards Proalcool II: A Review of the Brazilian Bioethanol Programme." *Biomass and Bioenergy* 14(2): 115-124.

Wyman, C.E., R.L. Bain, N.D. Hinman, and D.J. Stevens. 1993. "Ethanol and Methanol from Cellulosic Biomass." In *Renewable Energy,* edited by Johansson *et al.*: 866-923.

SECTION 5.4.

Appel Consultants, Inc. 1993. "Strategic Analysis of Biomass and Waste Fuels for Electric Power Generation." TR-102773. Palo Alto, California: Electric Power Research Institute.

——. 1993. "Biomass Energy Fundamentals." TR-102107. Palo Alto, California: Electric Power Research Institute.

Babcock and Wilcox. 1998. *Steam, Its Generation and Use,* 40th ed., Barberton, OH: Babcock and Wilcox, Inc.

Larson, E.D. 1993. "Technology for Electricity and Fuels from Biomass."

Turnbull, J.H. 1993. "Use of Biomass in Electric Power Generation: The California Experience." *Biomass and Bioenergy* 4(2): 75-84.

van Den Broek, R., A. Faaij, and A. van Wijk. 1996. "Biomass Combustion for Power Generation." *Biomass and Bioenergy 11(4):* 271-281.

Williams, R.H., and E.D. Larson. 1993. "Advanced Gasification-based Biomass Power Generation." In *Renewable Energy,* edited by Johansson et al.: 729-785.

SECTION 5.5.

Beenackers, A.A., C.M and K. Maniatis, guest eds. 1998. "The International Biomass Gasification Utility Scale Projects Meeting." Collection of articles as a special issue of *Biomass and Bioenergy* 15(3).

Carpentieri, A.E., E.D. Larson, and J. Woods. 1993. "Future Biomass-Based Power Generation in Northeast Brazil." *Biomass and Bioenergy* 4(3): 149-73.

Consonni, S., and E.D. Larson, 1996. "Biomass-Gasifier/ Aeroderivative Gas Turbine Combined Cycles, Part A: Technologies and Performance Modeling, and Part B: Performance Calculations and Economic Assessment." *ASME Journal of Engineering for Gas Turbines and Power* 118 (July): 507-525.

Elliott, T.P., and R. Booth. 1993. *Brazilian Biomass Power Demonstration Project.* Special Project Brief (September). London: Shell International Petroleum Company.

Larson, E.D. 1993. "Technology for Electricity and Fuels from Biomass."

Stahl, K. (project leader). 1997. *Varnamo Demonstration Plant: Construction and Commissioning,* 1991-1996 (July). Malmo, Sweden: Sydkraft AB: 169 pages.

Williams, R.H., and E.D. Larson. 1993. "Advanced Gasification-based Biomass Power Generation." In *Renewable Energy***,** edited by Johansson *et al.: 729-785.*

6 IMPLEMENTATION AND REPLICATION

This chapter discusses some key institutional and strategic issues regarding the successful implementation and replication of bioenergy projects.

Modernised bioenergy systems have the potential to provide cost-competitive energy services in environmentally and socioeconomically desirable ways. Whether a given project is beneficial and sustainable can be difficult to evaluate, given the variety and magnitude of determining factors. These factors include the level of indigenous agricultural productivity, pressures on water and land resources (which are in turn affected by the density and growth rate of population), access to capital, competition for biomass for non-energy uses, awareness of ecological vulnerabilities, local participation, etc.

Whether modern bioenergy is the "right" choice in any specific case will require a careful analysis of alternatives. Assuming that the bioenergy option is environmentally and socially sustainable, analysis of any specific case can produce four possible outcomes:

(1) The bioenergy option is the least-cost option to the recipient of the energy services and there are no appreciable barriers to its implementation; it is thus commercially viable without external support or policy intervention.

(2) The bioenergy option will be the least-cost option to the service recipient in the longer term, but requires initial external support to overcome barriers and to get started.

(3) The bioenergy option is not the least-cost option for users, but it does provide external benefits (job creation, ecosystem services, etc.) that make it attractive from a societal perspective. In such cases, bioenergy will often be a lever for development, but more-or-less continuous policy interventions may be needed to support it.

(4) The bioenergy option is not the least-cost option for users, and it carries with it unacceptable societal costs. In such cases, if policy interventions are used to support the bioenergy option, the chances or bioenergy contributing to sustainable development in the long term are minimal.

In cases where modernised bioenergy option appears to be the "right" option, pilot projects can have a catalytic role—verifying that a technology or process is feasible, providing lessons for subsequent activities, serving an educational role for the public and other actors, etc. A pilot project's impact will be limited, however, unless it is part of a broader vision for widespread replication. This chapter discusses some key institutional and strategic issues regarding the successful implementation and replication of bioenergy projects.

6.1. Institutions

Successful implementation and replication of a project will involve coordinated interactions among different institutional actors, each with its own priorities and interests. These actors might include:

- Central government, for example:
  - the Ministry responsible for rural development,
  - the Ministry responsible for agriculture,
  - the Ministry responsible for environment and forests,
  - the Ministry responsible for energy or electricity,
  - the Ministry responsible for revenue and financing, or
  - the Ministry responsible for international affairs (if the project involves international financing or technical cooperation);
- State-level government, including offices analogous to the national ministries cited above;
- County-, community-, or village-level governing or administrative bodies;
- Nongovernmental organisations, for example:
  - NGOs dealing with environment and development, and
  - NGO labor organisations, farmers organisations, and trade organisations
- Energy parastatal, for example:
  - Electric utility,
  - Regulatory bodies (such as a public utilities commission);
- Local, international, or joint local/international private enterprises, for example:
  - Enterprises that would generate or use biomass,
  - Enterprises that would supply, construct, and maintain bioenergy facilities;
- Other industries, for example:
  - Industries innovating in bioenergy technologies;
- Financing institutions (banks, micro-credit unions, etc.);
- Bilateral and multilateral organisations (United Nations, World Bank, national aid agencies, etc.); and
- Individuals and families.

Discussed here are institutions at two levels—national and local—that can play key roles in coordinating the activities of these many actors.

Coordinating Institution at the National Level

If bioenergy is to be implemented and then replicated at a significant scale throughout a country, some degree of coordination is required at the national level. A coherent bioenergy policy that is coordinated at a high level will more effectively promote and expand bioenergy than an uncoordinated set of disparate local activities. A central institution (which could be housed in an appropriate governmental agency, for example) would support this coordination in many ways.

A central coordinating institution could serve as an authorising agency, i.e., a rule-making body with legal authority to design a coherent legal framework that clarifies rules and roles of participants. Such an institution must demonstrate a legal commitment to bioenergy by initiating enabling legislation that helps bioenergy surmount typical barriers. For example, legislation or regulatory rulings requiring electric utilities to purchase biomass-derived electricity (at the utility's avoided cost of generation) helps to foster bioenergy development. In the United States, the 1978 Public Utilities Regulatory Policy Act (PURPA) helped lower barriers to bioenergy by providing bioenergy producers with secure access to the electricity market and fair long-term prices. This led to large expansion in biomass power-generating capacity, which totals about 8000 megawatts today in the United States.

Rationalising electricity tariffs and fossil fuel prices, e.g., by lifting subsidies and otherwise reflecting more fully all costs (including social and environmental costs), would greatly help to level the playing field for bioenergy. This type of policy change would generally need to be initiated at the central level.

A central coordinating institution could also develop and promulgate socioeconomic and environmental guidelines for bioenergy projects, including rules regarding access to project information and provisions for public participation. This would provide investors and project developers a uniform and consistent set of general principles as well as specific rules for sustainable bioenergy activities. The successful replication of bioenergy activities will rely in part on actors that can initiate novel activities, i.e., those with access to capital, inclination toward innovation and entrepreneurial risk-taking, autonomy, flexibility, etc. A role for the private sector in expanding bioenergy is important to consider in this regard. To make sure that private sector involvement proceeds in a sustainable way, consistent policies and regulations might need to be instituted at the central level.

A central coordinating institution could serve as an information clearinghouse for scarce or difficult-to-assess but useful information such as: regional biomass assessments; descriptions and contacts for ongoing activities; reviews, evaluations, and lessons from past activities; technical and engineering data; meteorological data; information on energy crops, multi-purpose crops, and agricultural management practices; contacts for private sector vendors, developers, and investors; legal regulations; information on development and environmental NGOs; etc.

Financing is invariably a major stumbling block for many projects. A central coordinating institution could provide financing or coordinate the interactions between other financial institutions and project developers. This task will especially require an institutional presence at the national level if financing originates with multilateral or bilateral aid agencies or other international organisations. If the Framework Convention on Climate Change spurs investment in bioenergy through the Clean Development Mechanism, there will be, at the very least, supervisory roles for a national institution.

A central coordinating institution could also give support to local coordinating institutions. It could help bring about the main enabling conditions for strong local institutions, including legal authority to make and enforce decisions affecting biomass resources and bioenergy projects; public access to information; and active dissemination of information, technical extension, and financing assistance.

Coordinating Institution at the Local Level

Bioenergy projects are likely to be most successful—indeed they may *only* be successful—if local coordinating institutions have considerable roles contributing to the design, implementation, and ongoing management of projects. Such institutions provide constancy over time in administering a project, and serve as a well-defined point of contact for interactions with outside organisations. Responsibility and authority in the hands of the local community endows the intended beneficiaries with a sense of equity in the project, as well as accountability. Not only will the intimate participation of the local community make projects responsive to local needs, but also experience has demonstrated that a high degree of participation generates a sense of ownership that is a critical ingredient for project success.

In some cases, existing local administrative governmental bodies such as village councils can effectively manage bioenergy matters (Chaturvedi, 1997). But in many cases, specially constituted bodies might be more effective, flexible, and democratic (Agarwal and Narain, 1990). One successful example of such a local institution is the "Village Development Society," formed to manage the community biogas digesters in Karnataka, India (see section 7.1).

Successful implementation and replication of a project will involve coordinated interactions among different institutional actors, each with its own priorities and interests.

A local coordinating institution serves as the primary forum for community participation in a bioenergy project. Successful local bioenergy institutions have been constituted through transparent and open processes that ensure the participation of a broad cross-section of the community including women, poor small-holders, and the landless poor, who are especially dependent on common land and other common resources. Too often, the visible and prominent community members are easily accessed, while the disenfranchised are—almost by definition—unrepresented. Their participation, therefore, is elusive and must be deliberately sought. A local coordinating institution will be more successful in eliciting their participation if it targets the poor, is unthreatening, and perhaps comes with a minor incentive, such as a meal offered during meetings. In many cases, women can only effectively voice their opinions and discuss their concerns in separate women-only forums.

The local coordinating institution should provide a forum for articulating local needs and concerns, and for building political consensus. When a project calls for cooperative action, the local institution can coordinate or mobilise the community members after having identified their shared objectives. It can resolve disputes among community members, and between the community and other outside actors. By fulfilling these needs, a local coordinating institution can not only enhance a project's sustainability, but contribute to the broader aim of fostering democratisation and effective governance at the community level. For women especially, involvement in local governance institutions is empowering and can help to address the root cause of gender inequity, i.e., disparity in power. By providing a transparent decision-making process and an open source of information, the local institution can minimise opportunities for abuses of office or corruption (Agarwal and Narain, 1990).

What are some key elements to replicate a successful bioenergy concept on a widespread basis?

The local institution can be given official legal authority over common resources, which often play important roles in community projects. Through the local institution, communities can decide how to manage common resources such as bioenergy feedstock grown on common land, irrigation water derived from common rainwater harvesting, other products that are publicly accessible (fodder, dung, etc.) and communally controlled funds (for example, funds intended for or arising from bioenergy projects).

Too often, communities do not have legal authority over their common resources. They might have certain traditional use-rights, but insufficient authority to make decisions about land-use, capital improvements, harvesting and sale of crops, etc. Then when the common land acquires an economic value because of the prospect of harvesting a marketable crop, the default response of governmental authorities is to lease the land to wealthy private concerns, while the poor end up without access to previously accessible resources.

6.2. Replicating a Bioenergy Project: Key Elements

An isolated project involving a modernised bioenergy system can have important benefits, but such benefits fail to extend to a regional, national, or global level. Successfully replicating such a project spreads the benefits to far greater numbers of people. What are some key elements to replicate a successful bioenergy concept on a widespread basis?

Sound technology. Projects based on proven technologies that work reliably and are economically viable have the best chance of succeeding and being widely replicable. But pilot projects that seek to demonstrate emerging technologies are needed as well. Development of new technologies is an iterative process that takes place within both the developer's laboratory and the user's environment. Pilot projects and demonstration activities with the user's participation in his or her environment are therefore an important part of the technology development process. Not all such user-involved demonstration efforts will succeed, due to technical or non-technical problems (e.g., compatibility with local social, institutional, economic, or cultural factors). However, the testing of new ideas and technologies is critical to advancing the state of technologies for bioenergy modernisation.

Sufficient scale of demand for the technology. Because bioenergy projects typically are relatively small in scale, establishing cost-competitiveness is often challenging because of diseconomies of scale associated with small systems. On the other hand, the small scale of most bioenergy systems is a potential advantage in that it is possible to achieve economies of scale in manufacturing and economies of scale in learning through repeated applications. This advantage can only be exploited, however, if there is a sufficient demand for the bioenergy systems (and there is an effective means for learning from past experiences, such as how to effectively engage the private sector – see examples below). The critical levels of demand needed to achieve cost reductions through scale economies can be created through regulatory or other mechanisms.

For example, in Brazil, the demand for ethanol fuel was created initially by subsidies that made it attractive for private producers to make ethanol instead of sugar (Goldemberg, 1996). Ethanol production grew at over 30 percent per year for the first decade of the program, reaching some 12 billion liters per year by 1985 and 16 billion liters in 1998. Considerable technology learning took place and standard distillery designs were developed by equipment manufacturers, both of which helped reduce the costs of ethanol production and enabled the industry to continue producing ethanol at a high level of output. This occurred even as price subsidies started to decline beginning in the mid-1980s, and were lifted entirely by early 1999.

Granting concessions similar to those granted for oil and gas exploration and production is another approach to encouraging the widespread replication of bioenergy systems (Shivakumar, Rajan, and Reddy, 1998). The key steps in developing a resource using a concession approach include (1) conducting a regional survey to identify prospective areas to be developed, (2) delineating the resource area into concession areas, (3) soliciting bidders under published terms and conditions, and (4) licensing successful bidders. In using a concession approach to replicate bioenergy systems, the key objectives are to encourage the development of a large number of applications and to enable successful bidders to take advantage of cost reductions arising from multiple applications in their concession area (e.g., equipment, learning, administrative, and overhead cost reductions).

A concession approach might work well for installing and operating village-scale, biomass-based electricity-generating systems in a region. In countries where construction of new electricity-generating capacity is not keeping pace with growing demand (which is the case in many countries), governments might find it effective to grant biopower concession areas. While a single biopower unit would contribute relatively little, a large number of units in aggregate would have generating capacity equivalent to other conventional (large) generating units in the utility system. The concessionaire would benefit from the opportunity to reduce overhead costs associated with contract negotiations, marketing, manufacturing, installation, operation, maintenance, etc.

Concession-based approaches to rural electrification based on renewable energy systems are being taken in several places around the world (section 7.4).

Access to the electricity grid. An important consideration in many projects where biomass-based electricity generation is involved is access to the electric utility grid. This is important because the economics of any biopower system depend to a large extent on how extensively the installed capacity is utilised, i.e., on the system capacity factor. Low capacity factors mean that the capital investment in a project must be amortised over a smaller number of kWh generated, leading to a higher cost per kWh.

In rural areas, local demand for electricity often is not high or sustained enough to result in economically viable capacity factors. To achieve sufficiently high capacity factors, additional purchasers of electricity are required. The utility grid can provide this option. The grid can carry electricity to urban demand centers until the size and diversity of local power demands grow to the extent that larger amounts of power can be consumed locally.

Regulatory measures generally are required to overcome the historical reluctance of electric utilities to purchase power from independent generators. In the United States, the 1978 Public Utilities Regulatory Policy Act obliged utilities to purchase electricity at fair prices. Similar legislation is appearing in a few developing countries. Regulators in Brazil are considering mandating that utilities buy biomass-generated electricity at an attractive price to sellers. (Bagasse-based electricity generation at sugarcane processing facilities is expected to grow significantly as a result). For several years, India has had a fixed purchase price for biomass-generated electricity that has encouraged expansion of biomass-generating capacity.

Involvement of the private sector. With appropriate public-sector oversight and competitive bidding for projects or concession areas, the private sector is essential in replication efforts. Large or small commercial enterprises can facilitate replication by applying accumulated experience and knowledge to new projects. A local community organisation or local NGO generally is less motivated to see an idea spread to other sites than a commercial company.

The private sector can play especially important roles in the manufacturing, marketing, installation, operation, and maintenance of technology (Jain, 1995). In addition, private companies are often the source of technology improvements, either via their own applied research and development or in collaboration with research institutes or other companies (e.g., joint ventures between local and foreign companies). Private companies also serve important roles as energy service providers (sometimes called energy service companies, or ESCos). ESCos typically handle all the "headaches" associated with designing, financing, installing, and operating an energy system and simply provide their customers with the amenities associated with energy (heat, light, water, etc.). ESCos first emerged in a substantial way in the 1980s in urban areas of industrialised countries, where their activities focussed on energy efficiency improvements. More recently, ESCos are also found in rural areas of developing countries (Shivakumar, Rajan, and Reddy, 1998).

Despite these important opportunities for involving the private sector, its role in delivering energy services to rural areas is severely limited in that it responds only to effective demand, that is, demand that is backed by purchasing power. Some of the unmet demand for energy services in rural areas of developing countries comes from potential customers not yet served by the market, even though they have sufficient resources to pay for energy services. However, much of the unmet demand comes from rural residents who do not have sufficient resources to pay for energy services, even if there were an active market. Energy services will only reach this population if there is public sector involvement, either directly or through incentives to the private sector. ■

References for Chapter 6

Agarwal, A., and S. Narain. 1990. *Towards Green Villages: A Strategy for Environmentally-Sound and Participatory Rural Development*. Delhi: Center for Energy and the Environment.

Chaturvedi, P. 1997. "Promoting Biomass Energy Utilisation through Village-Level Self-Governance Institutions." Bangkok: Rural Wood Energy Development Program/Food and Agriculture Organisation (RWEDP/FAO).

Goldemberg, J. 1996. "The Evolution of Ethanol Costs in Brazil." *Energy Policy* 24(12): 1127-1128.

Jain, B.C. 1995. "Facilitating Wise Bioresource Development and Use: The Role of Commercial Enterprises." *Energy for Sustainable Development* I(5) (January): 35-44.

Shivakumar, A.R., S. Chella Rajan, and A.K.N. Reddy. 1998. *Phase I Implementation of Rural Energy and Water Supply Utilities (REWSUs)* (July).

7 CASE STUDIES: BIOMASS PROJECTS IN ACTION

This chapter presents case studies of operating or planned modernised biomass energy projects or programs, especially where widespread replication has occurred or is a goal.

This chapter presents case studies of operating or planned modernised biomass energy projects or programs, especially where widespread replication has occurred or is a goal. Brief summaries are presented, and references are provided for more detail or related information.

7.1. Biogas-Based Electricity and Water Supply in Indian Villages

Pura is a village with about 500 residents in the Kunigal Taluk of the Tumkur District of Karnataka State, India. Beginning in 1987, traditional means for obtaining water, illumination, and fertiliser in the village were replaced with a biogas-based Rural Energy and Water Supply Utility (REWSU), which subsequently operated successfully for a decade. The Pura system was developed and implemented by the Center for the Application of Science and Technology to Rural Areas (ASTRA) at the Indian Institute of Science in Bangalore. Beginning in 1995, the International Energy Initiative (IEI) based in Bangalore launched an effort supported by a grant from the Rockefeller Foundation to replicate the Pura experience in nine additional villages. The Pura experience has been widely reported in the literature (see references). This case study briefly reviews that experience and discusses lessons learned in IEI's replication efforts.

Pura Village

Hardware installed at Pura included a biogas generator, a diesel-engine generator, a water pump and borewell, and electricity and water distribution networks to individual households equipped with tubelights and water taps. The institutional arrangements around the REWSU included a Grama Vikas Sabha (GVS), or Village Development Society, consisting of about fifteen villagers. The GVS managed the operating revenues and expenditures of the REWSU (and achieved very high revenue-collection efficiencies). Additionally, a plant operator handled day-to-day operations, including dung collection, sludge disbursement, revenue collection and expenditure, etc. An implementing agency, the Karnataka State Council for Science and Technology, provided initial (government grant) financing, managed the plant construction, and provided training and ongoing technical support (in conjunction with ASTRA) to the GVS. A key administrative step contributing to success at Pura was the establishment of the dung collection and sludge return system based on a set delivery fee that went primarily to women, thereby ensuring their involvement.

Analysis of extensive data collected at Pura indicated that the REWSU was highly successful in providing physical benefits to villagers in the form of electricity, water,

Credit: Eric Larson

Street lamp lit by biogas-derived electricity (top). Biogas and engine electricity generator with operator in village of Pura, Karnataka State, India (bottom).

and an improved fertiliser, as well as social benefits of village cooperation, improved quality of life, and training and employment opportunities for a few villagers.

Based on the capital and operating costs incurred at Pura, the cost of electricity generated by the REWSU would be competitive with central station, coal-based power delivered to the village if the REWSU operated for at least fifteen hours per day. During the decade of operation at Pura, the electricity demand in the village did not reach high enough levels to enable this much running time. The addition of small industries or irrigation pump sets in the village would create the demand for more operating hours, as would sale of excess electricity to the utility grid.

Replicating Pura's Success

The IEI is now in the process of extending the Pura Village concept to nine additional villages in Karnataka state as the first step toward a more ambitious dissemination program. IEI has adopted a "Train, Build, Operate, and Transfer" approach, whereby sequential steps in each project include motivating village interest in a REWSU, training the needed operators and administrators, constructing the facility, insuring successful initial operation, and finally turning over administrative and operating responsibilities to the village GVS. A key objective of the nine-village replication effort is to explore the feasibility of replicating REWSUs through the involvement of independent implementing agencies, which could then individually pursue additional replication efforts in the longer term. Grant funding was secured to cover capital costs. Training and technical support was to be provided by ASTRA and IEI.

Construction of eight of the nine plants was completed by June 1998, and seven of the plants were operating by end 1998. (The project in the ninth village was abandoned after several construction delays led villagers to lose confidence in the activity). The process involved in developing the eight projects is reviewed here, along with some of the salient lessons learned.

The first step taken by IEI was to call a meeting of senior government officials concerned with rural development in Karnataka and representatives of NGOs and engineering colleges to solicit interest in the project. Out of this process, seven organisations—NGOs or engineering colleges in most cases and a local government body in one case—were ultimately identified and selected as implementing agencies. Especially favorable project results were obtained where the implementing agencies were large local NGOs, which have extensive local support networks. The best implementation arrangements included local-government backing of the NGO that enabled the REWSU effort to be coordinated with other rural development activities.

Detailed tracking of costs found that the economics of the replication projects were similar to those in Pura Village: the cost of REWSU-generated electricity would be competitive with central-station, coal-fired electricity if enough electricity demand allowed the REWSU to operate sixteen or seventeen hours per day. Local dung supplies for the biogas plant were sufficient to support this amount of operating hours, but electricity demand in the villages was not. One option to explore for the future is to connect the REWSU to the local electric utility grid to enable high operating hours until village electricity demands rise as new industries, more irrigation pumps, etc., are introduced.

Lessons Learned

Assimilating the lessons learned from the replication efforts in all nine villages, the IEI formulated a set of general guidelines for future replications (see Shivakumar, Rajan, and Reddy, 1998). The following guidelines contain lessons relevant to other types of small-scale rural energy development projects as well.

Project Commencement

- Villagers must want a REWSU; i.e., there should be a perceived need for drinking water, lights, etc.
- Sufficient resources of dung, well water, and land must be available, and villagers must be willing to commit these to the REWSU.
- There must be clear communications regarding villagers' obligations to the REWSU, including dung requirements, operating costs, tariffs per household, GVS involvement, record keeping, periodic meetings, etc.
- Women must be involved in the decision to establish a REWSU.
- Local and state government officials should be fully informed of the project goals and should provide official support for implementation, placing a REWSU on par with government-sponsored rural development.

Construction of REWSUs

- Quality construction (qualified supervisors, clear reporting procedures, etc.) and practical schedules are important.
- Expenses should be carefully monitored; escalations above budget should be adequately justified.
- Project promoters should be sensitive to any discomfort on the part of villagers with the project and take confidence-building steps to address any concerns.

Initial REWSU Operation

- Revenues must be sufficient to cover operating expenditures, including a 10 to 20 percent contingency fund (this assumes grant funding of the capital).
- Local and state governments should be kept aware of the implementation to avoid any potential conflict with government-sponsored schemes planned for the village.
- Villagers must have confidence in the GVS.
- Women must be sufficiently represented in the GVS. A suggested guideline is 50 percent women in the GVS, including an office-bearer such as President or Secretary.

Financial Sustainability

- Revenue collection should be sufficient to allow for long-term capital replacement in the future.
- Proper, transparent, and public record keeping, along with regular GVS meetings, are important to ensure that villagers are fully aware of monthly revenues and expenditures.
- Villagers must have confidence that the GVS is committed to the long-term welfare of the REWSU.
- The possibility of selling excess power to the grid should

be explored to provide for additional revenues.

Overall Lessons Learned

- A variety of implementing agencies can successfully replicate the original Pura village experience.
- The local village needs a strong stake and confidence in the REWSU concept, or there must at least be a non-local-implementing agency with a strong desire and the capability to build such confidence.
- Democratic and transparent institutional arrangements at the village level are critical for sustained operation of the REWSU.
- Government agencies should be closely involved with large-scale REWSU implementation, treating REWSU projects on par (e.g., offering similar administrative and financial support) with other rural development schemes to ensure that no conflicts arise between a REWSU and other government-backed schemes.
- Government involvement is essential, but government organisations as implementing agencies may not be efficient.
- Records, proper accounts, regular GVS meetings, and transparency are all crucial for sustaining a REWSU.

Extending the Replication Effort

With the apparent success of the village REWSU replication effort, IEI is now exploring alternative approaches to much larger-scale dissemination. IEI is exploring the idea of using the concession approach commonly employed to encourage oil and gas exploration (See chapter 6 discussion of concession approach).

7.2. Sustainable Transformation of Rural Areas in India

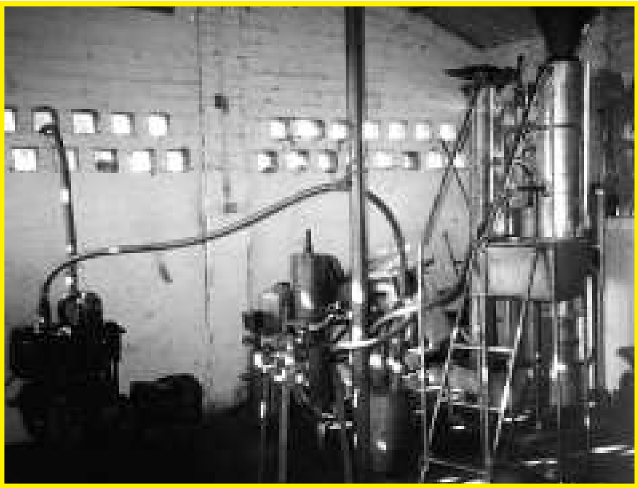
This proposed program for rural energy services expands upon the experiences of the Pura program (see section 7.1) to include leaf litter in addition to cattle dung as fuels for anaerobic digesters. The program also includes producer gas generators fueling diesel generator sets. In addition to dung and residues, feedstocks are provided from a multiple-use tree plantation. The plan is for democratic village-level institutions to control the energy utilities. A proposal has been submitted to the Global Environment Facility for support to implement the concept in twenty-four villages in the Tumkur district in the state of Karnataka, India.

7.3. Projects Using Producer-Gas/IC-Engine Technology in India

Until the 1990s, most projects involving rural applications of biomass-gasifier—IC-engine electricity generators failed because of inadequate technology (see chapter 5). However, persistent research and development efforts by a few Indian scientists have resulted in the development and commercialisation during the 1990s of technically sound gasifier-engine systems. The Ministry of Non-Conventional Energy Sources in India has supported these developments and the trial implementation in India of more than 1600 gasifier-engine systems having a total installed capacity in excess of 28 MW_e. A few private companies now offer Indian gasifier technologies on a commercial basis, with warranties and performance guarantees. Recognising the importance of ongoing technical support, these companies generally also provide after-sales support or act as energy service companies. The most successful projects to date have been at industrial sites, where waste biomass is the fuel and where industrial prerogatives encourage technical and economic success.

7.4. Rural Energy Concessions: Pilot Programs

Innovative pilot programs are being initiated in Argentina, Bolivia, Peru, and the Philippines built around the sale of concessions to private companies for the provision of energy services, especially electricity services, to dispersed rural populations (see chapter 6 discussion of concessions). Renewable energy systems, including biomass systems, are



Biomass gasifier making producer gas from mixed-species wood chips to fuel an engine-generator for electricity production in the village of Hosahalli, Karnataka State, India.

expected to be lowest-cost options in many cases. All four of these programs are supported by the Global Environment Facility (GEF).

The Argentina program is the most ambitious. As part of its electricity sector privatisation and restructuring efforts, the government of Argentina is seeking to increase private sector participation in electricity supply to rural areas and to minimise rural electrification costs. It is in the process of selling rural electricity concessions to private companies in the northwest provinces of the country, where some 1.4 million rural inhabitants currently have no access to electricity. Winning bidders will provide electricity to rural homes and public facilities (schools, health clinics, etc.) at the lowest government subsidy per electrical hook-up. Analysis of various options for electricity supply in the region suggest that off-grid electricity generation will be much more competitive than grid extension, and renewable energy technologies will often be the lowest-cost off-grid option.

7.5. Modernising Corn Stover Use in Rural Jilin Province, China

The northeast Chinese province of Jilin, with 2 percent of China's population, produces some 14 percent of China's corn. Corn production residue, primarily stalks, is generated in large quantities. The stalks are burned in rural homes for heating and cooking, leading to significant indoor air pollution. Uncollected stalks are burned on the field to prevent insect infestation, leading to substantial outdoor air pollution at certain times of the year. The government of Jilin province has put a programme in place to convert corn stalks via thermochemical gasification in individual villages for use as a cooking fuel. A pilot project to demonstrate combined cooking fuel, home heating, and electric power generation via gasification of corn stalks in the Jilin Province was launched in March 2000. China is an ideal place for expanding the biomass gasification industry because it has the rural development needs, an emerging industrial base in this field, and the government commitment to ensure substantial growth of this new industry through the institution of supportive policies.

7.6. Producing Ethanol from Sugarcane in Brazil

One of the best-known, large-scale, biomass energy modernisation programs is Brazil's program to produce fuel ethanol from sugarcane, initiated in 1975. The political objectives of the program were to reduce Brazil's dependence on imported oil, to stabilise sugar production in the face of a volatile international sugar market, and to create employment in rural areas. It has been successful in achieving these objectives.

Ethanol can be used either as a neat fuel (100 percent ethanol-fueled cars) or for blending with gasoline (up to 26 percent ethanol). At some facilities (autonomous distilleries) ethanol is made directly from cane juice; at others (annexed distilleries), ethanol is made from the molasses by-product of sugar production. The Brazilian ethanol industry today consists of some 350 distilleries, supplied with biomass from areas ranging in size from 5,000 to 50,000 hectares, with cane production carried out by some 60,000 suppliers. The industry provides direct employment to about one million people. Nearly 200 trillion liters of ethanol have been produced since the inception of the program.

The Brazilian program initially was launched through government subsidies that made ethanol prices attractive to

Sugar cane on its way to crushing for juice extraction at an ethanol factory in the state of Sao Paulo, Brazil.

consumers and that made ethanol production more attractive than sugar production among producers. Ethanol production grew at over 25 percent per year for the first decade of the program, and reached some 16 billion liters in 1998. Considerable technological advance and learning took place during the first two decades of the program, both in conversion of sugar to ethanol and in production of sugarcane.

The costs of growing sugarcane in Brazil are now among the lowest in the world. Equipment manufacturers standardised distillery designs, which led to reductions in the costs of producing ethanol. Such advances enabled the industry to continue producing ethanol at a high level of output even as subsidies were reduced beginning in the mid-1980s. Even though price controls and subsidies on ethanol were lifted entirely in early 1999, causing a large drop in prices paid to producers, ethanol production levels are expected to continue at high levels. Producing ethanol will still be profitable as a result of technological progress and organisational learning that has occurred since the launching of the program.

7.7. Cogeneration of Heat and Power at Sugarcane Processing Facilities

The production of sugar or ethanol from sugarcane generates a fibrous biomass by-product (bagasse) that is used as a fuel for combined heat and power generation to supply the sugarcane processing facility with its process energy requirements. The quantities of bagasse available are typically large enough that, with appropriate technology, sugar factories can meet their own energy needs and be net exporters of electricity (see Section 5.4). The amount of sugarcane tops and leaves (cane trash) generated as an additional biomass resource is comparable to the amount of bagasse available. In most countries, cane trash is burned on the fields to facilitate replanting or harvesting, though the resulting air pollution has motivated some governments to ban this practice. Historically, sugar factories have exported little energy, but in many countries, sugarcane-processing industries are increasingly interested in exporting bagasse and trash-derived electricity from their mills. Some governments are providing incentives to encourage sugarcane-based electricity generation, and demonstration projects are being developed in a number of countries.

7.8. Biomass-Gasifier/Gas Turbine Power Generation in Northeast Brazil

The objective of a new project in Bahia state, Brazil, is to demonstrate on a commercial scale a new technology for electric power generation from biomass (the biomass-gasifier/gas turbine--see Section 5.5) that promises to be cost-competitive with conventional alternatives in Northeast Brazil, including new hydropower. The project includes fuel

Mountain of bagasse from sugarcane outside a sugar factory in Barbados.

supply from dedicated energy plantations, as well as purchase of residues from wood plantations of local forestry companies. Supported by the Global Environment Facility, the project was conceived in the early 1990s, but construction will only begin in 2000. Institutional difficulties are responsible for the slow pace of the project. These have included negotiation of power purchase agreements during ongoing privatisation of electricity generation, negotiation of fuel supply contracts, and the forming of a joint venture company with a substantial equity stake in the project. If the demonstration effort is successful, the scope for expanding biomass-based power generation in northeast Brazil, and many other regions of the world, is very large.

7.9. Farm Forestry in Rural Brazil

Small-scale farm forestry in Brazil offers an attractive alternative to the large-area approach that has characterised industrial wood production in Brazil since the 1950s. The development of industrial plantation forestry began in earnest in Brazil in 1966, when federal tax incentives were introduced to encourage tree planting. Plantation area grew from 470,000 hectares in 1966 to some 6.2 million hectares in 1992. Until the mid-1980s, Brazilian forestry companies, especially those associated with pulp and steel production, expanded tree production primarily by purchasing land and establishing large-area plantations. Since the mid-1980s, companies have pursued a different strategy, increasingly contracting with small private farmers to expand their wood supply. Small and medium-sized wood consumers have also begun to mobilise themselves to assist farmers in tree planting in an effort to ensure that local wood will be available for the long term.

The idea of farm forestry is not new in Brazil—it was promoted as long ago as the early 1960s. But three new developments are accelerating implementation of the idea. First, the federal tax incentives introduced in 1966 to encourage tree planting were eliminated in 1988, making it much less attractive for forestry companies to expand their own plantation areas. Second, in regions where natural forests were being cut for wood (especially the states of Minas Gerais and Sao Paulo), natural forests within reasonable transportation distances have essentially been completely cut, with insufficient replanting to meet local needs. Third, objections of environmentalists and others to "overplanting" of trees have discouraged expansion of large tracts of company-owned plantations.

Farm forestry is now growing rapidly in Brazil, with encouragement from the private sector; from federal, state and local governments; and from farmers. Several hundred thousand hectares (in unit sizes of 1 to 50 hectares per farm) have been established in less than a decade. This compares favorably with the rate at which industrial plantations were established leading up to 1988.

Private Sector Farm Forestry Activities

In a typical private-sector farm-forestry program in Brazil, a well-established forestry company provides the material inputs and technical know-how to establish trees on a farmer's land. The forestry company then contracts with the farmer to buy some or all of the first harvest for an agreed upon price that incorporates repayment for the initial inputs and services. The inputs include saplings (usually some species of Eucalyptus), fertilisers (applied at planting), herbicides (applied at some point after planting), and pesticides. The company samples the farmer's soil and provides fertilisers and species "tuned" to that farmer's soil.

Because of the sophisticated material inputs and the careful tending provided by the farmer, the biomass yields reported from small-farm plantings are not much below those reported for large-scale plantations owned and operated by forestry

Credit: Eric Larson

Farmer in the state of Minas Gerais, Brazil, standing next to a eucalyptus sapling planted as part of biomass production activity on his multi-product farm.

companies, and yields can be expected to increase as both farmers and their contracting companies learn improved methods and approaches (most programs in Brazil started only about a decade ago). Moreover, the slightly lower yields from small farms are offset by the considerably lower costs associated with farm forests than with large plantations.

Limited data suggest that delivered costs for biomass from farm-forests are comparable to costs for biomass from large-area company plantations. Farmer-owned plantations account for as much as 20 percent of some forestry companies' total planted area, with percentages expected to rise in the future. As of the mid-1990s, the largest farm forestry activities were at Aracruz (30,000 hectares under contract), Champion (13,000 ha), and Cenibra (8,500 ha). Despite the large total areas under contract, the per-farm area contract is small, ranging from less than 2 ha to about 50 ha. The per-farm area planted with trees on average represents 10 to 30 percent of a participating farmer's land area.

Forestry companies use various approaches to engage farmers in forestry programs. For example, one company in Minas Gerais state, Pains Florestal (the forestry arm of a steel manufacturer), puts on "Field Days" at its forestry research site. Farmers spend the day seeing experimental results and talking with Pains staff. The Field Day activities often convince farmers of the merits of tree growing, but the farmers often have neither the capital nor the confidence to proceed on their own. They may seek Pains backing on both counts. A key element in the success of the Pains program has been the Pains staff of extension agents, who interact directly with the farmers. The farmers, who are often illiterate, come to rely on the agents for information and advice.

Farmers have several motivations for participating in tree farming programs, including additional income from a secure market, productive use of marginal areas, opportunities to create cooperatives with fellow farmers, and availability of wood for on-farm use. The case of one farmer may be typical. This farmer entered into a contract in the early 1990s with Pains Florestal. He established thirteen hectares of Eucalyptus trees, in addition to raising sugarcane (for cattle fodder), rice, beans, citrus fruit, chickens, and some other crops. Some 90 percent of his non-tree production is for self consumption. He has land available to plant trees because he was unable to expand his conventional farming activities in a profitable way. He lacked access to investment capital, and there is no profitable market for production in excess of his own needs, because middlemen who control access to markets pay poor prices.

With the loan of inputs and know-how from Pains, the farmer established a healthy tree crop and committed 20 percent of the first harvest to Pains as repayment for the initial loan. The farmer can sell the remaining 80 percent on the open market at market prices. (Pains would probably be willing to purchase additional wood from the farmer, but an agreement to do so would be negotiated between Pains and the farmer.) The contract with Pains stipulates that Pains will harvest its 20 percent share so that the farmer does not need to invest in harvesting equipment. The farmer's first harvest of trees will generate a sizeable revenue, which the farmer can then invest as he pleases, e.g., in technology to increase the productivity of his food crop production.

Forestry companies have sound economic reasons for contracting with farmers, as the Pains experience illustrates. Pains operates its own tree plantations in an area around the relatively large town of Divinopolis, the site of its steel factory. The average transport distance for charcoal produced on or near Pains' own plantations is 485 km. After federal tree-planting incentives were ended, Pains essentially stopped expanding its own plantations around Divinopolis. Instead, Pains purchased additional charcoal from the nearest source, in the state of Mato Grosso do Sul. The average transport distance is 1,100 km, making this charcoal very expensive.

Aware that reliance on charcoal from Mato Grosso do Sul was not an acceptable way to meet its charcoal needs over the long term, Pains initiated its farmer forestry program. The lower capital investment per hectare required for Pains to establish farmer-owned plantations, zero maintenance costs to Pains, and the average transport distance of only 45 km to the mill, combine to make the farmer-forestry program financially attractive. Also, Pains is assisting the farmers in forming cooperatives, through which it can contract for larger volumes of wood with less administrative cost. The cooperatives have additional advantages; they help farmers increase productivity, e.g., by sharing the use of costly machinery, and give them bargaining power in their negotiations with middlemen.

Public Sector Farm Forestry Activities

In addition to farm-forestry programs run exclusively in the private sector, the public sector has initiated a variety of programs to promote farm forestry.

- PRO-FLORESTA, in the state of Minas Gerais, was launched by the state government in 1989 with a $90 million loan from the World Bank. Its goals included the establishment of 165,000 hectares of farmer forests.

- A joint public-private effort in Sao Paulo state was started in 1989 with the goal of distributing 1.2 million seedlings (provided by forestry companies) to some 260 farmers, each of whom would plant an area no larger than 5 hectares. The forestry companies also contribute to a fund (Fundo Florestal) managed by the Forest Foundation of Sao Paulo (Fundacao para a Conservacao e a Producao Florestal do Estado de Sao Paulo); this money is used to provide technical assistance to the farmers.

- A similar program was started in Rio Grande do Sul at about the same time. In that program, any farmer interested in planting up to 10 hectares per year of trees could request seedlings; state extension agents provide advice on planting, fertilisation, and care. The farmers are obliged to give 10 percent of the first harvest to Riocell, a local private company that provides the seedlings and helps train the extension agents. The farmers are free to sell or use the remainder of the harvest as they choose.

Timber Replacement Associations (TRAs) are another institutional mechanism for encouraging tree planting. TRAs developed beginning in the late 1980s as a result of stipulations in the 1965 Forestry Code requiring wood and charcoal consumers in Brazil to either directly plant trees to replace those they used or pay a "replacement tax" to IBAMA, the Brazilian Institute for the Environment and Natural Resources. Small consumers—sawmills, bakeries, potters, brick makers, barbecue restaurants, etc.—paid the tax, but by the mid-1980s, it became clear that IBAMA was not effectively using the revenues for replanting.

In 1988, a group of wood consumers in Sao Paulo state initiated a civil disobedience movement to replace IBAMA as the collector of the replacement tax. Without formal legal recognition, they created an association that began collecting the replacement taxes and took responsibility for replacing their own wood consumption. Since then, other similar associations have been created. After four years of successful, but "illegal" replanting activities, these associations were officially recognised by the Sao Paulo Department for the Protection of Natural Resources. In 1993, they were also recognised by IBAMA and officially authorised to collect the replacement tax. There are currently 18 TRAs distributed throughout Sao Paulo state, and TRAs have been initiated in other states as well.

In Sao Paulo, the TRAs produce and distribute seedlings to small and medium-sized farmers and provide the necessary technical support in planting and forest management. The main advantages for farmers in working with a TRA (rather than a forestry company) are low planting costs, free technical advice, and no commercial obligations at production time.

Summary

The overall result of farm forestry programs in Brazil has been minimal changes in land ownership and use patterns; reduced pressures to cut natural forests; increased local supplies of wood at reasonable costs; training of farmers in sound plantation forestry techniques; and creation of a new revenue source for farmers (including formerly subsistence farmers). Anecdotal evidence also suggests that the new economic activity of tree growing has helped reduce rural-to-urban migration in some areas.

7.10. Social Forestry in India

India's recent social forestry effort is among the largest in the world. Largely with the assistance of international bodies such as the World Bank, SIDA, and USAID, more than 14 million hectares of relatively small parcels of land were afforested in India during the 1980s.

Credit: Eric Larson

A mixed-species energy plantation established on village common land, Hosahalli village, Karnataka State, India.

The afforestation effort has had two primary objectives: (1) to provide forest products such as fuelwood, fodder, small timber, and other minor forest supplies (fruits, herbs, medicinal plants, flowers, artisan materials, etc.) for rural populations; and (2) to restore the ecological integrity of the land, regenerating its ability to sustain the rural populations that depend on the land for their livelihoods.

"Social forestry" is a general term that has actually been used loosely to refer to many different types of forestation projects, which have had varying degrees of success in achieving these objectives. Social forestry includes the afforestation of private land by individual farmers relying on government support or private sector contractors (see section 7.9 on farm forestry in Brazil). It also includes forestation of common land through arrangements with individuals, NGOs, or specially constituted community organisations. It also includes forestation on government lands, ranging from directed activities (where a government authority selects species, plants and tends tree plantations, and reaps the harvest) to participatory activities (where communities help select species, are employed to manage the forestation area, and share the products of the forestation efforts).

Social forestry programs have had mixed success in providing forest products to rural populations. In many cases, they did provide increased fuelwood for local populations. When trees are grown, tree tops, crooked branches, and twigs are often made available for local use as fuelwood, even if the main forest product is used for other purposes. However, the social forestry activities tended to be directed not toward satisfying local demands, but toward supplying urban markets that could pay higher prices.

Programmes therefore usually focused on construction materials such as poles (and similar market commodities) and hence relied overwhelmingly on exotic species (such as Eucalyptus) in monocultures, rather than the multipurpose afforestation that would have more directly benefited the rural poor. Social forestry programmes often failed to supply fodder, any food items, or other locally required artisan or other materials. In limited cases, however, even if products were not used locally, the sales revenue was distributed to community members, so that they benefited even if they did not directly use the output of the afforestation effort.

One activity that did yield substantial local benefits was the experience of the Tree Grower's Cooperative Societies, of which there are about 400 spread over six states (Sudhakara Reddy, Parikh, Srinivasan, 1999). For example, the society in Mallanahally, Karnataka, received grants from a centralised cooperative organisation for a period of five years to meet the initial expenses for land development and sapling cultivation on twenty hectares of land leased from the forest department. Species consisted primarily (~85 percent) of *Eucalyptus globulus, Cassia siamea, Acacia nilotica,* and several other species. Village residents were encouraged to become members, and to take part in regular meetings to decide questions of plantation management. Member families received fodder for cattle, construction poles for houses, and fuelwood. Some products were sold in the market, and some distributed to member households. Distribution of benefits among households was such that poorer households acquired a greater proportion of their income from the project than did wealthier households. (It is not clear from the cited report what the absolute distribution of benefits was, but in relative terms, household income among the landless increased by 22 percent, compared with 2 percent for high-income households. Some households surveyed were reportedly dissatisfied with the distribution of benefits.)

Some intangible benefits resulted from the program. Cooperative decision making was apparently successfully achieved, with some measure of empowerment of the rural poor states (Sudhakara Reddy, Parikh, Srinivasan, 1999). Interaction with government officials, including a willingness to speak up for their rights, was also reported. ■

References for Chapter 7

Section 7.1.

Rajabapaiah, P., S. Jayakumar, and A.K.N. Reddy. 1993. "Biogas Electricity: The Pura Village Case Study." In *Renewable Energy: Sources for Fuels and Electricity,* edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 788-815.

Reddy, A.K.N. 1995. "The Blessing of the Commons." *Energy for Sustainable Development* II(1): 48-50.

——, P. Rajabapaiah, and H. Somasekhar. 1995. "Community Biogas Plants Supply Rural Energy and Water: The Pura Village Case Study." In *Energy as an Instrument for Socio-Economic Development,* edited by J. Goldemberg and T.B. Johansson. New York: UNDP: 80-89.

Shivakumar, A.R. 1996. "Attempting to Fulfil Rural Energy Needs with Community Participation." *Energy for Sustainable Development III(1): 5-6.*

——, S. Chella Rajan, and A.K.N. Reddy. 1998. *Phase I Implementation of Rural Energy and Water Supply Utilities (REWSUs)* (July). Final Report to the Rockefeller Foundation from the International Energy Initiative. Bangalore, India.

Section 7.2.

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Section 7.3.

Ankur-Energy and Development Alternative. 1994. "Biomass Gasification Based Power Generation System for Captive Use and Grid Paralleling: A Case Study." In *Commercially Successful Biomass Energy Projects in Developing Countries,* edited by Blanco Rodriguez, Biomass Users' Network, Central America and Caribbean Office, P.O. Box 1800-2100, San Jose, Costa Rica: 7-28.

DeLaquil, P., and F.S. Fische, 1999. "Installation, Operation, and Economics of Biomass Gasification in Indonesia." In *Proceedings of the Fourth Biomass Conference of the Americas,* edited by R.

Overend and E. Chornet. Oxford, UK: Elsevier Science, Ltd. Also, see http://www.bgtechnologies.net/

Government of India. Ministry of Non-Conventional Energy Sources. New Delhi. http://www.nic.in/mnes/

Jain, B.C. 1995. "Facilitating Wise Bioresource Development and Use: The Role of Commercial Enterprises." *Energy for Sustainable Development* I(5) (January): 35-44.

Mukunda, H.S., S. Dasappa: J. Paul, N.K.S. Rajan, and U. Shrinivasa. 1994. "Gasifiers and Combustors for Biomass—Technology and Field Studies." *Energy for Sustainable Development* I(3) (September): 27-38.

Section 7.4.

Fabris, A., M. Servant, R. Gallo, Betlido, E. Sotelino, E. Quiles, A. Frigerio, A. Combetto, and M. Marazzi. 1996. "Argentina Dispersed Rural Population Electricity Supply Program." *Energy for Sustainable Development* II(5): 38-41.

Global Environment Facility (GEF). n.d. "Program of Rural Electrification with Renewable Energy, Using the Popular Participation Law." Project Document. Project No. BOL/97/G31/A/1G/99. New York: United Nations Development Program/Global Environment Facility (UNDP/GEF), Regional Bureau for Latin America and the Caribbean (received August 1999).

——. n.d. "Photovoltaic-Based Rural Electrification in Peru." Project Document. Project No. PER/98/G32. New York: UNDP/GEF, Regional Bureau for Latin America and the Caribbean (received August 1999).

——. n.d. "Palawan New and Renewable Energy and Livelihood Support Project." Project proposal. New York: UNDP/GEF, Regional Bureau for Asia and the Pacific (received August 1999).

Sotelino, E.J., E. Quiles, and A. Fabris. n.d. "Electrificacion Rural en La Argentina 1970-2001: Abastecimiento Electrico Rural con Tecnologias Convencionales y con Fuentes Renovables de Energia." Buenos Aires, Argentina: Secretaria de Energia y Comunicaciones (received July 1999).

World Bank. 1999. "Project Appraisal Document on a Proposed Loan and GEF Gran to the Argentine Republic for a Renewable Energy in the Rural Market Project." Report No. 17495-AR (February 6). Washington, DC: World Bank, Latin America and Caribbean Regional Office.

Section 7.5.

China Council for International Cooperation on Environment and Development. "Working Group on Energy Strategies and Technologies." *Proceedings of Workshop on Small-Scale Power Generation from Biomass* (in English and Chinese). Workshop held January 12-13. Changchun, Jilin Province, China.

Dai, L., J. Li, and R. Overend. 1998. *Biomass Energy Conversion Technologies in China: Development and Evaluation* (in English and Chinese). Beijing: China Environmental Science Press.

Li, J., J. Bai, and R. Overend. 1998. *Assessment of Biomass Resource Availability in China* (in English and Chinese). Beijing: China Environmental Science Press.

United Nations Development Programme (UNDP). 1999. "Modernised Biomass Energy in China: Jilin." Draft Project Document (August). New York: UNDP.

Zhang, Z., K. Deng, and R. Overend, 1998. *Design for Market-Oriented Development Strategy of Bioenergy Technologies in China* (in English and Chinese). Beijing: China Environmental Science Press.

Section 7.6.

Copersucar, Proalcool: Fundamentos e Perspectivas (in Portuguese). 1989. Sao Paulo, Brazil: Copersucar.

Coelho, S. 1999. Personal communication (October) Centro Nacional de Referencia em Biomassa. cenbio@iee.usp.br.

Geller, H. 1988. "Ethanol from Sugarcane in Brazil." *Annual Review of Energy* 10: 135-164.

Goldemberg, J., L.C. Monaco, and I.C. Macedo. 1993. "The Brazilian Fuel Alcohol Program." In *Renewable Energy,* edited by Johansson et al: 841-863.

Macedo, I.C. 1995. "Converting Biomass to Liquid Fuels: Making Ethanol from Sugar Cane in Brazil." *Energy as an Instrument for Socio-Economic Development,* edited by Goldemberg and Johansson: 107-112.

Moreira, J.R., and J. Goldemberg. 1999. "The Alcohol Program," *Energy Policy* 27: 229-245.

Rosillo-Calle, F. and L.A.B. Cortez. 1998. "Towards Proalcool II: A Review of the Brazilian Bioethanol Programme." *Biomass and Bioenergy* 14(2): 115-124.

Walter, A., and L. Cortez. 1999. "An Historical Overview of the Brazilian Bioethanol Program." *Renewable Energy for Development* 11(1) (July): 2-4.

Section 7.7.

Alexander, A.G. 1985. *The Energy Cane Alternative.* Amsterdam: Elsevier 509 pages.

Biomass Users Network. 1997. *An Overview of Sugarcane Cogeneration in Six Central American Countries* (December). San Jose, Costa Rica: BUN Regional Office for Central America.

Cane Cogen India. Quarterly newsletter of the Global Environment Facility (GEF) Project, India. See http://www.renewingindia.org/technologies/bioenergy/html/bioenery.htm.

Coelho, S.T., M.F. Bolognini, and D. Zylbersztajn. 1999. "Policies to Improve Biomass-Electricity Generation in Brazil." *Renewable Energy* 16: 996-999.

Government of India. Ministry of Non-Conventional Energy Sources. New Delhi. http://www.nic.in/mnes/

Section 7.8.

Carpentieri, A.E., E.D. Larson, and J. Woods. 1993. "Future Biomass-Based Electricity Supply in Northeast Brazil." *Biomass and Bioenergy* 4(3): 149-173.

Elliott, T.P. 1994. "Brazilian Biomass Power Demonstration Project." *Energy for Sustainable Development* I(1): 41-43.

Elliot, P., and R. Booth. 1993. *Brazilian Biomass Power Demonstration Project.* Special Project Brief. Shell Centre, London: Shell International Petroleum Company.

Waldheim, L., and E. Carpentieri. 1998. "Update on the Progress of the Brazilian Wood BIG-GT Demonstration Project." Paper no. 98-GT-472. New York: American Society of Mechanical Engineers.

Section 7.9.

Capitani, *et al.* 1992. "Novos modelos para as atividades florestais." *Simposio IPEF Sobre Silvicultura Intensiva e o Desenvolvimento Sustentavel.* IPEF Serie Tecnica. 8(24): 37-55.

Castro Filho, F.P. 1990. "Politica de fomento florestal do Estado de Minas Gerais." *Seminario Sobre Aspectos Economicos* (15-16 October). *Sociais e Ambientais do Fomento Florestal.* Minas Gerais: 3-17.

Couto, L., and D.R. Betters. 1994. *Short-Rotation Eucalyptus Plantations in Brazil:* Social and Environmental Issues (June). Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Fujihara, M.A. 1990. "Fomento florestal: necessidade de uma acao integrada." *Seminario Sobre Aspectos Economicos* (15-16 October). *Sociais e Ambientais do Fomento Florestal,* Minas Gerais.

Larson, E.D., L.C.E. Rodriguez, and T. Rezende de Azevedo. 1994. "Farm Forestry in Brazil." Presented at BioResources '94 *Biomass Resources: A Means to Sustainable Development* (October). Bangalore, India.

——, and R.H. Williams. 1995. "Biomass Plantation Energy Systems and Sustainable Development." In *Energy as an Instrument for Socio-Economic Development,* edited by Goldemberg and Johansson.

Oliveira, C.A.S. 1991. "Fazendeiro florestal: uma realidade em Minas Gerais." *Encontro Tecnico Florestal.* Belo Horizonte, MG, 20-21 (August): 119-123.

Section 7.10.

International Tree Clearinghouse Project (ITCP). 1986. *Aspects of Non-Governmental Organisation Participation in Social Forestry* (September). Proceedings of the NGO Consultation on Social Forestry (September 8-11, 1986), Whitefield, Bangalore, India.

Sudhakara Reddy, B., Jyoti Parikh: P.V. Srinivasan. 1999. "Plantation Programmes Through People's Participation: A Case Study from India. *Biomass and Bioenergy* 17: 257-271.

Information Sources

Listed here are information sources relevant to biomass energy modernisation, organised under the categories Conference Proceedings, Journals, Newsletters, and Other Publications. Some are listed earlier in specific chapters, but are included here because they are broadly relevant; others are additional sources not listed elsewhere. Unless otherwise specified, these publications are in English.

Conference Proceedings

Bioenergy '94: Proceedings of the Sixth National Bioenergy Conference. 1994. Hosted by Western Regional Biomass Energy Program, US Dept. of Energy. http://www.doe.gov

Bioenergy '96: Proceedings of the Seventh National Bioenergy Conference. 1996. Muscle Shoals, AL: Southeastern Regional Biomass Energy Program, Tennessee Valley Authority, CEB 2A: O. Box 1010, 35662-1010.

Chartier, P., G.L. Ferrero, Henius, Hultberg, Sachau, and Wiinblad, eds. 1997. *Ninth European Bioenergy Conference: Biomass for Energy and the Environment.* New York: Pergamon Press.

First Biomass Conference of the Americas. 1993. NREL/CP-200-5768, DE93010050. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov

R. Overend and E. Chornet, eds. 1997. *Third Biomass Conference of the Americas.* Oxford, UK: Elsevier Science, Ltd. http://www.nrel.gov

——. 1999. F*ourth Biomass Conference of the Americas.* Oxford, UK: Elsevier Science, Ltd. http://www.nrel.gov

Second Biomass Conference of the Americas. *1995.* NREL/CP-200-8098, DE95009230. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov

Journals

Biomass and Bioenergy. http://www.elsevier.com/locate/biombioe.

Energy for Sustainable Development. Benson Town Bangalore, India: International Energy Initiative, 25/5 Borebank Road, 560046.

Newsletters

BUN-India. Bangalore, India: Biomass Users Network India. Combustion, Gasification, and Propulsion Laboratory. Indian Institute of Science. 560 012. http://144.16.73.100/~mukunda/home.html

CENBIO (in Portuguese). Sao Paulo, SP, Brasil: Centro Nacional de Referencia em Biomassa Brasil. Av. Prof. Luciano Gualberto, 1289 – Cidade Universitaria, CEP 05508-900. http://www.iee.usp.br/energia/cenbio/

International Cane Energy News, Winrock International, 1611 N. Kent St., Suite 600, Arlington, VA 22209, USA.

Renewable Energy for Development. Stockholm: Energy Programme of the Stockholm Environment Institute. Box 2142, S-103 14. http://www.sei.se/

Renewable Energy Newsletter. Oxfordshire, UK: IEA CADDET Centre for Renewable Energy. ETSU, 168 Harwell, OX11 0RA. http://www.caddet-re.org

REPSource. Arlington, VA: International Network of Renewable Energy Project Support Offices. Winrock International, Renewable Energy and Environment Program. 1611 N. Kent Street, 22209. USA.http://www.winrock.org

Rural Energy in the Asia-Pacific Region. Bangkok, Thailand: Food and Agriculture Organisation, Regional Office for Asia and the Pacific. Maliwan Mansion. 39 Phra Atit Road, 10200.

Wood Energy News. Bangkok, Thailand: Food and Agriculture Organisation, Regional Wood Energy Development Programme in Asia. Maliwan Mansion, 39 Phra Atit Road, 10200. http://www.rwedp.org/wen.html

World Rainforest Movement *(WRM) Bulletin.* Montevideo, Uruguay: WRM. International Secretariat Instituto del Tercer Mundo. wrm@chasque.apc ; http://www.wrm.org.uy

Other Publications

Bentley, W.R., and M.M. Gowen. 1994. *Forest Resources and Wood-Based Biomass Energy as Rural Development Assets.* New Delhi: Oxford & IBH Publishing Co., Pvt., Ltd.

Blanco Rodriguez, J. Ma., ed. 1994. *Commercially Successful Biomass Energy Projects in Developing Countries.* San Jose, Costa Rica: Biomass Users' Network. Central America and Caribbean Office. P.O. Box 1800-2100.

Carrere, R., and L. Lohmann. 1996. *Pulping the South: Industrial Tree Plantations and the World Paper Economy.* London: Zed Books.

Cook, James, and Jan Beyea. n.d. "An Analysis of the Environmental Impacts of Energy Crops in the USA: Methodologies, Conclusions and Recommendations." www.panix.com/-jimcook/data/ec-workshop.html

Food and Agriculture Organizaisation (FAO). 1999. *Wood Energy and Gender.* www.rwedp.org/i_gender.html

Goldemberg, J., and T.B. Johansson. 1995. *Energy as an Instrument for Socio-Economic Development.* New York: United Nations Development Programme, 1 UN Plaza, 10017.

Hall, D.O., F. Rosillo-Calle, R.H. Williams, and J. Woods. 1993. "Biomass for Energy: Supply Prospects." In *Renewable Energy: Sources for Fuels and Electricity,* edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Washington, DC: Island Press: 593-651.

Larson, E.D. 1993. "Technology for Electricity and Fuels from Biomass." *Annual Review of Energy and the Environment* 18: 567-630.

Office of Technology Assessment (OTA) of the Congress of the United States. 1992. *Fueling Development: Energy Technologies for Developing Countries* (April). OTA-E-516. Washington, DC: Government Printing Office.

——. 1993. *Potential Environmental Impacts of Bioenergy Crop Production – Background Paper.* OTA-BP-E-118. Washington, DC: Government Printing Office.

Ravindranath, N.H., and D.O. Hall. 1995. *Biomass, Energy and Environment: A Developing Country Perspective from India.* Oxford, UK: Oxford University Press.

Reddy, A.K.N., R.H. Williams, and T.B. Johansson. 1997. *Energy After Rio: Prospects and Challenges.* New York, NY: United Nations Development Programme, 1 UN Plaza, 10017.

Sargent, C., and S. Bass, eds. 1992. Plantation Politics: *Forest Plantations in Development.* London: Earthscan.

Smil, Vaclav. 1983. *Biomass Energies: Resources, Links, Constraints.* New York: Plenum Press.

World Rainforest Movement (WRM). 1999. *Tree Plantations: Impacts and Struggles.* Montevideo, Uruguay: WRM. www.wrm.org.uy