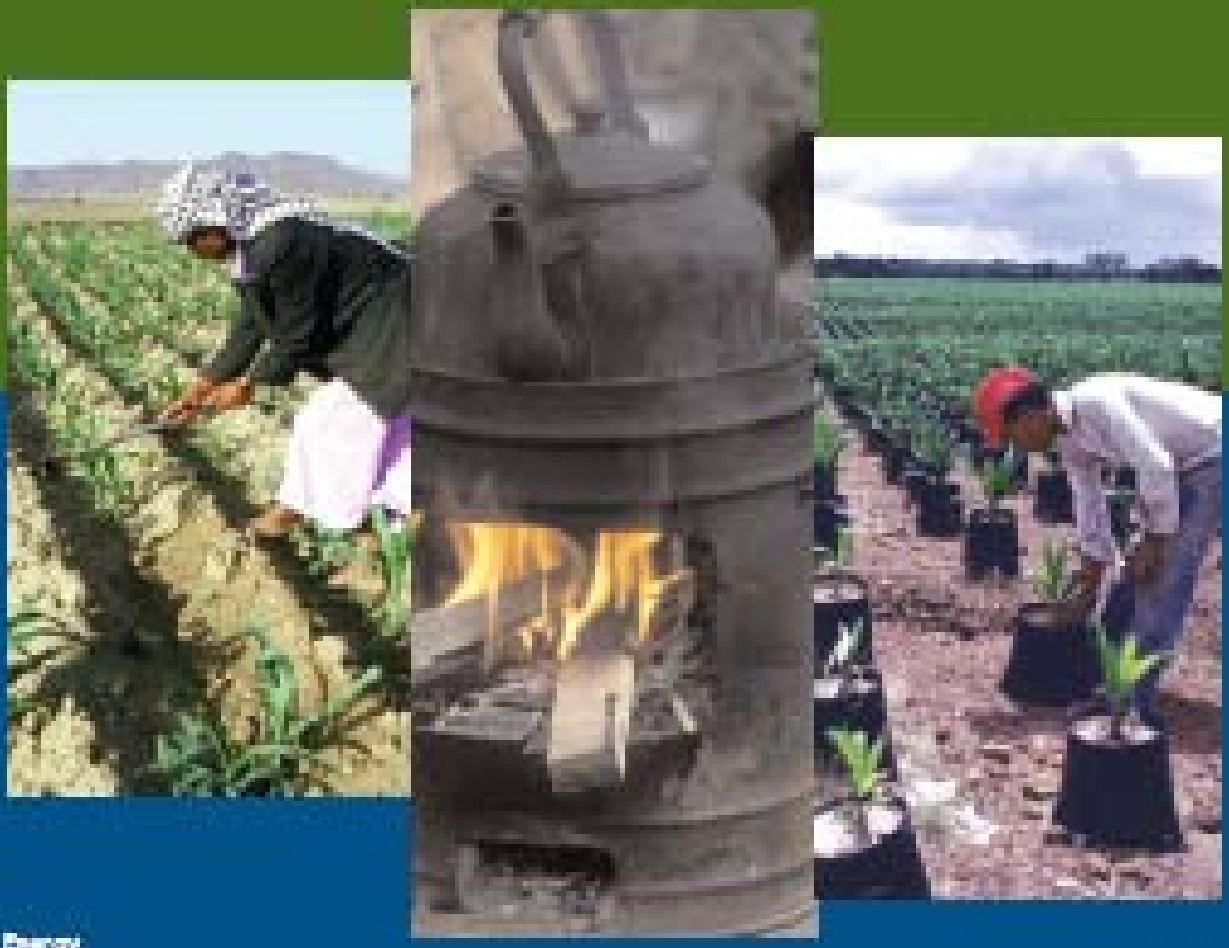
Advancing Bioenergy for Sustainable Development

Guideline for Policymakers and Investors

Volumes I, II and III



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Advancing Bioenergy for Sustainable Development Guideline for Policymakers and Investors

Volumes I, II, and III

April 2005

Sivan Kartha

Gerald Leach

Sudhir Chella Rajan

Stockholm Environment Institute

Energy Sector Management Assistance Program

(ESMAP)

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To the Memory of Gerald Leach

This document is dedicated to the memory of Gerald Leach, a creative thinker, pioneer, and doer whose far-reaching influence in the field of energy and development will be forever valued. A self-professed bemused observer, Gerry was also an insightful analyst who brought a vision of sustainability to his work long before it was fashionable. ESMAP and his coauthors thank him for carrying out this project, and even more so for the many years of stimulating collaboration and warm friendship. His peers and students thank him for his many contributions to the energy field.

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Executive Summary

Audience for this Report

The intended reader is not an energy expert, and certainly not a bioenergy expert. The reader is someone (most probably in government, but perhaps in an international aid agency or NGO) in a position to make decisions or advise decisionmakers regarding programs in support of rural development. The intent of the document is to provide such a reader with background information and motivation regarding bioenergy's role in promoting sustainable rural development. It discusses ways to support the implementation of bioenergy through policies, including those that can mobilize private sector activity.

Thus Volume I, the main report provides an overview of implementation issues for bioenergy projects and programs; Volume II provides technical information regarding biomass resources and technological options; and Volume III provides discussions of real-world bioenergy implementations through case studies and profiles.

Purpose of this Report

This report provides a broad review of the issues that a policymaker or project developer may face when endeavoring to advance biomass energy for sustainable development. The report provides guideance with respect to multiple dimensions of bioenergy project design and implementation for policymakers, entrepreneurs, and other actors. Its main focus is on less developed countries, although some lessons and methods from industrialized countries are included where appropriate. The report divides these issues among three volumes.

Volume I

Chapter 1 of the first volume provides an introduction to the main features of biomass energy and its place in meeting the larger goals of sustainable development. It outlines the main benefits of biomass energy, which include: widespread availability, availability on demand (in contrast to intermittent renewable energy sources), convertibility to convenient energy carriers (such as fluid fuels and electricity), potential to support environmental objectives, and ability to contribute to sustainable rural livelihoods by providing employment and energy services. The chapter also discusses key aspects of biomass that inevitably make its implementation in a manner that contributes to sustainable development a complex challenge: resource competition, land intensity, labor intensity, and environmental impacts (which can be either positive or negative). Bioenergy activities will therefore directly and keenly affect the communities in which they are located. One can envision best case scenarios in which bioenergy becomes major source of quality employment and provides a means through which energy services are made widely available in rural areas while it gives rise to environmental benefits such as carbon reductions, land restoration, and watershed protection. On the other hand, one can also envision worst case scenarios in which bioenergy leads to further consolidation of land holdings, competition for cropland, and displacement of existing livelihoods while it incurs the environmental costs of decreased biodiversity and greater water stress. Neither one of these is a "right" or "wrong" forecast, as the ultimate outcome will depend on the objectives of those implementing the bioenergy activities and whether or not the objectives include sustainable development as a primary goal. Thus, the challenge is to create a policy and market environment that supports the design and implementation of bioenergy activities that contribute to sustainable development. Ensuring that those beneficial outcomes occur requires the policymaker and project developers to be sensitive to the conditions and needs in rural areas. Bioenergy

activities will be consistent with sustainable development and its objectives of livelihood generation and environmental restoration only if those goals are built into the project design and implementation.

The chapter details the various biomass supply options: residues, energy crops, and natural biomass resources.

Chapter 2 focuses on what the decisionmaker must consider in order to support bioenergy projects and facilitate their widespread replication. After reviewing the five categories of implementation modes that bioenergy activities generally have employed to date, the chapter details several key issues for any bioenergy program whose aim is to reduce barriers to the operation of markets for bioenergy and to establish conditions that make it easier for markets to serve communities and groups that currently lack access to energy services. It provides an extensive overview of the ways in which bioenergy programs can support private sector participation by undertaking general market creation activities and providing support to individual entrepreneurs. The chapter discusses financial incentives and the impacts of environmental and trade policies on bioenergy activities. It discusses the need for fair access to existing energy sector infrastructure and the importance of supportive land tenure arrangements. It finishes with a discussion of supportive financing arrangements and technology development and transfer.

Chapter 3 shifts the perspective from supply to demand, that is, from the standpoint of the bioenergy program developer to that of the local community and potential end user of biomass and biomass related services. Biomass energy, because it is inherently land intensive, dependent on local labor, and closely tied to resources upon which rural livelihoods rely, has a strong potential to affect rural communities, either positively or negatively. This chapter discusses the prospects for ensuring those impacts are positive. It discusses the roles of biomass in meeting energy services needs and employment generation needs, placing biomass options in the context of rural development. It addresses methods for engaging local communities to help answer the question: "How could advanced biomass energy systems help meet sustainable development goals?" That engagement can take a range of forms, from consultation on project design to participation in project implementation. The chapter reviews different modes of implementation at different scales, ranging from large-scale private sector investments down to community initiatives and commercial energy services companies.

Volume II

The Technical Annexes discuss in more technical detail two key issues in bioenergy. The first part of the Technical Annex provides a detailed methodological description of resource assessments. A biomass resources assessment is the crucial first stage of bioenergy development at any level, from the formulation of national energy policy and planning through to village scale operations. The chapter proceeds from the broad brush, large-scale assessments that are inevitable at the national level to the more detailed estimates required at local levels. The chapter outlines the major steps involved in making such assessments, using actual examples wherever possible. Intended to help determine priorities for further studies and the development of particular bioenergy options, they are thus aimed at providing rough working estimates of potential residue resources, how much of these are actually used, and residue costs and prices.

The second part of the Technical Annex is an introductory overview and discussion of bioenergy technologies. Its aim is to provide an overview of the technological options and preliminary information necessary to decide which technological options may be relevant and feasible in the local context. The chapter discusses the general technological factors relevant to all bioenergy technologies: cost, load factor, efficiency, feedstock, scale, and robustness. It then provides a short profile of several technological options for converting biomass into electricity, gas, liquid fuels, and solid fuels, most of which are

currently commercial or undergoing commercialization, and some of which are emerging. The technologies reviewed are steam turbines (including cogeneration), gasification (to produce fuel for process heat and internal combustion engines), anaerobic digestion (to produce fuel for cooking and internal combustion engines), ethanol and ethanol gel, biodiesel, efficient cookstoves, briquetting, charcoal production, and various emerging technologies. These technology profiles are meant to give the general reader an understanding of the applications and some of the technical issues that arise in employing the technology in bioenergy implementations.

Volume III

The third volume of this report contains nine concise profiles of bioenergy projects and three extended case studies of major bioenergy activities. The short project profiles are of bioenergy activities undertaken in a range of countries; they provide useful examples and lessons regarding problems encountered and solutions found in recent bioenergy experience. The profiles include: (1) ethanol in Malawi and Zimbabwe, (2) bagasse cogeneration in Mauritius, (3) biomass power in Bolivia, (4) gasification biomass power production in Sweden, (5) small-scale gasification power production in India, (6) anaerobic digestion in Colombia, (7) gasification process heat in Indonesia, (8) biomass power in Philippines, and (9) biodiesel in Hawaii. These are presented to provide a variety of technologies, biomass supply systems, and national contexts. Throughout the main text of this report, these profiles are referred to as specific illustrations of important points.

The three extended case studies are all co-authored with collaborators who are involved in bioenergy activities in India, which has one of the world's longest standing and most developed national bioenergy programs; it also has considerably more dispersed activities outside the formal national program. The first case study is of an NGO coordinated program that created an entrepreneurial cadre to develop and commercialize advanced biomass devices for entrepreneurs in the nonformal sector. The second case study relates a long term experiment based on village managed small-scale energy and water utilities. The third case study is an overview of the national bioenergy program of the Ministry of Non-Conventional Energy Sources.

Advancing Bioenergy for Sustainable Development Guideline for Policymakers and Investors

Volume I

Main Report

1

The Challenge of Biomass Energy

An Old Fuel with New Life

1.1 Biomass energy, or bioenergy, refers to the use of plant and other organic materials to provide desired forms of energy and energy services such as heat, light and motive power. Since the discovery of fire, it has been a major source of energy worldwide. Even in today's fossil fuel era, bioenergy provides about 11percent of the world's total primary energy supply of 420 exajoules (EJ) a year (IEA 2002), with much larger fractions in most developing countries and some industrialized countries.

1.2 Most of this bioenergy consists of unrefined fuels used in traditional ways; that is, solid fuels such as firewood, charcoal, crop and animal residues, typically used with cheap and simple devices such as three stone cookstoves and earthen kilns, for essential survival needs such as cooking, space and water heating and crop drying. In this role, bioenergy provides about 38 ±10 EJ/year globally, roughly one third of all energy in less developed countries as a whole, and as much as 90 percent or more in the poorest countries. Increasingly, biomass fuels are converted to higher value and inherently more efficient, versatile and convenient energy carriers (electricity, liquid and gaseous fuels) or are used as solids in efficient equipment to provide process heat or space heat. This usage is collectively termed "modern" bioenergy, amounts to about 10 EJ/year or 2.3 percent of world primary energy use (IEA 2002), and is the main focus of this report.

1.3 This global role may seem very small but modern bioenergy is in fact the leading form of renewable energy, lying just ahead of hydropower (9.5 EJ/year) and well above all other renewables such as geothermal, wind, solar and marine energy, which combined provide 2.1 EJ/year (IEA 2002). It plays an even greater part than this in several countries and economic sectors, especially in well forested countries with large forestry based industries and/or with cold winters and large space heating demands, and in countries with thriving sugar industries. For example, in Finland, Sweden and Brazil, modern bioenergy accounts for 33-36 percent of total energy use by industry and, in the first two of these countries, some 11-12 percent of energy used for electricity generation, combined heat and power (CHP) and district heating (IEA 2002, 2003a). In Latin America, about 8 percent of primary energy comes from modern bioenergy, especially from industrial wood energy, the conversion of sugarcane to alcohol as a transport fuel in Brazil, and the more widespread use of cane processing waste (bagasse) to generate electricity. This and further information on the role of modern and traditional biomass by major world region is presented in Table 1.1.

Table 1.1: Role of Biomass Energy by Major Region in 2000: EJ/year

Region	World	OECD	Non-OECD	Africa	Latin America	Asia
Primary energy [a]	423.3	222.6	200.7	20.7	18.7	93.7
of which biomass (%)	10.8%	3.4%	19.1%	49.5%	17.6%	25.1%
Final energy [a]	289.1	151.2	137.9	15.4	14.6	66.7
of which biomass (%)	13.8%	2.5%	26.3%	59.6%	20.3%	34.6%
Estimated modern bioenergy [b]	9.8	5.2	4.6	1.0	1.9	1.5
as percent of primary energy	2.3%	2.3%	2.3%	4.7%	10.0%	1.6%
Modern bioenergy inputs to:						
Electricity, CHP & heat plant	4.12	3.72	0.39	0	0.14	0.07
as percent total sector inputs	2.7%	4.1%	0.6%	0%	3.4%	0.2%
Industry (approx.)	5.31	1.34	3.97	0.98	1.45	1.44
as percent total sector inputs	5.8%	3.0%	8.6%	30.3%	26.0%	6.3%
Transport	0.35	0.10	0.26	0	0.29	0.03
as percent total sector inputs	0.5%	0.2%	1.1%	0%	6.3%	0.4%

Source: IEA 2002, 2003a. See also IEA 2003b.

[a] Primary energy: IEA 'Total Primary Energy Supply'. Final Energy: IEA 'Total Final Consumption'.

[b] Estimated modern bioenergy is the sum of bioenergy inputs to the three sectors shown in the table: electricity, combined heat and power, and district heating plant; industry (which might include some traditional bioenergy); and transport fuels.

1.4 Interest in modern bioenergy has been increasing worldwide. In many countries, less developed as well as industrialized, it has become a centerpiece of renewable energy plans and policies because of its many practical, social and economic advantages. More fundamentally, modern bioenergy is now widely regarded as an important player in the global transition to a low carbon energy future, which is needed to reduce human induced climate change.

1.5 This enthusiasm is based on five key advantages that modern bioenergy offers compared to fossil fuels and/or other renewable energy sources:

- *Widely available resource:* Biomass resources are diverse and widespread, often in large volumes. Bioenergy can be produced, in principle, wherever trees and food are

grown and wherever food and fiber are processed. This is in marked contrast to the global concentration of the oil and gas resources that drive today's industrial activity.

- *Available on demand:* Biomass is a form of stored energy and can therefore provide energy at all times, without the need for expensive storage devices such as batteries. In this respect, bioenergy is like fossil fuels and differs markedly from intermittent renewable energy sources such as solar, wind, wave and hydropower, with their nightly, seasonal or sporadic supply shutdowns. Bioenergy is also presently much cheaper—and further advanced—than likely alternatives for nonintermittent renewable energy supplies, such as stored hydrogen derived from wind or solar photovoltaics (PV) via the electrolysis of water.

- *Convertible to convenient forms:* Biomass can provide all the major energy carriers—electricity, gases, liquid fuels for transport and stationary uses, and heat. It is well suited to doing this on a decentralized (standalone) basis at scales of 10s or 100s of kilowatts (kW) and upwards. Biomass can therefore substitute for fossil fuels or other energy supplies in many contexts and is well suited to supply the fuels and power at small scales that are needed to underpin poverty reduction, development and growth for the two billion or so people who now lack access to modern forms of energy. Modern bioenergy technologies can also serve similar ends by replacing traditional cooking fuels with clean, smokeless, efficient and easily controlled liquid and gas alternatives based on renewable biomass rather than fossil fuels.

- *Potential to contribute to greenhouse gas reductions and other environmental objectives:* Bioenergy is climate friendly. In sharp contrast to fossil fuels, its production and use emits little or no carbon dioxide, a potent greenhouse gas, providing the biomass is sustainably generated. In this case, the carbon dioxide that is released when biomass fuels are burned will be reabsorbed from the atmosphere during biomass regrowth. It is important, however, to also consider the net lifecycle emissions of greenhouse gases other than carbon dioxide. Nitrous oxide and methane in particular can be important contributors to the net greenhouse gas impacts of agriculture intensive activity. As to these greenhouse gases and other pollutants, bioenergy can score both better and worse than fossil fuels: the situation is complex and depends on precisely how the biomass is grown, transported, converted and used. Bioenergy can advance other environmental goals as well. If it is undertaken with these goals in mind, biomass production can contribute to habitat preservation, soil restoration, and watershed protection.

- *Source of rural livelihoods:* Much of bioenergy systems' added value and income generation is retained locally and can help to reduce rural poverty—in sharp contrast to fossil fuel or central electricity production and distribution systems and many other renewable energy technologies. Indeed, modern bioenergy is widely thought to be a key means of promoting rural development (UNDP, 1995; Ravindranath and Hall, 1995; Kammen et al., 2001, Utria and Williams 2002). In many developed countries, biomass fuel production has been promoted as a way of supporting and diversifying unstable farm incomes. In developing countries, modern bioenergy can provide a basis for rural employment and income generation, thus helping to vitalize rural economies and curb urban migration. For many forestry and agroprocessing

industries, biomass provides an abundant, dependable and cheap fuel which can reduce energy costs and earn substantial revenue from the sale of surplus power to the electricity grid or biofuels to urban demand centers or export markets.

1.6 Despite these potential advantages, one must not take for granted that expanding bioenergy will automatically contribute to sustainable development. Bioenergy activities are almost inevitably labor, resource and land intensive undertakings. Land requirements are at least an order of magnitude greater for biomass electricity than for an equal amount of photovoltaic electricity[1], for example, and labor requirements for producing biomass energy feedstock would be considerably higher than for conventional capital intensive forms of extracting fossil fuels like coal and oil. Bioenergy activities will therefore directly and keenly affect the communities in which they are located. One can envision best case scenarios in which bioenergy becomes major source of quality employment and provides a means through which energy services are made available widely in rural areas and give rise to environmental benefits such as carbon reductions, land restoration, and watershed protection. On the other hand, one can also envision worst case scenarios in which bioenergy leads to further consolidation of land holdings, competition for cropland, and displacement of existing livelihoods as it incurs the environmental costs of decreased biodiversity and greater water stress. Neither one of these is a "right" or "wrong" forecast, as the ultimate outcome will depend on the objectives of those implementing the bioenergy activities and on whether the objectives include sustainable development as a primary goal. Thus, the challenge is to create a policy and market environment that supports the design and implementation of bioenergy activities that contribute to sustainable development. Ensuring that those beneficial outcomes occur requires the policymaker and project developers to be sensitive to the conditions and needs in rural areas. Bioenergy activities will be consistent with sustainable development and its objectives of livelihood generation and environmental restoration only if those goals are built into the project design and implementation.

Biomass Resources and Supplies

1.7 Bioenergy systems require sufficient, reliable, sustainable, and affordable biomass supplies. These supplies must be grown, harvested, gathered, and transported to the energy conversion plant, sometimes from a large number of dispersed suppliers. They must usually be stored and perhaps dried to avoid deterioration. In many cases the biomass must be chopped, pelletized or otherwise prepared for use as a biofuel.

1.8 These supply side activities set bioenergy apart from other renewables, in which the primary solar, wind, wave or hydro energy resource is freely provided and converted to delivered energy in a single technical step. While the additional steps in the biofuel supply chain can bring substantial benefits in the form of local employment and income (benefits which have, of course, to be paid for by energy users) they may also raise serious problems which do not apply to other energy resources. These may occur because biofuel supply and use is embedded in the production and use of all forms of biomass, which are in turn embedded in highly complex, dynamic, multipurpose and competitive land use and labor systems that form the bedrock of rural economies.

1.9 Critical aspects of these systems vary greatly from place to place and also over time as economic, social and environmental conditions alter. Yet these site specific and varying conditions

[1] See Box 1.3.

govern to a large extent the amounts and kinds of biomass resources that can be produced, the costs of production and associated benefits such as farm income and rural employment, resulting biomass prices, vulnerability to supply failure, environmental impacts (positive and/or negative), and risks of harming existing biomass dependent social groups. There are thus rarely any "one size fits all" solutions: bioenergy projects must usually be tailored to the biophysical and socioeconomic circumstances of each location and must be supported by a great variety of stakeholders. These factors must be carefully assessed before each project or program can be successfully implemented. Frameworks and methods for doing this are presented later (see in particular Chapters 2 and 4).

1.10 In general, there are seven main areas of particular pertinence to anyone concerned with developing bioenergy resources and supplies. These are discussed in some detail throughout the report but are summarized below.

Resource Competition

1.11 Most biofuels have alternative nonenergy uses (see Box 1.1). Bioenergy systems can therefore face a two sided price competition (Sedjo 1997). Low biofuel prices may be needed for bioenergy to compete with fossil fuels and other renewables. High prices must often be paid to secure biofuels in a competitive market. Frequently the required price is "too high" and the bioenergy proposal must be abandoned. Competition with nonmonetized traditional biomass supplies that provide essential "survival" energy services is common and must be dealt with at early stages of project planning and, more generally, by efforts to assess and meet local needs and where necessary to introduce policy controls over biofuel markets. Similarly, careful planning and good information on resource flows are required to ensure that new bioenergy schemes do not compete with other schemes for the same resources.

Box 1.1: Residue Supplies: Competition and Uncertainties

In developing countries most types of biomass have many alternative uses, sometimes known as the Five Fs: fertilizer, fodder, fiber, feedstock (for chemical processes) and fuel. Some principal nonenergy uses are:

Wood logs, branches	Construction materials, paper industry
Wood chips, bark, sawdust	Construction materials (for example particle board)
Cereal straws	Animal feed, soil conditioner, paper & board industries, roof thatching
Maize stalks	Cattle feed, soil conditioner
Rice husk	Cement & brick industries
Bagasse, cane tops & leaves	Animal feed, paper & board industries
Animal dung	Soil conditioner & fertilizer

Biomass prices and availability are mainly determined by these nonenergy demands, in sharp contrast to fossil fuels, whose prices reflect use as fuel and not other end uses such as plastics. Many of these biomass demands are site specific, difficult to identify from aggregated statistics, and the cause of sharp changes in price (and hence biomass availability) as market conditions alter.

In Northeast Thailand, for example, rice husk was once a waste disposal problem but has recently become a valuable raw material for making bricks (Junginger 2000). Prices have varied as a result from US$1.4/tonne to US$8.1/tonne in times of extreme husk scarcity. Many rice mills have responded by buying electricity for process requirements and selling rice husk rather than using it to generate power. In parts of India, rice husk is considerably more expensive, with large price differences between the harvest season (US$13/tonne) and off harvest season (US$31-33/tonne) (Mishra 2002).

Similar price volatility is also found with energy crops. In the Indian state of Karnataka, for example, the price of eucalyptus logs obtained by farmers increased over 1995-98 by 160 percent, from US$40 to US$106 a tonne[2] (PC-GoI 2001). In sharp contrast, prices in Madya Pradesh and Maharashtra were much higher, at US$191 and US$199 a tonne respectively in 1998, but hardly altered in the same 4-year period. In all three states, the log prices are now so high—respectively US$7.3, 13.1 and 13.6 per GJ of energy content—that use of purchased logs as fuel is more or less ruled out. These prices are equivalent to oil at US$44-82 a barrel. Yet in the 1980s, thousands of farmers in the same region ripped up their eucalyptus trees when log and wood pulp prices crashed following a tree planting boom (Saxena 1990).

Compounding this problem is the high sensitivity of final energy prices to biomass fuel prices and the relatively large costs of mitigating seasonal shortfalls in fuel supply (see Chapter 2). Ensuring fuel security involves a combination of adequate storage capacity and suitable fuel preparation and conversion plant design to allow the use of several types of biomass feedstock (or cofiring with a fossil fuel such as coal).

Land Competition

1.12 Energy crops may compete for land with other uses, such as production of food crops or raising livestock on rough grazing land. This so called "fuel/food" problem is widely recognized but may

[2] Prices converted from current Rupees per cubic meter by use of the all India consumer price index, the average Rupee:US$ exchange rate for 2000, a density of 0.77 tonnes/m^3 and an energy content of 17.9 GJ/tonne for air dry wood with 20percent moisture content.

easily be exaggerated. In some places it may well be a problem: while fuel/food competition can be avoided by growing energy crops on marginal or "waste" land, doing so may mean high production inputs and costs to achieve financially acceptable crop yields. Conversely, the best net returns and profits for energy crop producers may arise from using good quality, though expensive, crop land.

1.13 However, these problematic situations are by no means universal or inevitable. In many places new biofuel crops can fit in well with conventional farm production. Rather than generate food/energy conflicts, by careful system design they can help to reduce overall farm costs, improve rural infrastructure and access to markets, and generally raise farm incomes.

1.14 Given these divergent situations, it is crucial that biofuel crop projects and programs base their design and site selection on sound, local information about the relative merits of bioenergy and alternative crop production—and do so using a broad, rural development based perspective (See Phillips 2002). This process will often require careful consideration, for fuel and alternative crops, of the tradeoffs between land quality, land cost and crop yield, in the context of local development needs (see Box 1.2).

Box 1.2: Crop Yields and Land Quality

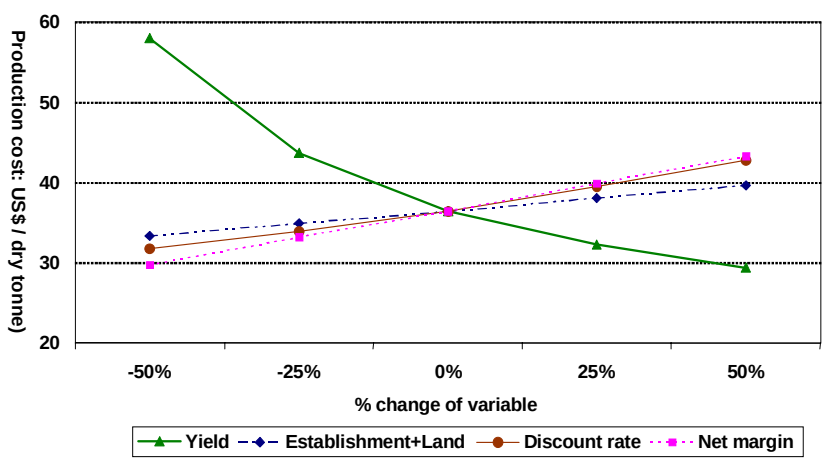
A key issue with energy crops is the local availability of land and the possibilities of competition between fuel and food production. Bioenergy proponents usually deal with this issue by assuming that energy crops will be grown on poor or degraded lands that are marginal or unsuited for conventional crops. They also suggest that globally and in many countries, large areas of such land are currently unused and available for growing trees or grasses as energy sources.

A problem with this argument is that while fertile lands may cost more to buy or rent, they typically cost less to prepare and maintain. They also give higher and more dependable crop yields. As a result, they are generally more profitable and lead to lower biofuel costs than marginal land. Poor lands may be cheaper and more available, but they often have many physical limitations such as infertile and stony soils, low rainfall, steep slopes, or brush cover that must be cleared. These problems can both reduce potential yields and lead to high land preparation or harvesting and transport costs. Most importantly, they may require greater technical expertise and more careful management to avoid soil erosion, soil nutrient depletion and other problems which can lead to major setbacks or failure.

A key challenge for the successful implementation of bioenergy crops is therefore to identify suitable and available sites, a task that can involve making difficult tradeoffs between yield, output prices, site quality, and quality dependent production costs, often in the context of highly demanding rural development constraints and objectives. In the temperate industrialized countries, these factors generally balance out in favor of planting energy crops on good quality land rather than marginal cropland, forest land and pasture (Perlack et al. 1995). Furthermore, most of these countries have more cropland than they need for food production and are seeking to diversify agriculture and farm incomes. Bioenergy production is a leading candidate in this strategy.

In tropical developing countries bioenergy crops are grown on a much greater variety of land types. However, as in the developed world, many energy crops are sited on good quality farmlands and can equal or exceed the profitability of conventional food crops.

Yields are critical to biofuel production costs because establishment, land, maintenance and overhead costs, as well as net returns ("profits"), do not increase with greater yield. Only harvesting, transport and other post harvest costs are yield dependent. Consequently, total production costs per tonne fall steeply at higher yields, and vice versa. This cardinal point is illustrated in Figure 1.1, based on data for small-scale tree plantations in China (Perlack 1996). The figure shows, for example, that if the wood yield is reduced by 50 percent, the production cost increases by 60 percent. In contrast, a 50 percent reduction in land plus establishment costs, the discount rate and the grower's net margin, increases the production cost by only 9 percent, 18 percent and 13 percent, respectively.



Sensitivity of wood production cost to yield and major cost variables

For the baseline situation (0 percent change of variables), the production cost is US$36.4/dry tonne, yield is 10 dry tonnes/hectare/year, establishment plus land cost is US$400/hectare, harvest and transport costs US$15/dry tonne, discount rate is 10 percent a year, and net margin US$100/hectare/year (just over 25 percent of the gross revenue). Data based on Perlack (1996) for plantations in China established for bioenergy production and harvested on a 7-year rotation.

Land Intensity

1.15 Bioenergy crops are very land-intensive (see Box 1.3). For example, they typically require roughly 100 times more land than solar photovoltaics (PV) to produce the same electricity output. This limits the feasible scale of bioenergy systems: a 50 MWe biomass-fuelled power plant is said to be large to very large scale whereas a fossil fueled plant of this size would be called small to medium scale. One consequence is that national utilities may be institutionally disinclined toward buying the small amounts of surplus energy produced by bioenergy projects. Another is that major national bioenergy development must proceed via myriad small- to medium-scale schemes, with no shortcuts based on large-scale plant. Yet another is that biofuel supplies must often be obtained from large numbers of scattered producers, with major implications for fuel security and fuel transport costs.

Box 1.3: Land Needs and Size Constraints

Bioenergy requires a lot of land. This cardinal fact means that individual bioenergy projects are limited to small- to medium-scale operations.

Consider a region with 1000 mm annual rainfall (the borderline between semiarid and subhumid) where wood energy crops are grown with good management on marginal lands. The plantations might produce about 12 tonnes of harvested dry biomass a year, with a lower heating value of 18 GJ a tonne. A fairly sunny region receives an average of around 20 $MJ/m^2/day$, so one hectare receives an annual 73,000 GJ. With these assumptions, only 0.3 percent of the incoming solar energy is converted to biomass. If the biomass is used to generate electricity, the overall conversion efficiency is only 0.1 percent or so. This compares with around 15-20 percent for solar photovoltaics, and hence electricity from biomass is one or two orders of magnitude more land intensive than electricity from solar photovoltaic (accounting for the lower capacity factor). Each planted hectare provides enough fuel for an average electricity capacity of approximately 2 kilowatts, an amount that would match the average consumption of two modern homes. Similarly, one hectare could yield a quantity of ethanol that would roughly match the consumption of four standard passenger cars (that is, 65 tonnes of cane per hectare per year and 75 liters of ethanol per tonne of cane approximately matches the needs of four cars getting 12 liters per 100 km and traveling 12,000 km per year.).

This low efficiency limits the practicable size of bioenergy systems for power production. Consider a baseload biomass fueled power plant with 500 MWe capacity, 30 percent efficiency and annual load factor of 80 percent. This is not very large by fossil fuel or big hydropower standards. The plant generates 3.5 million MWh of electricity a year by consuming around 2.9 million tonnes of air dried biomass (with 20 percent moisture content), or 2.3 million tonnes on a dry wood basis. So the power plant needs less than 200,000 hectares (2,000 square kilometers) of plantations to keep it going. However, the plantations would have to be spread over a much larger area than this to reduce risks of fire and pest attack, minimize biodiversity losses, and to fit the plantations into a rural landscape of farms, woodland and villages. With fairly intensive, compact system, this total area might be around three times greater, or some 6,000 square kilometers. (The factor could be lower in areas that are already overwhelmingly agricultural if very intensive plantation agricultural is environmentally and socially tolerable, or might have to be much higher if habitat and other considerations are severe constraints). If this area formed a circle centered on the power plant, the circle's diameter would be 86 kilometers. Even larger areas would be needed if forestry or agricultural residues were used for feedstock, as yields of these sources are rarely as much as 12 t/ha/year (sugarcane bagasse excepted).

Such a large scale also raises difficulties in securing fuel supplies from producers. At one extreme, the 500 MW plant operators could rely on a few very large plantations of, say, 10,000 hectare each. At the other extreme they must make firm agreements (or rely on an open market and good supply prices) with many thousands of small- to medium-scale producers. In the Philippines, a recent proposal for a 40 MW power plant fuelled with rice husks collapsed due to the complex logistics of securing fuel from the many surrounding rice mills (Shukla 2000).

A third constraint is the huge volume of biomass that must be transported and stored. With widely scattered harvest sites, haulage would have to be by road rather than the less obtrusive rail or pipeline systems typical of large fossil fuelled plant. In the example above, annual haulage would be about 86 million tonne-kilometers or over 23,000 tonne-km per day, or perhaps a few thousand lorry trips.

Smaller scales attenuate these problems by dispersing them. This is illustrated by the table below, which shows some key parameters for 50 MW, 5 MW and 500 kW systems, using the same assumptions as above. Of course, to achieve the same electricity output as the large 500 MW plant, proportionately more systems must be installed: as many as one thousand in the case of 500 kW (large village scale) units.

		50 MW	**5 MW**	**500 kW**
Total production area (plantation area x 3)	hectare	58,460	5,846	585
as circle with radius	kilometer	13.6	4.3	1.4
Average plantation area if 100 producers	hectare	195	19.5	2.0
Daily truck haulage	tonne-km	7,500	237	7.5

Labor Intensity

1.16 Energy crops and some important biomass residues are very labor intensive in most less developed countries (LDCs) owing to lack of capital for mechanization. Labor intensity per unit of biofuel energy produced is often one hundred or more times greater than it is for fossil fuel extraction (Kartha and Leach 2001). Bioenergy projects may therefore be attractive in regions with high unemployment and can contribute significantly to job creation and rural development.

1.17 However, large pools of cheap labor may not be available in higher income developing countries, where mechanization and off farm employment tend to push up agricultural wages but push down agricultural employment. In Brazil, for example, mechanization in the national alcohol program has cut agricultural jobs while substantially increasing wages. Bioenergy planners should be sensitive both to the opportunities for job creation in low income, low employment economies (for example in much of Asia and Sub-Saharan Africa) and to the more capital intensive production methods in higher wage countries. In particular, it is important to mitigate the potential harm and conflicts of interest that can arise as the process of rural mechanization begins to take place. At the very least, wherever this process displaces jobs, attempts must be made to soften or offset the impacts.

1.18 Energy crops can be divided into those that do, and those that do not, displace other crops. When energy crops that involve tree growing displace other crops in regions where there is little farm mechanization, the switch typically involves a reduction—sometimes a huge reduction—in local employment. Generally speaking, tree crops normally require much less labor than agricultural crops (Saxena & Srivastava 1995; Saxena 1989; Kartha & Leach 2001). This is not usually the case with nontree energy crops, such as sugarcane, which may employ more people than the nonfuel crop that they displace. Nor is it the case with energy crops that do not displace other crops, because these involve expanding crop production on to “new” lands, such as currently unproductive land and the margins of productive farm fields. Biomass energy crop production can therefore contribute to rural employment creation, provided it is designed and implemented in a manner that involves carefully assessing and addressing local employment needs. Positive job impacts cannot be assumed automatically.

Handling Requirements

1.19 Biofuels are relatively bulky, may have high water content and need drying, and may need seasonal storage to even out month by month variations in availability. Fuel quality may be unpredictable and biomass may need chopping to even sized pieces that flow. These processes require substantial management, capital costs and labor and can give biomass an old fashioned image, like coal. However, technologies for upgrading raw biofuels into pellets, briquettes or chips are advancing. The development of dedicated energy crops will also improve fuel standardization (Clancy 1996), and technical advances in handling equipment and conversion devices promises to increase the tolerance to feedstock variation.

Environmental Concerns

1.20 By virtue of their land intensive nature, biomass activities invariably affect the environments in which they occur. The effects of well designed activities can be positive. Energy feedstocks can be produced in a way that helps restore degraded soils, especially if nitrogen fixing species are used with sufficiently long rotation periods and fertilization (Shukla 2000), and helps maintain watershed health. As an alternative to annual row crops, perennial energy crops can require fewer chemical inputs and provide better habitat for indigenous species. However, if not well designed, large-scale biomass production can have negative impacts. Soil fertility, water resources, biodiversity and

landscape values can all be compromised by bioenergy activities that do not explicitly take these environmental issues into account (Kartha and Larson, 2000). Indeed, water shortages may be the limiting constraint on energy crops in many places (Rogner 2000). Biofuel transport will increase vehicle and road use with associated airborne emissions. However, some environmental risks may not be as great as often assumed (Clancy 1996). Not all residues make good fertilizers when they are left on the land rather than removed as fuel: farmers already select those residues best suited to this purpose. Farmers also remove field residues or burn them in the field for sound agricultural reasons, including differing effects on the soil, disease prevention and ease of planting succeeding crops. Use of these materials for energy would have no harmful agricultural impacts, provided care is taken to avoid nutrient depletion, for example by returning ashes from biomass based power plants to the soil.

Supply Uncertainty and Risks

1.21 These and other crucial aspects of biomass supply vary greatly from place to place and, in any one place, over time. For example, residue prices can vary several fold from one region to another or from one year to the next because of crop failures or booms in a residue using industry. Yet potential project investors often require assurances that fuel supplies will be adequate and reliable. It is therefore essential that bioenergy projects and programs are founded on careful and wide ranging fuel resource and supply assessments, estimates of future trends, and measures to minimize the impact of supply shortfalls. Supply risk can be reduced by strengthening links between biofuel producers and consumers; increasing biofuel stockpiles; densifying biofuels to reduce transport costs and thus increase the economic supply area; designing conversion plants to accept a greater range of biofuels; and designing the entire bioenergy system to be resilient to rising fuel costs. The eventual development of large-scale feedstock markets should lessen many of these difficulties.

Types of Biomass Supply

1.22 Biomass fuels come in many forms but can be classified into three broad types: agricultural, forestry and urban *residues*; dedicated *energy crops*; and material harvested from *natural biomass resources* such as woodlands, grasslands and water plants. These classifications and their important subdivisions are outlined in Table 1.2.

Table 1.2: Types and Examples of Biomass Fuel

Residues	**Examples**
Primary residues residues produced in the field or forest from biomass production and harvesting	
(a) dispersed residues: *substantial labor or other costs to collect for on site energy production or onward transportation to energy facility*	- biomass collected from natural resources: for example fallen tree branches, woody weeds and shrubs, grasses, swamp and water plants. - forestry thinnings, logging wastes and bark. - crop residues normally left or burned in the field: for example cereal straw; cotton, tobacco and maize stems; sugarcane tops and leaves. - dung from grazing cattle.
(b) concentrated residues: *few costs to collect for o -site energy production or onward transportation to energy facility*	- harvested cereal straws, crop stalks. - dung from stalled cattle, caged poultry.
Secondary residues residues arising from the processing of wood, food and other organic materials, at or close to the energy production site	- sawmill bark, chips, sawdust; black liquor from pulp mills; slaughterhouse wastes. - sugarcane bagasse; sugarcane tops and leaves if harvested; cereal husks and cobs; fruit wastes, oil pressing pulp (for example olives, palm oil); nut shells and husks.
Tertiary residues wastes arising after the consumption of biomass (and other organic materials)	- municipal solid organic wastes (incineration for energy production or gas from landfills); sewage gas. - wood recovered from demolition of buildings, wooden containers,.
Energy crops	
Dedicated energy crops agricultural or forestry crops with biomass fuels as the sole or principal product	- trees, bamboo, palms, grasses including sugarcane, cereals such as maize, starchy roots (for example sweet sorghum, sugar beet, cassava), oilseed crops.
(a) crops do not displace other crops	- energy crops grown on presently unused land, field boundaries, or roadsides.
(b) crops do displace other crops	- energy crops replace agricultural or forestry crops.
Biofuel co-production agricultural or forestry activities designed to provide several products including biomass fuel	- integrated sugarcane production providing a mix of sugar, alcohol, molasses (animal feed) and use of bagasse to generate electricity. - timber or fruit, nut and other trees grown principally for nonenergy purposes but designed to deliver thinnings, prunings or harvest wastes as biomass fuel.
Harvesting natural resources	
cutting live trees, shrubs, grasses, water plants. growing naturally: harvesting may be at sustainable or unsustainable rates	

Primary (field and forest) Residues

1.23 Most countries produce large quantities of biomass residues in relation to the volume of their conventional energy supplies. For example, an estimate for the 16 main countries of South & Southeast Asia in 1994 found that the energy content of agricultural residues alone amounted to 90 percent of total primary energy use excluding biomass (see Table 1.3). However, close to 80 percent of this total comprised relatively high cost primary (or "field and forest") residues while only 20 percent were secondary (or "processing") residues, which are typically more easily accessible and lower cost. Probably coincidentally, 20 percent of all residues produced in the region were used for energy purposes, including traditional uses. The remaining 80 percent were either used for nonenergy purposes or were unused and therefore constituted a potential resource for energy and nonenergy uses. A cardinal task of bioenergy assessment is to discover in a robust way what fraction of the presently unutilized residues is available for fuel at affordable prices, without disruption of important nonenergy activities that depend upon biomass residues, particularly within rural communities whose needs are often poorly documented and less understood than those of industrial users.

Table 1.3: Crop Residue Production and Use in S & SE Asia in 1994: PJ/year

	Nonbiomass energy	Residue production			Residue use		Residue production as percent of nonbiomass energy
	Total (PJ)	Total (PJ)	Field (percent)	Process (percent)	Total (PJ)	percent of production	(percent)
Bangladesh	210	981	82	18	181	18	470%
Cambodia	14	81	83	17	7	9	580%
China	23,866	14400	84	16	4103	28	60%
India	5,822	9100	75	25	328	4	155%
Malaysia	898	136	53	47	3	2	15%
Nepal	23	190	83	17	53	28	830%
Pakistan	1,066	1160	76	24	307	26	110%
Philippines	507	921	63	37	48	5	180%
Sri Lanka	79	122	69	31	5	4	155%
Thailand	1,352	1320	73	27	313	24	98%
Vietnam	260	940	79	21	507	54	360%
Total above (11 countries)	34,097	29349	79	21	5855	20	86%
Total region (16 countries)	36,159	32,522	79	21	N/A	N/A	90%

Source: Koopmans 2000

Notes: All residues amounted to 2.14 billion tonnes (field based 1.7 billion; processing based 0.44 billion). In energy terms, the most important residues were (with percentage of total residue based energy in brackets):

Field based: rice straw (40.0 percent), maize stalks (13.3 percent), wheat straw (11.7 percent), sugar cane tops (6.7 percent).

Process based: rice husk & bran (7.7 percent), sugar cane bagasse (7.4 percent), maize cobs & husks (2.7 percent).

1.24 Primary residues are produced in the forest or field from tree felling, thinning and pruning, harvesting agricultural crops and animal raising. They fall into two distinct classes:

(a) *dispersed residues*, which must be gathered together before they can be used for energy production. Examples are forestry logging wastes, dung from grazing cattle and cereal straws which are normally left in the field (and perhaps burned) after the grain is harvested;

(b) *concentrated residues,* which arise in already concentrated forms. Examples are dung from stalled cattle and cereal straws that are harvested and hauled to a central point together with the grain.

1.25 Costs of primary residues vary greatly, depending on the labor required to gather and concentrate the material, the degree of mechanization of these tasks, and the distance and costs of transport to the energy conversion plant. Residues such as rice and other cereal straws, and sugarcane tops and leaves, which are often left in the field, can in principle be collected, bale pressed, and transported to an energy conversion plant, with additional field operations and cost. Farmers may give them a low priority compared to harvesting the main (higher value) crop, particularly in the absence of a reliable market for them. Methods and machinery for harvesting residues simultaneously with the main crop are not yet available for all crops but in many cases are under development.

1.26 Other problems with primary residues include variable quality, deterioration in the field or during storage and drying, and the lack of supplies during the off harvest months. The latter problem may require interseasonal storage for the principal residue or the use of mixed fuels, perhaps including dedicated energy crops or fossil fuels. As noted above, care must be taken to avoid conflicts with other residue uses, including traditional fuel supplies. Also to be avoided are harmful resource impacts such as depletion of soil nutrients, soil erosion during periods when land is not covered by crops or residues, or soil compaction by machinery.

Secondary (processing) Residues

1.27 Secondary residues account for most of today's bioenergy supplies worldwide and are normally the first option for new bioenergy schemes. They are produced when wood, food and fiber crops and other organic materials are processed, usually at or very close to the energy production site. Examples are sawmill wastes, wastes from wood pulp and paper processing, sugarcane bagasse and many types of food processing wastes. Although some of these residues may have high value nonenergy uses ("too valuable to burn"), others may require costly disposal and have effectively a negative price for the bioenergy facility ("too costly not to burn"). Transport costs are normally low to zero as residues are concentrated on site. Supplies are fairly dependable and predictable as they form a known proportion of the total biomass coming into the site for processing, although changes in demand and prices paid for competing use can upset this comfortable situation. However, as illustrated in Table 1.3, while secondary residues may be extremely important locally as cheap and dependable fuel supplies, at the national scale their potential for energy use may be quite limited.

Tertiary Residues

1.28 Industrialized countries generate about 0.3 – 0.7 tonnes of municipal solid wastes (MSW) per person each year (Rogner 2000). With an energy content ranging from 4-13 GJ/tonne, this is a sizable potential resource which can be converted by incineration, gasification or biodigestion (for example in landfill sites) to electricity, heat and even liquid and gaseous fuels. Costs vary greatly. However, in most urban areas, energy generation forms only one approach to the larger issue of waste management, along with actions such as waste recycling, composting waste into fertilizer, and reduced packaging.

1.29 In developing countries, the situation is more complex and difficult. Data on residue generation and disposal costs are sparse or lacking. In many cities MSW is already recycled or disposed of effectively by ragpickers, cattle and dogs. Even for projects that make good economic sense, municipal authorities may be too hard pressed by other concerns to show interest, although this may change as authorities become increasingly concerned with the sanitary disposal of waste. A few successful demonstration schemes may be needed to kickstart the widespread use of tertiary residues as a source of energy.

Energy Crops

1.30 In most places, a large expansion of bioenergy means that biomass supplies must come increasingly from dedicated energy crops. This is simply because available residue supplies are somewhat limited (see, for example, Table 1.3). But apart from sugarcane alcohol production in Brazil and a few other countries, present experience of energy crops is limited and costs are generally high. Energy crops can rarely compete with fossil fuels solely on financial grounds. If fossil fuels are taxed, however, or biofuels receive incentives in recognition of their environmental and social benefits, bioenergy can be a sound financial and development option. As noted above and in Box 1.1, tradeoffs between crop yield, land quality and land development costs are critical to the siting, design and long term future development of energy crop systems and their integration with rural development objectives. In essence, while good yields are critical to the profitable production of low-cost biofuels, the use of marginal land, often with low yields, is critical to the growth of bioenergy into a major world energy source.

1.31 Costs and yields vary greatly, depending on many location specific variables, including insolation, rainfall patterns, soil quality, irrigation and fertilizer use, management skills, species choice and matching to local growth conditions, interest rates, and labor, mechanization and transport costs. For example, in Europe yields of *Miscanthus* (elephant grass) have been found to range from 2 dry tonnes/hectare/year on poor soils without irrigation in central Germany to 44 dt/ha/year in Greece with irrigation and fertilizers (Lewandowski et al. 2000). A study of wood yields from agroforestry in Asia (Jensen 1995) found a mean of 7.8 t/ha/year for 29 subhumid agrosilvicultural systems, but with a range of 1.4-27.5 t/ha/year. In humid zones (n=11) the mean was almost double this at 14.1 t/ha/year, also with a huge range of 3.5-42.3 t/ha/year. Bioenergy developers must obviously have a clear idea of expected yields (as well as likely production costs) before proceeding far with any crop based system. If yields are overestimated, serious supply shortfalls could result. (See Bioenergy Profile 8). A third and potentially very attractive form of energy crop is *bioenergy coproduction.* The classic example is the integrated sugarcane facility that produces the most profitable mix of sugar, alcohol, and electricity, animal feed or industrial fiber from bagasse and other cane residues. The term also applies to forestry or agroforestry schemes that are designed to produce nonenergy products such as timber or fruit, but that are also designed from the start to favor the production of bioenergy as a joint product from tree thinnings plus pruning and harvest residues[3]. This opens up the opportunity for significant innovation in conventional cropping and harvesting practices, most of which currently treat potential energy feedstocks as a wasteful residue to be *minimized*. Further innovation in coproduction can provide opportunities for bioenergy implementations that simultaneously meet energy feedstock needs and multiple other needs of local communities.

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[3] Further information on multiproduct agroforestry can be obtained from organizations such as Agroforestry Net (www.agroforestry.net), the World Agroforestry Centre (www.worldagroforestrycentre.org), and the International Center for Research in Agroforestry (www.ciesin.org/IC/icraf/ICRAF.html).

Natural resources

1.32 In some places natural biomass resources, such as forest, woodland, grassland and aquatic plants, can be harvested on a sustainable basis for modern bioenergy production without compromising the needs of traditional biomass users who rely heavily on these resources. These opportunities may be locally important but are unlikely to amount to much on a national scale without compromising natural habitat. Some opportunities exist for harvesting invasive weeds (such as water hyacinth and ipomoea) to good environmental and social effect, but under most circumstances the use of natural resources imposes highly site specific risks. Natural resources are not considered further.

Biomass Conversion Technologies

1.33 Bioenergy can be obtained from a variety of conversion technologies and feedstocks. Table 1.4 outlines the principal conversion technologies according to the forms of energy that they deliver.

1.34 The choice of the appropriate conversion technology involves several technoeconomic considerations, including capital and management costs, load factor, efficiency, type of feedstock and its cost, scale, and robustness. Despite high willingness to pay for modern energy services in most developing country settings, initial cost is an especially important consideration for nearly all users. The load factor (that is, the fraction of total hours for which the system provides an energy output) has a large impact on overall operating costs. These can be greatly reduced if the load factor can be kept high by adding additional energy demand to the system; for example, a local manufacturing enterprise, irrigation pumping, or sales to the grid. Because efficiency determines the “effective” cost of the biomass resource, efficiency improving capital expenditures can decrease overall cost of energy services. Scale strongly affects the cost, efficiency, and operating characteristics of a bioenergy system, so it is very important to size a system at the appropriate scale for its application.

1.35 A final consideration for small-scale standalone systems is whether a bioenergy technology is sufficiently robust and mechanically simple to operate in a village setting. Building capacity to meet these needs at the village level can be challenging but is necessary. Mature, proven technologies are more likely to succeed, and attempts to disseminate widely emerging technologies should not be made until after a careful program of field testing and capacity building.

Table 1.4: Some Biomass Energy Conversion Technology Pathways

Electricity	
all systems include biomass feedstock plus generator set; some may provide low to medium temperature heat (cogeneration)	- combustion boiler + steam turbine - thermal gasification: gasifier + gas turbine or gas engine - external combustion engine (for example Stirling engine) + generator - anaerobic fermentation: biogas digester – gas engine
Transport fuels	
sugar and starch crops (for example sugarcane)	- fermentation + distillation – ethanol
lignocellulosic biomass	- hydrolysis + fermentation – ethanol - gasification + gas processing – methanol, hydrogen - gasification + Fischer-Tropsch synthesis – synthetic gasoline/diesel
oil seed crops	- esterification – biodiesel
Cooking energy	
wood, woody residues	- charcoal
wood wastes, residues	- briquettes, pellets
sugar and starch crops	- ethanol (+ gel)
prepared biomass	- gasifier – producer gas (+ methanol)
biomass & animal wastes	- biogas digester – biogas
Process heat	
any biomass	- direct combustion
prepared biomass	- gasifier – producer gas
pyrolysis oils	- substitute for fuel oil

Conclusion

1.36 This brief introduction suggests that there is considerable potential in many places across the world for biomass to help increase access to modern energy and meet rising energy demand in an environmentally safe manner. But that potential must be soberly assessed in the context of local resource endowments and constraints, as well as technical opportunities and limitations, as a first step in project and program implementation. Bioenergy must also be implemented with careful regard to the many

policy, fiscal and institutional factors that may enhance or limit what can be done. And all bioenergy activities must be aware of their many possible socioeconomic and environmental impacts, and implemented with the benefit of a development perspective. The technical, economic, policy and other factors which both constrain and could potentially enhance the development of bioenergy are the main focus of this report.

2

Implementing Bioenergy Programs

2.1 The current chapter focuses on what the decisionmaker must consider in order to develop bioenergy programs that support bioenergy projects and facilitate their widespread replication. We define a bioenergy *project* as a particular application of bioenergy in a specific locality. A bioenergy *program* is more comprehensive. It is a larger scale (perhaps national) initiative to create the conditions conducive to bioenergy activities that support development, particularly in rural areas. This chapter discusses generally the broad range of issues a decisionmaker will need to address to compose an effective bioenergy program. Precisely how the decisionmaker addresses these issues will depend on the nature of the intended bioenergy activities and the context in which they are taking place. These activities and contexts are tremendously varied, thus there are no universally applicable solutions that can be handily offered here. What can be offered are discussions of the key issues that arise, and some transferable lessons learned over the course of many years of efforts to promote bioenergy across the world. In particular, we draw on the extensive experience that the government and NGOs in India have gained over the past three decades implementing and adapting a diverse range of biomass activities.

2.2 Two central objectives of a bioenergy program are to reduce barriers to the operation of markets for bioenergy and to establish conditions that make it easier for markets to serve communities and groups that currently lack access to energy services. Although bioenergy activities are expected to be predominantly undertaken by the private sector and NGOs, there remains an indisputable role for the government insofar as supportive policies are a fundamental aspect of an enabling environment.

Implementation Modes

2.3 Bioenergy projects can be implemented through any of a wide range of possible modes. These modes are virtually as varied as the contexts in which they take place. Still, the various implementation modes can be usefully characterized as falling within the following general categories.

2.4 "**Bioenergy industry**": This implementation mode refers to an industrial scale bioenergy plant whose primary business is to procure feedstock and produce an energy commodity (such as biofuels or electricity). Such plants may be viable in areas with ample feedstock availability, significant employment needs at appropriate wage and skill levels and access to large demand centers and transportation infrastructure. Examples are ethanol distilleries such as those promoted by Proalcool, Malawi & Zimbabwe (see Bioenergy Profile #1) and biomass power plants such as the megawatt scale wood fired CHP plants in Europe. A facility might be vertically integrated with feedstock supply or might purchase from smaller growers. While the facility primarily produces a commodity to satisfy large-scale energy market demands, it also generates local employment (for feedstock production) and could also

meet local energy service needs, to the extent that it is explicitly designed to identify and respond to such needs.

2.5 "**Capital investments**": Here, an existing agroprocessing facility or other biomass intensive industry such as a saw or paper mill invests in energy production from residues, either for its own consumption or for export, as an ancillary business activity. Such entities would be most appropriate in regions with the capacity to support processing of agricultural or forestry products (for example, rice milling; lumber production in sawmills) and where sufficient biomass residues are available for use as energy feedstock. The energy output could be process heat (for example, for crop drying; small- to medium-scale pulp and paper industry) and potentially cogenerated electricity to meet internal needs or for export to the grid. Generally, a vendor markets to a small or medium industry (gasifiers for thermal applications in agricultural processing plants, bagasse cogeneration). Examples include sugarcane cogeneration in Mauritius (Bioenergy Profile #2), India, Cuba, and Brazil; the Pozo Verde biogas plant (Bioenergy Profile #6); the Sumatra wood gasifier for cocoa (Bioenergy Profile #7). This mode could meet rural industrial energy needs.

2.6 "**Community infrastructure**": In this implementation mode, a village or cluster of villages could own and manage energy facilities with or without contracting to private operators (for example, REWSU Case Study). In addition to the availability of adequate biomass resources, these systems require the presence of sufficient social capital to maintain institutions of self governance and management. A public sector program or NGO might facilitate the implementation in villages via minigrids, as in Riberalta (Bioenergy Profile #3) and Orchha (Bioenergy Profile #5). These are energy systems constructed as public infrastructure, to satisfy basic energy service needs for an entire community, and possibly additional energy to support livelihoods.

2.7 "**RESCOs**": Here, independent private Rural Energy Service Companies act as entrepreneurs providing energy services (rather than equipment) at a profit to villages, households or enterprises. These differ from the previous modes primarily in their operations and management structure. Adequate biomass resources, financing and entrepreneurial capacity are needed for this mode. In addition, RESCOs may need to rely on an extensive service network to collect payments and provide service among its customer base. A bioenergy RESCO could satisfy local energy service needs and provide jobs through its own operations as well as through the support of other energy using enterprises.

2.8 "**Retail appliances**": In this mode, several small entrepreneurs are engaged in manufacturing and marketing a bioenergy technology (for example, cookstoves, biogas digesters, biofuels), which is ultimately widely distributed through standard retail channels. The manufacture is relatively small-scale and market based to satisfy market demand (which could be augmented through subsidies). This mode primarily serves basic energy service needs but may provide some jobs as manufacturers and retailers.

2.9 ***Distinguishing characteristics of implementation modes*—**These are the major distinguishing features of the implementation modes. The different modes require different supportive infrastructure (policy, capacity building, business development, incentives.):

1. *Scale*: Could vary widely, from household, to small enterprise, to community, to "small" industry (for example, agroprocessing facility), to large industry (for example, ethanol producer).
2. *Design and implementation*: Could be planned at high level (government) or individually (at a facility or household).

3. *Ownership and governance*: Could range from purely private sector (commercial facility), to community (municipal infrastructure), to household (private "appliance").
4. *Management and Operation*: Possibilities include management by owner (private, community, household), management by a community organization or contracted to professional operator on a fee-for-service basis.
5. *Financing and profitability*: Could be unnecessary, vendor financed for consumer, or financed by a public entity or NGO. Projects could be purely market driven or supported by public resources.
6. *Major local needs*: Includes basic energy services, services for enterprises and employment.

Table 2.1 depicts these implementation modes and their key distinguishing features.

Table 2.1: Typical Implementation Modes and Their Characteristics

	scale	*design and implementation*	*ownership and governance*	*management and operation*	*financing and profitability*	*Major local need(s) satisfied*
Bioenergy Industry	Very large	Private sector	Private sector	Private sector	Private sector financing / market driven	Employment and local energy services (if so designed)
Capital investments	Large-Medium	Private sector	Private sector	Private sector	Private sector financing / market driven	Employment
Community infrastructure	Medium	Community + Private	Community	Community or Private sector	Public sector / Socially driven	Community energy services
RESCOs	Large - Small	Private sector	Private sector	Private sector	Private financing / Market driven	Community energy services
Retail appliances	Small	Private sector	Household	Household	Private financing (or none) / market driven	Household energy services

2.10 These are the implementation modes that are most commonly employed. Various individual bioenergy projects might mix features of different modes. For example, the implementation mode for household scale biogas digesters might combine features of retail appliances (for example, reliance on a widely distributed cadre of entrepreneurs for marketing and sales) and capital investments (for example, reliance on sophisticated financing structures to enable the household purchases). It is useful for the reader to keep in mind these various implementation modes when considering how the issues raised in the following discussion apply to particular contexts.

Institutional Framework

2.11 A national bioenergy program is multifaceted and requires coordination among several tasks within such areas as rural development initiatives, energy policy and infrastructure development, fiscal and trade policy, agriculture/forestry policy, capacity building, and technology development. Acquiring the necessary information, building consensus around an appropriate course of action, and executing it requires capacities and expertise across a broad spectrum: resource economics, ecology, agriculture, energy technology, project development, financing, and several aspects of rural development. Numerous actors are inevitably involved in these various tasks, such as those listed in the Table 2.2 below. An underlying premise of program level efforts is that a coherent bioenergy policy will more effectively promote and expand bioenergy than will an uncoordinated set of disparate localized activities, by establishing a common, consistent, and transparent framework within which these various actors function.

Table 2.2: Actors Potentially Involved in Successful Bioenergy Programs

Central government, for example:
- Ministry responsible for rural development
- Ministry responsible for agriculture
- Ministry responsible for environment and forests
- Ministry responsible for energy or electricity
- Ministry responsible for revenue and financing
- Ministry responsible for international affairs - (if the project involves international financing or technical cooperation)
State government, including offices analogous to the national ministries cited above
County, community, or village governing or administrative bodies
Agricultural extensive agencies, organizations, and workers
Energy related parastatals, for example:
- Electric utility
- Regulatory bodies (such as a public utilities commission)
Nongovernmental organizations, for example:
- NGOs dealing with environment and development
- NGO labor organizations, farmers organizations, and trade organizations;
- Community development organizations
- Civic organizations
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
- Industries innovating in bioenergy technologies and energy-using goods
Financing institutions (such as banks and micro credit unions)
Bilateral and multilateral aid organizations
Households

2.12 A central coordinating institution responsible for bioenergy development (which could be housed in an appropriate governmental agency, for example) could help formulate the needed policy and regulatory framework. Such an institution could serve as an authorizing agency, that is, a rule making body with legal authority to design a coherent legal framework that clarifies rules and roles of participants. By initiating enabling legislation that supports bioenergy activities, such an institution could demonstrate to the private sector and other actors a national commitment to bioenergy.

2.13 Many of the elements of a policy framework can be enacted only at the central government level, either because it is the natural seat of the relevant decisions or because it controls the resources needed for enacting the policy. Rationalizing electricity tariffs and fossil fuel prices, for example, by lifting subsidies and otherwise reflecting more fully all costs (including social and environmental costs), would help to level the playing field for bioenergy, and in most countries must be undertaken at the central level. Regulations requiring electric utilities to purchase biomass derived electricity (at the utility's avoided cost of generation) help 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, legally mandated access to the electricity market and fair long term prices. This legislation directly enabled a large expansion in biomass power generating capacity, which totals about 8000 megawatts today in the United States. In contrast, in some countries similar policies were explored and issued as recommendations by agencies not authorized to enact regulations, leading to only a partial and geographically uneven adoption of the policies and correspondingly less enthusiasm and confidence from the private sector.

2.14 A central coordinating institution can integrate development goals into bioenergy programs. It can create a framework within which the private sector, development NGOs and community based organizations can work (as discussed in Chapter 4). In particular, it can develop and promulgate socioeconomic and environmental guidelines for bioenergy projects, including provisions for public participation and rules regarding access to project information. This would provide investors and project developers a uniform and consistent set of general principles as well as specific rules for sustainable bioenergy activities.

2.15 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; and information on development and environmental NGOs.

2.16 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; land tenure issues, public access to information; and active dissemination of information, technical extension, and financing assistance. A major responsibility would be to establish the legal framework for assigning jurisdiction downward to appropriate levels and establishing the appropriate degree of devolution of authority to local government bodies, and bestowing rights and responsibilities on the private sector, NGOs, and communities for both service provision and biomass resource production.

2.17 Certain aspects of a bioenergy program entail collaboration with international groups, which generally requires some degree of involvement at the national level. This will be relevant where resources from multilateral or bilateral aid agencies or other international organizations are needed. For instance, if the Framework Convention on Climate Change spurs investment in bioenergy through the Clean Development Mechanism, there may be roles for a national institution on the bioenergy related aspects of technical issues such as the setting of emissions baselines. To the degree that international private sector actors are involved, either for purposes of technology development and transfer, or direct investment, a suitable framework for such international relationships will be needed.

2.18 In each of the sections to follow, there are elements that are best considered at a national level, while others are appropriately dealt with by devolving authority to local institutions. In all cases, the actors who are expected to engage in bioenergy activities will require a policy environment that comprises policies that are clear and consistent. A further requirement is monitoring and enforcement mechanisms that are transparent and designed to avoid the unnecessary bureaucracy that creates opportunities for corruption.

Support for Entrepreneurs

2.19 In order for bioenergy activities to grow to a large scale and reach a large proportion of the underserved households, it is necessary not only to implement successful projects but to replicate them broadly. The successful replication of bioenergy activities will rely on a field of actors who can initiate and sustain activities in diverse contexts. It will depend on those with a capacity to identify opportunities, act autonomously, innovate, react flexibly, mobilize capital, and engage in entrepreneurial risk taking. This inevitably implies the involvement of entrepreneurs.

2.20 Entrepreneurs can be drawn from both the private sector and civil society. Both private sector actors and civil society agents understand site specific conditions and can develop and tailor an entrepreneurial approach to local realities. States are beginning to learn the value of harnessing the capacities of private sector entrepreneurs toward social goals. Just as important, they are beginning to recognize that many of the most successful NGOs are driven by a spirit of civic entrepreneurship[4], that is, "entrepreneurship with civil will". Civic entrepreneurs, to the degree that their missions explicitly value objectives other than profit maximization, can be especially effective at rallying entrepreneurial spirit toward social goals.

2.21 Many government rural energy programs, including bioenergy programs, have evolved over the past half decade toward an entrepreneurial approach. The earliest government programs concentrated almost entirely on technology development, falsely assuming that once a technology was developed it would rapidly diffuse. Subsequent programs dispatched government employees to rural communities to carry out projects—building biogas digesters, disseminating cookstoves, establishing community fuelwood plantations, and the like. As they were not the beneficiaries of the projects and had no entrepreneurial incentive to satisfy a customer, they had little motivation to build well functioning digesters, disseminate a quality cookstove, or maintain a productive woodlot. In light of the routine failure of such efforts, some program administrators are beginning to understand the benefit of entrepreneurial approaches that focus efforts on creating the markets and supporting the entrepreneurs that will allow these technologies to diffuse broadly.

2.22 When entrepreneurs are enabled to operate through effective markets, they can offer several advantages over programs wholly designed and executed by governments. Entrepreneurs can have the flexibility necessary for customizing systems to respond to customer's demands for novel products, whereas government programs generally are embedded in ponderous bureaucracies and therefore more rigid. (For example, a government program was limited to delivery of solar home systems of two conventional sizes, while local entrepreneurs started marketing various sizes as well as battery chargers, miner's headlamps, and home systems of various sizes.) Entrepreneurs can respond quickly to demand from off the shelf stock and by establishing new supply chains and distribution channels in response to

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[4] See Banuri, Najam & Odeh (2002), a comprehensive seven volume set that provides a analysis of civic entrepreneurship and case studies written with input by practitioners from more than sixty countries.

price signals, whereas government programs are often constrained by limits to the availability of subsidies and formal decisionmaking processes regarding procurement protocols. Entrepreneurs have an inherent incentive to provide after sales service and maintenance that government employees generally do not have.

2.23 Governments are often reluctant to support entrepreneurs in achieving social objectives. They see their constituency as the poor, or possibly as NGOs serving the poor, but rarely as private entrepreneurs who may be serving the poor incidentally as part of a broader customer base. The same applies to donor organizations, whose philanthropic intentions usually tilt them away from any activities that engage entrepreneurs. Likewise, there are considerable disincentives for most NGOs to get into entrepreneurial activities. Legally, NGOs in many countries are prohibited from partaking in quasi commercial activities. Logistically, NGOs might face prohibitive barriers negotiating the world of entrepreneurial activity, for example investing in the overhead activities of commercial audits or monthly sales tax submissions, which in some countries expose them to harassment and corruption. Typically, NGOs operate in a world where they are responding to funding organizations that reward them for ideal showcase projects with public relations value rather than entrepreneurial activities that inevitably entail market uncertainties and risks.

2.24 Governments and donor organizations characteristically avoid risky approaches, and market development is inherently risky. Identifying effective, novel approaches for creating new markets requires a "venture capital" approach, whereby a portfolio is constructed containing several projects, some of which are expected to fail and others to succeed, with all projects contributing to learning. Whereas private venture capitalists invest for high private return, governments and donor agencies should construct portfolios aiming to achieve high social return by providing energy services to underserved communities, supporting livelihoods, and yielding environmental benefits. Over time, as successful models for creating markets emerge from this venture capital approach, these models can be the focus of further replication efforts. Subsequent efforts can be directed at additional market innovation, achieving scale economies, sustaining technological learning, and expanding consumer awareness. In the best of cases, the resulting markets will be self-sustaining, allowing the government eventually to withdraw support. In other cases, markets that are self sustaining on a purely financial basis will not emerge, but the social welfare benefits will warrant continued government involvement in a manner that allows public resources to be efficiently targeted at producing the desired welfare outcome for the appropriate groups.

2.25 It can be difficult for governments and donor agencies to demonstrate the stamina that this process demands. It requires taking risks and seeing market development activities through to their completion, or until it is definitely shown that a market cannot survive. Simple one off demonstrations are much easier to execute and exit quickly. Without technical capacity building, maintenance followup, evaluation, awareness building, and the creation of an entrepreneurial cadre, such demonstrations are unlikely to spawn lasting benefits.

2.26 Some government programs have made partial steps toward involving private sector actors in ways that only partially capture these entrepreneurial characteristics. In these programs, so called "entrepreneurs" are assigned an area and a delivery target. This usually defeats the purpose of involving an entrepreneur, as it is likely to stifle entrepreneurial spirit. It tends, on the one hand, to eliminate the incentive to develop the market and expand beyond the target and, on the other hand, to remove competition that motivates operators to deliver a quality product and maintenance service and reduce cost, which dampens any incentives for innovation.

2.27 Few entrepreneurs in either the private sector or NGOs are equipped with all the skills and resources that will allow them to forge ahead and develop a new market toward social ends without substantial and targeted support. If governments are to enlist the involvement of entrepreneurs more effectively, they will need to provide this support. The remainder of this section discusses the steps governments can take in providing this support.

What can governments do to support entrepreneurs and spur markets?

2.28 Governments can play diverse roles in facilitating the creation of private sector participation in bioenergy development (UNDP, 2003; CDASED, 2001, Utria 2002). The key to providing effective support to entrepreneurs is to identify market creation activities that cannot be undertaken by entrepreneurs themselves. There are many market creation activities that are needed to kickstart a market, but in which individual entrepreneurs will not invest because they would be unable to recover their investment. For example, it is well documented that the private sector worldwide tends to underinvest in research and development of new technologies, since their investments would lead to technological innovations that benefit the entire market, including their competitors. This is a main reason that governments allocate considerable public funding to research and development. Similarly, the market benefits of building consumer awareness of a new technology will accrue to all the entrepreneurs selling that technology, which makes it unlikely that any given entrepreneur would recover the costs of building consumer awareness and thus discourages any given seller from making the required investments. With new technologies and hard to reach rural markets, such barriers are all the more daunting.

2.29 Governments could either be directly involved in these market creation activities or work through organizations or firms that provide the entrepreneurship support services. (See Case Study 2, for example, which discusses an NGO that is involved in supporting entrepreneurs and establishing markets.) The specific type of support needed will ultimately depend on the sort of entrepreneur involved and the context in which a market is to be established. For example, in enlisting the support of sugar producers to expand bagasse cogeneration, it was observed that farmer collectives behave very differently from privately owned sugar mills. The former are more conservative and less predisposed to innovation and risk taking, but often can access a broader range of sources of investment capital.

2.30 Much of the following discussion applies not only to bioenergy related enterprises, but also to other rural enterprises that could emerge once energy services are available. This latter set of enterprises might well provide more income generating opportunities and contribute to rural development than the bioenergy activities alone; they should be a central focus of embedding a bioenergy initiative in a broader rural development context.

2.31 Before discussing concerns particular to entrepreneurs, it's important to note that a major role of government is to provide stability and suitable macroeconomic and social conditions for sustainable development, whose impacts go far beyond their bearing on entrepreneurial bioenergy activities. The underlying conditions are determined by the nature of fiscal and monetary policy, the presence of democratic institutions and the rule of law, the condition of basic infrastructure (roads, communications), the health of the workforce and prevailing labor conditions.

2.32 Beyond establishing these general positive enabling conditions, governments can take specific steps to catalyze entrepreneurial activity, which can be broken down as below. NGOs can also effectively take part in many of these steps.

Identifying markets

2.33 Bioenergy program planners can play important and helpful roles in identifying markets. When a technology is not yet commercial, a publicly supported effort to establish the nature and scale of the potential market can provide key information that will induce entrepreneurs to take notice. Once a market analysis is undertaken, entrepreneurs can be attracted with documented and substantiated information about the market's scale and potential profitability. Such a study should involve an analysis of the prospective consumer's willingness to pay. It should also explore the unique needs of various market niches, such as differences in intended function, space constraints, availability of operation and maintenance expertise, willingness to adopt new operating practices, and need for reliability. This information can be used not only to assess the market, but to orient product design. The market analysis should ascertain both the size of the aggregate market demand and its spatial distribution in order to determine whether it is "dense" enough to be served by entrepreneurs working within an area bounded by practical constraints. These conclusions should be based on realistic estimates of potential market penetration, taking into account that perhaps 50 percent or less of the apparent market might actually adopt the product. Biomass projects have shown that low penetrations occur for a variety of reasons: some users will defer investment until time to replace their existing capital (even if it is cost effective to do it immediately). Some users might strategically delay investment on the presumption that a subsidized version will be offered; others with low capacity factors might not find investment to be economical, and some might be too remote to be served.

2.34 In many countries, there are various commercial household products (such as salt, soap, and batteries) that have reached even the most remote rural villages, each accompanied by its own complex distribution channels. These often rely on a mix of formal and informal sector entrepreneurship to create an extensive retail network. Such markets can serve as a useful model and can provide valuable information regarding the prospects for establishing new markets and assessing their scale and characteristics.

2.35 It is important to recognize the practical difficulties inherent in trying to market household energy services to a poor clientele. Entrepreneurs will be likely to neglect the poorest households, especially in the early phases of market development. The poorest stratum of the prospective consumer base is difficult to reach for several reasons. Obviously, poor households have the lowest ability to pay, yet heavy subsidies are very difficult to administer. They often have the most stringent product requirements, especially low price, high durability, and reliable performance, since they have less access to after sales service. Poor households are the most risk averse, making them yet more reluctant to attempt novel products. And poor households should not have to bear the cost of commercializing new technologies, which invariable face technical glitches.

2.36 Once markets have developed somewhat, however, it will become easier for entrepreneurs to target poor households. Product costs will have decreased through innovation, access to after sales service will increase as distribution infrastructure grows, and marketing and awareness raising activities will decrease as a product diffuses more widely. For these reasons, there may be an argument for focusing entrepreneurial activity on less poor households initially. To the extent that social welfare benefits justify it, public resources could be allocated toward facilitating entrepreneurs' efforts to reach the poorest households through various incentives.

Training a cadre of entrepreneurs and incubating enterprises

2.37 Some areas, especially in rural regions of developing countries, do not have a population of entrepreneurs who can take up the challenge of marketing a novel product. The government could help provide some basic training, either to prospective entrepreneurs or to NGOs who could then serve as trainers, which would equip people with the necessary skills and information to take up entrepreneurial tasks.

2.38 Entrepreneurs need the basic skills and information necessary for:

- Understanding technological options and their applications
- Analyzing markets and ability/willingness to pay
- Assessing resources
- Conducting feasibility analysis
- Carrying out cash flow analysis, business accounting, and financial planning
- Designing a business plan
- Assessing and managing risks
- Understanding competition
- Securing financing
- Establishing procurement channels
- Overseeing operations
- Ensuring quality control
- Controlling inventory
- Marketing and advertising
- Obtaining permits and licenses
- Ensuring regulatory compliance

2.39 These will be required to varying degrees, depending on the scale and sophistication of the bioenergy activity in question. In addition to capacity building, entrepreneurship support programs could go further by "incubating" incipient private sector enterprises, providing support during the particularly challenging startup phase. This support can take different forms depending on the particular market, social context, and on the scale and sophistication of the enterprises that are to be supported.

2.40 Incubator support could be primarily institutional in nature, providing contacts and information rather than physical facilities and capital assets that require substantially more money. It may involve facilitating networking by convening workshops and other forums and establishing trade groups to allow entrepreneurs to learn from one another. Such opportunities to share experiences among peers and to receive mentoring from experienced entrepreneurs are particularly beneficial for small entrepreneurs, who lack the economies of scale and financial resources that would readily allow them to access information and experiment with different marketing approaches. Small entrepreneurs, who require reliable and cost effective upstream and downstream linkages, can benefit from assistance in comparing suppliers and establishing procurement channels.

2.41 In many contexts, incubator support that provides access to physical facilities and fixed capital assets can greatly benefit entrepreneurs. At the simplest level, incubators can provide entrepreneurs with secure storage space for their stock. At a more substantial level, incubators can provide facilities for offices, workshops, or manufacturing facilities, where entrepreneurs can share jointly purchased assets or have access to facility owned assets for individual rental. Depending on the type and scale of the enterprises, entrepreneurs can make use of assets ranging from simple recordkeeping and telecommunications conveniences to manufacturing capital and administrative infrastructure.

Facilitating legal compliance (registration, permitting, and licensing)

2.42 The process for maintaining compliance with legal requirements should be transparent and streamlined. One of the major reasons cited for the dramatic variation across countries in the level of entrepreneurial activity is the extent to which the government bureaucracies facilitate or impede the process through their formal processes of registration, permitting, licensing, and the like. (ILO, Studies of Policies, 2002; 2003)

2.43 Straightforward processes that limit opportunities for abuse and corruption reduce barriers and increase the practical opportunities for engaging in entrepreneurial activity. Simple measures, such as making applications and guidelines available on the Internet where access is available, have been identified as being effective means to increase transparency.

Working with entrepreneurs to assure quality control in manufacturing and service

2.44 Quality control is critical in the early stages of technology commercialization and market development. For novel or unproven technologies that do not enjoy extensive infrastructure for providing after sales service and retail parts, consumers will want special assurance that the product is reliable and of high quality.

2.45 Governments can provide support in several ways. They can establish a certification procedure based on clear technical specifications, an openly available testing protocol, and officially authorized third-party certifiers. The certification procedure should be streamlined and transparent, and designed so as to preserve incentives to keep the process rigorous. Consumers should have recourse when products don't perform as certified, and the third-party certifiers should be held accountable for their assessments. In cases where trademark protections are in place, product branding can also provide a form of certification of product quality and accountability.

2.46 Standardization is one means of introducing quality control. For example, developing a manufacturing template for earthen cookstoves proved very effective at making production less costly and more reliable in Mysore area in India. Since the effectiveness of cookstoves depends strongly on precise adherence to design specifications, entrepreneurs in this area were able to produce better performing stoves considerably faster with the template, which in turn built confidence in the stove and increased dissemination.

2.47 Governments could establish technical assistance centers (in some contexts called "Technical Back-up Units") to provide small entrepreneurs with expertise on demand to which they would not otherwise have access. Such centers can provide direct technical assistance by, for example, visiting production facilities, inspecting units after installation, assisting with troubleshooting, and resolving technical problems that the entrepreneur alone cannot address. In various cases, the role of the technical assistance center has been filled by government applied technology laboratories, NGOs who have received special training, private sector groups funded by the state, and academic institutions.

Entrepreneurs who can claim ready access to competent technical support can build confidence in prospective customers, and some have made this support an integral part of their marketing efforts. For example, entrepreneurs marketing efficient biomass dryers to small enterprises in southern India distributed brochures and posted advertisements that featured the logo of the NGO who supported them in developing the technology, creating markets, and providing after-sales service. (See Case Study #1.)

2.48 Such measures can be extremely helpful, as poor service is regularly cited as the reason for failed projects, especially in remote areas where outside expertise can otherwise be difficult to access. Indeed, although entrepreneurs may well have the inclination and commercial acumen to initiate an undertaking, they may lack the technical expertise that will be critical to the project's success. Several examples exist of entrepreneurs who have failed because they had neither the technical expertise nor the backup technical support needed to commercialize an emerging technology. This is true even of industrial-size activities, such as the Riberalta Electricity Cooperative's operation of a megawatt-scale facility operating on Brazil nut shells, which was interrupted for several months because of problems that arose from the lack of regular maintenance. (See Bioenergy Profile 3.) The widespread dissemination of small-scale systems, such as biomass gasifiers, might be particularly susceptible to the scarcity of skilled labor at remote sites. Existing gasifier projects, which have provided training for operators, have reportedly had to deal with loss of trained operators to competing employment opportunities. (See Bioenergy Profile 5.)

2.49 The fact that bioenergy conversion technologies may often be imported and/or unfamiliar is a further reason why linkages must be created between those who design and install the system and those who operate it. A biogas plant in Malawi was shut down after only a brief period of successful operation; the plant had been funded by a foreign donor and it proved difficult to clarify and follow the proper operational procedures (see Bioenergy Profile 1). In larger developing countries where systems are more likely to be designed domestically, the organizational linkages between design, installation, and operation in the field can be easier to create. The success of biogas systems and gasifier-engine systems in India has been due in part to the consistency and continuity provided through the research groups at the Indian Institute of Science, which follow the projects from design through installation, field testing and implementation (see Bioenergy Profile 5 and Bioenergy Profile 10). Overall, such risks are probably greater in smaller developing countries that are more dependent on both foreign suppliers and foreign technical expertise. One channel for building indigenous technological capacity is through joint ventures between local enterprises and foreign private sector actors, who might have considerable experience, technical expertise, and investment capital to contribute to the project.

2.50 Another important measure for increasing the confidence of prospective consumers is to offer service plans or insurance, and to create a policy environment in which they, as well as product guarantees or warrantees, are legally enforceable. This creates an expectation among consumers that they are entitled to a reliable product, and makes available to them the necessary market mechanisms and the legal wherewithal. This is especially necessary if there is an active market in refurbishing and reselling products, which is almost inevitable in rural areas of developing countries.

Helping products reach a "threshold of visibility"

2.51 Governments should help entrepreneurs to market new products by supporting their efforts to reach a "threshold of visibility" where consumer awareness has risen to the point when the market can continue to expand over time. Up to this point, entrepreneurs face high risks and low returns, and are likely to fail for reasons other than whether their product is inherently viable. Government efforts in this regard have proven critical to some household energy initiatives, such as the dissemination of high-

efficiency kerosene stoves in Karnataka, India, where adoption rates remained low until the appearance of a government-assisted advertising campaign, when adoption dramatically accelerated.

2.52 Reaching this threshold requires sustained marketing efforts through culture- and context-appropriate media. For some products (such as an improved household wood stove or alternative fuel targeting very poor communities), a household's exposure might most effectively come through development workers or street theatre. Other products might be effectively promoted through carefully selected advertising. One NGO in northern India supported entrepreneurs by widely distributing posters and flyers. This approach was selected as it was expected to be far more cost-effective than a formal mass media advertising campaign conducted through radio and TV, as it was better targeted, more cost-effective, helped confer the NGO's credibility on the entrepreneurs, and avoided direct competition from large established companies who regularly advertise through mass media.

Working with financial institutions to improve access to financing

2.53 Insufficient capitalization is the primary reason why the vast majority of startup entrepreneurs fail within the first few years. One obvious means for governments to provide support is to give large direct capital subsidies to entrepreneurs, but these very often fail to achieve either the welfare or entrepreneurship benefits that are sought. (See section 2.10.) In contrast, credit financing creates access to capital, while preserving incentives and situating responsibility within the entrepreneurs, financing institutions, and customers. It allows risk management to remain in the hands of those generally better positioned than the government to deal with it. That said, governments do certainly play important roles in helping to create those credit delivery modes that provide entrepreneurs access to capital. Government support can take a range of forms designed to meet the diverse needs and contexts of entrepreneurs.

2.54 Governments can support activities that build capacity within financial institutions for supporting entrepreneurs. Basic understanding is a prerequisite before any financial institution will consider a bioenergy project (or any other project based on an emerging technology). Financial institutions will be much better equipped to evaluate financing requests from entrepreneurs once they have been exposed to training with several important objectives:

- understand the bioenergy technologies and their level of commercial maturity;
- appreciate the financial benefits of using biomass resources;
- understand risks unique to biomass, such as feedstock procurement risks, and mechanisms for risk mitigation;
- account for the effects of supply seasonality on cash flow in negotiating repayment terms;
- familiarize themselves with the entrepreneur's target customers and recognize their potential for improved income generation once they acquire reliable access to energy services;
- consider similar projects as candidates for bundling into larger loans with lower transaction costs;
- acquaint themselves with policy incentives (such as renewable portfolio standards, power purchase agreements, and carbon offset arrangements) that contribute to biomass project viability;

2.55 Given an adequate understanding of such issues, financing institutions will be better able to assess projects, and having established a portfolio of projects will have gained experience that will enable them to help entrepreneurs design viable projects and advice governments on creating effective incentives. For example, the accumulated experience of financing institutions can help governments refine and target credit subsidies, rather than broadly directing support to sometimes ill-defined "priority sectors". Further experience can also help governments design graduated interest rate subsidies for bioenergy project types that differ with respect to their degree of social and technology-advancing benefits, as a refinement to the fixed interest rate subsidies that are usually offered to sets of disparate project types.

2.56 Projects involving emerging technologies frequently have greater, and sometimes unexpected, expenses associated with learning from early implementations. Before adoption of a product has become widespread and routine, there can be unexpected costs associated with redesign, installation, training, operation, outreach, licensing, and other elements that can evolve significantly between the laboratory and the field. Financing packages should account for such contingencies. Some government energy technology financing schemes stipulate that their funds be used for initial capital expenses only, which invariably results in entrepreneurs who have deep investment commitments being stranded with unforeseen cash flow problems. Government, in collaboration with their financing intermediaries, should study these cases, learn from them, and design financing programs that can handle such contingencies. For some projects carried out during early commercialization stages of a new product, financing schemes should recognize that a profitable undertaking might begin with an unprofitable phase, and determine conditions under which to capitalize the early losses and enable the entrepreneur to surmount the initial profitability barrier.

2.57 Financing schemes, especially those designed at the small scales of households or micro enterprises, should be tailored to local cultural requirements, capacities and constraints. Those designing and implementing them should recognize the importance of locally acquired information, such as the sources, seasonality, and types of income, so as to allow repayment terms that are suitable to the borrower's cash flow. They should understand whether the installed capital can serve as collateral, accounting for such things as the technical and social feasibility of repossessing assets. They should recognize the significance of social connections in assessing a prospective borrower's creditworthiness (for example, the borrower's access to the assets of the extended family) and ability to make payments (for example, the role of peer group pressure ensuring payments), particularly given that the effective identification of creditworthy borrowers and efficient collection of payments are critical to a successful credit program. They should design outreach efforts so as to account for social factors such as level of education, ability to complete loan agreements, and attitudes toward indebtedness.

2.58 For small-scale borrowers, financing institutions should identify opportunities to couple their credit services with other needed services that can contribute strongly to local welfare. Various models have developed for providing savings services, for example, relying on local saving associations, "self-help groups", or women's organizations, that can both provide social support for savings and reduce transaction costs for administering savings systems. Insurance services also are being demonstrated to be valuable to households and micro enterprises, which are vulnerable to volatility from economic, political and natural causes.

Creating mechanisms to assess, manage, pool, and reduce risk,

2.59 New entrepreneurs are generally savvy about many of the local conditions in which they operate, but invariably can still benefit from assistance identifying, analyzing, and managing risk.

Governments can help entrepreneurs address risk in ways that still maintain accountability and incentives for success with the entrepreneurs. They can support training for entrepreneurs in basic risk management concepts, such as a quantitative assessment of uncertainties and the simple methods of sensitivity analyses, in using risk management tools. Governments can also help establish institutional arrangements for pooling risks among groups of entrepreneurs or diversifying to reduce risk. Some of the same mechanisms for helping the agricultural sector manage risk can apply to entrepreneurs in bioenergy markets, particularly those dealing with feedstock supply or procurement.

2.60 One source of risk for entrepreneurs in energy services is that their prospective consumers may potentially be adopting a product that is shortly rendered obsolete. Villages have been known to be disinterested in investing in village energy systems in the expectation that the grid power will eventually be introduced, and households have been reluctant to adopt an improved cookstove in the expectation that an source of LPG will eventually be available. Governments can help by backing up guarantees by entrepreneurs that capital investments will be refunded if the system is rendered obsolete by such developments.

Financial and Fiscal Incentives for Bioenergy Activities

2.61 ***Purposes of incentives:*** Many governments, in both developing and industrialized countries, have put in place fiscal and financial incentives intended to make energy services and energy using products more affordable. These have many underlying purposes. First, they are rationalized on social welfare grounds. Many energy services, such as heat for food preparation, are indispensable basic goods that dramatically increase a household's well-being. Poor households typically spend a large percentage of their income and/or time to acquire them. Moreover, each unit of energy service tends to cost poor households even more than wealthier households in terms of money, time, and health impacts. Poor households tend to use less efficient end use appliances and lower quality fuels, purchase energy sources in smaller quantities, have worse access to energy markets, and have poorer terms of trade with energy providers.

2.62 Second, energy incentives are sometimes targeted to support specific political or environmental objectives. For instance, subsidies to ethanol in the United States serve as agricultural support, subsidies to industrial charcoal in Brazil have helped preserve foreign exchange, and subsidies in the EU for wind power are justified on environmental grounds. Since energy is seen as a key strategic sector responsible for catalyzing economic growth, broad, permanent incentives are sometimes offered on macroeconomic grounds, either in the form of inducements to invest in production or subsidies for consumption.

2.63 Third, incentives are often offered in order to develop and commercialize new technologies and create new markets. There are distinct steps in this process. Initially, resources are directed at research and development and proof of concept. This is followed by demonstrations and awareness building, and then incentives to bootstrap and scale up commercial markets. Some technologies might warrant further continued long term support for social and/or environmental reasons.

2.64 Incentives for energy activities take several forms. Governments establish incentives on the energy production side—exploration, infrastructure expansion, research and development—through direct financial incentives (capital subsidies, concessional loans, accelerated depreciation, tax holidays, tariff exemptions), preferential regulatory treatment, or mechanisms to reduce risk. Governments also provide incentives on the energy consumption side, through policies that subsidize energy prices (for example, keeping them below fuel production costs or world market prices for internationally traded

fuels, or below long run marginal cost prices for electricity), or by providing capital incentives for energy appliances (such as improved cookstoves). Sometimes energy related incentives achieve their objectives, providing a cost effective way of transforming markets and changing consumer behavior.

2.65 Sometimes, however, energy related incentives do not achieve their objectives or do so at an unacceptable cost. Designing effective incentives requires crafting policies and mechanisms for implementing them that are attuned to local circumstances and needs. Typical problems with incentives are discussed below.

2.66 ***Typical problems with incentives:*** Government offered incentives can strongly influence the market environment for bioenergy activities—for better or worse. Flawed incentives are often recognized by governments as unsustainable, but once in place, it can be politically challenging to reduce or eliminate them. There are always parties with vested interests in incentives who are strongly motivated to resist their removal. Indeed, in recent years, attempts to phase out incentives have precipitated political crises.

2.67 The reasons why incentives may fail are manifold, and they should be understood in the context of a particular bioenergy program that a policymaker aims to support. Typically, subsidies and other such incentives can fail or contribute to a market environment inhospitable to biomass activities because they are:

2.68 *Distortionary:* Subsidies for energy products such as electricity and fuels can render it difficult or impossible for energy efficiency and alternative energy sources such as bioenergy to compete. For example, subsidized rural electrification that is exclusively based on grid extension can end up displacing electrification initiatives based on community minigrids or household systems that might be more economically sensible. Subsidies for fuelwood, in the form of uncontrolled free access for commercial woodcutters to state controlled woodlands, invariably lead to degradation of the resource base in areas pressed by high demand. Underpricing fuelwood eliminates incentives for restoring forestland or adopting wood conserving cookstoves and charcoal kilns or for fuel substitution.

2.69 *Poorly targeted:* Often, subsidies that are justified on grounds of welfare are diverted from their intended beneficiaries. For example, subsidized kerosene that is intended to serve as a low cost cooking fuel for poor households primarily benefits wealthier families because they consume much more kerosene. Moreover, it sometimes is diverted as a highly polluting fuel additive in vehicles. Similarly, electricity subsidies often benefit wealthier households or farms with electrical pumpsets rather than poor households and farms. The poor therefore receive a small fraction of the total outlays for such subsidies.

2.70 *Expensive:* Subsidies can impose considerable demands on public sector resources and become fiscally unsustainable. Globally, conventional energy subsidies were estimated at $250-300 billion per year in the mid-1990s (UNDP, 1997). In some countries, support for broad, permanent, expensive subsidy programs has left public energy authorities severely decapitalized and unable to make the investments needed to maintain existing service, let alone extend service, due to distortionary effects and chronic fiscal strain. Especially where fuels are imported, extensive subsidies can seriously strain foreign exchange resources.

2.71 Sometimes, incentives can even be a “kiss of death” for an emerging technology. They can diminish the perceived value of a technology, or associate the technology with poor households in a way that makes it less attractive for broader communities. In certain regions of India where poor households were offered improved cookstoves at heavily subsidized prices, recipients were observed to remove the chimney (thereby eliminating the smoke reduction benefits of the stove) because households

with chimneys were assumed to be the homes of the poorest families. In other programs, potential buyers who desired and could in principle afford the improved stove would refuse to buy at cost, because they assumed (rightly or wrongly) that eventually they would get a subsidized stove. Often, incentives undercut prices that can be offered by unsubsidized private sector entrepreneurs, which has the effect of curbing the total market penetration to a level determined by the targets and timetables established by the subsidy program and the distribution capacity of the government, which could be much less than the actual market size.

2.72 ***Characteristics of effective incentives for commercializing bioenergy technologies:*** Government incentives can be justified for technologies that are not competitive under existing market conditions yet have good long term prospects and/or provide other environmental and social benefits. They should be carefully tailored to the situation. While this requires a careful, context specific analysis of the setting and objectives of a bioenergy program, the following general rules of thumb are helpful when designing incentives.

2.73 *If incentives are intended to increase energy access for poor households, they should be carefully targeted so that they are efficient and effective.* An example is the so called lifeline rate, whereby a subsidized rate is offered to households for a "subsistence" level of consumption, for example up to 50 kWh per month or a few kilograms of fuel. Consumption beyond the lifeline level is charged at an unsubsidized rate. This scheme ensures that poor households have access to low cost energy services, while wealthier consumers pay unsubsidized rates for most of their consumption. This arrangement is less fiscally burdensome for the government authority, yet still delivers the intended welfare benefits. A second strategy that increases the effectiveness of welfare based subsidies is to focus on initial access as opposed to continued operating expenses. Often, the barrier to acquiring services is not the price of energy per se, but the cost of establishing the connection (in the case of electricity), or paying initial fees and services (in the case of establishing a "subscription" for higher quality fuels), or for appliances (stoves for clean fuels).

2.74 *Incentives should be suitably long term and predictable to provide the intended incentive, but with a sunset clause that phases out the incentives and encourages developers to continue to advance the technology until it is cost competitive with conventional alternatives with no subsidies.* Ideally, incentives that are required initially to commercialize a technology and create a market are no longer needed once economies of scale, continued technological progress, and market innovations have made the technology cost competitive and accessible. There are some situations where it might be reasonable to implement incentives that are intended to remain in place for the long term. In particular, long term support would be warranted if there are welfare benefits that are large enough to justify public sector investment. In the case of bioenergy activities, such welfare benefits could arise in a program that cost effectively provides access to basic energy services to the rural poor, or in a program that is a cost effective channel for investing in the creation of rural jobs producing biomass feedstock.

2.75 *Incentives should not impose a fiscal obligation that is likely to compromise the financial stability of the responsible agency.* Incentives must not be so large as to be a serious drain on public resources, especially if they are intended to remain in place for an extended period of time. Care should be taken that incentives do not become embedded entitlements that cannot be removed on political grounds. The following are two types of revenue neutral subsidies that energy authorities might be able implement with less fiscal discomfort than could result from a straight subsidy. The first is a cross subsidy from one consumer sector to another (for example, urban to remote consumers) provided there is sufficient purchasing power in the sector that is absorbing the cost. The second is a cross subsidy from the

future to the present, by setting prices so as to subsidize the early phases (while consumer demand is growing), but recover these costs in the subsequent phases once economies of scale have been realized. This provides an implicit credit element that makes initial outlays less burdensome for investors and/or consumers.

2.76 *Incentives should be designed so as to minimize the potential for corruption.* Systems that involve complex, multitiered monitoring and verification structure invite abuse. Such systems are only as robust as those monitoring schemes, and their outcomes can only be as successful as those schemes are effective. Some programs—ranging from household scale cookstove programs to industrial scale gasifier programs—have been shut down after millions of dollars of investment when independent investigations uncovered that the monitoring and verification systems were rife with abuse and the actual biomass activities undertaken where substantially less than officially reported. Systems were not being installed, or were being installed and then relocated and then claimed as new installations. Programs that preserve some of the checks and balances of the market, for example by requiring recipients to contribute to the equipment cost and allowing them recourse if unsatisfied with the performance or the after sales service, motivate vendors to supply quality services and are more resistant to abuse.

2.77 *Incentives should encourage, not undermine, entrepreneurship.* Sometimes, for example, subsidies enable NGOs to carry out activities (cookstove dissemination, household lighting) at prices that undercut private sector efforts and result in a lower total volume of supplier activity. If the aim is to reach poor households that the private sector cannot reach, this should be done in a manner that allows or enables the market to continue to respond to effective demand.

2.78 *Incentives that are intended to develop and commercialize a given technology should be directed to the appropriate point in the chain of commercialization.* If a technology is in the research and development phase, incentives should be directed at building technical expertise, coordinating links among research organization, and supporting research. Both governments and donor organizations face a strong temptation to invest in highly visible field installations, but when these investments are made prematurely the result too often is eventual technical breakdown, and a decrease in the level of public interest and the enthusiasm of funding agencies. If a technology is in the demonstration and outreach phase, incentives should be carefully directed at projects that provide for continued learning (both technical and commercial) and maximize awareness building. If the technology is in the market scale up phase, incentives should be carefully designed to address the particular barriers faced by the technology, such as high first cost for the intended market, real or perceived technological risk, low consumer awareness, and inadequate access to technical support and after sales servicing. It is important that government incentive programs are designed with this natural evolution in mind, that authorities demonstrate the required stamina to provide the needed support throughout this lifecycle, that they approach the entire chain as a learning process, and that they be willing to invest with the knowledge that some ideas will succeed, while others may fail.

2.79 *Incentives should be based on performance, rather than capital investment alone.* In the past, poorly designed subsidies and incentives have resulted in facilities' being deployed in the absence of an ongoing incentive to continue operation. For example, an early program aimed to provide electrification in Indian villages by heavily subsidizing the initial capital cost of biomass gasifier/diesel engine generators, but most of the gasifiers were abandoned and the heavily subsidized generators were run on diesel alone. Heavy capital subsidies eliminate or greatly limit the user's exposure to performance risk. Whether at the level of a household cookstove user or that of an industrial facility installing a new

piece of energy equipment, heavy capital subsidies can result in users who undervalue the product and have a lower level of commitment to its successful implementation.

2.80 *Incentives should extend flexibility for the investor and/or consumer to choose from among a range of technological and institutional options, so as not to predetermine a specific winning option.* This makes it most likely that technological advancements will continue. unanticipated innovations can emerge, and consumers can express their preferences.

2.81 Ultimately, policies must comprise consistent packages that are realistic to implement. Policies that impose new burdens on some sectors—such as fiscal policies that remove subsidies or impose new taxes—may be particularly difficult to implement. For example, in the Niger Household Energy Project (ESMAP, 1997; Kerkoff, 2001), project designers initially proposed that the initiative to establish village managed rural fuelwood markets should be coincident with a substantial increase in the tax levied on wood from unmanaged woodlands. Unfortunately, the government was able to impose a tax at only one quarter of the proposed level and proved unable to collect it at much more than 30 percent efficiency. This weakened the incentive for fuelwood transporters to acquire wood from village fuelwood markets instead of natural woodlands.

Environmental Policies

2.82 The market environment for bioenergy activities is conditioned not only by explicit financial incentives, discussed in the previous section, but also by environmental policies such as regulations to prevent environmental damage or incentives to encourage environmental preservation. Bioenergy activities are intrinsically linked to the environment because they are a land and resource intensive undertaking. They have a range of potential environmental benefits that biomass related policies should seek to encourage through incentives as well as adverse impacts that policies should aim to prevent though regulations. This section discusses some of the linkages between bioenergy activities and environmental policies.

Policies relating to environmental externalities

2.83 The term "externalities" refers to economic impacts that are not felt as financial costs by the producer or user. Externalized costs include environmental costs from fuel extraction (for example, strip mining of coal or unsustainable harvesting of wood from forests), treatment (effluents from refining), and consumption (pollutant emissions from combustion). In most cases, the externalized costs of fossil fuel cycles are higher than those of renewable energy cycles, so markets are generally distorted in favor of conventional fossil fuels. But the case for bioenergy is more complex than for other renewables. These environmental impacts are likely to be wider reaching for bioenergy than for most energy sources, given the intricate chain of activities from feedstock production to final consumption that bind bioenergy systems so tightly with the environment. Many proponents of bioenergy have asserted that biomass feedstock production can be done in ways that advance other environmental goals, such as land restoration, watershed protection, greenhouse gas mitigation, or the disposal of wastes that would otherwise pose a pollution hazard, such as air pollution from burning agricultural residues or freshwater pollution from dumping sewage. (See Bioenergy Profiles 3,6 and 9.) But in reality, much commercial scale feedstock production worldwide currently involves unsustainable practices such as harvesting at rates that degraded the underlying resource base or creating plantations of questionable environmental soundness.

2.84 Various policy measures can help to internalize externalized costs, to account for the full economic cost of energy consumption. The state can tax the responsible product, fine the offending

activity, or impose regulations that reduce the externalized damages. Although it is complex to quantify the externalized damage and to assess a precise monetary value, corrective policies are widely implemented, cover a range of externalities, and can be economically efficient and fairly straightforward to implement. Approaches have ranged from mechanisms that are market based (such as pollution taxes, "cap and trade" regimes, and renewable portfolio standards) to those that are largely "command and control" (such as efficiency standards, technology requirements for end of pipe cleanup, and fuel content standards).

2.85 *Water:* Biomass activities can very positively affect hydrology by revegetating degraded areas and thereby improving ground water replenishment and surface water health. A highly successful example of revegetation measures that revive watersheds is the activity of the Watershed Organisation Trust in India (www.wotr.org). If biomass activities increase the use of agricultural inputs, however, they can increase chemical loadings to freshwater. They can also contribute a large water demand if fast growing energy crops are grown or bioenergy facilities are operated with large water demands.

2.86 *Greenhouse gases:* Increasing attention is being paid to mechanisms for quantifying and internalizing the greenhouse gas benefits of biomass, due to both the carbon emissions reductions from displacing fossil fuels, and the increased carbon sequestration on restored land (IEA, 2003 – Task 23). The former is invariably a large positive gain, while the latter would be positive, for example, if degraded land is restored, or negative if the consumption of agricultural residues leads to a decrease in soil carbon or if natural biomass stocks are harvested without replanting[5]. In cases where the financial benefits of carbon reductions are sufficient to make a project viable that otherwise would not have been, the project might be eligible for carbon credits through a modality such as the Clean Development Mechanism[6].

2.87 *Forests, habitat, biodiversity:* Tremendous benefit could result from the integration of biomass energy with the restoration of degraded land. Biodiversity—ranging from the soil organisms that keep soil healthy, to the plants on the soil, to the animals living among the plants—could benefit from judicious planting of plant species that provide environmental services while simultaneously serving as an energy feedstock. It is vitally important that measures are put in place to ensure that the environmental benefits are not sacrificed for the sake of maximizing yields of biomass feedstock, which will be the case if optimizing bioenergy profits is not tempered by environmental and social guidelines that protect biodiversity and human habitat. Participatory methods of resource management will help to safeguard this balance (see Chapter 3).[7]

2.88 Some policy measures are intended to address not the environmental externalities per se, but to recognize positive externalities associated with disseminating new technologies, such as market transformation benefits that arise from ushering novel technologies into the marketplace. These include public benefits that are not exclusively appropriated by the investor, such as technological innovation,

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[5] For technical analyses regarding the GHG impacts of bioenergy, see Schlamadinger et al.(2001), IEA(1998), Borjesson (1996). A quantitative model that helps project developers assess GHG impacts is COMAP (LBL, 1999).

[6] For additional information on the CDM and carbon credits, see cdm.unfccc.int and prototypecarbonfund.org. For reference, a project developer can expect that carbon credits for a sustainable, zero carbon biomass electricity plant would yield on the order of US$ 0.01/kWh, assuming a carbon price of $10/t$CO_2$ and a baseline of natural gas power. Revenue would be higher assuming a higher carbon price or a more carbon intensive baseline generating source.

[7] For general treatments environmental impacts of bioenergy, see for example, IEA (1998), OTA (1994), OLADE (1994).

consumer awareness, and economies of scale in ancillary services such as maintenance. These mechanisms are an accepted rationale for supporting precommercial technologies. The Global Environment Facility, for example, has adopted as one of its Operational Programmes a portfolio of projects aimed at demonstrating emerging technologies and bringing down their long term costs. Biomass based electricity and biomass based fuels are specifically targeted under this GEF effort.

2.89 ***Waste disposal regulations and practices:*** Waste disposal regulations and practices affect the incentives for creating and expanding bioenergy systems. In considering formal regulatory options, it is important to consider informal resource management practices, which sometimes evolve into more environmentally sound practices without the need to resort to bureaucratic regulations. Indeed, such regulations might in fact be a hindrance where they are inconsistent with locally respected common property regimes. Even best intentioned environmental regulations might not improve resource management, if the cost of their enforcement proves prohibitive.

2.90 Land use and land based disposal regulations and practices often affect the availability of biomass feedstocks. In industrialized countries, tightening landfill regulations have contributed to the emergence of new feedstocks. Waste products that can be incinerated are often restricted from being used as landfill in EU countries or must pay a significant fee, which in many cases is greater than the cost of shipping it to a nearby biomass power plant. Other unconventional waste product streams can be channeled toward bioenergy as a result of the hazards they create in landfills; a biodiesel plant in Maui relies on used restaurant oil and grease that was causing fire and contamination problems in the landfill (see Bioenergy Profile 9). In activities that substitute waste inputs for virgin inputs, resource efficiency can be an effective motivation even where there are no regulations. A gasifier installed in Sumatra in Indonesia was valued not only for its improved efficiency but also because it reduced deforestation through the substitution of waste (palm shells) for wood (see Bioenergy Profile 7).

2.91 Improvement of water quality or water resources can provide a useful incentive for bioenergy systems, particularly in developing countries where clean water may be a scarce resource. Provision of feedstock for a bioenergy plant in Bolivia found special motivation from the fact that the feedstock (brazil nut shells) had previously been a waste product dumped into the river. The local community recognized that this practice was wasteful in two respects—it polluted the river and it wasted a useful energy resource (see Bioenergy Profile 3). An integrated biogas plant in Colombia produced decontaminated water at the same time that a new energy source was being tapped (see Bioenergy Profile 6). In both cases, environmental practices were thereby changed without recourse to regulations. Where such improvements are sustainable, the underlying institutions, albeit informal ones based on community standards, have effectively been transformed.

Effects of Trade Policy on Bioenergy Activities

2.92 Policies and regulations on regional and international trade affect bioenergy systems through impacts on the technologies and resources employed, as well as the demand for final goods and services. The extent to which import or export issues are most significant to the development of bioenergy systems depends of course on the case in question—it is not possible to generalize as to whether policies that encourage exports or discourage imports will benefit bioenergy activities. The tremendous differences in size and technical capacity among countries will naturally give rise to significant differences in such benefits. Trade issues can be addressed generally and a few examples offered across four major product/service categories with respect to bioenergy systems: inputs, conversion technologies, distribution infrastructure, and final products.

2.93 *Feedstocks:* The impact of trade on bioenergy feedstocks is muted by the relatively high costs incurred in the logistics and transportation of feedstocks, given the nonhomogeneity, bulkiness and lower density of biomass compared to most conventional fuels including coal. Nevertheless, where international trade is relatively unrestricted, opportunities will arise for biofuels to find valuable markets abroad where they do not find domestic markets. The case of forest industry waste and other waste products traded freely within the EU (the world's largest free trade zone) presents a good example. At the same time, it is important to recognize that transportation of bioenergy feedstocks in fossil fuel driven vehicles diminishes the environmental benefits of bioenergy. Similar detriments are equally applicable to lengthy intranational transport, such as long distance shipment of molasses for ethanol production (see the case of Malawi in Bioenergy Profile 1).

2.94 *Conversion technologies:* With the exception of household level technologies such as cookstoves and mature technologies, the manufacture of bioenergy conversion technologies is largely restricted to industrialized countries and larger developing countries. Consequently, smaller developing countries generally rely on imported equipment and turnkey plants, which may face import tariffs that result in barriers to investment in bioenergy. Some countries have acted to encourage the use of domestic and/or renewable energy sources by eliminating or reducing such tariffs. Alternatively, innovative approaches based on local manufacture and installation (through international joint ventures) can minimize imported parts, maximize domestic benefits, reduce costs drastically, and create a competitive domestic industry in bioenergy manufacturing. An ethanol plant in Zimbabwe cut capital costs by more than half through reliance on local labor rather than buying a turnkey plant (see Bioenergy Profile 1). Larger developing countries will generally benefit from domestic design and manufacture through the operational feedback and innovation thereby facilitated, as evidenced by the success of Indian gasifiers (see Bioenergy Profile 5). Again, globalization, particularly relocation of manufacturing facilities, is also contributing to such synergies and the need to adapt to local conditions.

2.95 *Distribution infrastructure:* Larger scale bioenergy systems could benefit from the existence of compatible distribution systems and policies that allow unified markets across national borders to be created. In the case of electricity, this requires bilateral agreements or regional arrangements to invest in grid interconnections and form power pools. For biofuels, this would involve cooperation on transportation policies (such as the harmonization of emissions standards or alternative fuel legislations) or household cooking policies (such as coordinated incentives for biofuel use and creation of common markets for corresponding stove types), as well as coordination of the fuel distribution systems themselves. The highly political nature of transport fuels has tended to prevent easy migration across borders, as evidenced by the national focus of most current ethanol programs. There are other factors such as harmonization of equipment standards that have a direct effect on crossborder trade for various energy carriers and at various scales (EC/UNDP, 1999).

2.96 *Final energy products:* This is the area in which trade policy can have a major impact on expansion of bioenergy systems, particularly for biofuels. It is here that the value added in production reaps benefits through lower labor costs, favorable growing conditions, preferential markets (for example, because of environmental standards), or other comparative advantages. Once biomass is processed into biofuels, it is highly transportable and could conceivably become a widely traded global commodity (Williams, 1995), given the enormous current global trade in fuels, the pressures to shift toward low carbon fuels, and the growing interest in diversifying fuel supplies as remaining oil supplies grow more regionally concentrated. International trade in biofuels will require a degree of harmonization of technical and fuel quality standards.

Access to Existing Infrastructure

2.97 In order for bioenergy systems (both biofuels and bioelectricity) to achieve wide application, they require access to existing infrastructure and the institutions that support that infrastructure. In the case of electricity, biomass projects will generally be more economically attractive if they are able not only to serve local demand, but to "export" electricity to the electrical grid. In rural areas, local demand for electricity is often too low and sporadic to fully utilize a power system, especially in the initial years of a project. The economic viability of any electrification system depends to a large extent on how extensively the installed capacity is utilized—that is, on the system capacity factor. Low capacity factors mean that the fixed costs of a project must be amortized over a smaller number of kWh generated, leading to a higher cost per kWh. To achieve sufficiently high capacity factors, additional purchasers of electricity are required. Sales to 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.

2.98 Regulatory measures are generally required to overcome the historical barriers to the purchase of power by electric utilities from independent generators. In the United States, for example, the 1978 Public Utilities Regulatory Policy Act obliged utilities to purchase electricity at fair prices. This policy was largely responsible for the 8,000 MW of biomass based electricity installed by independent power producers in the 1980s in the US. 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 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, with 3,000 MW of cane based generation now planned. Mauritius recently commissioned a bagasse cogeneration facility (funded in part by the GEF) that helped to establish a model power purchase agreement based on avoided cost pricing, which should streamline the commissioning of subsequent facilities. (See Bioenergy Profile 2.) Thailand has a Small Power Producers (SPP) program designed for generators under 90 MW.

2.99 Access cannot simply be available in name only—that is, in legislation—but must be backed by regulatory instruments and contractual models that are enforceable and can promote a level playing field. Effective institutions are needed that can overcome the historical monopoly culture of electric utilities that can result in efforts to obfuscate existing requirements or delay planned changes so as to maintain existing competitive advantages. A secure regulatory and legal context helps to encourage the private sector to invest in independent power production. Long term power purchase contracts allow investors to secure a predictable revenue stream and eliminate a potentially prohibitive source of risk. Investors can thus more easily obtain financing. Standard contracts that are preapproved by the appropriate regulatory agencies (electrical authority, environmental authority, safety authority) allow prospective investors to understand their market and to reduce transaction costs.

2.100 In the case of biofuels, access to both distribution and transportation infrastructure is required. Where biofuels are satisfying a local demand, such access is not necessarily a prerequisite. The use of locally produced biodiesel, for example, can spur direct substitution without specialized institutional arrangements regarding the diesel supply and distribution (see Bioenergy Profile 9). If such markets are to be expanded, however, broader integration is necessary. In the case of fuels to be used for blending, like ethanol, access to distribution infrastructure is, by definition, a prerequisite, and in fact should be established at an early stage. One of the ingredients that made the Zimbabwe ethanol program

an early success was the fact that all the necessary agreements for logistics and distribution were set up before the ethanol plant was built (Bioenergy Profile 1).

2.101 As with electricity, for bioenergy activities to gain access to infrastructure requires the acceptance of stakeholders (even if grudgingly so) who may directly operate or control the infrastructure (for example, electricity utilities operating T&D infrastructure). . A consensus based approach (rather than an adversarial approach) to dealing with such vested private sector interests proved successful in the Swedish biofuels program, where a public foundation coordinated oil companies, automakers, and other stakeholders in an extensive negotiation process for standards, blending targets, distribution mechanisms, and other elements. Without an authoritative party coordinating such efforts, private interests will drive the process towards specific profit goals. By contrast, the Swedish process was explicitly based on environmental goals, so that private sector participants were forced to adapt their profit goals to the basic structure of the program. At the same time, the technical and operational expertise that the private sector brings to the process contributed to its success. The number of filling stations with blended fuels has been increasing steadily in recent years. The biofuels program also included infrastructure measures to establish stable sources of "articulated demand," the best example of which is in the unique Swedish ethanol bus program, which has stirred interest in many developing countries looking to improve urban air quality. Overall, the Swedish biofuels program demonstrates the importance of improving access to existing infrastructure so as to facilitate "mutual adaptation" that allows the bioenergy system to move forward (BAFF 2000).

Feedstock Procurement

2.102 A major focus of implementing any bioenergy undertaking – from the household-scale cookstove to the large-scale industrial biofuel production facility – must be feedstock procurement. The biomass consumer is dependent on a feedstock that often requires more sophisticated procurement arrangements and greater certainty of price and availability than do conventional fuels. Indeed many past bioenergy activities have faced difficulties and in some cases failed due to an insecure feedstock supply. A policy environment supportive of bioenergy activities must take into account the need for a secure biomass supply.

2.103 Conversely, as is emphasized throughout this report, biomass has numerous locally important uses beyond energy, and therefore should not be treated cavalierly by policymakers as if its use as an energy feedstock for bioenergy activities should automatically be prioritized. Sometimes, biomass could be simply less valuable as a source of energy than as a resource for fulfilling other needs, or there could be more economical options than bioenergy for meeting energy needs. In cases where bioenergy cannot be justified on strict financial terms, it is possible that public support might still be warranted if environmental or social benefits more than offset the cost disadvantage.

2.104 Competing demands do not necessary mean that biomass should not be used for energy purposes, since opportunities exist for implementing certain bioenergy activities while also satisfying nonenergy needs that might at first seem to conflict. The basic reason is that bioenergy activities need not be a zero-sum game with respect to the underlying biomass resource. There are many opportunities to design bioenergy activities so as to increase the total biomass productivity, and increase the efficiency with which biomass is utilized.

2.105 For example, dung does not sacrifice its value as a fertilizer when it is diverted for use as a feedstock for biogas digesters. Dried digester effluent provides a fertilizer that is superior to dung – it is less contaminated with weed seeds, less likely to harbor pathogens, and is more convenient to store and

handle. Another example is the use of agricultural residues that farmers currently turn into the soil after the harvest. With some crops and soil types, farmers should ideally recycle some optimum proportion of residues, but they often recycle more residue because they have no alternate use for the excess. In such cases, removal of the excess residues for use as a bioenergy feedstock could improve soil quality and crop productivity. Where dung, residues, and wood are heavily used, bioenergy activities can be integrated with the introduction of more efficient end uses—cookstoves, charcoal kilns, agricultural dryers. Bioenergy activities can also be directed toward improving agricultural productivity, for example by providing power needed for irrigation.

2.106 Bioenergy resources are in effect highly specialized assets due to the spatial constraints in supply, nonhomogeneity (particularly in comparison to fossil fuels), and the localized nature of key factors in production. Therefore, unless feedstock supply chains are carefully determined, taking into consideration local conditions and contexts, bioenergy activities could face serious difficulties or fail entirely because of an insecure feedstock supply.

Factors contributing to the challenges of biomass procurement

Biomass feedstocks are diverse and bioenergy technologies are finicky:

2.107 Biomass technologies are generally suited to a specific type of biomass, and cannot tolerate much deviation from their design specifications. Cookstove designs that were super efficient and smokeless in the lab have failed utterly in the field, because households users were unable or unwilling to cut the fuelwood to the precise dimensions required and allow it to dry to the required moisture content. Similarly, in industrial applications different fuels require different facility designs, operating procedures, and feedstock handling processes. Feedstock that has too much sulphur could lead to sulphuric acid corrosion in certain metals, while excessive alkalis could lead to fouling of boiler tubes. Light feedstocks could be unsuitable for a high-pressure boiler, and slight variations in feedstock physical properties could confound feedstock handling apparatuses. A biomass system that was carefully designed to operate well on coconut shell—a relatively ideal, easily handled feedstock—was found to require a reworked feedstock handling system when installed in the field and operated on slightly different coconut shells. (Lilley, 2001)

Biomass is bulky, constraining the market to those consumers and suppliers within a limited area.

2.108 The bulkiness and lower energy density of biomass compared with conventional fossil fuels results in greater costs for preparation, handling, and transport. Transport costs, in particular, impose a spatial constraint in feedstock supply, which forces the biomass consumer to rely on a limited pool of potential feedstock suppliers, and likewise forces the producer to rely on a limited number of potential consumers. This could increase risks by reducing competition, potentially making prices more volatile and making both producers and consumers more vulnerable.

2.109 The moment the biomass consumer who relies on a specific feedstock supplier begins operations, the supplier would be in an advantageous situation that could be exploited by increasing the price or otherwise changing supply terms. Suppliers who depend on sales to a single local consumer would be similarly vulnerable. The small number of suppliers and consumers in a single market is further constrained by the specificity of feedstock requirements (or, alternatively, the costs of feedstock processing to assure consistency). Both supplier and purchaser are aware of this situation, and the vulnerability thereby implied may be deemed too great or too risky in terms of the likelihood of striking an acceptable and secure agreement.

Producers are often small and dispersed

2.110 Often, biomass feedstocks are provided from many small sources, which might be farms generating a particular crop residue or growing energy crops on a fraction of their land (for example, through a farm-forestry or agroforestry arrangement). While this might increase competition among producers and yield lower prices, biomass consumers could face significant transaction costs in establishing and coordinating a reliable supply chain from many different small sources.

Supply shortfalls due to variability or uncertainty about yields

2.111 As with any agricultural product, biomass feedstock yields are vulnerable to the whims of weather, outbreaks of disease or pests, and other unpredictable conditions. Zimbabwe's ethanol program was severely hobbled by an extended drought in the early nineties, in contrast to Malawi's ethanol industry, which was protected by the availability of irrigation water. (See Bioenergy Profile 1). Crop yields that fell well below expectations plagued the Philippines dendrothermal program from an early stage and, coupled with the relative inaccessibility of the plantations, this drove up transportation costs considerably (Bioenergy Profile 8).

Biomass has lower value as an energy feedstock than for many competing demands.

2.112 The price of biomass feedstocks could be driven to unaffordable levels by competing uses. Bioenergy projects consume biomass feedstocks to extract their most basic quality: their energy content. In order to deliver an affordable and competitive energy service, biomass consumers generally cannot afford to offer prices as high as those that could be paid by users of higher value qualities of biomass, such as its nutritive value (biomass as food), chemical properties (biomass as industrial feedstock), or structural usefulness (biomass as building material). This presents a two-sided price competition, whereby biomass consumers cannot afford very high prices, yet they need to pay a high enough price to provide a worthwhile profit to producers and/or fend off competition from other users. It might become economically preferable in a certain situation to exploit markets for products (for example, spirit quality ethanol, sugar) that are more attractive than domestic transport markets for fuel ethanol, resulting in supply uncertainty that is prohibitively risky to domestic consumers and auto manufacturers. In Brazil, rising international sugar prices were among the factors that contributed to the rapid decline in the 1990s of Brazil's large market for ethanol only vehicles. Similarly, IMF inspired legislation extending tax breaks to exports of spirit quality ethanol to the EU contributed to the demise of ethanol blending for transport fuels in Zimbabwe (see Bioenergy Profile 1).

2.113 In some cases, the biomass consumer could exploit a waste product or weed for which there is no competing use and low production costs. The use of a weed with essentially no alternative uses (ipomea) at the Orchha biomass power plant in India greatly improved the economic outlook for the plant's operation (Bioenergy Profile 5). However, competing uses for bioenergy feedstocks could sometimes arise after the project begins, even if the feedstock is a waste product. The case of brazil nut shells at the Riberalta plant poses an example—whereas previously the shells had been dumped in the river, they gained market value after being successfully used in the plant, as neighboring industries became competing buyers for them (Bioenergy Profile 3). Even in cases where there is no competing use for a particular feedstock, biomass consumers could lose their supply if competing market pressures induce farmers to shift their crop choices. Shifts in markets for the primary products linked to waste feedstocks could affect the bioenergy portion of the industry based on the associated relative profit margins. Preferential markets for sugar have tended to squeeze out investments in bioenergy from sugarcane that would otherwise be cost effective.

Relieving supply uncertainties

2.114 In the longer term, when biomass markets are more mature, it is likely that certain of the above supply risk problems would have lessened, as institutional schemes would have been established and proven, and technological advances (in harvesting, handling, storage) would have occurred. In the meantime, early projects need to establish mechanisms for reducing the level of supply risk. Governments could offer incentives and institutional support to encourage secure, long term supplier/consumer contracts. Official agencies responsible for licensing biomass projects could initially protect the supplies of biomass consumers by granting concessions for certain areas from which they could exclusively (or semiexclusively, if monopoly power is a concern) procure feedstock. Governments could also allow for force majeure clauses, similar to ones used in power purchase agreements between independent power producers and utilities.

2.115 In an early phase of the development of a market in biomass feedstock, potential suppliers may be reluctant to invest in biomass production before witnessing a real and robust demand. The biofuels sector in Sweden successfully addressed this chicken and egg problem by building the sector from the final user and moving backward to feedstock production as the last step, thereby creating the final link in the chain (Carstedt 2000). Imported fuel filled the gap until local feedstock production came on line. This basic institutional approach of first building an "articulated demand" and a distribution chain has been adopted in the renewable energy plans of other countries.

2.116 Some projects might choose to secure feedstock through a direct vertical integration between supply and demand, although this might be less efficient in the long term because it reduces the competitive discipline of the market and erodes the technical efficiency gains that come with specialization. Feedstock procurement for the Orccha biomass power facility, for example, was initially based on a vertically integrated approach, which then evolved into an apparently successful market approach. (See Bioenergy Profile 5.) Some creative schemes for partially insulating biomass consumers from supply risks while preserving some role for markets have been implemented. For example, smallholders growing trees for a Philippine project were permitted to sell the wood on the open market at higher prices than specified in their contract with the buyer, but the buyer contractually retained the right to match any such outside offers (Ramsay, 1985).

2.117 The provision of feedstocks in many developing countries often requires a tighter coupling with energy conversion than might be the case in industrialized countries. One common example is in the use of molasses to produce ethanol, which has tended to lead to integrated ownership of ethanol distilleries and sugar factories, due to the high transaction costs associated with negotiating prices and terms of delivery (see the case of Malawi in Bioenergy Profile 1). Another type of institutional arrangement that smoothes over transaction problems occurs when affiliated companies that produce different products find a synergy that allows for feedstock supply (for an example, see the Indonesian gasifier project in Bioenergy Profile 7). In general, the significance of transaction costs has helped to block the formation of more general markets for feedstock supply, although in industrialized countries with advanced bioenergy sectors, specialized feedstock markets have begun to appear. For example, several companies in Sweden specialize in the provision and operation of mobile pelletizing units for feedstock preparation, mainly for supply to district heating plants (Karlsson 2000).

2.118 A technological approach that is likely to advance over time is to design multifuel capability into a project—through boiler design, flexible fuel handling, and feedstock densification. Such measures could add costs that need to be balanced against the benefits of feedstock diversification. In some cases, operators have developed simple innovations such as increasing the capacity of lorries by

raising sides with inexpensive fencing; that has expanded the accessible market of feedstock suppliers. Some biomass consumers would find it cost effective to stockpile feedstock as a supply buffer. This is practical in some cases, but would generally be more difficult than with conventional fuels as biomass feedstocks are bulky and perishable. A significant investment of working capital would be required if stockpiles are meant to provide a buffer against seasonal supply variability.

Box 2.1: An innovative solution to feedstock supply chain problems

Vijay Engineering, located near Bangalore, was set up as a manufacturing unit for building small-scale wood gasifiers for use in the silk reeling industry (see UNDP, 2003). While demand for the gasifiers was relatively low, the company quickly discovered that one of the barriers to further penetration of the systems was the difficulty end users had in chopping wood into suitable sizes for the gasifiers. The silk dyers and reelers had no space to store wood, no machinery to cut it and no extra staff to do this job either.

Vijay Engineering came up with an innovative solution. Since it had sufficient space at the factory premises to cut wood into chip, it took charge of the entire supply chain (procurement of waste wood in bulk from lumber producers, cutting into pellets, and scheduling van or truck deliveries of chips to gasifier owners). In other words, the manufactures sold not only gasifiers, but also "subscriptions" to preprocessed feedstock, thus easing concerns from the silk reelers and dyers about securing a reliable biomass fuel source.

Land Tenure and Resource Custody

2.119 As discussed in Chapter 1, biomass energy is land intensive and thus interacts strongly with the local patterns of land tenure and resource use. Development of bioenergy programs requires an understanding of the land tenure systems determining how land resource rights and duties are distributed among individuals and groups within a given community. The incentives for managing biomass resources are embedded in such rights, and these will ultimately determine the success of bioenergy systems. They will determine whether biomass feedstock can be sustainably provided to a given bioenergy project over the long term and how this can be done in a manner that ensures that other local resource related needs continue to be satisfied.

2.120 The complex issues raised here in relation to land tenure are by no means uniquely of concern to developers of bioenergy programs. They are central to many issues of rural development. This section raises issues that are particularly of import to bioenergy program design.

Long term sustainability of biomass feedstock production

2.121 Presently, a principal impediment to the environmentally sound and economically productive management of land is the perversity of many land tenure and usufruct arrangements. Modifying these arrangements could go far toward improving land management and making biomass resources more available and more sustainable. Many rural families do not have secure land tenure over the land they work. Frequently, large (often absentee) landholders cultivate land through wage labor, sharecroppers, or tenant farmers, or they allow land to remain idle. Much land is in the hands of the state, which maintains sole authority to bestow rights to cultivation, grazing, and wood cutting, often according to political considerations rather than principles of sound resource management. Historically, governments have treated local communities as the primary threat against which forests were to be protected.

2.122 Such arrangements have long been recognized as not only inequitable, but usually inefficient. Insecure or unrecognized land tenure is antithetical to a long term approach to land management. It removes incentives for sustainable practices and discourages long term investments. Laborers and farmers without secure land tenure have little incentive to be vigilant about the long term productivity of the land they work, or even the short term productivity if they do not reap the marginal product of their labors (Binswanger and Elgin, 1998). Commercial wood cutters who are granted cutting rights to forests (or who cut illegally) similarly have little incentive to restrict themselves to sustainable harvesting levels or to take measures to protect the harvested land. Neither do local communities or entrepreneurs strive to protect or regenerate the land if they may have no legal claim to the benefits of their efforts or are explicitly prohibited by the state from doing so. Indeed, as local communities witness the unsustainable exploitation of neighboring lands, they often come to regard these lands as an inevitably dwindling reserve from which they should quickly extract their share or sacrifice it altogether. Forest lands, especially those in the urban periphery, can therefore lay severely over harvested and vulnerable to erosion, with no efforts to facilitate their regeneration. Even when reforestation efforts are funded by forest departments and use hired local labor, local communities still lack a long term commitment to protecting the resource unless they have secure usufruct.

2.123 By increasing the demand for biomass resources, bioenergy activities can exacerbate the pressures on natural resources and accelerate their decline. Where such adverse impacts might occur, measures should be explicitly designed into bioenergy programs to protect and enhance the health of natural resources.

Formalizing and devolving land resource rights

2.124 A measure for enhancing the long term sustainability of natural resources that has gained currency over the past few years is to involve local communities by radically expanding their management and ownership rights to the land and its resources (Bruce and Mearns, 2002). Devolving control over land from a centralized forest authority to the village, user group, or individual households can create committed guardians out of local communities. When local communities are authorized to manage the land, in a context of sound environmental and governance principles, and are granted secure usufruct with respect to the product of the land, they are motivated to preserve the land through productive, sustainable practices. This strategy reverses the trend toward state control that had been widespread since colonial times. It also creates opportunities for creating sustainable and secure sources of bioenergy resources in ways that benefit local communities.

2.125 This devolution of authority over natural resources requires a genuine transfer of decisionmaking power, not merely a conferring of certain limited access or usage rights. Over the last two decades, states have shifted from perceiving local communities as trespassers on neighboring forests toward accepting them as legitimate beneficiaries of forest products and services. Correspondingly, they have implemented programs, such as the sharing of revenue from timber concessions, tourism, and other economic activities, and licensing of minor activities such as small branch cutting, grazing, beekeeping, and food gathering, or the right to plant and harvest crops planted between rows of state owned trees. However, such arrangements have not proven to engage local communities wholly and reliably. A sentiment commonly expressed by community members has been, “Through comanagement we gained the right to collect fuelwood and some other products, but we lost the forest”. Experience is accumulating that only when true decisionmaking power devolves to local communities can a robust management regime emerge. Communities that have been empowered to make decisions and exercise control have demonstrated the ability to manage resources to their benefit and that of the environment.

2.126 A sufficient level of devolution may require several concurrent actions. It may involve fully restoring traditional land tenure and usufruct arrangements. It may involve granting formal ownership titles over land parcels, which codifies the holder's tenure and enables one to acquire, retain, and transfer land rights. (Titles can also serve as collateral and improve the holder's access to credit.) It may also involve conferring titles not to formalize private holdings as individual property, but also to formalize local commons as group property. An example is the recognition of customary rights held by communities, as instituted through Communal Land Associations in South Africa and Uganda (Wily, 2000). Such arrangements allow communities to acquire formal rights with no need to subdivide into individual plots.

2.127 It is necessary to ensure that there is a management structure that is accountable to community members. Sometimes, common land is the only resource base to which the poorest members of a community have access. If they are marginalized during the process of devolving land rights, they will lose access to those resources on which they relied. This could be especially harmful if it happens along with a sudden increase in demand for biomass resources such as might arise from the implementation of a bioenergy activity. It is important to ensure that rights are distributed in a manner that does not amplify the inequalities existing within a given community, providing yet more privileges to the local elites at the expense of the already marginalized. In many countries some degree of devolution of political power is underway, establishing formal local, village level government structures equipped to take on the management responsibilities attending the conferral of new land rights. In others, it is necessary to constitute new local institutions, such as forest associations, that are granted the right to decide how resources are used and by whom, to enact and enforce laws binding on village members as well as outsiders, and to raise and manage revenue.

2.128 Devolution of land rights must obviously be carried out with a high degree of sensitivity to local circumstances—recognizing the various actors who are dependent on the land resources and the complex relationships among them—or risk failure. For example, past efforts have failed because they neglected the dependence of pastoralists on land resources and their legitimate, if unofficial, claims to periodic grazing rights. Historically, traditional land tenure and resource custody arrangements have been complex, extralegal, social agreements among several interdependent actors. Bioenergy programs should be designed in light of such preexisting arrangements.

2.129 An apparently successful example of this type of initiative is the support for village managed fuelwood markets in the periphery of urban Niger (around Niamey, Zinder, and Maradi), where unsustainable fuelwood harvesting had decimated natural woodlands. It has demonstrated that woodlands can be restored and made productive, relying primarily on local efforts and minimally on forest services outlays. As of around 1997, village managed woodlands were providing 16 percent or the urban fuelwood demand on an apparently sustainable basis (ESMAP, 1997). Another example is Tanzania, where more than five hundred communities have been empowered to control and manage woodlands and have proven they have the will and ability to return them to healthy condition and to prohibit unsustainable forms of exploitation that had previously been defended as essential to their livelihoods (Wily, 2000).

Financing

2.130 In the context of rural areas in developing countries, financing is a daunting problem at all scales: government, industry, small-scale enterprise, and households. Energy authorities, investors, rural enterprises, and households are often prevented from making the "best" decisions regarding energy investments. In many cases, a bioenergy or other renewable energy option offers a range of benefits—least cost energy service, the most efficient use of a resource, the best environmental performance,

socioeconomic benefits—that would ideally make it the energy solution of choice. But, *initial cost* is all too frequently an insurmountable barrier for decisionmakers at all levels, from government authorities to households. Where financial markets are undeveloped and capital is chronically scarce, financial choices are regularly made using extremely high effective discount rates. For the poor in particular, deeper structural problems contribute further to this problem: they are exposed to many sources of risk, suffer chronic insecurity of assets, and face immediate subsistence needs, all of which discourage long term investments. Bioenergy technologies, which often have relatively high capital costs, commonly suffer from this initial cost barrier.

2.131 It's important to note that although end users are often incapable of making large initial outlays, they have a very high willingness to pay for energy services. Village energy surveys have found that households already pay rates that are exorbitant from the perspective of, say, the typical electricity consumer from an industrialized country who is accustomed to paying approximately one US cent for several hours of high quality illumination.

2.132 There are different ways to address the initial cost barrier at different levels within the energy sector. At the higher levels are energy authorities and large firms (say, in biomass power plants or biofuels facilities) that make decisions about major investments. Their ability to make economically sound long term decisions would benefit from more developed capital markets and greater macroeconomic stability. For the global energy sector, investments in the 1990s were being made at a rate of roughly $400 billion annually, and this is expected to almost double in the next two decades (UNDP, 1997). Even now, investment requirements are difficult for developing country energy authorities to meet. The major source of investment capital—retained earnings from revenue—is inadequate, in large part because consumer subsidies keep tariffs well below long run marginal costs. Governments also are unable to invest sufficient resources because they face chronic fiscal pressures. Development assistance to energy sectors has been declining over the past decade, at the same time that the set of recipients has expanded and now includes Central and Eastern Europe. The remaining source of capital is foreign investment, which may be able to inject significant resources if the macroeconomic and political conditions in developing countries are hospitable. Foreign direct investment in developing countries is approximately $250 billion annually and growing. An environment hospitable to further growth would require transparent laws regarding property, a consistent regulatory regime, accepted protocols for accounting and auditing, and reasonably stable currency situation. It would also require some deep structural elements that are fundamental to development itself, such as a capable and healthy workforce and political stability based on democratic institutions (World Bank, 1996; 2000).

2.133 At the lower levels are the end users of energy services. Rural enterprises and households, for example, would benefit from credit financing through commercial banks, development banks, micro credit institutions and other financing arrangements. 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 per year. This source of capital is primarily available to a limited commercial clientele, and even subsidized credit programs targeted at rural development do not regularly reach 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 provide both liquidity and returns.

2.134 Thus, for the poor it is extremely difficult to finance the acquisition of assets such as bioenergy appliances. In recent years, however, innovative microfinance initiatives have stepped in to fill the gap in financial services. The well known Grameen Bank in Bangladesh, for example, has conclusively 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, unsubsidized, commercial undertaking, *without* levying the exorbitant rates that characterize 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).

2.135 Financing schemes are most likely to succeed if conducted in parallel with programs that enable income generating activities. In many cases, income generating activities are severely limited by the lack of access to energy services such as lighting, shaft power, process heat, and pumped water. Bioenergy activities, coupled with financing schemes, could therefore serve as an effective platform for the provision of enterprise enabling energy services with access to enterprise investment capital (Barua, 1998; GEF/FAO, 2002).

2.136 Financing for energy services could take several forms (UNESCO, 2000), as follows.

2.137 *Supplier financing:* Financing could be provided directly to the end user by the entrepreneur, under agreed payment terms and recourse measures stipulated in a loan contract. This scheme has been used for biomass gasifiers, for example. It provides the entrepreneur a strong incentive to provide a quality product and regular maintenance, in order to secure regular payments. But, as the entrepreneur assumes the risk of default, and is often passing along his own credit costs, it could also lead the entrepreneur to require a high down payment, charge relatively high interest rates, offer only short loan terms, and avoid low income customers who might appear less creditworthy.

2.138 *Third party financing:* Financing could be provided by a third party micro finance institution or other organization that operates a loan fund. This approach allows the entrepreneur and the creditor each to focus on his area of specialization, and the entrepreneur does not have to arrange credit or tie up his financial resources. Interest rates tend to be lower and loan terms longer, especially if the creditor has access to concessional financing targeted at development. The incentive to provide a quality product and regular maintenance is muted, but a service agreement with the entrepreneur can help reduce the risk to the creditor of default due to technical failure or inadequate maintenance. This approach has been used in some bioenergy programs, such as government programs for disseminating biogas digesters.

2.139 *Leasing:* Financing could be provided in the form of a lease agreement, whereby the entrepreneur retains ownership of the energy system until the full cost of the system is repaid. The entrepreneur has a strong incentive to maintain the system, at least until it is fully repaid. This type of financing is already in place in many rural areas for agricultural machinery and rural micro enterprise assets.

2.140 *Fee for service:* A further form of financing is the fee for service agreement. The three above financing models are most appropriate for bioenergy systems that are small enough for single household ownership (for example, cookstoves, household biogas digesters). Fee for service is more appropriate for systems (for example, community minigrids) that would service a larger community of end users who are financially unconnected to each other. The entrepreneur who owns and maintains the system is responsible for providing the energy service, such as electricity for lighting or biogas for

cooking, or perhaps a further step removed: pumped water, refrigeration, or milling services. Fees for these services allow the owner to recover investment costs and earn a return in his investment.

2.141 There are several examples of financing programs for energy products. One example is the FINESSE program, *Financing Energy Services for Small-Scale EndUsers*, established by the World Bank, the UN Development Programme, and the US and Dutch governments and operational in several African and Asian countries. A major FINESSE objective is to use financial resources of multilateral lending institutions to make "wholesale" loans to intermediary organizations such as commercial banks, utilities or NGOs, who onlend them to small-scale energy users at market rates. A second example is the Grameen Shakti loan program (a nonprofit affiliate of the Grameen Bank), which by 2000 had financed 800 small PV electric systems ranging in cost from $300 to $800, provided with a two year, 8 percent loan (UNDP, 2000; Grameen, 2004). An example of a fee for service arrangement is the village biogas model demonstrated at Pura village and its eight successor implementations (see Bioenergy Profile 10), where households make a monthly payments for an electrical connection and water tap. In this case, villagers have a further level of involvement in that they are participants in the cooperative style management of the system.

2.142 Especially with novel technologies or inexperienced entrepreneurs, government programs that make credit available should do so only if provisions are also made to ensure that technical support and maintenance are available. Several programs have provided subsidized credit to support the commercialization of new technologies and found that the survival rate of the technologies is very low. The user, who tends to be less acquainted with the novel technology and stranded with little service and maintenance infrastructure, also has a dampened incentive to invest in repairing the equipment since it was purchased with concessional credit. Typically, the government's only recourse is to blacklist from future government loans any users who become unable to maintain their debt payments, which can reduce the pool of first adopters willing to invest in the new technology while accumulating a portfolio of failed technology demonstrations.

Technology Development and Transfer

2.143 Because bioenergy systems are so context specific, ongoing technology development and adaptation will be an important part of a successful bioenergy program. Some of this technological development will be of a fairly incremental nature, consisting of minor adaptations to local circumstances and needs. Other technologies will require development of a more fundamental nature, aimed at spawning advanced technologies and pushing emerging technologies toward commercialization. The costs of the former will in many cases be borne by a country itself, whereas the latter might qualify for assistance from international aid agencies and organizations such as such as the GEF.

2.144 Ongoing development is likely to be needed with respect to both the production of biomass feedstocks and their conversion to energy services. Building this technical capacity can be an extensive process that involves educational and research institutes, private entrepreneurs, international actors, the feedstock producers and energy service end users.

2.145 Research needs are diverse and must usually rely on both imported innovations and local knowledge. On the biomass production side, there is a tremendous need to gain more location specific knowledge of the use of agricultural residues as a feedstock. Of particular importance is the need to understand well what fraction of biomass residues should remain on the cropland to preserve soil texture and nutrient content while preventing pests. There is also a tremendous amount of further development of energy crops, including both cellulosic crops (for example, quick growing trees) and starch or sugar based

food crops (for example, sugar cane) to tailor them to make them high yielding, low chemical input, and low impact on natural habitat, given specific climatic, soil, and biodiversity conditions. Developing cost-effective feedstocks will involve developing transport, processing, and storage strategies that are appropriate to the availability, skill level, and wage rates of local labor. There is also the need to identify crops that can be multi purpose or can be intercropped with other agricultural crops in response to the many needs of local communities. Crops that can contribute to the restoration of land will be highly beneficial in many regions. Traditional agricultural practices, such as water harvesting and agroforestry, can be learned from and adapted to bioenergy feedstock production.

2.146 On the biomass conversion side, a main requirement for technology development will be the adaptation of technologies to locally available residues (for example, bagasse, coconut husk, wheat straw, rice husk), indigenous weeds (for example, water hyacinth, ipomoea), and ecologically suited energy crops. Biomass handling and conversion technologies are sensitive to the characteristics of the specific feedstock, such as its content of moisture, ash and contaminants such as sulphur and alkalis; thus, designs will have to be optimized to the context. Household products (such as cookstoves and biofuels) and village scale systems (such as community biogas systems) are also highly unique to their particular cultural context. Biomass technologies for industry and small enterprises will depend greatly on the specific nature of the target sectors. Technology development should always be undertaken with a high degree of interaction with the intended end user.

2.147 Governments should facilitate the involvement of the private sector in technology innovation. Government could provide funding for research, subject to rigorous process of review and accountability. Effectively encouraging innovation in the private sector may require governments to put protections of intellectual property rights in place and ensure that legal systems can enforce licensing and royalty agreements and allow patent holders to benefit from their innovations. There may also be roles for international private sector actors, particularly in countries that are too small to support an indigenous technology development capacity. Joint ventures can be effective ways to indigenize technological capacity. An effective example of this was the government facilitated pairing of Swedish company Saxlund with small companies in Estonia, Latvia, and Lithuania, which created joint ventures that manufactured biomass feedstock handling equipment and biomass furnaces for district heating systems. The joint ventures then went on to expand the use of biomass in district heating and agroprocessing sectors and reached markets that neither the Swedish company nor the small local companies could have reached independently (Kartha et al., 1997).

2.148 Governments should design technology development endeavors as long term undertakings, with the understanding that trial and error, repeated iteration with the end user, and slow diffusion of research results all imply that research and development efforts can be a time-consuming process that require a significant resources.

2.149 Governments can support research efforts while building long term research capacity by supporting research fellowships that enable university students and researchers to devote time to priority technology development objectives in government facilities, academic laboratories, and the private sector. They can also encourage interaction between people in related fields in different regions by sponsoring seminars, conferences, and other forums for technical exchange. An example of the sustained support for this type of interaction is the All-India Coordinated Research Project of the government Department of Science and Technology, which brought together people from twenty regions who had knowledge of local small-scale enterprises (such as pottery, leather curing, and horticultural product processing) and

agricultural methods, and focused on developing modifications and adaptations according to regional needs.

2.150 When governments establish research laboratories, it is important to put in place administrative structures that ensure they remain connected to the actual needs of the intended beneficiaries. Many do not have natural channels through which they can learn about end users' needs, develop and field test products, and iterate with end users. Sometimes, the same government laboratories nominally working toward rural development needs are also expected to respond to requests for research from the private sector on a consultancy basis, resulting in their allocating time to private sector clients at the expense of rural communities or small-scale enterprises who cannot pay for research consultancy services. One model that has proven successful is for the government to fund NGOs to act as a sort of liaison, working with local communities, identifying research problems of concern to them (for example, reconfiguring a food dryer that dries unevenly, slowing rust formation at the overflow vent in a biogas digesters, developing an efficient cookstove designed for specific cooking practices), and working with end users to conduct field tests. NGOs can further receive funds to develop and submit formal requests for research services on a consultancy basis, just as private sector firms do.

2.151 Governments that have been supporting technology development are well positioned to bridge their *technology* development with *product* development. This involves the critical process of moving from research laboratories to the user's site: the industrial facility, enterprise, or household. Historically, most "appropriate technology" laboratories have focused predominantly on laboratory development, leaving a tremendous amount of work before a market ready product is developed. There are innumerable cases of NGOs picking up an appropriate technology and disseminating it, and only then uncovering serious technical problems and understanding the extent of product development that still remained. It is critical that in the precommercial phases the technology developer continues to play a role in ushering the product into the field. One researcher involved in biomass gasifier development insisted that the developer must play an "ombudsman" role and remain technically involved, and moreover offered that "If we were to simply hand over the engineering drawings for our technology we could provide a guarantee... a guarantee that the project will fail!"

2.152 Despite the prolonged process of introducing the product into the field, it is important to take a quasi entrepreneurial approach early on. After the initial proof of concept trials, further demonstrations should be treated as "market research" or "test marketing" rather than technology demonstration. All too often, the selection and citing of initial demonstrations is based on political considerations and "porkbarrel" decisionmaking. Entrepreneurs, rather than political patrons or even the technology proponents, should be involved in identifying the prospective users and proposing installation sites. While helping to build product awareness, this also leads to demonstrations that yield valuable information beyond mere technical performance data. It helps to determine the realistic characteristics and scale of the product's market and can help identify applications of which the technology developers might not have been aware. It makes important contributions to learning about the needs of consumers. In many cases, the interests of consumers are discovered to be completely unrelated to the objectives of the technology developers. There are several examples of efficient, biomass conserving technologies that had unanticipated features that were perceived by consumers to be significantly more valuable than their fuel saving properties. (See Box 2.1 on secondary benefits.) This is important for technology developers to know if they are aiming to develop a product that will be widely adopted.

2.153 Whenever possible, the user should be required to contribute to the cost of the implementation (and, if the product fails, the user's cost should be refunded only if the product is also reclaimed). This serves several purposes. A fully subsidized product is very frequently perceived as substandard. Requiring some payment from users ensures their motivation and investment in the operation and functioning of the installed unit. It motivates the user to seek proper training in operation and to follow it. Whether the product is a cookstove, biofuel, or industrial scale gasifier, the user's commitment and cooperation is necessary for a meaningful trial of the product. With a sense of investment, the user will feel entitled to a product that will perform well; this ensures honest feedback (both positive and negative) which is critical to a process of testing and revising the product design. In turn, it also trains the entrepreneurs to attend to and respond to the user's demands, provide followup services, and call in technical backup as necessary. Public opinion can be sensitive to demonstrations; and bad news travels faster and lingers longer than good news.

Box 2.2: The "Secondary" Benefits are Sometimes Primary

Many technology developers have been motivated by the desire to design an energy saving bioenergy technology: an improved stove, furnace or gasifier. Often, these developers have then found their technologies difficult to commercialize and disseminate.

One fundamental reason for this difficulty that the technology developer must recognize is that outside of the laboratory, energy efficiency is rarely a very salient feature to the end users. Fuel costs are often a small contributor to total costs. In some cases, although efficiency is not a salient end user concern, products manage to succeed because of other benefits that the developer had not initially anticipated. Several examples follow.

- Silk-reelers found that the steadier temperatures offered by biomass gasifiers improved silk thread yields by ~3 percent, increasing the value of their net output by more than the value of the fuel savings.
- Arecanut processors adopted an efficient stove because they found that the more even heat lead to less frequent boiling over of pots and less discoloration of their product.
- Producers of medicinal herbs invested in efficient dryers because they lead to a purer and more marketable product.
- Coconut processors found that efficient dryers lead to a better tasting product.
- Agroprocessors chose to shift from diesel boilers to biomass gasifiers that generated activated charcoal as a coproduct that more than offset the cost of the biomass fuel.

The technology development process should always be closely attuned to the needs of the intended end users, starting from their needs and iterating with them to ensure that the technology meets those needs, is adequately reliable, matches their operation and maintenance capacities, and is cost effective.

Conclusions

2.154 This chapter, whose focus was on facilitating the creation of bioenergy markets and supporting entrepreneurs, discussed the creation of institutional frameworks and the types and characteristics of well designed policy incentives. It highlighted the relevance of environmental and trade policy for creating hospitable policy conditions for promoting bioenergy ventures. In addition, it raised the issue of land tenure and resource management and use, which are intrinsically connected to biomass dependent activities such as biomass energy.

2.155 Many actors' involvement is required to implement effective bioenergy programs and achieve widespread replication. Chief among these actors will be private sector entrepreneurs and civic entrepreneurs, with the public sector playing key roles to create markets and facilitate the involvement of these entrepreneurial actors. There are several avenues for facilitating this involvement.

3

Designing Biomass Projects to Meet Community Needs

Introduction

3.1 In this chapter, we shift the perspective from top down to bottom up, from the standpoint of the planner and bioenergy program developer to that of the local community and end user of biomass and biomass related services. Until now, our focus was on what decisionmakers must consider in order to support bioenergy activities and facilitate their widespread replication. In the final analysis, however, both bioenergy activities are relevant only to the extent that they are framed by a larger question: how can they help achieve sustainable development goals?

3.2 The potential for such achievement is vast. First, bioenergy activities can provide access to energy services that enable rural communities to meet basic needs (for example, cooking, lighting, water) that are fundamental to human development[8]. Access to convenient and affordable energy services enables improved general health and living conditions and provides people with more time and opportunities for productive activities (World Bank, 1996; 2000). Decentralized energy technologies, including modern biomass, can help increase access by offering options when grid extension not viable. They can make use of local resources, are suitable for local rather than central management, and provide energy services that are locally in demand.

3.3 Second, bioenergy activities can create income generating opportunities. With appropriate institutional arrangements and corollary services, the final energy generated from bioenergy technologies (for example, electricity, steam, biogas) can be a critical input to enterprises such as food processing, milling, crop drying, mechanized production in cottage industries, and so on. Moreover, as biomass is locally and renewably available as an energy resource, its production, harvesting and processing can be a source of rural livelihoods. Biomass is, of course, already traditionally harvested and used for a variety of energy needs (for example, cooking, water heating) and nonenergy needs (for example, food, fodder, fiber). In principle, therefore, biomass feedstock production can be integrated with or built upon existing farming practices. New rural jobs, without radical disruption of existing livelihoods, can result from the growth of a market for biomass feedstocks for energy applications (See Utria 2004). Ultimately, biomass production can even become a major source of rural livelihoods, particularly if bioenergy expanded to the point of serving major urban demand centers.

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[8] UNDP (1995; 2000). While there is no Millennium Development Goal (MDG) explicitly associated with energy, meeting all the MDGs would require a significant improvement in the quality and quantity of energy services provided to people living in poverty.

3.4 Notwithstanding the apparent convergence of sustainable development objectives with bioenergy activities, it is a serious mistake to assume that large-scale deployment of advanced bioenergy technologies and the concurrent development of biomass resources for energy will *automatically* give rise to overwhelmingly positive outcomes. As discussed in Chapter 1, biomass is land intensive and labor intensive. Almost any intervention involving biomass will inevitably affect local communities through its impacts on the demand for land and resources and its influences on labor markets and practices. Biomass, unlike conventional fuels, has a staggering range of roles and functions, extending far beyond energy related uses. It serves a host of purposes locally: food, fodder, fiber, fuel, and fertilizer. Even the traditional uses of biomass for energy, particularly cooking, are deeply tied to local context and cultural norms and are often outside the money economy, implying that conventional techniques of cost:benefit analyses to determine the viability of advanced bioenergy applications may be misleading. Land too has multiple uses: human habitation, watershed protection, wildlife habitat. These can compete with production of biomass for bioenergy purposes, especially in regions of increasing scarcity of land or biomass resources.

3.5 Since biomass production is so closely linked to the local environment, economy and practices, and so dependent on local labor, bioenergy interventions can generate profound consequences for local communities through the complex interplay of labor markets, resources flows (both market and nonmarket), and land tenure practices. Bioenergy interventions can strongly affect local stakeholders—particularly the poor, who live largely outside the money economy and for whom the commons may be a major source of resources for subsistence.

3.6 The challenge, then, is to fulfill the promise of biomass energy without compromising other biomass resource needs or adversely affecting existing livelihoods and cultural practices. Any sincere attempt to use bioenergy as a means to promote sustainable development would therefore need to take careful account of the broader social consequences of biomass projects and programs.

3.7 In keeping with this perspective, in this chapter the report shifts attention from the bioenergy program to the local community in which it is imbedded. Section 3.2 discusses briefly some of the central concerns to consider if bioenergy activities are to be implemented so as to enhance local income generating opportunities. Section 3.3 translates some of the lessons learned over the recent past in participatory approaches to the context of bioenergy. It presents a step by step approach to selecting appropriate sites and conducting needs assessment using participatory approaches.

Income Generating Opportunities

3.8 Eliminating the root causes of poverty necessarily involves expanding access to jobs and increasing the purchasing power of poor households. Bioenergy projects can achieve this in two main ways: by creating jobs in biomass feedstock provision and bioenergy production; and by providing access to energy services that help to expand income generating opportunities.

Feedstock provision and jobs

3.9 Since biomass production is often labor intensive, feedstock provision could be an important source of both primary employment and supplemental income in rural areas. Many farmers would welcome the opportunity to sell residues or purpose grown wood to long term, steady consumers or a well developed spot market. Producing biomass could provide a new source of revenue and help farmers to diversify. Rural enterprises are also indirectly connected to the biomass feedstock production activity itself: providing and preparing agricultural inputs such as fertilizer, selling and servicing farm

equipment, handling and processing agricultural products, and transporting and marketing finished goods. Employment is also generated in processing biomass and working at the bioenergy conversion facility.

3.10 Certain bioenergy feedstock production and supply chains, if appropriately designed, could offer multiple avenues for income generation. One strategy is the coproduction of value added product along with the biomass feedstock. A bioenergy project in Hosahalli, India, provides an especially good model. 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 mulberry leaves, which 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.

3.11 In Brazil, sugarcane for ethanol production has been an important contributor to employment, especially in the Sao Paulo region. About 2,200 direct jobs (1,600 in agriculture and 600 in industry) were created for every 1 million tonnes of sugarcane processed each year (Macedo, 1995). These jobs had the following characteristics: 30 percent were for skilled positions (industrial workers and agricultural supervisors); 10 percent for semi skilled positions (for example, drivers); and 60 percent for unskilled agricultural and industrial work. An additional 660 indirect jobs were also created (per million tonnes) for equipment manufacture, engineering, repair and maintenance, and chemical supplies manufacture.

3.12 Countrywide, more than 700,000 jobs have been created, although it is unclear how many of these jobs are new ones. The investment to generate one job in the ethanol industry varies between $12,000 and $22,000, about 20 times less than in the chemical industry, for example (Goldemberg et al, 1992). While a large proportion of these jobs earned incomes that were greater than average incomes in the region, the seasonality of sugarcane production is a serious limitation on its ability to create high quality jobs. That is to say, employment for harvesting, in particular, tends to be temporary and therefore low wage.

3.13 Job creation from bioenergy feedstock production alone could indeed be highly seasonal unless mitigated by such practices as crop rotation, the use of perennials or forest residues, and storage. Each of these possibilities needs to be carefully considered against local needs, ecological concerns and social impacts.

Expanding income-generation opportunities through enhanced energy services

3.14 Access to energy services could 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, such as mechanical power, electricity, process heat, or transport fuel. Modern forms of energy could provide critical energy services for rural agriculture and nonfarm enterprises in many ways. 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, and could be cheaper (Wamukonya & Davis 2001). Efficient sources of process heat enable farmers to process agricultural output, increasing their revenue by turning an agricultural product into a value added, marketable good. Electric motors can dramatically reduce the amount of effort demanded by simple chores, enabling 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. Increased

availability of transport services provides better access to raw materials and markets. And increased access to information potentially enables rural producers to understand better the market conditions under which they are endeavoring to sell their output (see Table 3.1).

Table 3.1: Value of Different Energy Services to End Users

Energy services	***Income generating value to rural households and enterprises***
Irrigation	Better yields, higher value crops, greater reliability, lower vulnerability, growing during periods when market prices are higher
Light	Reading, many types of manual production, and other activities during evening hours
Pulping, grinding, milling, husking	Create value added product from raw agricultural commodity
Drying, smoking, curing (preserving with process heat)	Create value added product; preserve produce to enable selling to higher-value markets
Expelling	Produce refined oils from oil seeds, and other sources
Refrigeration, ice production and preservation via electricity	Preserve produce to enable selling to higher value markets
Transport	Reach markets, acquire inputs
TV, radio, computer, Internet	Education, access to market news, coordination with suppliers and distributors, weather information.
Battery charging	Wide range of services for end user

3.15 Policymakers and international agencies often neglect 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 female entrepreneurs, who frequently operate out of the home and are usually marginal, smaller producers. But it is now increasingly recognized that, especially in many parts of Africa, 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).

3.16 Farming could also benefit greatly from improved energy services. A reliable supply of irrigation water is a main factor enabling farmers to plant more than one crop during the year. This increases both the amount of food produced and agricultural employment per hectare. Motorized pump sets, powered by biomass derived gas or electricity, could irrigate land that would otherwise not benefit from gravity flow. 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.

3.17 Activities that raise incomes, expand enterprises, and improve agriculture in rural areas generate 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 would 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.

Enabling conditions

3.18 It is unlikely that the mere arrival of modern energy would spur rural enterprise. Bioenergy projects should explicitly seek to establish links with income opportunities. Rural enterprises are often linked to the biomass feedstock production activity itself: providing and preparing agricultural inputs such as fertilizer, selling and servicing farm equipment such as bullock carts, handling and processing agricultural products, and transporting and marketing finished goods.

3.19 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. In many cases, a further key obstacle facing rural enterprise is inadequate upstream and downstream linkages. Remote enterprises could find it difficult to procure raw materials at reasonable prices on a reliable basis, or to reach prospective sources of demand for their 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.

Points of caution

3.20 Bioenergy planners must bear in mind that a diffusion of energy services and an increase in mechanization do not always benefit rural development. In some situations, labor scarcity is indeed a problem and labor 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 could support development only to the extent that they expand employment opportunities.

3.21 Historically, mechanization has often conflicted with employment. From the displacement of English farm laborers by threshing machines up to today, this process of displacement is frequently rationalized on the grounds of improved economic efficiency. Its impacts on poor laborers are deemed a regrettable but unavoidable consequence of modernization. Too often, however, the displacement of labor cannot even be rationalized on the grounds of economic efficiency. In many economies, overvalued exchange rates, direct capital incentives, and subsidized 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.

3.22 One well studied example of the effects of mechanization 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 mechanized 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; UNDP, 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.

3.23 If they are to avoid such impacts, bioenergy projects must target energy services in ways that *increase* rather than *displace* opportunities for productive activity. Bioenergy planners should try to anticipate where workers might be displaced, design projects to minimize 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.

Participatory Methods for Needs Assessment in Biomass Energy Projects

3.24 The rather disappointing outcomes of several large-scale bioenergy programs—for example, early mistakes in dissemination of cookstoves and biogas systems in India (Kishore and Ramana, 2002); Brazil plantation biomass, (Couto and Betters, 1995); early social forestry programs)—illustrate how top down, technocratically developed formulas for widespread promulgation of specific technologies are less likely to truly support sustainable rural development than are participatory approaches that pay close attention to local needs and circumstances. The central purpose of this section is thus to highlight the issues surrounding three cardinal characteristics of bioenergy that we raise repeatedly in the report and that all point to the importance of participatory approaches: (i) biomass resources are locally varied and site specific; (ii) socioeconomic and other key nontechnical factors affecting demand and supply are also varied and site specific (particularly in the developing country context); and (iii) biomass and land play such fundamental roles in rural economies that for implementations to succeed they must build on the site specific and varied biophysical and socioeconomic circumstances. "Participation" is a crucial means to this end and must therefore be taken seriously by the biomass energy policymaker, who should adopt robust methods and approaches of participatory assessment.

3.25 This section develops some of the principles of needs assessment, techniques for carrying them out, and the consequences one could expect of different categories of bioenergy projects and programs. The emphasis here is on local needs assessment for designing village scale, locally appropriate biomass energy projects (involving, for instance, the development of a community scale biogas system or the dissemination of gasifiers for commercial applications), but similar considerations would be appropriate in larger projects involving entrepreneurs (for example, ethanol production) that will likely affect local livelihoods through biomass feedstock production and job creation.

3.26 This is not to say that "successful" bioenergy programs are impossible without local participation. Certain bioenergy activities are closely bounded in terms of their impacts on resources and labor. For example, an agroprocessing facility with its own biomass residue resources might be able to implement a biomass cogeneration technology in a straightforward manner with negligible impacts on broader resources and minimal additional labor requirements. However, such projects may be the exception rather than the rule. Any project that proposes to provide a significant contribution to local development through the creation of jobs or the provision of energy services is destined to be more effective if it is designed and implemented with the participation of the intended beneficiaries.

Participatory methods and bioenergy activities

3.27 The World Bank defines participation as "a process through which stakeholders influence and share control over development initiatives, decisions and resources which affect them"[9]. This perspective has evolved gradually over the several decade history of development intervention. Formerly, rural development was focused on capital intensive infrastructure investments that minimized interdependence with local communities (for example, Sachs, 1991; Scott, 1998). The conception phase of such development projects would involve interaction with local communities only to the extent that a project design team comprised of scientists, bureaucrats and development workers might appear on site to take field measurements of physical and economic characteristics like soil type, water resources, terrain and income. This limited site specific information would be taken back to metropolitan centers and used as input to the design of large-scale engineering projects, the objective of which was, for example, large-scale water or energy supply systems or irrigation schemes, roads,. Often, the planned capital investment was ultimately implemented, but the local socioeconomic impacts were rarely closely observed. Such impacts were manifold and often negative; they included the suppression of local innovation and coping mechanisms; the creation or sustenance of minority local elites with nearly exclusive access to limited resources; the formation of a culture of dependence on entitlements; and sometimes worsening poverty among the already disenfranchised.

3.28 Over time, there has been a gradual shift in the mainstream of rural development toward including participatory approaches in assessment, planning and implementation. In almost every field, from watershed management to rural health care, there is a growing realization that local people, on whose behalf substantial amounts of resources are expended, should be involved in every stage of the development effort. Participatory methods are similarly being recognized as central to biomass energy assessment and implementation efforts, largely as the outcome of failures in previous top down approaches (for example, Karekezi,1994; Shivakumar et al., 2000; see also the REWSU Case Study). Cookstove dissemination programs in Africa and parts of India have especially revealed the importance of participation. Successful programs have been accompanied by extensive community involvement in the design, testing and manufacture, and dissemination of stoves, whereas major disappointments have been associated with top down, technocratic approaches (Banwell and Harris, 1992; Rouse, 2002).

3.29 Participatory planning processes could help all involved parties to understand and address constraints affecting development programs, which in turn raises a sense of ownership in specific projects among local participants. From the standpoint of planners, this is a worthwhile cause since it has become quite apparent that programs delivered as if they were blocks of entitlements end up being inefficient, or

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[9]World Bank, 1994. A detailed discussion of the Bank's recommendations for participatory analysis is described in World Bank, 1998. Note that we use a somewhat different taxonomy in this report to describe different approaches.

even counterproductive, and help create a culture of dependence. For the policymaker, the advantages of participation include improved quality and sustainability of development efforts; increased stakeholder ownership of policies and projects, and greater willingness to share costs and help with maintenance; increased transparency, accountability and institutional performance; and, ultimately, greater program success. From the standpoint of local people, participation has several further benefits. Sustained participation by all segments of a village society could help break traditional hierarchies by giving a "voice" especially to women and those living in dire poverty. Empowering such groups sufficiently to form networks of trust is a worthy development objective in itself, because doing so creates opportunities and builds institutions to give them a voice and thereby provide them with supplementary tools to address their development needs in historically inequitable environments. For example, women's self help groups and cooperatives have often been successful in improving living standards across social groups in a given community, largely because they tend to create and rely on networks of exchange and cooperation rather than on traditional business models of individual entrepreneurship, which tend to benefit only whose who are already relatively affluent and upwardly mobile (Mayoux, 1995).

3.30 Various participatory methods have been developed over the years for assessment, implementation and ongoing program monitoring and evaluation. A number of these constitute an approach that is generically termed Participatory Learning and Action (PLA), which combines a set of interactive, visual techniques with underlying principles of grassroots participation that involve rethinking power relations and partnerships between development agencies, experts and poor people (Kumar, 2002). Its methods have been refined over the years to facilitate negotiations between different stakeholders in projects and policy dialogue. PLA is now seen as a "growing family of approaches, methods, attitudes and behaviors to enable and empower people to share, analyze and enhance their knowledge of life and conditions, and to plan, act, monitor, evaluate and reflect." (Chambers, 2003).

3.31 Table 3.2 below lists the different purposes, levels of participation and methods as three different axes for consideration.

Table 3.2: Participation: Purpose, Level and Methods.

Purpose

- Data Collection
- Needs Assessment
- Project Formulation
- Project Implementation
- Program Creation

Level of Participation

- Consultation
- Collaboration
- Collegial
- Self determined

Methods and Techniques

- Social Assessment
- Stakeholder Analysis
- Beneficiary Assessment

Increasing Local Stake and Impact

Increasing Local Participation

3.32 As is evident from the discussion up to now, local participation is important in nearly every aspect of biomass energy assessment, project design and development and implementation. In the remainder of this chapter, we focus on participatory approaches relevant to needs assessment for actual bioenergy project or program design.

3.33 There is a rich literature on Participatory Learning and Action that contains tools and methods for conducting needs assessments generally. We provide a list of such resources at the end of this chapter. In what follows, we discuss some salient features that would be appropriate in the context of needs assessment relevant to designing biomass projects specifically.

Step 1. When should participatory assessments be conducted, and by whom?

3.34 Ideally, participatory assessments should begin while conceiving any bioenergy program, irrespective of scale, that is likely to have nontrivial impacts on resource use and labor. The participatory activities should continue beyond the conception stage as much as the particular context of the intervention may warrant participation. The exercise should be moderated by development workers, preferably with experience in the area or, even more appropriately, by local residents trained in participatory methods.

3.35 Participatory assessments in rural areas tend to be complicated by user groups' justifiable suspicion of outside intervention. Far too often, the poor have been subject to insensitively designed surveys by visitors with strong interests, either benign or selfish, after which they have invariably seen a

loss of services, land, or income generating opportunities (Chambers, 1983). In the case of biomass, the stakes are perhaps as high as they could ever be, since biomass resources are so closely connected with livelihoods, food production and land. Therefore, it is important that the individuals carrying out site level assessments be unbiased with respect to any potential outcomes that may favor the siting of biomass projects in the area. In other words, project developers, financing entities, or entrepreneurs who are vested in the prospective project should not carry out assessments. Local government officials, to the extent that they are powerful actors with ties to business interests, should also play a relatively minor role, if any, in the assessments. Donors and other government professionals may be involved, but only as minor players.

3.36 The ideal facilitators of the needs assessment would be capable members of nongovernmental organizations, academic institutions and other development workers with some prior experience with participatory approaches as well as an understanding of biomass energy technologies and resource issues. Unfortunately, few individuals have this combination of skills and knowledge. In these circumstances, it would be preferable to provide some initial training on biomass energy to development workers who are skilled in participatory methods, but have them go on missions to rural areas accompanied by technical resource persons who would deliberately remain observers rather than trainers or facilitators. Step 3 below describes some further considerations for setting up the assessment team.

Step 2. Selecting Sites for Needs Assessment

3.37 In the Technical Annex, we detail a process for the broad assessment of biomass resources, including agricultural and forestry residues and dedicated energy crops. The procedure underscores the need for local level analysis, not only to verify these estimates but also to ensure that energy projects developed on the basis of the resource assessments would in fact be consistent with broader development objectives.

3.38 The national level analysis can be expected to provide a broad map of the biomass availability. While the resolution of the map would depend, of course, on the resources available to conduct the assessment, the assessment will nevertheless enable planners to discern at least three types of regions: resource rich, resource poor, and regions with intermediate biomass resource availability. At minimum, needs assessment should be conducted in each of these types of regions, with additional sites selected based on type of resource availability (for example, dominant in crop residues versus forest cover or cattle).

3.39 It is important to note that the main reason for carrying out the needs assessment exercise is not to identify suitable sites for preselected biomass energy projects. Rather, it is to generate a better understanding of actual (rather than imputed) local needs in the context of different levels of resource availability. Once the assessment team has come to a shared understanding with the local communities of the community's needs, then the team can present and discuss biomass energy options that could help to meet those needs. As this exercise is carried out in several representative areas, the assessment team can develop a map of project types that could be most appropriate to each type of region.

3.40 Depending on the financial and human resources available and the size of the region to be covered, sites chosen should be representative of the patterns of biomass resource availability (for example, rich, poor and intermediate), dominant resource type (for example, rice husk, woody biomass) and economic characteristics (for example, high, middle and low income). The actual villages where the assessments would be carried out could be determined through a further screening process that includes at least the following criteria:

- The presence of an NGO or other civil society group that has experience working in the area

- Moderate village size, say, 500 households or fewer, but bigger than a hamlet with a few isolated households
- Absence of political or ethnic strife that is so serious as to make intracommunity discourse of any form impossible

Step 3. Team Preparation

3.41 The facilitation team would comprise a small group of no more than 4 or 5 people, including a team leader; a local NGO representative, teacher, health worker, or person in a similar position who could evoke community trust and respect; and one or more biomass energy experts (or someone well versed in the national level assessment and bioenergy options). In the course of several initial meetings, they would assemble a broad array of visual tools, including resource maps, local ecological data, and descriptions of biomass energy technologies. They should also identify local spatial units of concentrated biomass availability (for example, existing forest, plantations, farms, biomass depots).

3.42 While electronic tools like GIS, videos and Powerpoint presentations could be visually stimulating, their use may require careful consideration on several fronts. In particularly impoverished contexts a visit by outsiders with glamorous technical equipment may confuse local residents and also firmly establish an asymmetric power relationship between the two groups. It would also be impractical, not to say ironic, to attempt to use such equipment in areas that have limited or no access to electricity. However, there may still be occasions (for example, where local ICT centers are proximate) where the use of computer technologies may be appropriate.

3.43 Explaining the purpose and approach of the assessment exercise to local community leaders is essential. An appropriate way to do this would be through a reconnaissance visit by team leaders along with local NGO contacts. It is important to describe fully the scope of the exercise, its participatory structure and the fact that no political or other promises ensue from it except insofar as it improves mutual understanding of community needs and the possibilities for resource development.

Step 4. Stakeholder Selection

3.44 In general, virtually every member of the community is a stakeholder in a needs assessment exercise. While it is impractical to include everyone in the exercise, special care must be taken not to exclude the disenfranchised. Representative groups would include, though not be limited to the following:

a. *Farmers*: It is important that both large and small landholders be represented, including landowners as well as sharecroppers and farm laborers. Farmers' needs typically cover a wide spectrum including the availability of agricultural inputs (water, fertilizer, seeds, labor, land, credit) and the market for their products. While they are often the most significant producers of biomass feedstock, this is no reason to afford them privileged positions in the participatory process.

b. *Household end users (especially women)*: Not only are women traditionally the most unlikely groups to be consulted during development efforts, they often also hold themselves back from participation in public affairs because of social mores. Nevertheless, by virtue of their roles as homemakers they are generally the most intense local users of biomass, from firewood collection for cooking to fiber generation for various "cottage" products. The facilitation team may have to make special efforts to recruit women and other end users of biomass.

c. *Local NGOs and academics involved in agriculture and development activities.* It is usually not difficult to locate a local voluntary agency, school or college teacher engaged in social work in a village or within its vicinity. Such players have a great deal of local knowledge but could often be relied upon to provide alternative perspectives on local needs because they may discern patterns within the larger local area or social context.

d. *Local forestry staff*

e. *Other local government officials.* There are obvious reasons to include representatives from these two categories, which include the reasons cited above for local NGOs. From the standpoint of potentially developing a project subsequently in the area, their early involvement would also create the necessary continuity for later, detailed site assessments and project preparation.

f. *Owners /operators of agroprocessing facilities.* These groups carry important information about the biomass availability chain, which could be illuminating to facilitators, end users and other biomass producers.

g. *Informal biomass procurement sector/municipal waste handlers.* The inclusion of this group could be as important as the last for participants to get a clear picture of feedstock availability.

3.45 One way to select participants would be to establish contact with community leaders and explain the need to select individuals from each of these groups and to formulate a team on that basis. In many situations, this may be the only realistic choice. Alternatively, if local NGO representatives have direct rapport with community members, they could help seek out participants. Sometimes, the existence of village level institutions (for example, agroprocessing cooperatives, self help groups, micro credit institutions) could greatly facilitate the involvement of otherwise poorly represented groups like women. Typically, no more than 20-25 participants should be chosen, in order to keep meetings manageable.

Box 3.1: Gender and Participation

Involving women in participatory schemes is especially critical. A bioenergy related activity is unlikely to benefit women—or succeed at all—unless it involves women directly. Indeed, women are likely to be the *main* local collaborators in successful bioenergy activities that rely on local resources and provide for household needs. Women are, in fact, indispensable to many local development organizations and movements. Owing to the considerable gender differences in access to, control over, and reliance on, bioresources (both for energy and nonenergy purposes), women will have different needs, opinions, knowledge, skills, and degrees of access to and control over resources. These differences 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).

Despite the value of doing so, it can be especially challenging to elicit women's participation. Women are frequently excluded from public decisionmaking forums or, if not excluded, their active participation and initiative are discouraged by attitudes about appropriate female conduct. Women face a "glass ceiling" in village committees and farmers organizations, 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).

Step 5. Learning on both sides

3.46 A schedule for 3-4 meetings should be developed by the team members and the local participants to ensure that sufficient time is made available for interaction and learning. A facilitator should be selected to set rules for discussion, set the agenda and promote communication among all the actors. S/he should be respected by the entire group and be skilled to manage unexpected situations and disruptions.

3.47 As discussed earlier, mutual engagement could take place through a variety of methods, including interviews, focus group discussions, and multimedia workshops. The actual process of deliberation could be determined either by the facilitator in the course of the needs assessment process or by reference to one of several participatory toolkits mentioned at the end of this chapter. The key point is to ensure that actors have opportunities to share knowledge with each other and build a clear picture of needs and resources while ensuring that traditionally weak constituents (for example, women, poor farmers) feel empowered to speak publicly. In some cases, it may be necessary for female team members to speak privately to some of these players and voice their concerns in public forums without misrepresenting them or putting their situations in jeopardy.

3.48 An important element of the exercise would be to use visual tools as imaginatively as possible. For instance, diagramming could give local people a share in the creation and analysis of knowledge, providing a focus for dialogue that could then be modified and extended. Local categories, criteria and symbols are used during diagramming; tools to achieve this may include mapping and modeling, comparative analyses of seasonal, daily and historical trends, ranking and scoring methods to understand decisionmaking, and diagrammatic representations of household and livelihood systems. Visualizations help to balance dialogue, establish rapport and increase the depth and intensity of discussion.

3.49 A number of areas need to be covered in the discussion, including:

a. Ranking of primary needs felt by stakeholder group (for example, jobs, sanitation, water, credit, cooking, lighting)

b. Local livelihood concerns (for example, seasonality of farm labor, pressures on local industries and craft)

c. National level assessments and findings for local region

d. Local field assessment exercises carried out by stakeholders with assistance from facilitator and assessment team to confirm (or establish) distribution and volume of resource (including parameters such as residue ratios, yields, seasonal availability, and others)

e. Potential competitive demands for apparent biomass resources (for example, fertilizer, household fuel, artisanal materials, etc)

f. Ownership and access of biomass resources and land, land tenure, resource custody.

g. The practical availability of biomass to end users.

h. Physical constraints (is it too far? Does transport infrastructure exist?)

i. Biomass energy generation technologies and costs, potential for investment, issues, concerns relating to investors

j. Labor availability/cultural willingness (especially in the case of dung, human waste) and labor cost for harvesting, procuring, transporting

k. Availability of capital (access to necessary harvesting tools/equipment)

3.50 As emphasized earlier, the discussion on primary needs ought to remain the central focus rather than the biomass resource availability and related technology. Team members ought to make a conscious effort to treat the latter as offering potential, though not inevitable, solutions to the former and work with the stakeholders to identify all the potential conflicts as well as opportunities involved. The next two sections develop two of the most important themes that are likely to emerge in the course of the exercise: feedstock procurement and income generation. The discussion in these sections does indeed go beyond the first level of needs assessment—what stakeholders need—by highlighting practical considerations relating to project definition and development. Nevertheless, these considerations would very likely emerge during the needs assessment exercise and the facilitation team could benefit by having advance notice of these issues.

Additional Resources

3.51 Below are listed some of the main resources on participatory development approaches.

- PLA Notes www.iied.org/sarl/planotes/index.html
- Institute for Development Studies, Sussex www.ids.ac.uk/ids/particip/
- Participatory Research and Gender Analysis www.prgaprogram.org/
- World Bank Participation Methods www.worldbank.org/participation/methods1.htm
- UNDP/CSOPP Guide to Participation www.undp.org/csopp/CSO/NewFiles/docemppeople6.html

Conclusions

3.52 As is emphasized throughout this report, well-designed biomass energy projects and programs that increase the availability of energy services can amplify opportunities for productive work and thereby improve livelihoods. Conversely, poorly designed bioenergy interventions can appropriate resources unfairly, and thereby adversely affect rural livelihoods and even lead to the further impoverishment of the most vulnerable community members who rely heavily on common natural resources. This section stressed the importance of designing and undertaking bioenergy activities with community involvement, which could range from consultation on project design to participation in project implementation.

3.53 The importance of community involvement is warranted by the fact that bioenergy, even more so that other renewable technologies, is rurally based and land, resource, and labor intensive, and that will thus unavoidably affect the communities with which it is colocated. Ensuring that those impacts are positive, rather than negative requires the policymaker or project developer to be sensitive to community conditions and needs from the very conception of the bioenergy program. Bioenergy activities will be consistent with sustainable development and its objectives of environmental impacts and livelihood generation only if those goals are built into the project design and implementation.

3.54 Participatory approaches can help ensure that development benefits and their equitable distribution are intrinsic parts of bioenergy projects. Participatory approaches can moreover have positive effects by helping build social networks around projects and programs that make collaborative use of biomass resources for development needs.

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Advancing Bioenergy for Sustainable Development Guideline for Policymakers and Investors

Volume II

Technical Annexes

1

Biomass Resource Assessments

1.1 National policy and planning for bioenergy development must be based on information about the size of the biomass energy resource and the broad range of costs for producing and delivering energy from it. Broad brush information of this kind is needed for the most basic assessments of national energy R&D and policy options, including the potential role of renewable energy within the total energy supply mix, and the potential for bioenergy as a renewable energy source. Rather more detailed assessments of the main types of biomass resource, such as crop or wood processing residues or the land area that might be available for energy crops, are needed for the selection of bioenergy development priorities. Even more detailed, focused and data intensive assessments are required to establish the feasibility and outline design of actual bioenergy projects.

1.2 Reliable assessments of this kind are not easy to make. The lack of good quality data and uncertainties concerning basic assumptions often mean that even the most broad brush estimates come up with widely varying results. For example, four studies on the potential in India of cogeneration based on sugarcane bagasse found it to be 2.8, 3.5, 3.8 and 5.1 GWe (Bakthavatsalam 1999). Three studies on the same topic in Thailand gave answers of 190-296, 329 and 415 MWe (Junginger 2000). At the project level, where a dependable and affordable biomass supply is crucial for success, assessments must be sufficiently comprehensive and detailed to throw light on all the main risks outlined in Chapter 1 of the Main Report, including uncertainties about the size of accessible resources, competing uses, biomass price variations and other logistical risks.

1.3 This chapter outlines the major steps involved in making such assessments, using actual examples wherever possible. It focuses on broad brushed assessments for relatively large areas such as a nation. If the purpose is to help determine priorities for further studies and the development of particular bioenergy options, these assessments need do no more than make rough working estimates of potential residue resources, how much of these are actually used, and residue costs and prices.

1.4 However, in order to go beyond this initial scoping stage, national assessments have to reach down to the local level, with all their variety in most of the important parameters, and build up the national picture as the sum of the local parts, much as with a jigsaw puzzle. For example, one of the leading US biomass energy assessments relies in part on detailed crop production data for the 305 agricultural districts that make up the USA's farmland (see Section 1.4). The Indian National Biomass Resource Assessment project will be based eventually on detailed information from nearly 500 of roughly 3,000 subdistricts that make up the country. These local assessments form an important part of the assessment methodologies described below.

Methodology for Assessing Residue Resources

1.5 This methodology is designed to be used for any geographical scale, such as a nation, a national region, a district or a village. It focuses on agricultural and forestry residues and can be used for two main objectives.

1.6 The first objective is to portray, for each main crop/residue combination, the present structure of residue resources, supply and consumption. A major aim is to determine how much residue "waste" is immediately available for modern bioenergy applications. This structure can be depicted much like a national energy supply and consumption balance, as shown in Table 1.1.

Table 1.1: Outline structure of biomass residue Resource/Supply/Consumption balance

1. Potential Resource	All primary and secondary residues generated
2. Production	All *collected* residues
3. Supply	Production
	+ 3a. Imports
3b. Exports	
3c. Consumption	energy uses (traditional fuels, industry, etc.)
3d. Consumption	non-energy uses (various)
4. Unused or Uncollected Resource	
4a. Unused secondary "waste"	– concentrated: dumped near processing industries
4b. Uncollected primary "waste"	– dispersed: too costly to collect, or no local demand
4c. Uncollected primary "used"	– dispersed: left on ground or burned to protect/improve soils

Note:

Potential Resource (1) = Production (2) + Unused or Uncollected Resource (4)

Supply (3) = Production (2) + Imports (3a) = Exports (3b) + Consumption (3c, 3d)

1.7 The first two categories of Unused or Uncollected residues, the 4a and 4b "wastes", are in principle available as modern biofuels provided costs for collection, fuel preparation and transport are not too high.

1.8 The second objective is to estimate to what extent these consumption patterns can be changed in the short to medium term, by policy or project interventions, in order to release more residues for modern bioenergy production. In most places there are many possibilities for doing so. For example:

- with 3c (Consumption for energy uses), by providing more efficient cookstoves;
- with 3d (Consumption for non-energy uses), by changing industrial practices, such as using bagasse as fuel rather than as a paper feedstock;
- with 4a (Unused secondary "wastes"), by improving residue collection and preparation technologies to lower the residue supply cost;
- with 4b (Uncollected primary "wastes"), by changing crop harvesting practices also to reduce the supply cost.

1.9 Taken together, the two objectives provide estimates of how much of the potential resource might, in principle, be tapped for modern bioenergy application (for various residue prices) by short to medium term policy changes and project interventions.

1.10 A third possible objective is the estimation of long term residue potentials as a result of major changes in key parameters such as crop yields, processing technologies, or industrial production patterns. This may help to define long term bioenergy options and strategies but is so site and region specific, and so fraught with uncertainties, that the concept is not covered in this report.

1.11 With all these objectives the analysis can employ any desired level of disaggregation, depending on how many local studies are conducted.

1.12 With the first objective, which requires only the most broad brush preliminary assessment, one might rely solely on national aggregate statistics (which are, of course, often compiled from local data). However, a representative sample of local studies can help to build a more reliable picture, and the more such studies, the more reliable the final results are likely to be.

1.13 With the second objective, local variation of nearly all the relevant conditions is typically so great that a (large) sample of local studies must be used for the results to be credible. Furthermore, any actions to effect short to medium term changes in residue use must be designed in the light of local information.

1.14 An obvious initial step of the methodology is to define the geographical area of the study. This will normally be defined by political boundaries (nation, state, county, district) as these divisions normally are used for agricultural and other relevant statistics. The remainder of the methodology is outlined in the section below and leans heavily on an approach developed by Martin Junginger (2000; also Junginger et al. 2001). However, it contains some significant departures from Junginger's method, especially in terminology, largely because the latter was designed principally to assess potential residue resources for specific bioenergy projects—the subject of Chapter 2 of the Main Report but not of this chapter.

Step 1: Construct a Residue Resource/Supply/Consumption Balance

1.15 The first major step of the methodology is to estimate the annual weights of the main types of field and forestry crops and associated residues in the study area in terms of the principal production, consumption and "waste" categories outlined above. The main aim is to obtain a broad brush picture of biomass production and residue generation, residue consumption and, not least, the quantities of unutilized residues which might possibly be available, or made available, as modern biofuels. The physical and chemical properties of residues can be determined at this stage, including especially average moisture contents and associated energy values (e.g. MJ/kg) so that all categories of residue can be quantified in terms of energy units. Seasonal availability can also be examined.

Step 1a: define the important residue types

1.16 The aim here is to identify the main agricultural and forestry activities that give rise to biomass residues. Depending on the resources available and the required accuracy for the study, the analysis might select only the major activities and ignore the minor ones. The number of activities that need to be selected depends very much on local circumstances. For example, under the ongoing Indian National Biomass Resource Assessment, in one group of villages (*taluk*) 96 percent of potentially surplus crop residues came from just two sources (sugarcane trash 61 percent and rice straw 35 percent). In a neighboring *taluk* the largest two crops provided only 74 percent of the total residue resource while inclusion of the top five crops is needed to account for 93 percent of the total (Pranam 2001). For each selected crop the corresponding primary and secondary residue types must be identified.

1.17 The main task in this preliminary stage is to establish a good statistical data base. The necessary data can be sought from national or regional statistics, relevant government authorities (for example the ministry of agriculture or forestry), research institutes, agricultural/forestry organizations and

the crop processing industries or their trade associations. The published and gray literature, as well as experts from the relevant industries and university departments, might have relevant information.

1.18 In the likely event that these sources are not sufficient, further data collection by survey methods should be considered. A good start is to request information from a sample of the main producers/processing industries in the research area, such as sugar producers, logging companies, sawmills, and rice mills. Many of these should have good information on crop yields and associated residue volumes in their biomass feedstock supply area. For maximum scientific credibility, the sample should be constructed from a list of all identifiable producers/processing industries, using standard random sampling techniques that ensure that the sample is representative of the whole study area.

1.19 The quality of nearly all relevant statistical data should be treated with caution. The data may have been gathered annually, with greater or lesser rigor, or may have been extrapolated over several years using various (unstated) assumptions from one historical base year (for example, from an agricultural census). Efforts should therefore be made to check for inconsistencies between various statistics and, most important, between the statistics and direct evidence of recent productivities and volumes from the residue using industries.

1.20 It is also important to establish, as reliably as possible, time series for each crop (perhaps in several regions) with regard to the area planted, annual yield, and/or annual production. These basic factors usually vary from year to year in response both to climatic factors, such as droughts and floods, and economic factors, such as the price of the crop and of fertilizer. The extent and frequency of these deviations, as well as the long term average trend, provide important information for estimating both the size of current potential resources and possible future resource levels.

Step 1b: quantify the main supply and consumption categories (by weight)

1.21 Very few, if any, national or regional statistics record volumes of crop or forestry residues. However, as suggested above, some data are usually available if the residues are already utilized by industry. For example, the sugar industries of many countries use bagasse as fuel (or sell it to paper makers and other users) and often record the amount produced per tonne of sugarcane reaching the sugar mill. In many cases, though, residue quantities must be calculated indirectly from the amounts of goods produced, such as timber, plywood, rice, and palm oil. This product information is very likely to be available at the national or regional level in government and industry sector statistics.

1.22 To estimate how much residue is generated, one needs to know the Residue to Product Ratio (RPR), which indicates the weight of residue per unit weight of product; for example, the weights of rice husk and of rice straw per unit weight of rice grain. This method is often used for annual crops. A similar and more direct method sometimes used for perennial crops is the Residue to Area Ratio (RAR), which is based on the amount of residue per unit of cropped or forest/plantation area (Koopmans & Koppejan 1998). Multiplying these ratios by the volume of crop production or product output gives the potential resource for each residue (in tonnes a year).

1.23 Examples of the RPR and RAR method from a resource assessment in Malaysia are presented in Box 1.1. The Box outlines the methodology for palm oil residues (RPR) and rice production (RAR). The Box illustrates clearly how broad brush resource assessments can be very useful in defining bioenergy policy and development priorities. In this case, while the potential residue resource for rice husk and rice straw amounted to only 1 percent of Malaysia's total primary energy consumption (including biomass) the equivalent figure for oil palm was nearly 44 percent. A more comprehensive analysis for Malaysia is presented in Table 1.2 and discussed below.

Box 1.1: Estimating palm oil and paddy residues in Malaysia

A study of biomass production from the major crops in Malaysia—oil palm, rice, rubber, coconut, sugarcane, cocoa and logging—provides good examples of residue estimates based on production areas and on residue/crop ratios (Lim et al. 2000). The full study is outlined in Table 1.1; the sections on oil palm and paddy are detailed here.

Oil Palm: an estimate based on areas

In 1996 (the study year) Malaysia produced 9.17 Mt of crude palm oil and palm kernel oil from 2.326 Mha of mature productive plantations. Previous studies had estimated the average per hectare production of all components of these plantations as well as their typical energy content. From this it is a simple matter to draw up the table below.

Oil palm residues: per hectare per year	dry tonnes	GJ per tonne	GJ	Present practice
Fronds from annual pruning	11.0	18.7	206	left on ground to rot
Shells from fruit nut	2.8	22.5	63	often burned for mill heat & power
Fruit fibers	1.8	19.5	35	often burned for mill heat & power
Empty fruit bunches after oil extraction	1.5	20.5	31	
Fell and replant every 25 years: felled trunks	2.6	14.9	39	left on ground to rot
Fell and replant every 25 years: cut fronds	0.6	18.7	11	left on ground to rot
Sub-total	20.3		385	
Liquid palm oil effluent used in 2 mills to produce biogas: 11.3 m^3 effluent x 27.9 m^3 biogas per m^3 effluent x 22.8 MJ/m^3 biogas			7*	*if all effluent is converted to biogas; only 1% is with present practices
Less shells & fibers used for energy in mills			- 98	
TOTAL UNUTILIZED per hectare			294	
National total (x 2.326 Mha): 684 PJ/year				

This huge unutilized resource of 684 PJ/year amounts to 32 percent of Malaysia's primary energy consumption (including biomass). There is thus a strong case for further study on how the unutilized residues, especially discarded tree fronds and trunks, might be used for energy production without jeopardizing soil quality. On the other hand, biogas production has a much lower priority, although it may be important to the finances of some mills.

Rice paddy: an estimate based on residue production ratios

In 1996 Malaysia produced 2.128 Mt of rice paddy (rice husk + grain) from a planted area of 0.639 Mha. A survey of rice mills established that roughly 23 percent of the paddy is rice husk, the remainder being milled grain. Other studies found that the ratio of straw to paddy is about 1:2, so production of straw was 1.064 Mt. With estimates of moisture levels and the energy content of dry biomass the following table can be constructed.

Total annual data	Production (Mt)	Moisture (%)	Production (dry Mt)	Energy content (GJ/dt)	Energy in residues (PJ)	Present practice
Rice husk	0.489	13.5	0.423	14.93	6.32	} Most burned or left in fields
Rice straw	1.064	16.0	0.894	15.85	14.17	} and around rice mills **
TOTAL residues					20.49	
(Rice grain)	(1.638)	(10.3)	(1.47)	(16.0)	(23.5)	

** Attempts have been made to use rice husks for energy (by gasification) but so far with little success. Some husks are processed into fertilizer, mosquito coils, and chicken feed. Some straws are used for mushroom cultivation and the manufacture of paper and particle board.

The total unutilized resource of under 20.5 PJ/year amounts to less than 1 percent of Malaysia's primary energy use (including biomass), suggesting that these residues have a low priority for further study and actions. This conclusion might change if rice husk gasifiers could be developed as a mainstream technology, although competing nonenergy (and higher value) uses must be carefully considered.

Table 1.2 Crop and residue production and utilization in Malaysia (c. 1996)

-1- Crop / Activity	-2- Crop Area (M ha)	-3- Total productivity (GJ/ha/year)	-4- Production: total (PJ/yr)	-5- Production: main product (PJ/yr)	-6- Residues: energy use (PJ/yr)	-7- Residues: not used + non-energy use (PJ/yr)	-8- (Cols 6+7 as % of TOTAL)
Oil palm	2.326	546	1270	358 (palm & kernel oil)	228	684 (595 fronds, etc. left on ground)	63.5%
Rubber trees	1.714	182	312	108 (93 rubber, 15 wood)	31	173 (150 leaves, twigs, etc. left on ground)	14.2%
Coconut	0.249	173	43	7.3 (copra)	14.5	21.2 (7 wood & fronds left on ground)	2.5%
Cocoa	0.235	494	116	2.5 (cocoa bean)	--	113.5 (113.5 pruning wastes left on ground)	7.9%
Rice	0.639	69	44	24 (rice grain)	--	20 (6 husk, 14 straw)	1.4%
Sugarcane	0.018	339	6.1	1.7	2.6 (bagasse)	1.8 (1.8 tops & leaves burned in field)	0.3%
Logging	N.A	N.A	336	218 (harvested wood)	--	118 (118 left on ground)	8.2%
Sawmills	N.A	N.A	83	54	23	6 (6 sawdust, bark, chips)	2.0%
TOTALS (percent)			2210 (100%)	774 (35%)	299 (13%)	1137 (52%)	100%
--- [left on ground]						--- 985 (45%)	

Note: National primary energy consumption (including biomass) = approximately 2100 PJ/year

Source: Lim et al. 2000

1.24 The same data sources as in Step 1A can be used. Field tests may be needed to check or determine RPR and RAR values, which are subject to considerable uncertainty. Residue Production Ratios (RPR) vary widely, even for the same crop/residue combination. With primary/field residues, values depend on the crop species (short versus long straw varieties); crop yield (a high yield grain crop may have no more straw than a low yield crop so may therefore have a lower RPR ratio of grain to straw); and harvesting practices (for example, the length at which straws and stalks are cut off and left in the field). These values may differ between regions and districts depending, for example, on the degree and type of mechanization. With secondary/process residues, RPR values depend on the efficiency and type of machinery employed and user skills. Although estimates from the global literature are unlikely to result in serious errors for the broad brush national assessments considered here, local data based on substantial numbers of sample measurements are essential for local assessments. This point is underlined by the range of RPRs found in the literature for the same crop-residue combination, shown in Table 1.3.

Table 1.3: Residue/product ratios: estimated ranges and midrange values

Crop & residue	N	Mid range	Range	Crop & residue	N	Mid-range	Range
Rice straw	12	1.80	0.45 – 4.00	Rice husk	8	0.27	0.20 – 0.35
Wheat straw	8	1.46	1.00 – 1.80	Maize cob	8	0.48	0.20 – 1.80
Millet, rye, oat straw	6	1.55	1.10 – 2.00	Maize husk	3	0.23	0.23 – 0.23
Barley straw	7	1.54	0.60 – 1.80	Groundnut husk/shell	4	0.67	0.48 – 1.20
Sorghum straw	8	2.34	0.90 – 4.90	Sugarcane bagasse	6	0.40	0.10 – 1.16
Groundnut straw	4	2.43	2.20 – 2.90	Sugarcane tops/leaves	3	0.18	0.10 – 0.30
Cassava stalk	6	0.15	0.06 – 1.00	Coconut husk	3	0.84	0.42 – 1.60
Maize stalk	8	2.10	1.00 – 4.33	Coconut shell	4	0.53	0.12 – 1.10
Jute stalk	4	1.82	1.37 – 2.25	Oil palm fiber	3	0.13	0.11 – 0.15
Cotton stalk	5	3.61	1.77 – 5.00	Oil palm shell	3	0.06	0.05 – 0.09

N: number of independent data sources in the literature
Mid-range value: the unweighted mean of lowest and highest estimates
Source: Koopmans & Koppejan 1998

Step 1c: quantify the main supply & consumption categories (as energy)

1.25 The next step is to determine the energy content of the residue resource, production and consumption categories estimated above. Other data relevant to the suitability of residues as biofuels can also be collected. The following quantities are required for this step:

- the moisture content of residues at the point where their weights are estimated in Step 1b. Moisture content can vary from above 50 percent for freshly harvested "green" residues to 10 percent or less for air dried material, with correspondingly large effects on the weight, density and unit energy content of the biomass.
- the corresponding energy value (MJ/kg) in terms of lower heating values (lhv) or higher heating values (hhv). The appendix (see end of Annex 2) presents formulae and values for estimating energy content according to moisture level.
- it is also useful in support of later analyses to collect at this stage information on the bulk density and physical form of residues at key points in the collection and utilization chain, especially whether they are woody stalks (cotton stalks), soft stems which can be baled and

compressed (cereal straws); or free-flowing particles (rice husk). This information has strong bearings on the ease of handling and transporting residues.

- the chemical composition, especially of soil nutrients (nitrogen, phosphates, potash), ash, and heavy metals.

1.26 Multiplying the weight of residue by its energy value gives the amount of residue in terms of energy as PJ/year. The chemical composition indicates possible environmental problems such as high heavy metal depositions and NOx emissions; the probable adequacy as fertilizer of returning combustion ashes to the field; and special demands placed on the conversion plant in the case of high ash or high alkali content (see the Chapter 2 of this Technical Annex).

1.27 Heating values are often given in the literature without noting moisture content or whether they are lower or high heating values. Similarly, moisture content may be given on a wet, dry, or dry and ash free basis without stating the basis used (see Appendix). Serious errors may result if these values are simply adopted from the literature without checking which parameters are used. Field or laboratory tests can provide more accurate and reliable results both on means and ranges for each residue. However, since sample variation is usually large, many samples must be measured to give reliable results. Field tests may well be judged too expensive for broad brush assessments.

Step 1d: determine the seasonal availability of residues

1.28 The final step in characterizing the potential resource and supply is to estimate in which periods of the year residues are and are not available.

1.29 The average length of the harvesting season (together with local and annual variations) should be determined for each residue type. Although some crops (for example, wood thinnings and animal wastes) may be harvested all year round, most residues from annual crops are available only during and for a brief period after the harvest season. Table 1.4 gives one example of how availability varies by month, in this case for agricultural residues in one region of India. The required information is usually available at agricultural and forestry institutions and from local farmers.

Table 1.4: Seasonal availability of agricultural crops in one region of India

Residue Availability:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maize stalks							✓	✓	✓	✓	✓	✓
Maize cobs							✓	✓	✓	✓	✓	✓
Cotton stalks	✓	✓	✓							✓	✓	✓
Mustard husk				✓	✓	✓						
Jute & Mesta sticks							✓	✓	✓	✓	✓	✓
Rice husks				✓	✓	✓	✓	✓	✓	✓	✓	✓
Groundnut shells				✓	✓	✓				✓	✓	✓
Athar stalks	✓	✓	✓							✓	✓	✓

Source: Junginger 2000, based on Tripathi et al. 1998

1.30 There are normally few uncertainties with this step, as the timing and length of the harvest period, plus possible variations of these, are reasonably well known for all major crops.

Step 1e: add results to determine study area total

1.31 In this obvious and final step, data from local areas are tallied to create totals for the whole study area. Much policy relevant information can be obtained from the degree and kinds of variation between regions and through the identification of regions with particularly high and low potential resources. Global Information System (GIS) techniques can be used to map these data according to each local area or group of neighboring areas.

Example of Step 1 results—Malaysia

1.32 The results of applying a methodology very similar to this one are shown in Table 1.2 and Box 1.1 for all of Malaysia in 1996 (Lim et al. 2000). Step 1D (seasonal availability) is omitted. The value of this kind of broad brush study in identifying priorities for further study is clearly shown in the table. For example:

- The entire residue resource (sum of Columns 6 & 7) is 1436 PJ/year, or 68 percent of the country's total primary energy consumption. Further study of this huge potential energy resource obviously deserves a high priority.
- Some 301 PJ/year, or 14 percent of total primary energy, are already used for energy purposes (Column 6). But most residues—the remaining 1135 PJ/year of Column 7—are either unused or are taken up for nonenergy applications. These two crucial categories are not clearly distinguished in this study for all residues (e.g. oil palm, rubber trees, and rice straw) and must obviously be examined more carefully by local surveys.
- It is clear, though, that most residues are never collected from the ground or processing factories (985 PJ/year: see foot of Column 7). As noted above and discussed below, the main reasons for this are high collection costs relative to local biomass prices, a lack of local market demand, and deliberate use of the residues to maintain or improve soil quality. There may also be some (or much) unrecorded collection by poor families for essential household fuel. How much of this huge potential resource can be mobilized for modern bioenergy applications—economically and without denying essential fuels to the poor—is the big question raised by this first cut survey.
- For prioritizing further studies aimed at answering this question, Column 8 provides a useful pointer to the crops which provide the largest (and smallest) potential residue resources (the sum of Columns 6 & 7). The four leaders, oil palm, rubber trees, cocoa and logging, account for 94 percent of the total and would appear to be the prime candidates. However, this score card may need modifying by looking at trends and future expectations for each candidate crop: in Malaysia, for example, cocoa production is declining.
- A final and interesting point revealed by the assessment is the very high per hectare bioenergy productivity of some crops. In order to establish this figure (Column 3) the production and energy content of all parts of the crop must be estimated, including the principal crop products such as palm oil and rice grain (Column 5). Remarkably, cocoa and oil palm turn out to have productivities close to or above 500 GJ/ha/year. This could be matched by trees as energy crops only if their productivities were about 27 dry tonnes/ha/year or more (assuming 18.8 GJ_{lhv}/dry tonne)—a high figure even for the tropics.

Step 2: Determine Local Biomass Resources, Supplies and Consumption

1.33 The first stage of the national assessment, discussed above, cannot distinguish with confidence between the major categories of residue consumption. Nor can it determine the various reasons why so many residues are not collected from the field, forest, or processing plant. This failing is well illustrated by the Malaysian example described in Table 1.2 and Box 1.1.

1.34 To reduce these uncertainties, detailed local scale studies are essential. Indeed, estimates of local residue use, associated costs and prices, and the reasons why residues are not used or collected, are a crucial step in the whole assessment methodology, for three main reasons:

1. simply to understand the present scale and patterns of biomass use (what types, how much, which consumers) and associated supply costs and prices. Local variation means that reasonably credible results must be built up from local studies.
2. to distinguish between present residue production (quantities of collected residues) and the present potential resource, which includes uncollected residues. Again, local studies are essential, especially in helping to determine what policy or project interventions might be made in order to generate more biofuel supplies.
3. to identify vulnerable consumers who may have no alternative to continued biomass use and therefore need protection from attempts to secure more biofuels for modern applications. Again, these issues are location specific.

Step 2a: construct a local residue resource/supply/consumption balance

1.35 The basic idea of Step 2 is the construction of a local biomass resource/supply/consumption balance, as outlined above and in Table 1.1. Ideally, this balance should include all forms of biomass that underpin the local economy, including food, feed, timber and other fiber as well as fuel, but it may be restricted only to residues. In the latter case, the balance should include harvested wood, as this is a major potential source of fuel, as well as crop and forestry residues. It should also include nonmonetized supply and consumption as well as monetized or traded supplies.

1.36 Most data for constructing the balance must be obtained by questionnaire, observation and other survey methods. Some local data may be available from state or district level government and industry associations, especially for biomass processing industries and forestry. National or subnational statistics cannot safely be relied on; nor can old data even for the same location. Surveys are required of all the main groups of consumers and producers, namely:

- a sample household survey to determine means and ranges of energy consumption by type of fuel (including nonbiomass fuels and electricity), whether collected or purchased; purchase prices; and perceptions of fuel problems.
- a similar survey of commercial energy users, including hotels and restaurants, schools and medical centers, offices and industries. Of particular importance are energy intensive industries such as brick kilns.
- surveys of biomass processing industries such as saw mills, rice mills, sugar mills, and producers of palm oil and coconut products. Ideally all industries should be surveyed; if not, a selected sample should include large and small industries as scale of operation usually has a major bearing on whether residues are used for fuel or dumped.
- a sample survey of farmers and any logging companies operating locally.

1.37 Uncertainties may be large but depend almost entirely on the quality of the surveys and their sample sizes. Checks on data quality and errors can be made by inspection of the supply and consumption items of the residue balance. For example, if recorded surpluses do not equal supply less total consumption, something is wrong and the data need to be rechecked or even resurveyed in part.

Example of Step 2A results – Gobbi taluk, India

1.38 A sample Resource/Supply/Consumption Balance is presented in Box 1.2, based on a detailed assessment for one district (*taluk)* in southern India. The data are laid out in a manner that conforms to but expands slightly on the seven category structure outlined above, especially (1) potential

resource; (2) consumption for energy and for nonenergy purposes, (3) exports, and (4) unused or uncollected residues. Other ways of laying out the data may of course be used.

Box 1.2: Residue resources and consumption in Gubbi *taluk*, Karnataka, India

Gubbi *taluk* covers 1,220 square kilometers in Southern India and had 346 villages with a combined population of just over 231,000 in 2000, the year it was surveyed as part of the Indian National Biomass Resource Assessment (Tide Technocrats 2001). The survey found that 230.8 thousand tons (kt) of residues were generated in the year, almost entirely (92 percent) as dispersed primary resources. About 71 percent of the residues were from coconut production: see the Supply row in the table below.

Resource–Consumption Balance

tonnes / year	Saw-mill wastes	Rice husk	Rice straw	Ragi straw	Areca fronds	Ground-nut stalks	C'nut coir pith	C'nut shell	C'nut husk	C'nut fronds	TOTAL (k tonnes)
Potential Resource	921	2290	11750	42150	7145	1700	3650	15200	58415	87620	230.8
(site)	(I)	(I)	(F)	(F)	(F)	(F)	(I)	(I, F)	(F)	(F)	
Consumption											
domestic (fuel)	921	72							47330	76120	124.4
industry (fuel)		1300						600	4600		6.5
thatching										4380	4.4
fodder			11750	42150							53.9
soil mulch						1700					1.7
Total consumption	921	1372	11750	42150	0	1700	0	600	51930	80500	190.9
Exports								14600	6485	7120	28.2
(Price: US$/t)								*18-22*	*4.4*	*3.3-4.4*	
Uncollected		918			7145		3650*				11.7

Sites: (I) industry, (F) farms or coconut plantations, mostly primary (field) residues, C'nut: coconut.

* most coir pith is not collected; very small amounts are used as soil conditioner.

The table also shows that nearly 191 kt (83 percent) of the residues were consumed in the villages, mostly as traditional fuel for cooking, etc., and as animal fodder. This leaves a "surplus" to local needs of just under 40 kt, the great bulk of it also arising from coconut production.

About 70 percent of this surplus, all of it coconut residue, was sold out of the *taluk*, mostly for energy use, producing a revenue of about US$ 0.33 – 0.40 million. These resources would make very suitable fuels for modern bioenergy applications and their prices are relatively low (under $US 1.5/GJ). However, any such use would deny fuels to present consumers outside the *taluk*. It might be better to try releasing for modern bioenergy applications some of the huge quantity of residues now used for domestic (and industrial) fuel—as much as 54 percent of the primary supply—by, for example, providing more efficient cookstoves and industrial boilers. Much of the 11,700 tonnes of uncollected residues might also be available but these are poor fuels and amount to only 5 percent of the primary supply.

The Table below gives some further information on these exports and the remaining (uncollected) residues.

Characteristics of Uncollected & Exported Residues

	Rice husk	Areca Fronds	Coir pith	Coconut shell	Coconut husk	Coconut fronds
	Uncollected	Uncollected	Uncollected	Export	Export	Export
Uses	none	Mulch	small amounts as mulch	mostly for charcoal	fuel, some industrial non-energy use	fuel
Suitability as modern biofuel	poor: high ash & dispersed sources	------	moderate: high ash, may need briquetting	good: dry, but high price	good: dry, and low price	good, if 60-90 days drying

Step 2b: collect and analyze costs, prices and their ranges

1.39 The aim here is to complete the study of local biomass supply and demand by collecting and analyzing the costs of prepared or delivered residues (supply costs), market prices and cost/price ranges. These quantities can change rapidly as supply and demand patterns alter; for example, as increasing firewood scarcity drives families and industries to burn more residue, driving up their price; or as larger scale agroprocessing industries begin to burn residues for their energy needs instead of dumping them as freely accessible resources. Potential biofuel resources must often compete with nonenergy uses, such as wood pulp or straw fodder, almost entirely on the basis of price. It is therefore imperative that the price analysis is extended to all local biomass supplies and uses. A good knowledge of local biomass prices is essential for studies to determine the feasibility of, and best locations for, new modern bioenergy facilities.

1.40 Taking this crucial point a little further, Junginger (2000) notes that there are three possible residue price situations:

1. Residues already have a monetary value. A study of residue utilization by different consumer groups and price ranges can provide important information for project interventions, including the maximum biofuel price that consumers can afford and the degree to which biofuels can be substituted by other energy carriers such as kerosene, LPG, and electricity.
2. Residues are utilized but without monetary value. This is common for low to middle income groups that collect primary/field residues (e.g. logging wastes and cereal straw) and secondary/process residues such as sawmill wastes, for cooking fuel, thatching and other needs. If these residues are collected and utilized for modern bioenergy on a large scale, lower income groups may experience severe fuel shortages. Unless they can be adequately compensated, such residues should arguably be considered unavailable for modern bioenergy.
3. Residues are not utilized at all at the moment. If they have any potential uses as fuel or other purposes, one needs to know why not. They may be sold out of the locality (as with coconut residues in Box 1.2) or the cost of collecting and preparing them for use (their supply cost) may exceed the present price of biomass alternatives. If the prices of the latter increase, it may be economic to mobilize these unutilized resources.

1.41 The method, data sources and data uncertainties are all similar to those for Step 2a, as price data are collected alongside the data on quantities supplied and consumed. However, data collection may be much easier in this step as local price competition is likely to ensure that each residue has a similar price and a small price range.

Step 2c: determine the quantity and supply costs of unused and uncollected residues

1.42 The aim of this Step is to quantify the residues that are left uncollected or burned in the field or forest/plantation floor or dumped outside agroprocessing facilities—the categories 4a, 4b and 4c in the Resource/Supply/Consumption Balance (Table 1.1)—and the reasons why this happens. With this information, one can begin to examine what might be done to bring at least some of these resources into the biofuel supply pool.

1.43 There are several reasons why residues are not collected, all of which can be altered by appropriate policy initiatives (including subsidies) or project interventions. They include:

- *Equipment constraints*: Mechanized harvesting can collect all of the above ground parts of a crop, including all or most of the straw or stalk. But this may require high investment or rental costs and may not be feasible for many farmers.
- *Physical constraints*: Mechanization may also be precluded by steep slopes, wet soils, or small field sizes.

- *Labor constraints*: Where mechanical harvesting is ruled out, labor availability and costs may be an issue. Residue collection is often very labor intensive. Unless there is plentiful cheap labor, or a ban on burning residues in the field, farmers generally give residue collection a low priority during the extra busy harvest season unless they fetch a good price (Clancy 1995).
- *Harvest practices:* Primary residues are often left on the ground, burned, or plowed in for various agroenvironmental reasons, including improvement of soil quality, weed suppression, mulching to preserve soil moisture or reduce soil erosion, and the avoidance of soil damage by heavy harvesting equipment. Sugar cane tops and leaves are often burned in the field to facilitate manual harvesting.
- *Animal feed*: Primary residues may be left on the ground for animals to graze ("uncollected fodder").
- *High preparation costs*: Secondary residues are often dumped outside processing plants because the costs of residue treatments such as sizing, baling, drying and storing, exceed the local demand price.

1.44 Estimates of the impact of these constraints, how their removal or adjustment might increase the collected fraction of a residue resource, and the costs of doing so, are all important for project and program assessment. This is so for one locality, let alone for all of the localities in the overall assessment.

1.45 *With the harvest related constraints*, one needs to determine the local degree of mechanization, the topography of the area, current harvesting methods, labor requirements and costs, and the costs and availability of mechanical equipment. The number of crop processing sites and their respective output volume may also be an important parameter, as it may be worth intervening economically only at sites with substantial production volumes over extended harvest periods.

1.46 The environmentally collectible fraction should also be estimated. The beneficial effects of leaving residues in the field or forest vary greatly depending on crop type, soil type, weather conditions, and so forth. In some cases, residues may have little effect as fertilizer, so that their replacement by chemical fertilizers may result in a great increase in both crop and residue production. On the other hand, removing a residue mulch layer on a sloping field may cause severe soil erosion. In forests and plantations, removing dead wood may destroy an important habitat for insects and thus reduce biodiversity. In some cases, current harvesting practices may indicate whether or not there are agroenvironmental risks. For example, if residues have been burnt in the field for many decades without harming the soil, collecting the residues and returning boiler ashes to the fields will probably have no adverse effects.

1.47 *Preparation costs* are incurred mainly because fresh residues normally have very high moisture content (40-60 percent) and are too bulky to handle and transport efficiently. Drying—in the field or in a shed— increases unit heating values, reduces risks of deterioration during storage, and lowers the weight that must be loaded and transported. Many residues must also be broken down in size (that is, chipped) or densified (by compression to bales, pellets or briquettes). Preparation at the production site is usually concerned with improving the transportation characteristics (drying, higher density). Size reduction and compression requires relatively expensive equipment, such as balers and chippers, so that unit costs are sensitive to the scale of operations. These processes are normally carried out only at substantial demand centers such as a power plant, or by large scale producers (or cooperatives of small producers). It is obviously important to assess which preparation processes are (or can be) carried out by local producers, or middlemen, and which are (or have to be) coordinated and carried out by large scale users such as a power plant. Many publications that are available in the literature describe preparation methods for specific residues and specific regions, including related uncertainties: these include Gemtos & Tsiricoglou 1999, BTG 1996, USAID 1991, and Bhattacharya & Ram 1990.

1.48 The required information for all these estimates may be found at local producers of harvesting equipment, universities, agricultural and forestry organizations and research centers, and with local farmers. Past developments in labor prices, or use of fertilizers and mechanical harvesting equipment, may help to indicate possible changes in the future in the absence of interventions. Experiences from other countries with the same crop and soil types may be helpful in estimating possible changes and related costs (Unger 1994).

1.49 *Residue supply costs*. (the costs of collection and preparation) can be estimated from all this information. The most important items for this estimation are local labor costs, operating costs and performance of available harvest equipment, the weight and density of residues, transport distances to collection site (for example, a site at the edge of a forest accessible to trucks), costs and performance of residue preparation machines already available and costs of equipment that will have to be purchased. Owing to variations in most factors, cost ranges rather than point values should be estimated. With some secondary/process residues (such as rice husks) the calculated supply cost may be negative because using the biomass for energy avoids substantial costs for its disposal as waste. However, these negative costs should not be used, as the *price* of these residues may increase substantially and come to exceed disposal costs, once the demand for these residues increases. Supply costs based on labor and preparation costs will give a more reliable result.

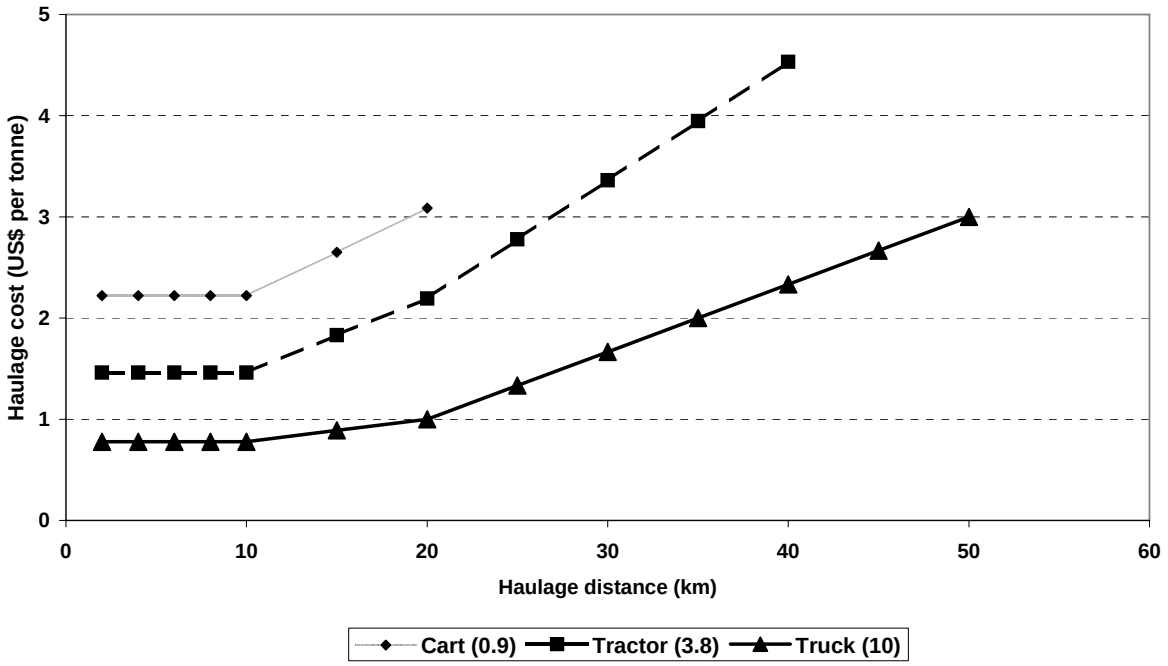
Step 2d: determine the cost of transporting residues

1.50 Estimates of transportation costs are an optional requirement for broad brush resource estimates. However, it is useful to have them as a guide to the maximum economic distance between biomass supply sites and demand centers, and hence the geographic scale of biomass supply areas and supply/consumption markets; for example, which areas of a country, or which major towns, might be supplied at competitive prices by particular resource rich areas. For more localized studies and project analyses, transport costs are an essential ingredient. As with biomass preparation processes, transportation may be a substantial component of the final residue price.

1.51 Not surprisingly, transport costs vary considerably by region, type of operator, vehicle type and load capacity, trip distance, whether vehicles return from a delivery with another load ("back hauling") or empty, and road conditions (paved or unpaved). Cost estimates need to be based on surveys that include a wide range of these defining parameters, including in particular different types of vehicle and operator, such as the informal farm sector (bullock carts, tractor & trailer) and the more formal commercial truck system.

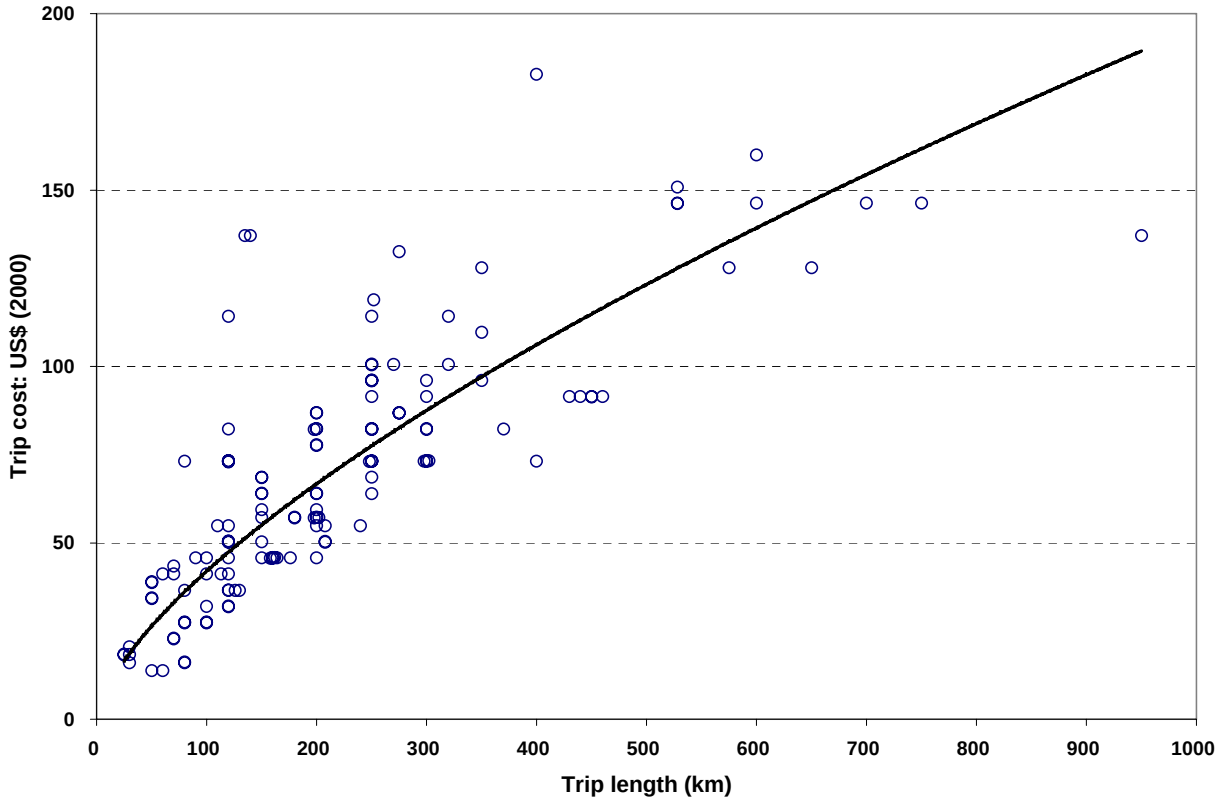
1.52 One example of transportation costs, taken from the biomass assessment in Gubbi *taluk*, Karnataka, India, which was presented in Box 1.2, is shown in Figure 1.1. The cost comparisons are for hauling coconut fronds. These have a relatively high packing density, so that maximum loads are determined by the weight carrying capacity of the vehicle rather than its volume carrying ability. In this case, trucks prove to be considerably cheaper than tractor trailers, which are, in turn, cheaper than bullock carts, in large part because of the differences in attainable loads: 10, 3.8 and 0.9 tonnes for trucks, tractor trailers, and carts, respectively. However, transportation in this case is not cheap compared with the basic biomass price. Stacked coconut fronds sell for around US$ 3.3-4.4 per tonne in Gubbi *taluk* (see Box 1.2). Transporting a tonne about 30-40 km by tractor trailer would also cost about this amount, giving a delivered price of around US$ 7-9 per tonne.

Figure 1.1: Transport costs by vehicle type (Gubbi taluk, Karnataka, India) c. 2000



Vehicle loads shown in brackets: e.g. Cart 0.9 tonnes

Figure 1.2: Costs of long-distance wood transportation by truck, Pakistan 1991



1.53 A second example of biomass transportation costs highlights the need for large samples to counter the effects of cost variation. The example is presented in Figure 1.2 and is based on a large survey of woodfuel markets in Pakistan (Leach 1993). Part of this survey examined the cost of just over 140 winter journeys by trucks carrying wood over distances ranging from 25 km to 950 km. One outstanding result clearly shown by the figure is the large variation of the trip cost for each trip length. Variation of the cost in terms of tonnes hauled would be even greater, as the trucks, although typically having an 8-tonne capacity, carried a wide range of wood loads. A second outstanding but common result is the tendency for costs to rise more slowly with greater trip length. The best fit power curve shown on the figure is: Trip cost in US$ = 1.92 * (Trip length in km) $^{0.670}$, with a coefficient of variation (R^2) of 0.710. As a result, the haulage cost per kilometer falls from about US$0.7-0.8 for the shortest trips to a low of around US$0.14-0.18 for the longest journeys.

1.54 As a third illustration, Table 1.5 provides some costs for fuel preparation, storage and transportation for various residues in Khon Kaen province, North East Thailand, in early 2000 (Junginger 2000), as well as costs for collection and initial transportation from the field/forest site to a preparation center. The table is useful in showing the relative importance of the various cost factors and how these differ by type of residue. Rice straw, for example, has much the highest combined storage, shredding and transportation cost as well as a high demand price. Eucalyptus waste wood, on the other hand, has low preparation, storage and transport costs but also has a high collection cost and demand price.

Table 1.5: Residue collection, preparation, and transportation costs, North-East Thailand, 2000, in year 2000 US$/tonne

	Rice husk	Rice straw	Sugarcane tops & leaves	Eucalyptus waste wood	Eucalyptus logs
Cost of collection & haulage to preparation site	0	13.5-17.6 [a]	16.5	14.9	6.8
Local demand price [b]	2.7-8.1	13.5-17.6 [a]	16.5	13.5-16.2	7.4
Average storage time (months)	-	5	3	1	1
Cost of storage	0	5.0	2.7	0.28	0.28
Cost of shredding/chipping	0	4.1	1.6	2.5	2.5
Cost of transportation (80 km)	1.8	3.3	3.4	0.17	0.17
Total cost of storage, preparation, transport	1.8	12.4	7.7	3.0	3.0
Additional data					
Bulk density (kg/m^3)	130	140	147	500	500
Load capacity 10-wheel truck (tonne)	6	4.5	4.4	20	20

Notes:
For rice straw and sugarcane residues, transportation costs are for baled material
[a] Higher cost is for collection from field of all straw
[b] Demand price is local market price of residues
Source: Junginger 2000

Step 2e: integrate all results

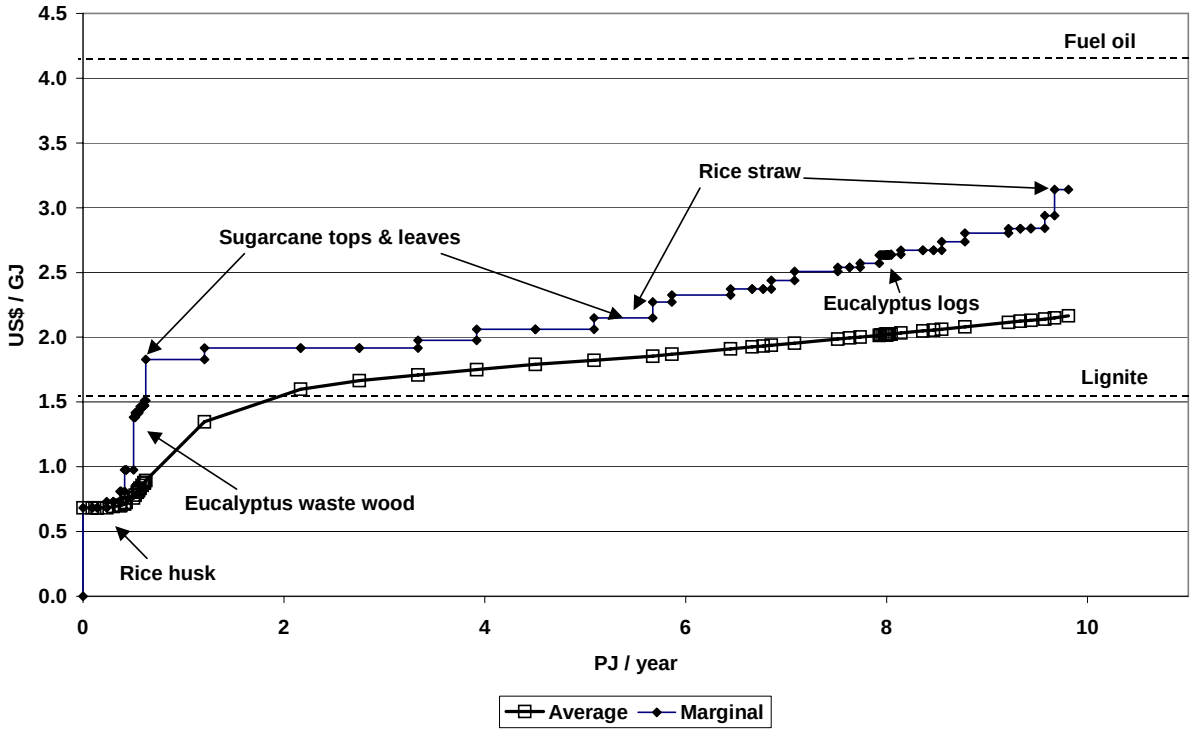
1.55 When all the factors outlined under Steps 2C and 2D have been collected and analyzed, the total quantity of Uncollected or Unused residues and their supply costs can be tabulated for each local surveyed area and then by summation for the entire study region. Supply costs may be presented without transportation costs to reflect costs at the site of origin, or with them in order to reflect transportation over a chosen distance (or range of distances). As noted above, inherent uncertainties and variation in the key factors mean that quantities are best tabulated in terms of ranges of supply cost.

1.56 Two final substeps remain. The first is to perform similar summations of the local results for the other major items of the resource/supply/consumption balance discussed above and outlined in Table 1.1. The second is to sum the local results into totals for the entire study area (the entire nation) and its major subregions as desired.

1.57 These final results can be presented in many ways. To provide information for modern bioenergy planning, one of the most useful and commonly used ways is to display quantities of residue resources according to their supply cost. Such supply/cost curves provide a clear presentation of how much biomass can be obtained for various costs and how these costs compare to fossil fuel and other energy prices. This can be done for all resources and supplies or only for the Unused and Uncollected resources, as these indicate how much biomass might be available for modern energy applications. An example for Khon Kaen province, Thailand, is presented in Figure 1.3. The upper (marginal cost) curve shows the actual costs for every residue supply site. The lower (average cost) curve shows, at each point on the curve, the average cost of all residues up to that point. The latter curve shows, for example, that up to about 2 PJ/year, residues cost less than the local lignite price—enough to fuel a 32 MW power station (assuming 35 percent efficiency and a 70 percent annual load factor)—and that the entire potential of 10 PJ/year costs less than fuel oil. Environmental taxes or subsidies would make biomass residues even more competitive compared with fossil fuels.

1.58 Although these curves are based on deliveries to one potential demand center (an existing sugar mill) the approach can be adapted to show broad brush estimates of supplies and costs for any geographic area, by estimating supply costs without the transportation component and then adding transportation costs for a fixed distance (see Figure 1.5 for similar estimates for the United States).

Figure 1.3: Cost-supply curves for residues: North East Thailand, 2000



Methodology for Assessing Energy Crop Potentials

1.59 Potential resources from energy crops are, in principle, much easier to assess than potential residue resources. This is mainly because there are fewer physical parameters to consider: energy production is simply the product of harvested area, per hectare harvest yield, and unit energy content: hectare x tonnes/hectare x GJ/tonne. Production methods are similar to those used for conventional agricultural crops, so production costs are generally well known and easy to estimate. And the key financial criteria that determine whether or not energy crops will be produced on a given parcel of land are simple and familiar. Is there a market for the crop at this production price? Will the energy crop make more money at this price than growing something else, or putting the land to other uses than growing biomass of any kind?

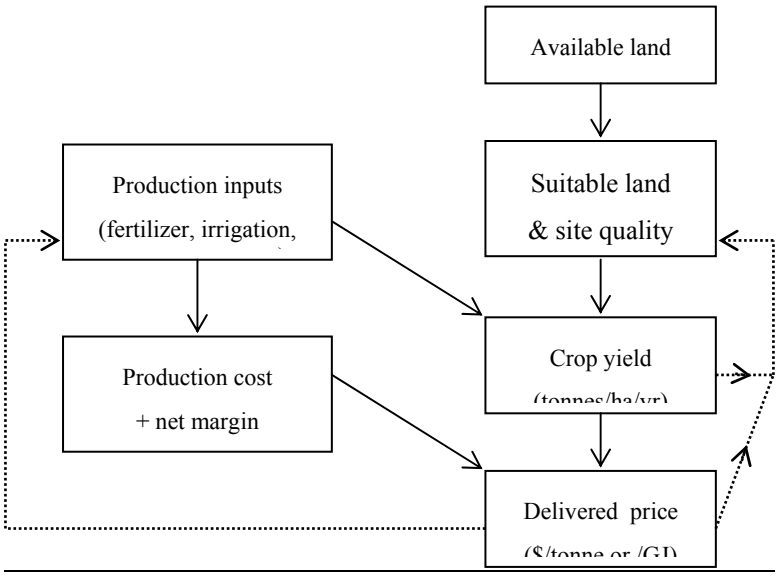
1.60 Other parameters and criteria may also be relevant, while the three main ones noted above—land area and yield, production cost, and profitability—are also to a considerable extent interlinked. These considerations complicate the picture but do not alter the point that any credible resource assessment must be built on these three basic parameters. They form the basic structure of the methodology presented here. However, because they are interlinked, an iterative process can be used to improve the assessment and explore alternative land, production, yield and output cost scenarios.

1.61 This iterative process is outlined in Figure 1.4. Essentially, on suitable land the site quality (soils, rainfall) plus production inputs combined with management skills procure a certain annual yield (productivity). Production costs plus the grower's net margin (revenue from sales less costs) define the delivered biomass price. For market acceptability, this price must be the same as or lower than that of competing energy sources. Furthermore, the net margin that helps to set this price must be at least as

much as the margin gained from alternative uses of the land: if not, the land user is unlikely to grow the energy crop.

1.62 For each parcel of land these steps can be adjusted in an iterative manner (see the dashed arrows in Figure 1.4). For example, greater production inputs may increase yield more than they increase production costs: consequently the delivered energy price can be allowed to fall without reducing the net margin. Or the delivered price may be low compared to other energy sources, opening the door to the use of lower quality land with lower yields.

Figure 1.4: Outline structure of energy crop resource assessment



1.63 As with biomass residues, the methodology can be used for any geographic scale, from a nation to a village, and with any desired level of detailed disaggregation versus rough, broad brush estimation. It can also be used for any type of energy crop. However, to avoid possible confusion, the discussion here is based on tree (or "wood energy") plantations.

Step 1. Estimate areas of potentially available and suitable land

1.64 The land of any region can be divided into areas that are and are not available for energy crops. The available areas can also be categorized in terms of their suitability for tree growing. A first step in the methodology is therefore to estimate which parcels of land (and their areas) pass the tests of being potentially available and, more subjectively, potentially suitable for energy crop production. The main filters that can be applied to this process are shown below in terms of constraints: for instance, land that is *not* available or suitable.

Land not available:

- Legally protected land: national parks, game reserves; forest, woodland and wetland in some countries. (Clear definitions).
- Socially protected land: nonagricultural areas of high amenity or leisure value, such as uplands, forests and woodlands. (Subjective definitions).
- Built over land: urban and industrial areas and infrastructure; other human habitats. (Clear definitions but subjective for low density periurban and rural habitats, roads.)

Land not suitable:

- Climatic constraints: high/low temperatures; high altitude; low precipitation (desert and arid land, unless irrigation is feasible). Semiarid land may or may not be suitable depending on production inputs needed to achieve profitable yields.
- Terrain and soil constraints: steep slopes, broken and rocky surfaces which entail very high production and harvesting costs, poor soil quality as reflected in low yields or high production inputs to achieve "reasonable" yields.
- Remoteness and lack of infrastructure: remote or inaccessible areas with few people to provide labor and skills; weak local energy demand; lack of infrastructure such as roads.
- Productive land under high-value crops: horticulture, high-value timber plantations.

1.65 The sum of all available and suitable land types that pass these tests can be considered an upper bound— gross theoretical potential—of the land area potentially available for energy crops. As this sum will probably include most crop, pasture and rough grazing land, as well as marginal "waste" land, it is likely to be very much an upper bound. This point can be addressed by counting only present "surplus" or "set aside" crop and pasture land or by assuming that some arbitrary fraction of productive farmland might be available for energy crops. The fact that these criteria are rather arbitrary and subjective does not matter much. Any biases and errors will be corrected when further constraint filters are applied which take account of yield, production costs, and profitability (see Figure 1.4). For this reason one can be fairly generous in allowing land types to pass through these initial filter tests—but should place little credence on the results[10].

1.66 Data for this step can be obtained mainly from national geographical, environmental, forestry, and agricultural statistics and/or from appropriate university departments and research institutions. In countries where satellite based land surveys have been carried out, remote sensing of vegetation cover can do much to differentiate land by its suitability or otherwise for energy crops.

Step 2. Estimate yields associated with areas of suitable land

1.67 The information used to define suitable land areas in terms of climatic and soil characteristics will probably be accompanied by information on annual yields, based on "standard" production practices. Many agricultural and forestry production models can also be used to estimate yields on a given parcel of land, based on meteorological soil and crop data and experience of production practices and yields in other regions. A good description of one such model, the Silva crop growth model, and its application to eucalyptus plantations in Nicaragua is provided in van den Broek et al. (2001).

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[10] As with the flurry of global bioenergy scenarios published during the 1990s which were mainly based on multiplying large estimates of potentially available, mostly marginal, land by yields of 10-15 dry tonnes/hectare/year, to predict huge bioenergy outputs ranging from 94–450 EJ/year by 2050 and the use of hundreds of millions of hectare dedicated to bioenergy crops. See for example: Lashof & Tirpak 1990, Hall et al. 1993, WEC 1993, Ishitani & Johansson 1995, Nakićenović et al. 1998, Fischer & Schrattenholzer 2000.

***Step 3. Calculate* the gross potential resource (by land type and/or subregion)**

1.68 This step merely involves multiplying the areas of available and suitable land (Step 1) by associated yields (Step 2) to produce an initial estimate of the gross potential resource from the energy crop in question, both in total as well as by subregion or land type, depending on the level of land disaggregation used in Step 1.

1.69 An example of Steps 1-3, with average data at the county level in Yunnan Province, China, is presented in the upper section of Table A.1.6, based on Perlack (1996). Annual yields vary considerably, from 8 to 25 dry tonnes per hectare, with a weighted average of 18 dt/ha for the six counties. The gross potential resource is 986,000 dry tonnes of wood per year, or close to 18.5 PJ—enough to run nearly 300 MW of wood fired electricity generation capacity (assuming 35 percent conversion efficiency and a 70 percent load factor).

Table 1.6: Wood energy crop potentials, production costs and yields in 6 counties of Yunnan Province, China, c. 2000

		Funing	Guang-nan	Shuang-jiang	Teng-chong	Yongde	Yong-sheng	Weighted means & TOTAL
Step 1: Available/suitable land (k ha)		6.97	18.36	4.75	5.00	9.60	10.24	54.92
Step 2: Standard yield (dt/ha/year)		15	25	15	25	15	8	18
Step 3: Gross potential (k dt/yr) (rounded)		105	459	71	125	144	82	986
Step 4: Production costs - US$(2000) [1]								
Establishment (per hectare)	Year [2]							
Land [3]		0	0	0	0	0	0	0
Research, Design, Administration	0	9.2	5.3	9.2	9.2	5.3	16.2	8.5
Roads	0	9.2	4.0	6.9	9.2	4.0	9.9	6.5
Land preparation	0	44.9	7.5	35.6	47.5	59.4	50.2	35.4
Seedlings	0	79.2	29.0	64.2	84.5	106.9	84.5	67.4
Establishment + nurturing	1	13.2	7.0	11.6	15.8	19.4	15.8	12.8
Fertilizer (manure)	1	88.4	25.1	71.3	97.7	148.2	110.9	81.3
Disease + fire control	1	52.8	21.1	30.9	37.0	52.8	49.1	38.2
Re-planting	8, 15	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Total Establishment cost		311.5	113.5	244.2	315.5	410.5	351.1	264.5
Annual costs (per hectare)		13.2	13.2	13.2	13.2	13.2	13.2	13.2
Weeding + overseeing								
Harvest costs (per dry tonne) [4]		13.2	13.2	13.2	13.2	13.2	13.2	13.2
Wood production cost (per dry tonne) [5]								
- with zero net margin		17.5	14.6	16.8	15.8	18.4	21.9	17.3
- with net margin of US$100/ha/year		24.6	18.9	23.9	20.1	25.6	34.5	24.2

Source: based on Perlack (1996)

[1] US$(2000) values converted from Yuan (1975): x 1.092 for 1975-2000 inflation, using Consumer Price Index; x 1/8.279 for US$/Yuan exchange rate in year 2000. Data from IMF (2001).

[2] Year within three 7-year rotations in which costs occur.

[3] Land costs are assumed to be zero because the planting sites are highly degraded, with no potential alternative uses, and are owned by the state.

[4] Harvest cost breakdown (US$ per dry tonne): cutting 3.96, handling 3.04, chipping 0.92, hauling 5.28 [calculated from original data in Perlack (1996) which assumes constant harvest cost per hectare].

[5] Production cost = wood price that gives zero NPV at applied annual discount rate (in this case 10 percent).

Step 4. Estimate production costs and delivered energy prices

1.70 The costs of growing biomass are similar to those for any agricultural crop, although the terminology differs somewhat. Using the terminology of forestry, the basic cost categories are: (1) the "stumpage" cost (the capital cost of establishing the crop and the much smaller cost of maintaining it until harvest); (2) harvesting and haulage to the fuel preparation site; (3) fuel preparation (chipping and drying); (4) transportation to the market or contracted purchaser such as a bioenergy power plant; and (5) overheads or fixed costs. In addition, there must be a sufficient "net margin" or "net income" for the grower. This can be a very large element in the total cost structure (see below) but is often ignored in studies of bioenergy costs. Whether biomass production is an additional activity on "new" land, or a replacement of some part of the existing production pattern, growers normally want net returns that are at least as great as those from present land uses, bearing in mind the possibly greater production and market risks of relatively novel energy crops.

1.71 This cost structure is outlined in Table 1.7. The main cost items are discussed briefly in Table 1.8 and in the text below.

Table 1.7: Cost structure for primary bioenergy production (usually on per hectare basis)

Gross output or gross return *= Item 2 + Item 3 + Item 4*	crop yield x unit energy crop price
2. Variable costs	establishment, maintenance, harvesting, storage, transport in-field, transport to purchaser [a]
3. Fixed costs	Portion of overhead costs and labor charges for the complete farm/forestry enterprise (land cost: purchases, lease, rental, etc.) [b]
4. Net margin or net return	often ignored in energy crop studies

[a] costs of harvesting, storage and transport to purchaser (conversion plant) may be paid by the purchaser.

[b] land costs are often ignored when comparing one production system with another on the same piece of land.

Table 1.8: Major factors affecting costs and revenue of energy crop production

Type of cost or revenue	Commentary
Establishment costs - Land purchase/lease - Land preparation (inc. irrigation works) - Plants & planting - Fencing	These initial capital investments are of major importance: they often account for the largest part of the total investment and have to be carried until they begin to be offset by earnings from harvest sales.
Maintenance costs - Fertilizer & application - Pesticides & application - Weeding, pruning - Irrigation charges - Thinning (for long rotations)	Sometimes called silvicultural costs, these vary widely according to location, species, and the management regime. Costs also differ because they can be adjusted by omitting or including various treatments in order to alter the returns and risks of the project.
Overhead costs - Insurance; rates and levies; management; financing costs	Overhead costs are generally stable and apply mainly to large scale commercial enterprises.
Harvesting & transport costs - Felling - Cutting up, trimming, stacking - Hauling to farm/roadside - Drying and storage - Transport to conversion plant	These costs are incurred at the end of the production cycle. Although often high, they are not "carried" for a significant period. On difficult sites, hauling costs can be extremely high. Many of these costs may be met either by the wood producer or by the purchaser (energy conversion plant). Drying and storage are not always necessary.
Revenues / Income - Intermediate harvests (grazing, grass, leaf fodder, tree seeds, pruning for firewood) - Thinning (for long rotations) - Final harvest	At the start of a project, estimates of future revenue—based on volumes produced times price—are subject to considerable uncertainty. Intermediate products and thinnings provide the earliest revenue streams, with the greatest certainty in product markets, and may occur frequently throughout a rotation. The final harvest will normally provide the greatest volume but with large variation across agricultural users and systems.

Source: based on FAO (2000)

Establishment costs – and site quality

1.72 Establishment costs depend on a host of site specific factors and vary widely. This point is well illustrated by the case study from China presented in Table 1.6, where establishment costs differ nearly fourfold across the six regions.

1.73 These and other production costs (as well as yield) depend on *site quality.* This indicator has biological components that strongly influence yield, including the amount of solar radiation received; water availability; and soil depth, acidity (pH), texture and nutrient levels. Site quality also influences production costs and management practices in many ways, including land purchase cost or rent; how much land preparation is needed; choice of suitable tree species, spacing and rotation length; and the required soil and cultural management (fertilization, weed control, animal control, and pest management).

1.74 Selecting suitable production sites therefore involves quite difficult assessments of site quality and tradeoffs between these quality components: a technique commonly known as Land Evaluation (see, for example, FAO 1980). Biologically favorable sites may give the best yields but are also likely to have high land costs and/or be in use for high value conventional cropping. Poorer sites may be cheaper and more available, but they require greater areas to deliver the same output, typically have higher production costs and are generally more risk prone. In particular, they require greater technical expertise and more careful management to avoid soil erosion, soil nutrient depletion and other problems which can lead to major setbacks or failure.

1.75 In the temperate industrialized countries, these factors generally balance out in favor of using good quality land (Perlack et al. 1995). Furthermore, many of these countries have more cropland than they need for food production and are seeking to diversify farm incomes and support the rural economy generally. Bioenergy production is a leading candidate in this strategy.

1.76 In contrast, in less developed countries bioenergy plantations are grown on a much greater variety of land types. Increasing populations and pressures on land for food production may mean that energy crops will increasingly be forced onto degraded or marginal lands. Such land types typically have many physical limitations such as poor and stony soils, low rainfall, steep slopes, or brush cover that must be cleared— factors that go with low yields, high land preparation and harvesting costs, but also typically low land (and labor) costs. Yet there will also be pressures to continue growing energy crops on productive farmlands, where they can be as profitable or more profitable than the conventional food crops they displace.

1.77 The Chinese case study illustrates these points. Although establishment costs vary fourfold, the final wood energy production costs differ at most by 80 percent. As outlined in Chapter 1 of the Main Report, this is largely because final costs are strongly dependent on yield: Yongsheng county has the highest final cost not so much because of its (second highest) establishment cost but because of its poor soils and very low yield.

Land costs

1.78 These can be a major component of total production costs and can be so high that energy cropping can never be financially feasible. Generalizations about such costs are not possible: land costs are fundamentally dependent on locational factors such as topography, soil productivity, potential yields of alternative crops; proximity to transportation infrastructure and markets, and, not least, local demand for building land. Very high cost variations are possible even across a kilometer or two of farmland.

Labor costs

1.79 In areas where wages are low and there is little farm mechanization, energy crop production can require huge amounts of human labor. For example, Perlack et al. (1995) cite 150-300 person days per hectare for establishment and maintenance of tree plantations on severely degraded sites in Southeast China and 170 person days for manual site preparation, planting and maintenance on brushland in the Philippines. In India, Saxena & Srivastava (1995) estimate 438 person days over a 6 year rotation for eucalyptus plantations, of which 160 person days are for tree establishment and 200 are for manual harvesting. Also in India, Yadav (1989) describes plantations of Acacia and Eucalyptus on sodic soils which require 1092 and 940 person days per hectare over a 7-year rotation, of which about 215 person days were for establishment. With a wood production of 7.8 and 4.6 dt/ha/yr respectively, the labor productivity is as low as 20 30 workdays per dry tonne.

1.80 These large labor inputs seem to support the common assertion that energy crops have a major development role to play by creating rural jobs and income. This is certainly the case when energy crops are *additional* to conventional field crops or other sources of employment; for example, when a farmer plants trees on field boundaries or a community plants on village "waste" land. It may also be the case when bioenergy provides modern energy carriers and services to a community, perhaps for the first time, and thereby opens the door to new job creating and income earning activities as well as employment for maintaining the energy conversion system itself.

1.81 However, jobs are usually destroyed when tree based energy crops *replace* other crops or land uses. In a wide ranging review of conditions in India, Saxena and Srivastava (1995) conclude that the main field crops (rice, wheat and sugarcane) require about 250-300 annual workdays per hectare, but eucalypts (the dominant tree type for farm and social forestry) require only about 50-70 annual workdays per hectare. Another study found that switching from groundnuts to eucalypts more than halved labor requirements from 112 to 45 workdays/ha/yr (Saxena 1989). Furthermore, most of the lost jobs belonged to women, who provided 100 days/ha/yr for groundnut production but none at all for tree growing.

1.82 These examples contrast strikingly with typical labor inputs for highly mechanized energy crops in the industrialized countries of just a few days per hectare each year. One estimate for Europe is that growing short rotation eucalypts requires about 1-2 work *hours* per tonne of wood produced, while miscanthus ("elephant grass") requires only 0.6-0.7 hours per tonne (Gielen et al. 1998). Assuming two 2 person hours per tonne, we find a remarkable differential of 100:1 in labor inputs per unit tonnage output compared to the sodic soil plantations in India.

1.83 Across much of the developing world, where capital is scarce and/or expensive, the ability to produce energy (and other) crops competitively is obviously predicated on having a substantial pool of cheap labor. This may be regarded as an advantage in regions with high unemployment, as bioenergy projects will create new jobs. But it may be problematic in rather more developed rural regions, where farms nay be losing labor to higher paying off farm jobs and wage rates generally are rising. As wage rates increase, mechanization will increasingly be necessary to hold costs down to competitive levels. This crucial aspect of biomass energy production calls for careful technical and economic choices, which must be sensitive to local employment and other socioeconomic issues. This important topic is discussed more fully in the Main Report.

Net margins

1.84 The producer's net margin or net return can be a major fraction of biomass production costs. As a general rule, large scale commercial producers may work to net margins of only 5 to 15 percent on top of production costs. At the other extreme, small farmers with few opportunities for off farm employment, as in much of the less developed world, may require very high margins in order to support the farmer's entire family. Net returns for energy crops also reflect the profitability of the crops which they replace: a farmer is unlikely to switch to the latter unless he/she earns as much by doing so.

This helps to explain why in 1995 average annual net margins for energy crops were as low as US$160 per hectare in Greece and as high as US$1,800 per hectare in the same year in the Netherlands, where high quality farm land and a suitable climate allow many profitable nonenergy crops with excellent yields (Calliope & Dalianis 1996). For miscanthus grass, assuming a yield of 20 dt/ha/yr, the Greek figure corresponds to about US$ 8/dt or US$ 0.4/GJ—a relatively small amount. The upper figure, however, represents about US$ 5/GJ—a cost penalty so high as to make it most unlikely that the land would be used for energy crops unless these were heavily subsidized.

Interest (or discount) rate

1.85 With tree plantations it is usually several years before the initial investments are offset by the first cash returns from harvesting. The financial and economic viability of wood energy projects must therefore be evaluated by some form of cost and revenue discounting. With formal discounting assessment methods, projected costs, returns, available net margins, and benefit/cost ratios depend heavily on the chosen interest or discount rate. Care must be taken to match this to actual rural interest rates paid on loans, and to test for the impact of future rate changes. For growers who live in the real world of daily and monthly cash flows, as well as possibly very high interest rates on cash loans, the delay between initial investment and harvest revenue is often a severe deterrent to tree growing. This contrasts sharply with conventional crops with their one, two or even three harvests each year in favorable tropical locations, and with energy crops such as sugarcane and starchy roots.

1.86 As a result, there are often strong financial pressures to adopt three alternative crop management strategies: first, to use short rotations for wood energy plantations, often of 5-7 years; second, to grow very high density plantations equivalent to the willow and poplar coppices of the temperate industrialized countries, with planting/harvesting cycles as short as two years; and third, to grow annual field crops such as grasses (including sugarcane), sorghum and other starchy crops. With a high discount or financial interest rate, annual crops and short rotation tree coppices may be preferred even though other aspects of their production are not optimal.

Subsidies and production grants

1.87 Subsidies and/or grants are frequently used to lower the costs and hence promote the take up of energy crop production. Objectives include climate change mitigation, other environmental reasons, and support of rural regeneration policies. The subsidies/grants are usually made available before or soon after first planting in order to reduce the deterrent effect of establishment costs. They can be treated in energy crop cost calculations as negative (establishment) costs.

Step 5. Estimate delivered energy prices (and ranges)

1.88 When the yields and all the cost items discussed above have been assembled (for each location in the overall analysis) it is a fairly simple matter to calculate total costs per tonne of energy produced and associated sale prices. A computer spreadsheet can be used to tabulate the costs and revenue for each year of several growth harvest rotations, to discount these at the chosen interest rate (or rates), and to calculate measures of financial worth for hypothetical plantation projects. Commonly used measures are (1) the Benefit/Cost Ratio; the Net Present Value (NPV); and the Internal Rate of Return (IRR). Some useful ways of employing these measures are listed below:

- For a chosen sale price (e.g. US$/dt or US$/GJ delivered to a market), the resulting NPV can be compared to the NPVs of alternative crop systems, such as tree growing for wood pulp or conventional field crops. Economic rationality says that the project with the largest NPV should be pursued as it has the highest financial worth.
- A sale price can be calculated which gives a zero NPV. This price equals the breakeven production cost: that is, the cost with zero net margin (unless an assumed annual net margin has been included in the spreadsheet analysis as a cost). See the bottom rows of Table 1.6, for which net margins of zero and US$100/ha/year are included in the annual costs.

- At this sale price, the IRR (which is calculated on the basis of zero NPV) gives the equivalent bank interest rate that would be received for the stream of investments (initial and annual costs) and the resulting revenue from product sales. With small (farm scale) bioenergy projects in particular, IRR should not be used as the only measure of worth: the IRR can be high when the NPV is low and the net margin is zero.

1.89 These measures can be used to standardize the results of the analysis by selecting only one value, or a small number of values, for the discount rate, the assumed net margin, and subsidies/grants (if any). This will provide a unit price (per tonne or per GJ) for each location in the overall analysis, or a range of prices if several values are used.

Step 6. Final integration and assessment of energy crop potential

1.90 The standardized results from Step 5 can be used in three main ways to arrive at a final analysis of the total energy potential and associated prices for the whole study area and for subregions, if desired:

1. For each discount rate and assumed net margin, locations can be filtered out as being unsuitable for energy crops. Rejection can be based on very high breakeven costs (with or without net margins) relative to competing energy prices; or on low NPVs relative to alternative crops and land uses. The remaining locations that pass this test can be aggregated into a final tabulation of location areas, yields, total output, and output price(s).
2. For each discount rate and assumed net margin, the same process can be used to tabulate and plot energy outputs against price to produce a cost-supply curve like the one for residues shown in Figure 1.3. (See also Figure 1.5 for the USA).
3. If the data are available on how crop yields respond to site quality and to greater production inputs and costs, the iterative process outlined at the beginning of Section 1.3 and illustrated in Figure 1.4 can be carried out. This will greatly elaborate and complicate the analysis and might not be worthwhile unless the available data are reasonably reliable. Following the iteration process, the results can be refiltered as in method (1) above and/or used to produce a cost supply curve as in method (2) above.

A comprehensive national assessment: the case of the United States

1.90 To conclude this chapter we present what might be called a gold standard for national biomass assessments. Combining a wealth of disaggregated physical and financial data on farm and forestry production and outputs, as well as data on many kinds of biomass residue and on transportation and other downstream production costs, the assessment has been made by the Bioenergy Feedstock Development Program at the Oak Ridge National Laboratory, Tennessee; see for example Walsh et al. (2000). Most important, this ambitious exercise is rooted in a financial approach to the estimation of energy resource and supply potentials, by allowing for competing (nonenergy) uses of forestry and agricultural residues, and by considering financially based decisions by farmers as to which crops they will grow.

1.91 The basic methodology for energy crops employs highly disaggregated data for agricultural and forestry land use, conventional crop production and crop prices, and assessments of farm net margins for conventional and bioenergy crops. If in any district bioenergy crops give farmers higher returns than conventional crops, the model assumes that farmers will switch into bioenergy production. The methodology therefore provides something close to a maximum economic potential (with present prices and assuming no new fiscal incentives to promote bioenergy). Four bioenergy production costs

were assumed, namely US$11, 22, 33, 44, and 55 per dry tonne [11]. The highest of these prices is equivalent to about US$2.9/GJ for delivered dry biomass, or roughly US$75 per tonne of bituminous coal and US$18 per barrel of crude oil.

1.92 The overall finding is that, with the highest prices considered for delivered biofuels (US$55/tonne) the USA could potentially produce about 460 million dry tonnes of bioenergy crops and residues each year. This amounts to about 8.4 EJ_{lhv} per year or 9% of present US primary energy consumption: see Table 1.9 and Figure 1.5.

Table 1.9: Potential US bioenergy feedstock supply for prices up to US$2.9 per GJ

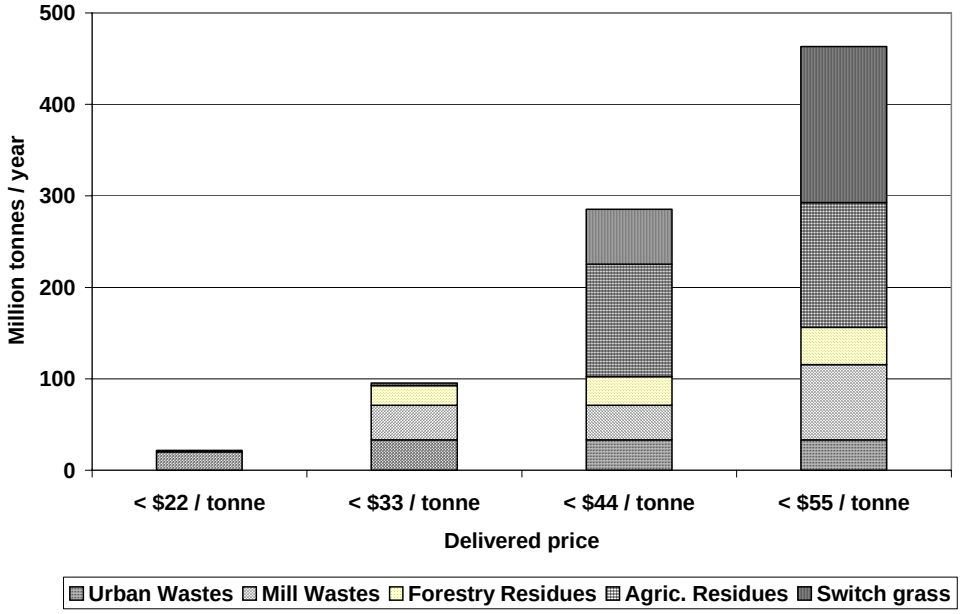
Potential availability of biomass for energy in the USA at prices up to US$2.9/GJ$_{lhv}$	
Forestry residues	9 %
Sawmill residues	18 %
Agricultural residues	30 %
Dedicated energy crops	37 %
Urban wood waste	7 %
Total biomass supply	100 %
Annual contribution to US primary energy	8.4 EJ/yr
As percentage of US primary energy consumption	9%

Note: a dry biomass price of US$2.9 per GJ is equivalent to roughly US$75/tonne of bituminous coal and US$18 per barrel of crude oil.

Source: based on Walsh et al. (2000)

[11] Original data in US short tons (2000 pounds, 907.2 kg) are converted here to metric tonnes. Prices per ton are also converted to prices per tonne.

Figure 1.5: USA 1999: Potential availability of biomass for energy by delivered price



1.93 *Forestry residues* account for 9 percent of the estimated total bioenergy potential in the highest price case. Estimates are based on state level forest inventories for the 226 Mha of US forest land. These include information on volumes of logging residues and salvageable dead wood, haulage distances, and limitations on equipment use such as steep slopes. Total volumes are revised downward to allow for constraints such as equipment retrieval efficiency, road access to harvest sites and the impact of slope on harvest equipment choice. Costs of recovering wood residues are made for each cost category: collection, harvesting, chipping, loading, hauling, unloading, stumpage fee, and producers' net margins.

1.94 *Mill residues* account for some 18 percent of the total bioenergy potential and comprise residues from all primary mills, which produce lumber, wood pulp, veneers and other composite wood fiber materials. Data are available at county and state level for quantities of residues generated and, most importantly, breakdowns by residue type and use category: that is, not used, and used for fuel, pulp, and composite wood materials). Because these residues are clean, concentrated at each source, and fairly homogeneous, usage is high. Nearly 98 percent of such residues generated in the USA are currently used as fuel or to produce fiber products:

- Bark (22.0 M dt/yr) is used mostly for fuel (79.4 percent); the remainder for mulch, bedding, and charcoal;
- Coarse residues (35.1 M dt/yr) are used for fuel (13 percent) with nearly all the rest going to the production of pulp or composite wood products such as particle board;
- Fine wood residues (25.9 M dt/yr) are used approximately 55.6 percent for fuel, 23 percent for pulp or composite wood products, 18.7 percent for animal bedding, mulch, and other minor uses, with about 2.6 percent unused.

1.95 In all, about 44 percent of the annual 83 M dt of residues is used as fuel, mostly onsite in low efficiency boiler systems to produce heat and steam. Based on sparse industry data, the assessment assumes that unused residues could potentially be available for energy production at delivered prices of

less than US$22/dt. Residues now used for pulp, composite wood materials, mulch, bedding, and other such uses could potentially be available as biofuels at delivered prices of up to US$55/dt.

1.96 *Agricultural residues* account for nearly 30 percent of the feedstock potential at US$55/tonne. Estimates are limited to corn (maize) stover and wheat, which had average planted areas of 31.2 and 29.1 Mha in 1995-97. The third largest crop, soybeans (26.3 Mha), is ignored because residue production is small and the material tends to deteriorate in the field. The estimation model considers only the volume of residues that can be removed from the field, allowing for maintenance of soil quality and erosion prevention across different crop types, soil types, typical weather patterns, and tillage practices. Available volumes depend on the price assumptions and allow for costs of residue collection (Walsh et al. 1998), premiums paid to farmers to encourage their participation in residue collection, and transportation costs.

1.97 *Dedicated energy crops* account for nearly 37 percent of the national potential. They include short rotation woody crops, such as hybrid poplar and willow, and grasses such as switch grass. Currently there is no commercial production of these crops for energy in the USA. The POLYSIS model, which is used by the US Department of Agriculture for economic and policy studies, was adapted to estimate the quantities of energy crops that could in theory be produced with a net margin at least as great as that from traditional crops on the same land, given the assumed energy crop yield and production costs, and the 1999 USDA baseline production costs, yields, and prices for traditional crops. Land included is that presently planted to traditional crops, idled, in pasture, or in the Conservation Reserve Program. Energy crop yields vary within and between states, are based on field trial data and expert opinion, and assume recommended management practices with respect to planting density, fertilizer and chemical applications and rotation lengths.

Urban wood wastes account for 7 percent of the total at the highest price level, but exclude large volumes of combustible municipal solid wastes (MSW) that are not wood: e.g. paper, cardboard and packaging. Data on volumes, costs, and prices are reportedly difficult to find, so the results are somewhat uncertain as well as underestimating the total resource potential.

1.98 Key results of this analysis are shown in Figure 1.5. At the lowest price band (US$22/dt, or about US$1.2/GJ) potential production is limited to quite small amounts of urban waste. Forestry and mill wastes make sizable contributions when the highest delivered price is raised to US$33 per dry tonne. Substantial agricultural residues and switch grass become available at the US$44/dt mark. Interestingly, there is no short rotation wood production even at the highest US$55/dt price. At the state level, production volumes for each energy crop and their dependence on price differ widely: for example, at the highest price level, the contribution of switch grass to state total bioenergy potential averages 27.8 percent but ranges from zero to nearly 80 percent. This variation underlines emphatically the importance of making local bioenergy resource estimates.

1.99 Because it employs the USDA's POLYSIS economic model, the analysis is able to estimate the extent to which a large switch to energy crop production will affect conventional crop production and prices. Preliminary results (Walsh et al. 1998) suggest that if bioenergy crops were to replace conventional crops in substantial volumes, prices of the latter could increase to markedly different extents. For example, in one scenario in which bioenergy crops are planted on 7.1 Mha of farmland, cotton prices rise by a relatively insignificant 1.5 percent, but the price of oats increases by a substantial 24 percent. Overall net farm income also increases, by as much as US$3,496 million a year, or nearly 7 percent over the present day. While farmers would gain, the wider community would face higher food prices. This provides a noteworthy illustration of the potential impact on food markets of a burgeoning demand for biomass feedstocks.

Conclusions

1.100 This chapter has discussed the main factors that define how much biomass energy might potentially be available in any given area of land, focusing first on crop and forestry residues and then on dedicated energy crops. It has also discussed the production factors and related considerations that help to determine the final cost of biomass energy and whether or not it will be competitive with alternative energy supplies, with alternative uses of biomass, and with alternative land uses. It has presented fairly simple methodologies for assessing these potentials and costs both for residues and energy crops.

1.101 While the main focus of the chapter has been on preliminary, broad brush assessments to aid national bioenergy policymaking and planning, for example, there has also been considerable attention to the need for more detailed local level data collection and analysis. This need follows inevitably from the site specificity and large variation from place to place of most of the important parameters related to bioenergy availability and costs.

1.102 This attention to local level analysis is taken up in much greater length in the Main Report.

2

Technologies to Convert Biomass to Modern Energy

2.1 A first step in implementing a bioenergy activity is to identify the energy services for which there is a clear demand at a given site. After that, choice of the appropriate bioenergy conversion technology involves several technoeconomic considerations. These can be broadly categorized as those pertaining to: cost, load factor, efficiency, feedstock, scale, and robustness. After discussing these characteristics briefly, this chapter gives a short profile of several technological options for converting biomass into electricity, gas, liquid fuels, and solid fuels, most of which are currently commercial or undergoing commercialization, and some of which are emerging. These profiles are meant to give the general reader an understanding of the applications and some of the technical issues that arise in employing the technology in bioenergy implementations.

Cost

2.2 While large scale energy producers think in terms of unit energy costs (costs per kWh or GJ), users generally do not. Rather, they tend to think in terms of end use services, taking into account reliability, convenience, safety, initial investment, availability, and other factors that can be hard to monetize. When all these factors are taken into account, users can show a remarkably high willingness to pay in terms of unit energy costs. This is illustrated by the fact that electricity services can be attractive and worthwhile based even on technologies such as PV panels or batteries, despite the fact that the per kilowatt price can be as much as *three orders of magnitude* more than the price of grid-supplied electricity that urban households are accustomed to paying yet satisfy a substantially narrower range of energy end use services.

2.3 Still, cost is extremely important. Initial cost is an especially important consideration for nearly all users, both institutional and household. Users are routinely forced by capital constraints to reject technological options that have the lowest life-cycle cost, because they have prohibitively high initial costs. Financing is often needed, especially in rural areas. (See Chapter 2 of the Main Report.) The capacity of users to pay for energy services will be greatly enhanced if they can apply the services toward income generating activities. This is a key element in the design of viable bioenergy systems and in their contribution to poverty reduction.

Load Factor

2.4 Load factor refers to the average output of a energy system compared to its peak output. (For example, a village power system with a capacity of 10 kW that is unused for 12 hours per day and operates at 5 kW for the remaining 12 hours has a load factor of 25 percent.) Load factor is a main determinant of a bioenergy system's cost of service, regardless of scale. Total cost of energy comprises fixed (capacity) costs and variable (energy) costs. For high capacity cost options (such as most renewables, including biomass) low load factors considerably increase total cost by forcing this fixed cost to be shared among less energy output. Since demand for electricity amongst poor households is driven by the need for lighting for a few hours in the evening, systems designed to meet the demand of households alone will have very low load factors. An energy system can become much more cost effective if it can increase its load factor by securing a baseload source of demand, such as a local

enterprise, irrigation pumping, or sales to the grid. For example, the aforementioned village power system, if it added a customer that would consume 10 kW of power for 8 hours a day, would increase its load factor to 75 percent. If, say, fixed costs in the low load factor configuration (25 percent) are about two thirds total costs, increasing the load factor (to 75 percent) will lower the cost of service by more than half.

Efficiency

2.5 Efficiency is also a critically important technoeconomic parameter. It determines the "effective" cost of the biomass supply, since it is inversely proportional to the feedstock requirement. The impact on the cost of service of increasing the efficiency from 12 percent (a reasonable full cycle efficiency for a gasifier/diesel engine system) to 30 percent (which might one day be achievable at the same scale from a microturbine or fuel cell bioenergy system), all other things being equal, would roughly halve the total cost of energy service. One might accept a technology with nearly four times the capital cost of the low efficiency technology in order to achieve this efficiency gain, achieving a comparable cost of service. This might be attractive, for example, in situations where it is important to make the most of a constrained bioenergy supply.

Feedstock

2.6 Most bioenergy technologies impose certain constraints on the feedstock characteristics. For instance, gasifiers operate most smoothly with biomass of a specified moisture content and density, anaerobic digesters require wet feedstocks such as dung, cookstoves function best with fuel of a specific size range, and biodiesel production requires an oily feedstock. Selecting a bioenergy technology for a certain site will obviously require a clear understanding of the expected type of biomass feedstock. Especially for large scale systems, for which biomass might have to be drawn from a broad area, assuring a secure biomass supply of the appropriate characteristics can be challenging.

Scale/sizing

2.7 It can be difficult to estimate the scale at which a bioenergy system should be designed, especially if growth of energy demand is expected due to new enterprises or expanding household incomes. However, scale strongly affects the cost, efficiency, and operating characteristics of a bioenergy system, so it is generally important to size a system at the appropriate scale for its application. Few technologies can be incrementally expanded to meet demand as needed, so it is important to make careful assessments of the anticipated end uses and the available biomass resource in order to estimate the required system scale as accurately as possible.

Robustness and maintenance requirements

2.8 A major determinant of the viability of a bioenergy technology is whether it is sufficiently robust and mechanically reliable to operate in at the intended setting, accounting for the availability operating expertise, service, repair parts, etc. Rural energy implementations have routinely failed because nonrobust technologies were coupled with inadequate training and followup service. Building capacity at the village level can be challenging but is necessary. It can also contribute significantly to rural development, providing skilled work and transferable skills valuable for a range of income generating employment. For periodic maintenance and infrequent servicing, capacity can also be built at a regional level, rather than village level, if there is enough dispersed demand to provide an economy of scale in delivering service. If manufacturing standards are clearly defined and carefully adhered to, and if installation protocols are followed, it will be more likely that village energy systems operate properly. Mature, proven technologies are more likely to succeed, and attempts to disseminate emerging technologies widely should not be made without a careful program of field testing and capacity building.

Biomass for Electricity

Combustion boilers with steam turbines

2.9 Today, in all parts of the world, the predominant route for generating electricity from biomass is based on steam turbine technology, which comprises approximately 40 gigawatts of generating capacity. Biomass is burned in a combustion boiler to heat water and raise steam, which is expanded through a turbine to generate power. Typically, biomass systems range from a single megawatt to tens of megawatts, and rarely to hundreds of megawatts. (Systems for biomass applications tend toward the smaller range because sources of biomass are generally dispersed.) Essentially the same technology is used to generate power from coal, making the steam turbine a foundation of the global electric sector. It is a mature and widely disseminated technology, having been commercially available for more than 100 years.

2.10 Combustion boilers are available in different designs depending on application and biomass characteristics. The main technological options are to burn the biomass on a grate (either fixed or moving), or to fluidize the biomass with air or some other medium to provide even and complete burning. Steam turbine designs also vary depending on the application. To maximize power production, "condensing" turbines are used, wherein steam is cooled and expanded to subatmospheric pressures. For CHP applications, "back pressure" turbines are generally used, which provide steam at temperatures and pressures higher than ambient conditions.

2.11 Most biomass fired steam turbine plants are located at industrial sites that have a ready supply of biomass available. At such sites, waste heat from the steam turbine can be recovered and used for meeting industrial heat needs, which enhances the economic attractiveness of such plants. Such combined heat and power (CHP) facilities (also called cogeneration facilities) are highly resource efficient in that they provide greater levels of energy services per unit of biomass consumed than facilities that generate power only.

2.12 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 and agricultural processing facilities, where biomass fuels are available as byproducts. Compared with the installed capacity in the industrialized (OECD) countries, there is relatively little capacity installed in developing countries, due in part to institutional barriers that keep agricultural policy distinct from energy policy and in part to chronic difficulties in acquiring financing for capital intensive agroindustrial investments. The most significant installation of steam turbine 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 processes, such as open vat boiling) typically includes a steam turbine CHP system fueled by bagasse, the fibrous biomass residue from crushing sugarcane.

2.13 Currently, virtually all biomass fired power plants rely on low cost (or negative cost) biomass residues. Many regions of the world still have significant untapped supplies of such residues, which could be converted into competitively priced electricity using steam turbine power plants. Sugarcane processing industries, for example, present major opportunities for steam turbine based CHP generation, as discussed below. To competitively produce electricity from higher priced feedstocks (such as energy crops) will probably require more efficient conversion technologies, as discussed in sections on emerging technologies.

Table 2.1: Technology summary: steam turbine power (and heat) systems

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, deaerator, 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; boiler feedwater purity (at minimum, demineralization and deaeration are required)
ENVIRONMENTAL AND SOCIOECONOMIC PARAMETERS	
Environmental strengths	Efficient use of biomass with CHP; mutiple-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/high skill	20 percent
Moderate skill level	75 percent
Low skill level	5 percent

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 percent and energy content of 18 GJ per dry tonne. Also, assumed overall conversion efficiencies to electricity are 10 percent (which might be representative of a system using 20-bar steam in a back pressure turbine) to 20 percent (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 percent capacity factor is assumed; that is, the annual electricity production per installed kW_e is 6575 kWh.

Promising application: CHP at Sugarcane Processing Facilities

2.14 One of the most promising agroindustrial sectors for the expansion of (CHP) is the sugarcane processing sector. A good base of experience has been gained in this sector, and many implementations are successfully in place. (The forestry products industry, including pulp and paper mills and sawmills, also has significant opportunity for expansion.) Brazil, China, India, Indonesia, and over 70 other developing countries grow sugarcane. The byproduct bagasse generated from sugar or ethanol production 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 with 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.

2.15 Historically, sugar factories have exported little electricity because most sugar mills have large steam demands and most bagasse fired CHP systems have low efficiency for production of electricity. However, sugar factories produce such large quantities of bagasse and trash that they could be significant electricity exporters. Sugar mills can implement cost effective energy conservation measures that greatly reduce steam demand while installing CHP systems that greatly increase the efficiency of electricity production. These two measures together enable a sugar mill to generate a large quantity of excess electricity that can then be profitably exported to the grid. 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.

2.16 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 utilize higher pressure boilers (40 to 100 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.

2.17 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 utilization systems are ongoing today in Brazil, Cuba, India, Thailand, and elsewhere. If the sugar industries in such countries were to implement efficient steam turbine technology on a widespread basis and sell electricity in excess of their onsite requirements to the national grid, the contribution of cane derived power to meeting national electricity needs could be substantial. (Table 2.2). Most such generating plants would be located in rural areas.

2.18 The costs of steam turbine 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 steam turbines and boilers is that their capital costs (per unit of capacity) are scale sensitive. This is the main reason why coal and nuclear steam electric plants are built big—500 to 1000 MWe. Moreover, biomass steam turbine systems are constrained to relatively small scales (because long distance transport of biomass fuels is costly). As a result, biomass steam turbine 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 with conventional fossil energy power plants.

Table 2.2: Potential for electricity generation from sugarcane (in excess of sugar or ethanol factory demands) using steam turbine systems in developing countries

	1995 Cane Production (million tc)	2025 Cane Production [a] (million tc)	2025 "Excess" Electricity Production [b] (TWh/year)	2025 Utility Electricity Production [c] (TWh/yr)	2025 Cane Electricity ÷ 2025 Utility Electricity
Brazil	304	550	165	623	27 %
India	260	470	141	883	16 %
China	70	127	38	2085	2 %
Carribean	48	87	26	102	26 %
Indonesia	31	57	17	141	12 %
Other Latin Am.	152	275	83	1063	8 %
Others	233	422	127	2214	6 %
Totals	1098	1988	591	7112	8 %

a. Projected from data for cane production in 1995 and assuming an annual 2 percent growth rate.

b. Projected from data for electricity generation in 1995 assuming an annual 3 percent growth rate.

c. Electricity available for export, that is., electricity in excess of the power requirements for the sugar cane crushing facility.

Note: TWh = billion kWh.

Source: Williams and Larson (1993)

2.19 Biomass steam turbine systems raise certain environmental issues, including the potential for particulate emissions to the air. Flue gas filtration systems are required to minimize 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.

Gasification with internal combustion engines

2.20 Biomass, like coal, can be an unwieldy and inconvenient fuel because it is solid. Converting biomass to a gas enables its use in a wider variety of energy devices. After appropriate treatment, biomass derived gas can be burned directly for cooking or heating, can be converted to electricity or mechanical work in a secondary conversion device such as an internal combustion engine, or can be used as a synthesis gas for producing higher quality fuels or chemical products such as hydrogen and methanol. We introduce the topic of biomass derived gas here, in the context of gasifying biomass for use with internal combustion engine generators, although it will return in later profiles.

2.21 There are two routes for converting biomass into a combustible gas: high temperature thermochemical processes and low temperature biological processes. The high temperature

thermochemical process uses a biomass gasifier and generates "producer gas". The low temperature process uses an anaerobic digester and produces "biogas". Thermochemical gasification is discussed in this section, and anaerobic digesters are discussed in the following section.

2.22 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 an energy content roughly 10 to 15 percent of the energy content of natural gas by volume, hence its French name "poor gas" (gaz pauvre).

2.23 Biomass gasification is technically analogous to coal gasification. Gasified coal was widely used in Europe and the United States until the mid 1900s for urban domestic cooking and heating. This so called "town gas" is still used in many urban areas of developing countries, including India and China. In the 1960s and 1970s, large scale coal gasification technologies were developed and commercialized for producing fuel and synthesis gas. Such facilities have remained in operation for many years.

2.24 Producer 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. 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.

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

2.26 One response to the problems related to tar formation is to use charcoal, as opposed to raw biomass. Charcoal does not produce significant levels of tar, because most of the compounds with tar forming potential are removed when raw biomass is made into charcoal. Gasifier engine systems used during World War II functioned satisfactorily, because they primarily used charcoal. A main drawback, however, is that a substantial fraction of the energy in the original raw biomass is lost in the process of converting it to charcoal, particularly with traditional charcoal production technologies. If biomass supply is constrained, then such energy losses might be unacceptable. (Such concerns with overutilization of the biomass supply during World War II led Sweden to ban charcoal use in gasifiers toward the end of the war.) A second drawback is that charcoal is more costly than raw biomass.

2.27 A second response to the problems related to tar formation has been the continued technological advancement in gasification and gas cleanup systems. In the past decade, a number of gasifier and gas cleanup designs have been developed that largely eliminate tar production and related technical problems. Transferring these research findings into commercial products is ongoing, and interest has resurfaced in gasification as a village scale source of electricity. Unlike in earlier gasification efforts, a growing number of companies worldwide now offer systems with warranties and performance guarantees. In comparison with charcoal gasifier systems, these systems entail somewhat more complicated gas cleanup and correspondingly higher system costs and maintenance requirements.

Table 2.3: 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	40 – 5,000 MJ_{th}/hour
Range of biomass input[b]	~5 to ~500 kg/hour		~ 3 to ~300 kg/hour	
TECHNICAL PARAMETERS[c]				
Basic equipment	Gasifier, gas cleanup, diesel engine		Gasifier, gas cleanup, gas distr., stove	Gasifier & furnace; or Gasifier, gas cleanup, furnace
Fuel inputs	Per kWh: 1-1.4 kg biomass + ~ 0.1 litre diesel (gives 60-70% diesel replacement)		Per MJ_{th}: 0.1 to 0.15 kg biomass	
Energy outputs	~ 1 kWh per (kg biomass + 0.1 litre diesel)		6 – 10 MJ_{th}/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 by-products	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 boilers + furnaces
ENVIRONMENTAL AND SOCIOECONOMIC PARAMETERS				
Environmental strengths	Reduced pollution compared with diesel fueled engine		Reduced particulate emissions compared with direct burning of solid fuel.	
Environmental concerns	Wastewater 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.
c. Systems are under precommercial development at much greater scales as well, ranging up to 10s of MW. See the discussion of gasifier/gas turbine systems in section A.2.1.4.

2.28 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 utilization 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. Since the electricity costs are generally higher than the cost of electricity generation from a new central station coal or natural gas 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 utilization, 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.

2.29 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 (for example, cooking stoves), is an additional danger. Other gaseous pollutant emissions are small in comparison with emissions from direct combustion of solid fuels. The solid residue from gasification of most biomass types is an inert inorganic material that has some byproduct value as, for example, a mineral fertilizer or as a construction material (as is the case with rice husk ash).

Biogas from anaerobic digestion as a cooking fuel and internal combustion engine fuel

2.30 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. The main application for which biogas systems have been disseminated is to supply cooking fuel for households, and there is considerable scope for further diffusion. Here, in addition to the use of biogas as cooking fuel, we discuss its use as a fuel for internal combustion engines.

2.31 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 byproducts, and landfill material have all been widely used. High moisture feedstocks are especially well suited for anaerobic digestion.

2.32 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 inadequate maintenance, insufficient dung supply, and difficulties with the organization of dung deliveries. Some 7.0 million household scale digesters were installed in China as the result of a mass popularization 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. Some 3 to 4.5 million digesters were operating in the early 1980s. Since then, research, development, and dissemination activities have focused greater attention on proper construction, operation, and maintenance of digesters, and 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 agroindustrial sites and some 24,000 digesters at urban sewage treatment plants.

2.33 Several thousand biogas digesters are operating in other developing countries, most notably South Korea, Brazil, Thailand, and Nepal. Nepal's program is particularly active, with approximately 100,000 systems installed with a very high success rate, and installations are continuing at roughly 20,000 per year. An estimated 5,000 digesters are installed in industrialized 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

2.34 Table 2.4 summarizes the characteristics of anaerobic digestion systems.

2.35 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 utilization 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.

2.36 Large scale industrial digesters have much lower costs per unit of gas production than do small digesters, in part because throughput rates are much higher. A recent estimate of the total cost of methane from a large scale digester (300,000 GJ/year capacity or larger) with a typical industrial feedstock is less than $2/GJ (less than $0.07 per litre of diesel equivalent) under European conditions and about $1/GJ under Brazilian conditions. Large scale digesters have thus become competitive with conventional fossil fuel options for grid connected power generation applications.

2.37 Compared with other biomass energy conversion technologies, anaerobic digestion has important, direct nonenergy benefits, which include pathogen destruction and production of a natural, nutrient rich fertilizer. 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 neutralization of wastes by reducing or eliminating pathogens and by reducing the high chemical or oxygen demand (COD) or biological oxygen demand (BOD) of feed materials.[12] Significant declines in parasite infections, enteritis, and bacillary dysentery have been noted in some developing country regions following installation of small scale digesters.

2.38 If pathogen destruction is an objective (as it has been in China) sufficiently long residence times 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.)

2.39 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.

[12] 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.

Table 2.4: 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 1000Nm3/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 litres diesel fuel per kWh	~ 30 kg fresh dung[c] + 30 litres water per Nm^3 biogas	Varies with feedstock	
Gas required for cooking	---	~ 0.2 Nm^3/capita/day[d]	---	
Useful by-products	Nitrogen fertilizer Pathogen destruction		Reduction of COD, BOD Fertilizer/irrigations	
Key to good performance	carbon:nitrogen in feedstock ~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 (as with 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 percentage) is 40percent CO_2 and 60 percent 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.

Emerging technologies

2.40 The technologies discussed above are advanced. They have been well demonstrated and are either commercial or well on their way. The following discussion describes three emerging technologies that are still in the process of technological development and have not been widely demonstrated or commercialized. These are mentioned because they offer the prospect of expanding the applications in which biomass could find widespread use. The first technology, the biomass integrated gasifier/gas turbine, is a multimegawatt scale electricity generation technology that could be of considerable interest for utility scale applications. Because this technology is expected to be significantly more efficient than the steam turbine technologies discussed above, it could render cost effective the use of higher cost, purpose grown biomass feedstocks. Using purpose grown feedstocks would dramatically expand the roles for biomass beyond what would be possible using residues alone. The second and third technologies are small scale and potentially robust technologies that could find use in decentralized applications where there are modest biomass resources.

Emerging technology: Biomass integrated gasifier/gas turbine

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

2.42 The steam turbine cycle is the predominant commercial technology used today with biomass fuel in the 5 to 100 MW output range. The overall economics of biomass based power generation are expected to be considerably better with a BIG/GT system than with a steam turbine system, especially in situations where biomass fuel is relatively expensive. In approximate terms, the BIG/GT technology will make electricity generation two or more times as efficient as the steam cycle, considerably lowering fuel costs. The capital cost per installed kW for BIG/GT units is also expected to be lower than for comparably sized steam cycles once BIG/GT units are technologically mature and produced at a commercial scale.

2.43 BIG/GT technology is expected to be commercially ready within a few years, based on the substantial demonstration and commercialization efforts ongoing worldwide today. Among the most advanced demonstration projects are those in Sweden, the United Kingdom, and Italy. At Varnamo, Sweden, a BIG/GT system operated for several thousand hours on forest residues, generating 6 MW of electricity at 33 percent efficiency and 9 MW of heat for the local district heating system. In Chianti, Italy, a facility operating on refuse derived fuel first started operation in 1992. And in Yorkshire, England, a BIG/GC (combined gas turbine and steam turbine) facility was operated in 2001and generated about 8 MW of electricity from short rotation biomass plantations.

Emerging technology: microturbines

2.44 Microturbines are gas turbines with a capacity of 100 kW or less. They have been commercially available only since 1999. Microturbines are scaled down versions of the highly efficient multimegawatt designs that have quickly become the standard for utility scale electric generation and large CHP applications throughout the world, and now have over 20 years of proven reliability. In recent years, gas turbines have become available at high levels of efficiency and competitive prices in the micro range, as well. Because of these recent advances, microturbines have attracted commercial attention for small scale applications such as small commercial and agricultural cogeneration applications, and even remote village power generation

2.45 As the technology becomes more fully developed and proven, microturbines are expected to have the following advantages compared with diesel engines: higher efficiency, lower maintenance requirements, longer lifetimes, and lower emissions, at a comparable capital cost. Low maintenance costs, high reliability, long lifetime, and low capital costs are the expected results of a dramatically simpler

design than their multimegawatt predecessors. If these features are borne out, microturbines may eventually be competitive with diesel engines for remote village power applications, particularly if further tests of the technology using biomass derived gases with suitable gas cleanup prove successful.

2.46 However, many technological and institutional hurdles remain before microturbines will be deployed in village applications. Their reliable operation must be demonstrated, particularly in remote areas, and large scale commercial production will be needed to bring capital costs down to levels that can compete with diesel engine. Availability of spare parts and trained technicians in the near term will also slow their acceptance for village applications. Because diesel engines already enjoy these advantages, they will remain the technology of choice for the near term.

Emerging technology: Stirling engines

2.47 The Stirling engine is an external combustion engine. In an internal combustion engine, combustion gases expand within a cylinder, where they press against a piston and convert heat into useable mechanical energy. In a Stirling engine, gases combust *outside* the cylinder; only their heat is transferred into gases sealed within a closed cylinder system. Because combustion occurs outside the cylinder, Stirling engines require less finely controlled combustion conditions and can therefore tolerate a wider range of fuel sources and a lower degree of fuel processing. Stirling engines can be powered by all fossil and biomass fuels (solid, liquid, and gaseous), and even heat sources such as concentrated solar energy. This fuel flexibility is their chief advantage over other small scale generation technologies.

2.48 Their second advantage is their efficiency relative to other currently available small scale technologies such as internal combustion engines and microturbines. Because Stirling engines can be fired directly with solid biomass fuels such as wood chips or agricultural residues, they do not suffer the efficiency penalty associated with biomass gasification. Furthermore, relatively new design advances (known as “free piston” designs) are especially efficient at very small scales. There are currently no large scale demonstrations or commercial sales of biomass fueled Stirling engines.

Liquid Fuels

Ethanol and ethanol gel

2.49 Ethanol is a clean-burning alcohol fuel that is traditionally 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.

2.50 A more recently explored ethanol based option is ethanol gel, a clean burning fuel consisting of gelatinized ethanol bound in a cellulose thickening agent and water with a heating value of 22.3 MJ/kg.. Cookstoves specially designed for use with ethanol gel have been developed in the last few years, as have ethanol gel burners that can be retrofitted into several traditional African cooking stoves. Used in such appliances, ethanol gel is a highly controllable, easily lit cooking fuel with high turndown (ratio is approximately six) and a heating efficiency of roughly 40 percent. Initial market penetration has occurred in Zimbabwe (since 2000) and South Africa, with the establishment of 80,000 liter/month and 30,000/month production facilities, respectively.

2.51 Ethanol can be produced from a variety of biomass crops, including starch laden crops like corn and casava, sugar laden crops like sugar beet and sugarcane, or lignocellulosic feedstocks like wood and grasses. Because sugarcane is grown in over 80 developing countries, and because it is generally the most efficient and cost effective source of ethanol today, the discussion here focuses on

ethanol production from sugarcane. With further technological developments, the economics of ethanol production from other crops might improve.[13]

2.52 With the exception of Brazil, most countries that produce fuel ethanol from sugarcane (Zimbabwe, Malawi, Kenya, and others) make anhydrous ethanol for blending and use the ethanol as a transport fuel. 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).

2.53 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 approximately 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 reevaluation driven in part by the economic impact of unprecedentedly low world oil prices.

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

2.55 The average cost of anhydrous ethanol production in Sao Paulo state, Brazil, in the early 1990s was $0.29 to $0.32 per liter in 1998 US$.[14] 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 (more liters of ethanol per tonne of cane), but more important, as a result of increased land productivity (more tonnes of cane per hectare). Average costs have continued to fall since the early 1990s. As a result, even with the further easing of subsidies on ethanol in early 1999 (due to which competitive pressures induced innovation that further lowered prices), ethanol production is undergoing further cost reductions.

2.56 The cost of the sugarcane feedstock accounts for over half of the cost per liter 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 maximize yield. Although the distribution of costs among the various inputs to the ethanol production vary by site, it can be expected that in other countries with higher cane costs, ethanol would be more costly to produce.

2.57 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, onsite energy demands can be met while producing a surplus of electricity for export and sale 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,

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[13] 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 and 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.

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

and the electricity revenue could be credited against ethanol costs. Such strategies are increasingly being considered by both ethanol and sugar producers. (See the discussion above on steam turbine combined heat and power.)

2.58 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.

2.59 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 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 (the liquid fraction remaining after ethanol is removed). As a result, in Sao Paulo state, topsoil loss per hectare of sugarcane is far below that for most other major monoculture crops.

2.60 Water quality issues arise with two liquid-waste streams generated at a distillery: run-ff 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 neutralized 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 overfertilization of cane plants.

2.70 Stillage is also a suitable feedstock for biogas production. Biogas from stillage could be a substantial energy resource (it contains 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.

2.71 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.

2.72 The following table provides typical characteristics of ethanol production from sugarcane. Sugar cane cultivation methods and ethanol production technologies vary among countries, so the figures below should not be construed as universally applicable.

Table 2.5: 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	Not financially competitive with gasoline when crude oil price 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; greenhouse gas benefits.
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 percent managerial/highly skilled; 10 percent medium skilled; 60 percent 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, for example 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 nonharvesting 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.

Biodiesel

2.73 Biodiesel is the common term for a clean burning diesel fuel and heating oil substitute that can be produced from vegetable oils or animal fat. Chemically, it is a mono alkyl ester ($C_{19}H_{36}O_2$) derived from lipid sources. It is also known as: soydiesel, methyl soyate, rapeseed methyl ester (RME), or methyl tallowate. The most common feedstocks for biodiesel are soy oil and rapeseed oil, although it has also been produced from sunflower seed, cottonseed, jatropha and used frying oil. Its chemical properties and performance characteristics are very similar to petroleum based diesel fuel. It can readily replace or be blended with diesel fuel or heating oil in standard diesel engines and boilers, requiring very few, if any, equipment modifications. Biodiesel fuel is nontoxic, biodegradable, and lower emitting than ordinary diesel fuel. It can be produced fairly inexpensively from a variety of biomass feedstocks in large oil refinery sized plants or at the village level using simple technology.

2.74 Biodiesel has been used as a fuel additive throughout Europe for roughly twenty years and is being introduced in the USA and Canada. In most applications to date, it has been mixed with ordinary diesel fuel at a 20:80 ratio commonly referred to as B20. No engine modifications are needed to consume this fuel mixture. However, fuel filters often need to be replaced following the first usage of biodiesel in an engine previously operated only on petroleum based diesel fuel, as biodiesel tends to have a cleaning effect on engine fuel systems. The additional cost incurred for fuel filters is reportedly more than offset by the improved engine performance and reduced maintenance requirements.

2.75 Higher concentrations up to 100 percent (or B100) can also be used without significant engine modifications. Biodiesel has a heat content similar to that of petroleum-based diesel and can slightly improve engine performance (due to its higher cetane number) and improve maintenance characteristics. Biodiesel can be stored in tanks designed for regular diesel fuel (provided they are not concrete lined tanks) and is significantly safer than regular diesel fuel because it has a higher flashpoint. Unfortunately, it is not uncommon for the various subtle benefits of biodiesel to remain unknown to the operator, or for fuel choice decisions to be made by someone other than the person to whom these benefits would accrue.

2.76 Biodiesel is currently used primarily as a subsidized additive with diesel fuel to reduce emissions, as it has been found to reduce pollutant emissions significantly[15]. Though currently subsidized, biodiesel is expected to become less costly at higher production scales. It is not yet directly cost competitive with diesel, but it compares favorably with many alternative fuels and fuel additives, such as propane, LNG, CNG, methanol, and ethanol, that are currently being used in trucks and buses in many parts of the world.

2.77 Rosenblum and Arunachalam (2000) describe a low tech, cost effective method for producing biodiesel at the village level using the oil of the jatropha curcas (or Physic nut) plant. The jatropha plant can produce as much as five times the amount of oil per hectare as soybeans and can be grown on more marginal lands. The simple process involves mixing the jatropha oil with methanol or ethanol, plus a base (NaOH or KOH) and allowing the mixture to settle. Biodiesel produced in this manner in a typical Indian village would cost roughly US$0.90 /liter. This is significantly higher than the cost of diesel fuel, but may be cost competitive in remote regions where inaccessibility or transport costs make it difficult to obtain fuels for diesel engines such as irrigation pumpsets and milling machinery. As with many bioenergy approaches, land requirements would be considerable. One hectare could typically yield approximately 300 liters of biodiesel per year.

2.78 As biodiesel fuel is nontoxic, biodegradable, and lower emitting than ordinary diesel fuel, it can help to reduce smog precursors and particulate matter areas in areas where diesel fuel combustion contributes significantly to air pollution. It also produces lower greenhouse gas emissions than fossil fuels

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[15] One comprehensive metastudy found that blending biodiesel with diesel produces a large decrease in emissions of particulates, carbon monoxide, and hydrocarbons, and a modest (~20%) increase in emissions of nitrogen oxides (EPA, 2002).

such as diesel. A 1998 biodiesel lifecycle study by the U.S. Department of Energy concluded that biodiesel production can reduce net CO_2 emission by 78 percent compared to petroleum diesel fuel. Its use can reduce foreign exchange expenditures for countries without domestic oil resources and can serve as a prudent hedge against sudden oil price shocks.

Solid Fuels

Efficient cook stoves for use with solid fuels

2.79 The primary use for fuelwood, charcoal, and other forms of biomass in most developing countries is domestic cooking. Domestic cooking averages over 60 percent of total national energy consumption in subSaharan Africa, for example, and exceeds 80 percent in some countries (Barnes et al, 1994). As at least two billion people use simple biomass cookstoves, improving the performance of these stoves can greatly benefit rural families and their environment. Improved stoves reduce indoor air pollution and increase the efficiency with which biomass resources are used.

2.80 Many smokeless, high efficiency, low cost stove designs exist. These are designed to optimize combustion of the biomass fuel and maximize transfer of heat to cooking vessels, and often are designed with a chimney to vent smoke to the outdoors. There are scores of cookstove research and dissemination programs operating worldwide with a wide range of success rates in terms of actual adoption and performance compared to the traditional “three stone” fire. However, achieving the intended clean and efficient operation in practice has proven to be difficult for several reasons. Stove performance often is sensitive to design parameters, but it can be difficult for semiskilled laborers to faithfully replicate stove design parameters in the field. Stove performance is also dependent on how it is used, but the user might not be aware of the specific operating instructions, or might not be able or willing to follow them if they are incompatible with cooking habits. Stove performance also depends on the characteristics of the biomass fuel used, which varies from site to site and seasonal to season, and even varies across cooking tasks.

2.81 One of the main benefits of improved stoves is their reduction in indoor air pollution. Poor indoor air quality, resulting from smoke given off by the family hearth, is a significant health hazard in many developing countries. Traditional hearths that allow smoke to collect and concentrate in cooking areas have been associated with incidences of acute respiratory infections (ARI) in mothers and children, eye infections, low birthweight, and various chronic lung diseases, including cancer. The World Health Organization estimates that 1.5 billion people live under conditions of unhealthy air and 4-5 million children die each year due to ARI. Air quality in kitchens in many developing countries has typically been measured at 3-10 times (and sometimes over 100 times) the allowable limits for particulate matter and carbon monoxide deemed acceptable in the USA (Kammen, 1995). Some stoves, particularly the more efficient Lorena designs with chimneys, can help to greatly alleviate this health hazard. A study in rural Mexico found that the Lorena stoves used there reduced concentrations of particulate matter and carbon monoxide by one half to two thirds (Saatkamp, 1997).

Biomass briquetting

2.82 Biomass densification, or “briquetting”, is the process of compacting loose biomass feedstocks into a uniform dense form, producing a higher quality fuel. Better and more consistent thermal and physical qualities than raw biomass allow for more complete combustion of briquettes, providing greater efficiency, reduced emissions, and greater control for residential or industrial applications. Briquettes offer easier transport and storage, and easier mechanical handling in both household and industrial settings.

2.83 Briquettes can be efficiently produced using relatively simple technologies. Stalks, husks, bark, straw, shells, pits, seeds, sawdust—virtually any solid organic byproduct of agricultural or silvicultural harvesting—can be used as feedstock. Biomass can also be briquetted along with other fuels such as coal. Biomass wastes with relatively low moisture contents (less than 15 percent) are most suitable for efficient production of briquettes.

2.84 Briquettes are primarily produced commercially for specific industrial niche markets. Only in a few countries do biomass briquettes currently compete successfully with fuel wood or other unrefined biomass products (such as cow dung) for household cooking or heating. Generally, briquette production is economically viable only with biomass wastes that are free (or negative cost). Table 2.6 shows the typical range for various production costs across several countries. Assuming feedstocks are free, production cost generally runs between US$20 to $36 per tonne of biomass briquettes. In Brazil, low electric costs and an abundance of sawmill wastes keep the cost of production at large briquetting plants at the lower end of this range. In some regions of India and African where fuelwood costs are higher than average, briquette sales to households are viable. However, in many other countries, this range is sufficiently higher than the local price of fuelwood that briquettes have not been able to penetrate the market.

Table 2.6: Typical non-fuel cost components for briquette production

	US$/tonne
Capital charge	9-12
Labor	3-5
Maintenance	3-8
Electricity	3-7
Raw materials	1-4
Taxes, Material Transport, & miscellaneous expenses	> 1

Source: Ericsson and Prior (1990)

Charcoal production

2.85 Charcoal is a higher quality fuel than raw biomass. It is extensively used as a cooking fuel, especially in urban areas where free alternatives such as collected fuelwood and agricultural residues are unavailable. Charcoal fires are more controllable and more convenient for cooking. They are relatively smokeless and generate less indoor air pollution than do raw biomass fires. Because charcoal has a higher energy density (by nearly a factor of two) than raw biomass and keeps better, it is more easily stored and cheaply transported, increasing its economic transport distance. This makes it more easily supplied to urban areas where high population densities necessitate the import of fuel from distant sources. As a market commodity that must be purchased by households, charcoal is most commonly in use where raw biomass fuel cannot be collected free. Charcoal is also used in some industrial applications, the most notable of which is the Brazilian iron sector, which uses charcoal (mostly from wood grown in government run tree plantations) in place of coke in smelting furnaces.

2.86 Despite the fact that charcoal stoves can be more efficient than raw biomass stoves, the lifecycle efficiency is lower because of the relatively inefficient process of producing charcoal from raw biomass. Using charcoal therefore consumes more of the biomass resource[16]. Charcoal is typically

[16] It is perhaps instructive to note that the energy losses incurred by charcoal production are comparable with (and often less than) the typical losses associated with electric generation: about 65 percent for combustion, plus an additional 8 percent for transmission. In both cases, the energy penalties of these processes are deemed acceptable

produced using a simple, traditional process that has changed little over the centuries. Wood or other biomass feedstock is heated slowly in an enclosed space with insufficient oxygen for complete combustion. This releases water and volatile compounds from the biomass through a form of pyrolysis, leaving behind primarily carbon. The most widely used method for producing charcoal is to enclose slowly burning raw biomass for a period of days to months in a simple kiln made of either a shallow pit or an earthen mound. This traditional method requires only local materials, can be built onsite, and entails minimal cost, but is subject to gross inconsistency in the quality of the product. Efficiencies are generally low and variable; they rarely exceed 25 percent on an energy basis.

2.87 Major improvements in charcoal production are attainable. Improved practices based on better understanding and control of the carbonization process can considerably improve efficiencies with no additional capital investments. Practices that have been successfully demonstrated in the field include more thorough feedstock drying, better stacking methods, improved air control, and more regular monitoring.

2.88 Further improvements can be attained using charcoal kilns with more sophisticated designs. These rely on more skilled construction and materials such as clay, bricks, or steel, and design improvements such as an external downdraft chimney.

2.89 In combination, improved practices and improved designs can increase charcoal production efficiencies by a factor of two or more compared with traditional, unoptimized methods. They also produce a higher quality charcoal that is more consistent and less contaminated by earth and stones.

2.90 However, these improvements come with additional costs due to greater labor and material expenses. Often, the requisite capital outlays or investments in labor are not justified from the perspective of the charcoal producer; the raw biomass is acquired at zero cost, and conserving it yields little or no financial benefit. Even where improvements would be cost effective, the requisite materials and construction capacity might be difficult or impossible to obtain onsite. Despite these barriers, charcoalers in many regions have adopted improved practices, particularly where there are supportive measures such as regulatory requirements, extension services, and demonstration activities targeted at traditional charcoalers in their customary environment.

Conclusion

2.91 The wide range of technological options for biomass rely on various feedstock and satisfy different energy service needs.

2.92 Some of these technologies are mature and fully commercial, such as industrial scale biogas production (especially landfill gas from municipal waste) and steam turbine CHP systems. Indeed, CHP systems already satisfy electricity demand in several agroindustries (such as sugar and pulp and paper industries) and provide several tens of gigawatts of excess capacity to the grid across the world. Tremendous opportunities exist for further expanding this potential. Implementing energy efficiency measures to cost effectively reduce onsite steam demand and upgrading boilers and steam turbines can vastly increase the total amount of electricity made available for export.

2.93 Some of the technologies are demonstrated and well disseminated but not yet marketed on a fully commercial basis. Ethanol for transport, household biogas digesters, improved cookstoves (both fuelwood and charcoal), and biomass gasifiers for thermal applications in agroindustries are examples of technologies that have reached high levels of penetration focused on specific geographic areas. These have benefited from publicly supported dissemination programs and have required varying levels of public sector financial input. They are continuing to progress in terms of technological advancement, institutional learning, and market development and have prospects for developing into mature markets. In some cases, they may become fully commercial and need no further public sector

because the original fuel is transformed into a more useful form—one that is easier to transport, more convenient to use, and has lower emissions at the point of end use.

involvement. In other cases, the environmental benefits (for example, GHG reductions) and/or social benefits (rural income generation) may warrant continued support.

2.94 Other technologies, such as biomass gasifiers with gas turbines, are just emerging. These are currently benefiting from continued research efforts (in gasification, gas cleanup, and gas turbine modification) and commercial scale demonstrations. A particularly compelling feature of this technology is that it can double the efficiency currently attained with conventional steam turbine technologie, at comparable scales. This could make generating electricity from purpose grown energy feedstocks cost competitive with fossil fuel power production, which would substantially expand the prospect of biopower beyond what is achievable based on residues alone. Section 2.11 of the Main Report discusses several aspects of supporting technology development and transfer. Various resources have been developed for helping prospective project developers and policymakers to assess technological and analyze project opportunities. Among those are sophisticated analytical tools and decision support systems such as the following:

2.95 **Retscreen** (Renewable Energy Technology Screen) provides training materials and a Clean Energy Project Analysis Software. The software utility is an "energy awareness, decision support and capacity building tool that consists of a standardised and integrated project analysis software which can be used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy efficient and renewable energy technologies compared to conventional energy projects. In addition to the software, the tool includes product, cost and international weather databases; an online manual; a case study based college/university-level training course and electronic textbook; and an Internet-based Marketplace. All of these are available free, in both English and French, at www.retscreen.net. For those with limited or no Internet access, all the materials are also available on CD-ROM."

2.96 **ProForm** "is a software tool designed to support a basic assessment of the environmental and financial impacts of renewable energy and energy efficiency projects. Given the necessary data, ProForm calculates basic financial indicators and avoided emissions of CO2 and local air pollutants expected from a project. As a spreadsheet-based tool, ProForm is designed to be simple enough to be easily usable, yet sophisticated enough to provide credible results. A typical application of ProForm would be in preparation of a project proposal that the developers might submit to potential investors, financiers, or a national climate change office." A downloadable software utility and documentation is available at poet.lbl.gov/Proform.

2.97 The United States National Renewable Energy Laboratory sponsors a site called the **Renewable Energy Analysis Studies Network** (REASN) (www.nrel.gov/reasn), which bills itself as a "one-stop-shop for reports, tools, and data related to financial and policy analysis of renewable energy technologies," including biomass.

2.98 The **Renewable Energy Supply Model** project provides "a compilation of definitions, characteristics, model-specific advantages, problems and success factors for different Rural Energy Supply models, illustrated with real-world examples" including decision support tools.

2.99 There are many other general sources of information. A good source of information and portal to other sources is the global Biomass Users Network, with nodes (each with its own website) located in several countries and regions.

2.100 This is only a small selection of the various web-accessible resources and utilities that are continually evolving. Information about developers and vendors of biomass energy technologies is also continuously changing, and is increasingly available on the internet.

Appendix Volume II

Biomass Moisture and Energy Content

The weight and energy content of biomass fuels depend critically on the moisture they contain. Unfortunately, both energy content and moisture content are recorded by different methods. This Appendix explains the methods that are used and how to convert between them.

Moisture content

The water contained within biomass material can alter by a factor of 4-5 between initial harvesting (as "green" crop or wood) and its use as a fuel after some time, during which the material partially dries, or loses water. The water content at any stage in this process, usually termed moisture content and given as a percentage, is measured in two ways, on a "wet" and a "dry" basis:

- Moisture content, dry basis (MCdb) is the weight of water in the biomass divided by the dry weight of biomass.
- Moisture content, wet basis (MCwb) is the weight of water in the biomass divided by the total weight of the biomass; that is, the weight of water plus the weight of dry biomass.

If the weight of water is W and the weight of dry biomass is D:

$\text{MCdb} = W / D$ $\qquad$ $\text{MCwb} = W / (W + D)$

To convert between these measures:

$\text{MCdb} = \text{MCwb} / (1 - \text{MCwb})$ $\qquad$ $\text{MCwb} = \text{MCdb} / (1 + \text{MCdb})$

The relationship between the two measures is illustrated in the first two columns of Table A.1.

Energy content

The energy of fuels is also measured in two ways. The Lower Heating Value (lhv), sometimes called Net Calorific Value, is a practical measure of the heat obtained by complete combustion of a fuel under the usual conditions of constant pressure. The Higher (sometimes Gross) Heating Value (hhv) also includes the energy contained in combustion products: namely, hot vapor from contained water, including its latent heat of vaporization; hot water vapor formed from hydrogen in the fuel, including its latent heat of vaporization; and carbon monoxide, carbon dioxide, nitrogen oxides and trace gases.

International and most national energy statistics are now given in terms of the lower heating value, in which one tonne of oil equivalent is defined as 10^{10} calories (10^7 kilocalories), or 41.868 GJ. Several countries, including the USA, and many biomass energy reports and projects, still use higher heating values. For fossil fuels such as coal, oil and natural gas, and for most forms of biomass, the lower heating value is close to 90 percent of the higher heating value. This relationship is used, for example, by the International Energy Agency in its comprehensive national energy statistics. It is adopted throughout this report, unless otherwise stated.

The conversion from commonly used higher heating values to lower heating values is based on the following formula for all biomass. In units of megajoules per kilogram (MJ/kg):

$LHV_w = HHV_w – E_w * (h_w * m_{H2O}) - E_w * W$

where:

LHV_w, HHV_w = lower, higher heat values of wet biomass

E_w = energy required for evaporation of water (2.26 MJ/kg)

h_w, h_d = hydrogen content of wet and dry biomass. For many types of biomass h_d is 0.06 (6%)

m_{H2O} = weight of water created per unit weight hydrogen (8.9 kg/kg)

W = moisture content of biomass, wet basis, as a fraction

HHV_d = higher heating value of dry biomass

So, using the quantities given above:

$$LHV_w = HHV_w – 2.26 * (h_w * 8.9) – 2.26 * W$$
$$= (1-W) * HHV_d – 2.26 * (1-W)* h_d * 8.9 – 2.26 * W$$
$$= (1 – W) * (HHV_d – 1.207) – 2.26 * W$$

The table below gives the higher and lower heating values of biomass, in GJ per tonne, according to moisture content and three typical values of the higher heating value of dry biomass (HHV_d).

Table A.1: Energy content of biomass according to moisture content and use of higher versus lower heating values

Moisture (percent)		Higher heating value of dry biomass (HHV_d)					
wet basis	dry basis	22 GJ	20 GJ	18 GJ	22 GJ	20 GJ	18 GJ
		Higher (HHV) and lower (LHV) heating values of biomass at given moisture content					
(MCwb)	(MCdb)	HHV	HHV	HHV	LHV	LHV	LHV
0	0	22.0	20.0	18.0	20.79	18.79	16.79
5	5	20.9	19.0	17.1	19.64	17.74	15.84
10	11	19.8	18.0	16.2	18.49	16.69	14.89
15	18	18.7	17.0	15.3	17.34	15.64	13.94
20	25	17.6	16.0	14.4	16.18	14.58	12.98
25	33	16.5	15.0	13.5	15.03	13.53	12.03
30	43	15.4	14.0	12.6	13.88	12.48	11.08
35	54	14.3	13.0	11.7	12.72	11.42	10.12
40	67	13.2	12.0	10.8	11.57	10.37	9.17
45	82	12.1	11.0	9.90	10.42	9.32	8.22
50	100	11.0	10.0	9.00	9.27	8.27	7.27

It is clear from the table that moisture has a large effect on the energy content per unit mass of biomass, whereas the use of lower versus higher energy values has a smaller but significant effect. As one would

expect, the difference between the lower and higher heating values increases with moisture content. For example, for an HHV_d of 20 GJ/tonne and zero moisture, the LHV is 94 percent of the HHV, but for green wood with an MCwb of 50 percent, the ratio falls to 83 percent.

Table A.2 presents some typical energy and moisture contents of biomass fuels with some fossil fuels as a comparison. With biomass, the values should be treated only as a rough guide and should be checked by field measurement whenever reasonably accurate values are important to project or other evaluations. The energy content of coal, lignite, and peat should also be checked by local field measurements.

Table A.2 Typical energy content of biomass and fossil fuels

	Moisture content (Wet basis - %)	Lower heating value (MJ/kg or GJ/tonne)
Biomass fuels		
Wood (wet, fresh cut)	40	10.4
Wood (air dry, humid zone)	20	14.6
Wood (air dry, dry zone)	15	15.6
Wood (oven dry)	0	20.0
Charcoal	5	29.0
Bagasse (wet)	50	8.2
Bagasse (dry)	13	16.2
Wheat straw	12	15.2
Maize stalk	12	14.7
Maize cobs	11	15.4
Rice hulls (air dry)	9	14.4
Cotton stalk	12	16.4
Coconut husks	40	9.8
Coconut shells	13	17.9
Dung cake (dried)	12	12.0
Fossil fuels		
Bituminous coal		25.7
Lignite & Peat		8.4
Crude oil		41.87
Liquefied petroleum gas (LPG)		47.3
Motor gasoline		44.8
Kerosene		43.8
Diesel oil		43.3
Heavy fuel oil		40.2
Natural gas (thousand m^3)		37.7

Sources: Biomass: based on Leach & Gowen 1987; Fossil fuels: IEA 2003a; Natural gas: BP 2003.

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Advancing Bioenergy for Sustainable Development Guideline for Policymakers and Investors

Volume III

Project Profiles and Case Studies

1

Bioenergy in Practice: Project Profiles

1.1 As with any resource, there exists a wide gap between the potential of modern bioenergy and the results that have been achieved in practice. Realizing bioenergy's potential requires identification of the key factors associated with implementation, operation, and dissemination of the technologies and systems that can best exploit it. Yet bioenergy arguably exhibits more variation in applications than any other class of energy resources, making it quite difficult to generalize about the key factors that lie behind success or failure. In spite of this variation, several decades of experience with modern bioenergy can help us to understand some common failure modes and promising approaches. This chapter provides a set of brief descriptions of a wide range of bioenergy projects and programs, drawn from both private sector initiatives as well as initiatives with a significant public sector component. These activities provide concrete examples of many of the general concerns and guidelines raised in the previous chapters.

1.2 The activities described in this chapter by no means yield an inventory of major bioenergy activities to date—the breadth and depth required for such a review put it beyond the scope of this work. Instead, examples have been chosen selectively, in order to:

1) Place special emphasis on developing countries and developing country resources

2) Provide a cross-section of bioenergy technologies and applications

3) Focus on modern bioenergy applications that are potentially widely replicable.

1.3 Although the chapter is focused on developing country applications and resources, there is a considerable amount of relevant experience in industrialized countries to which reference will be made. The relevance of industrialized country experience stems not only from specific factors related to resource utilization and technoeconomic adaptation, but also to more general factors, not the least of which is the ever-expanding volume of foreign investment and trade around the world. As capital, technologies, and resources flow ever more freely across national boundaries, investment capital available in the North will increasingly flow toward the plentiful bioenergy resources of the South. This trend will be encouraged by international efforts to address climate change via cooperative activities and carbon emission crediting.

1.4 It is not always easy to compare the experiences of smaller and larger developing countries. The larger and/or wealthier developing countries (for example, Brazil, China, India) have more technical resources, greater access to markets, more opportunities for financing, and larger government bureaucracies, all of which make it difficult to compare them with most smaller developing countries. Not all of these differences necessarily result in advantages—for example, a large government bureaucracy might hinder implementation of a bioenergy project whose scope and scale might be unfamiliar to it. However, bioenergy projects and programs that exhibit an innovative approach or appear to be widely replicable are relevant regardless of the country. It can also be argued that bioenergy applications in isolated areas (particularly islands) make the country distinction less relevant anyway. The need to represent a cross-section of applications is also recognized.

1.5 The wide variation in the economies of scale of bioenergy complicates comparisons across applications and specific projects. This report has considered a tremendous variation in scale, ranging from household energy to small village gasifiers to 100 MW power plants supplying urban areas. In general, the discussion here will tend to emphasize moderate-scale bioenergy suitable for a collection of villages or small towns. At the same time, larger-scale systems as well as national programs, such as those pursued for biofuels (for example, ethanol) are also addressed because of their important contributions. With due consideration for the diversity and localized nature of bioenergy, many of the same lessons, particularly with respect to institutional factors, can in fact be applied across the different scales.

1.6 The further need to generalize across geographical and technological boundaries, as well as across energy carriers (liquid fuels, gas, heat, electricity) requires recognition of the limitations thereby entailed. The *general* availability of a low-cost bioenergy technology does not imply low-cost *local* implementation. The highly localized nature of many bioenergy resources and markets requires great care when attempting the leap of faith toward implementation that may be reasonable and commonplace for other types of energy resources. Nevertheless, as bioenergy markets, technologies, and systems mature, the lessons from experience will become easier to interpret and adapt to localized conditions. The value of feeding back the lessons learned from bioenergy systems *in practice* to the design of bioenergy systems *in theory* will therefore only increase in importance.

1.7 The projects and programs considered here are those for which bioenergy systems have been in operation for a few years, thus excluding many bioenergy projects that are still in the design phase or have only recently gone into operation. This chapter also includes a few projects that faced difficulties and could not be sustained, based on the notion that one must learn from failure as well as success. It is more difficult to obtain information on those projects that failed, since there is considerably less documentation available and those persons who know the most about the projects are reluctant to discuss them. Therefore the discussion here of "failures" is arguably even more incomplete than what is already a highly limited and selective discussion of "successes." In spite of all these caveats, the activities discussed here provide some guidance regarding design and implementation of bioenergy systems.

1.8 The implicit metric applied here with respect to success or failure is the commercial viability of a given bioenergy application and the wider dissemination that is achieved as "successful" bioenergy projects lead to natural replication in the marketplace. But it is important to note that bioenergy projects and programs will often have other objectives, particularly where they are based on public–private partnerships. A project may be aimed at reducing greenhouse gas emissions, maximizing biomass utilization, or other objectives that may affect commercial viability. Pilot or demonstration projects will generally have other objectives and should therefore be judged by different standards. Optimizing on the basis of emissions or plant efficiency is quite different from optimizing the overall bioenergy system or optimizing the market value of final products. Yet, given that the ultimate goal in practical terms is, after all, commercial viability, these project experiences are nevertheless relevant, and the lessons from such projects can be qualitatively applied, with due consideration for differences in objectives, application, and scale.

Bioenergy Profile 1: A Tale of Two Ethanol Programs: Malawi and Zimbabwe

Both of these countries began looking at ethanol in the 1970s for the same reasons Brazil did: to address rising oil prices, save foreign exchange, and develop a domestic resource. In both cases, public–private partnerships and market coordination (for blending, distribution, and transportation) were critical to establishing the programs. In both cases, ethanol distilleries were to be built adjacent to existing sugar factories, where the availability of molasses as feedstock could be assured. In Malawi, the price of ethanol was pegged to that of gasoline, plus an incentive of 5 percent or more, depending on the volume of ethanol blended. In Zimbabwe, a cost-plus basis with a 5 percent return was originally used by the national oil company for purchasing ethanol, although this formula later also was pegged to the price of gasoline.

Triangle Ltd. (Zimbabwe) began ethanol production in 1980. Domestic labor and local construction reduced construction cost by 60 percent compared with a turnkey plant. All key aspects of prices, distribution, marketing, and related infrastructure had been finalized before the plant was built. The targeted blending ratios established through the national oil company were 8-13 percent. Annual production during the 1980s ranged from 30 to 40 million liters. A drought in 1991-93 resulted in almost no sugarcane production and thus almost no ethanol production, due to unavailability of molasses. After the drought, attempts to settle the arrangements to begin blending again were unsuccessful. Triangle needed to optimize sugar production for financial reasons, resulting in less molasses and less ethanol, and the national oil company was reluctant to blend at a lower scale. At the same time, structural adjustment programs and tax incentives in Zimbabwe were encouraging exports, and Triangle found international buyers for potable alcohol (for spirits and liquor), which generally commands a price premium. Consequently, even though Triangle is again producing 30 million liters of ethanol per year, it is mainly sold on the potable market and is no longer blended with gasoline.

ETHCO Ltd. (Ethanol company of Malawi) has operated since 1982, with annual production reaching 15-20 million liters and blends ranging from 15 to 22 percent. Since irrigation water is available from Lake Malawi, ETHCO is not susceptible to the climate-induced interruptions that affected Triangle. But the company has faced some difficulties in molasses supply. Unlike Triangle (where ownership of ethanol plant and sugar factory is unified), ETHCO is owned separately from the adjacent Dwangwa sugar factory, resulting in the need for price negotiations, additional costs, and increased uncertainty in feedstock supply. This factor, along with spare plant capacity and the desire to maintain blending targets, prompted ETHCO to secure additional molasses supply (as much as 40 percent) from the Sucoma sugar factory, located several hundred kilometers to the south. Ironically, use of diesel trucks to transport molasses from Sucoma reduces the otherwise positive environmental and economic benefits of ethanol substitution. Stillage waste from ethanol production was to be turned into biogas, using an anaerobic digester funded mainly by the Dutch government. However, a lack of training and standardized operational procedures resulted in the plant's being shut down without ever having operated for more than a few days at a time (Chanje 1998).

A comparison of these two cases reveals some key lessons for developing countries looking at ethanol or other biofuels for the transport sector. First, public–private coordination among oil companies, government, and ethanol entrepreneurs is critical to establishing and sustaining such programs. Second, feedstock availability, always a crucial element in bioenergy, must be assessed so as to include long-term climatic and market conditions unforeseen in short-term business planning. It was not only the drought that caused difficulties in Zimbabwe, but also the fact that private companies must respond as markets change, which in this case led to greater emphasis on sugar and reduced availability of molasses. Third, consistency in government policies and support is important, as has generally been the case in Malawi. The program in Zimbabwe was intended to reduce the need for imported gasoline, yet this effect was counteracted by encouraging exports (which too had foreign exchange benefits). Finally, careful planning for inputs (molasses) and waste streams (stillage) are needed if overall economic and environmental benefits are to be maintained.

Bioenergy Profile 2: Bagasse Cogeneration in Mauritius

The Sugar Bio-Energy Technology Project provided technical and institutional support for the Bagasse Energy Development Programme in Mauritius. The most tangible goal of the project was to expand electricity generation from the Union St. Aubin Sugar Factory to a target value of 120 GWh annually through provision of additional generating capacity of 22 MW with a Condensing Extraction Steam Turbine (CEST) unit. The electricity generation was needed to meet rising demand, which was otherwise expected to be met through construction of a diesel-fired plant. The seasonal availability of bagasse (during the six-month cane harvest season) resulted in a plan to use coal during the six-month off season. The project received $3.3 million in support from the Global Environmental Facility out of a total project cost of US$55.1 million (GEF 1992). The plant went into operation in 1996-97, and the bagasse-generated electricity reached 118 MWh in 1997, thus roughly meeting the established target of 120 GWh.

The technical success of the project was not unexpected, given the current level of maturity of CEST technology and the long experience in Mauritius with bagasse cogeneration. The sugar industry has been involved since 1957 in exporting electricity to the national grid, and in fact Mauritius already had four CEST units in operation at sugar factories. But the project also made substantial contributions regarding institutional and organizational issues. It helped by establishing model power purchase agreements that are more firmly grounded in the principles of avoided cost pricing, which offers independent power producers the full benefit of receiving payments for exported commensurate with the value to the utility. It improved management and coordination among the key stakeholders in industry and government. The project also led to improved bagasse utilization strategies, based on which the most efficient plants would have better opportunities for electricity sales in the future (Hosier and Sharma 2000). Overall, the project not only achieved commercial success, but demonstrated both technical and institutional improvements that are replicable in Mauritius and elsewhere.

In addition to the efforts in Mauritius, there are many ambitious bagasse cogeneration efforts underway around the world, the largest being in India, where several hundred MW of cane-based cogeneration are in operation and another 3,000 MW are planned. Australia, Brazil, Cuba, and several other countries have bagasse cogeneration programs or projects well underway. The low or negative cost of bagasse as fuel and the maturity of CEST technology make investments economically attractive in most cases where the scale is sufficient (20 MW or more) and where there exists a fair playing field for alternative smaller-scale electricity generation. The main obstacles are institutional in nature: (1) the lack of standardized (and enforceable) power purchase agreements with electric utilities; and (2) lack of financing, particularly for smaller developing countries. In addition to bagasse, the use of cane tops and leaves (cane trash) has been tested, although the costs of collection and the low density of cane trash have posed obstacles to widespread use.

Bioenergy Profile 3: Biomass Power Plant at Riberalta, Bolivia

Riberalta is a town of about 600,000 people in a remote area of the Bolivian Amazon, near the confluence of the Beni and Mamore rivers and the northern border with Brazil. Riberalta's economy rests upon the export of two forest products: tropical hardwoods and Brazil nuts. It is estimated that 30 percent of the world's Brazil nuts are processed in Riberalta. Electricity supply through Riberalta Electricity Cooperative was based on seven aging diesel generators; losses of power were frequent, and many larger users purchased their own generators. As part of USAID's Electricity for Sustainable Development project, the National Rural Electricity Cooperative Association (NRECA) assisted in a new effort to improve the generation system. Based on financial and environmental analyses, a new biomass plant was chosen as the best and least-cost option. Construction of the plant began in 1995 and was completed in September 1996. Financing was provided through a number of Bolivian sources along with a loan through NRECA. Plant operating personnel were trained during the construction process by an independent engineer hired by NRECA.

Riberalta Biomass Plant: Summary of Technical, Financial, and Operational Features	
Rated Generating Capacity	1000 kW
Actual Generating Capacity	790–900 kW
Fuel Supply 1	Brazil nut shells (80 percent) ; 2.5 kg/kWh
Fuel Supply 2	Chipped wood (20 percent) ; 5 kg/kWh
Feedstock reliability/accessibility	50 tonnes/day of shells produced locally
Electricity Production	12,000–20,000 kWh/day
Diesel consumption offset	4000–6670 liters/day (assumes 3 kWh/liter diesel)
Construction Cost	2.2 million USD
Electricity Generating Cost	US$.075/kWh (diesel generation would cost US$.13/kWh)
Consumers/users	4500 members of the Riberalta Electricity Cooperative

In 1999, the plant encountered some serious operating problems, as capacity had fallen rather precipitously. The plant was taken off-line for inspection, and as a result, the cooperative requested that NRECA repair the plant and operate it for a two-year period. The problems stemmed from poor water treatment and poor maintenance of the gear reducer and turbine. NRECA determined that there had not been enough operator training, nor had they made routine reviews of maintenance practices during startup. Maintenance was also complicated by the remote location, which posed difficulties with supplies and spare parts. The plant went back into service in September 2000 with a new operating crew and a highly qualified plant supervisor. Some rather simple problems had turned into major repairs after regular maintenance had been neglected. The problems showed that operators must be supervised by a knowledgeable plant manager who is highly disciplined with regard to the maintenance schedule.

With the exception of these maintenance problems, the plant has been successful in providing a new reliable electricity source with associated economic and environmental benefits. There had been a significant amount of unfilled demand for reliable power within the cooperative before the plant went into operation, so the plant resulted in many new users. Coupled with improvements in transmission and distribution, the plant has delivered reliable energy services that are contributing to strong growth and development in the local economy. The plant is an environmental success, as it not only replaces diesel but also avoids dumping of Brazil nut shells into the river, which had been a common practice. Initially, Brazil nut waste was free, but market forces have given value to the waste, leading to an increasing price, since some Brazil nut plants have their own biomass plants for steam production. But the plant is expected to remain economically competitive, as rising biomass feedstock costs will be offset by the current phasing out of existing diesel subsidies.

Bioenergy Profile 4: Värnamo Gasification Combined Cycle Power Plant

Sydkraft AB in Sweden constructed and operated the world's first Biomass Integrated Gasification Combined Cycle (BIG-CC) power plant, which used a pressurized circulating fluidized bed gasifier. Sydkraft was supported in the design and installation phase by an international consortium and received a small amount of financial support from the EC and the Swedish National Energy Administration. Plant construction began in 1993 with a demonstration phase during 1996–2000. The plant aimed to demonstrate the commercial feasibility of the biomass IGCC concept using the Bioflow technology. It was a moderate scale "working" demonstration plant that exported heat and power and allowed tests of operations, availability, and maintenance with different feedstocks, including forest residues, willow, straw, and various refuse-derived fuels. During the initial period from 1996 to 1997, there were a number of adjustments and maintenance requirements that kept the plant down for significant periods, but once these issues were addressed, the plant ran almost continuously.

Värnamo Biomass Gasification Demonstration Plant: Design and Operation	
Rated Generating Capacity	6 MW electricity; 9 MW heat
Technical Design	pressurized circulating fluidized bed gasifier
Gas Turbine Design	Typhoon (airblown) + minor modifications & controls
Operating Efficiency	Electric – 32 percent ; Plant – 83 percent
Fuel Supply 1	wood chips and forest residues (bark, branches)
Fuel Supply 2	Tested with bark pellets, sawdust, willow, straw
Feedstock reliability/accessibility	Widely available
Construction Cost	12–13,000 SEK/kW (1,500-1,625 USD/kW)
Years of Operation	Operated as a Demonstration plant,1996–2000

A great deal was learned about the suitability of different feedstocks and the adjustments that are needed to accommodate flexibility in feedstock. Bark proved to be an excellent fuel, as it is easily gasified and produces a cleaner gas for filtration and gas turbine operation. Tests performed with willow (salix) showed a negative effect only in the reduced heating value of the gas; there was little effect on gas turbine performance. Nor did the high levels of alkalinity in willow cause significant problems. Despite high ash levels and alkalinity, straw also functioned well in the system. Flexibility in feedstocks was deemed highly important, given the shifting economic competitiveness among fuels over time and changes in refuse disposal regulations in Sweden and within the EU. Refuse-based fuels are expected to become much more economical in Sweden as new regulations and fees for landfill disposal are applied.

At the time that the plant was planned and built, Sweden was not a member of the EU and the Swedish plan to phase out nuclear power gave the plant a high profile, as biomass was to fulfill a major part of Sweden's electricity supply in the future. Sweden's entry into the EU, the deregulation in electricity markets, and the overcapacity within the EU has driven prices for electricity in Sweden to low levels. Although the role of biomass has continued to increase in Sweden, the rate of increase has been somewhat less than expected. Also, biomass tends to be dedicated to heat production at cogeneration plants because the Swedish government taxes carbon (from fossil fuels) used in heat production but not in electricity production. A plant similar to Värnamo cannot compete in the current market unless Swedish electricity prices increase or additional incentives, such as carbon credits through the Kyoto Protocol mechanisms, are applied. As the learning curve brings costs down, the situation should change in the next five years, however. The Värnamo plant itself is being converted for use in further research and development, which may include dismantling and sale of separate parts as scrap.

Bioenergy Profile 5: Desi Power Gasifier at Orchha, Madhya Pradesh, India

DESI Power Pvt Ltd., a not-for-profit enterprise dedicated to the promotion of renewable energy, is linked to TARA, the commercial arm of Development Alternatives. In 1996, DESI Power established a biomass gasifier commercial demonstration plant at Orchha, as part of its program on Independent Rural Power Producers (IRPPs). The gasifier was designed at the Indian Institute of Science, which has been associated with implementation and monitoring of its units in the field, both to help debug technical problems and to get feedback from actual performance for further refinement of the design. The 80 kW Orchha plant supplies power to TARAgram, a campus where TARA has research and paper-manufacturing facilities that employ more than 100 workers.

Ipomea, an abundant weed with no competing uses, was chosen as the fuel for the gasifier. The 80 kW plant needs almost one tonne of fuel every day. The woody part of the weed needs to be harvested and then chopped into smaller pieces. The biomass in this form is still green and needs to be dried to reduce moisture content before it can be fed into the gasifier. Adequate covered storage capacity is needed for rainy days and supply holdups. Different methods for procuring the ipomea had varying degrees of success due to different perceptions of the economic value of the resource. Initially, the owners and operators of the Orchha unit tried to manage the process of procuring fuel internally. It soon became clear that a market-oriented approach was preferable, and a price was offered at which they were willing to purchase ipomea. The prices offered were designed to add up to a minimum daily wage or to the prevailing rates for transportation.

After several years of experience in procuring ipomea, it appears that regeneration of the plant biomass per hectare does fall off significantly after the first cutting, and sufficient extra acreage of ipomea must be accessible to ensure fuel sustainability when planning a unit. The current indications are that the quantity of biomass accessible to the plant in its first year should be at least 50 percent greater than the long-run annual requirements. Alternative feedstocks are being explored.

The gasifier has been running 10–12 hours per day during normal operation. Plant load factor is critical because it spreads out the fixed costs and also because it raises the diesel replacement rate, reducing the use of costly diesel fuel. The breakeven plant load factor for the Orchha plant is between 50 percent and 60 percent. Above 60 percent, developers report that it is highly competitive and able to sell electricity at prices below the electricity grid price. Even with 40 percent load factor and very high biomass cost, the cost of electricity has been in the range of Rs.4.0 to Rs 4.5 per kWH, which is still competitive with electricity from the grid.

The Orchha plant has shown that the cost of electricity can be competitive with conventional systems, provided that investment capital is obtained on terms similar to those available to larger independent power producers, which might be possible despite the smaller scale after an initial set of demonstrations has proven the project's financial and institutional viability. The two most sensitive determinants of production cost have been confirmed as the cost of biomass fuel and the plant load factor. Efforts are being made to raise the plant load factor at Orchha by adding new clients and industries with energy-intensive applications, reducing the high fluctuations in some of the loads (for example, the calendaring machine in the papermaking unit,) and staggering certain activities.

Cogenerated heat from the engine exhaust is fed to the drying rooms of the paper production unit, adding value and improving its economics. Other applications for the heat from the gasifier and the diesel engines are being investigated to further increase energy utilization and thereby improve overall economic performance. One of the most attractive options appears to be cold storage units using waste heat. In general, the extensive testing and performance monitoring at Orchha have provided detailed operational and maintenance data that will be invaluable in designing future plants. It has also led to significant modifications to make the technology more robust, safe, and suitable for field applications.

Bioenergy Profile 6: Biogas at Pozo Verde Farm, Cauca Valley, Colombia

The biogas system at Pozo Verde is part of an integrated farm in which the flows of resources and wastes are managed within a carefully designed multiproduct and multi-input enterprise. The system was designed to include electricity production, wastewater treatment, fertilizer production, and other agricultural functions and products. The initiative came from the owner of the farm, and it is operated on a strictly commercial basis. There were no subsidies, but technical advice was provided by the Colombian Research Center for Sustainable Agriculture Production Systems (CIPAV—Centro para la Investigación en Sistemas Sostenibles de Produción Agropecuaria). In addition to bioenergy, CIPAV provided technical assistance for aquatic plant production, tree foliage production, and dual-purpose cattle and buffalo husbandry. The general economic incentives arose from rising fossil fuel costs and organic waste disposal fees. The project sought to test the commercial feasibility of electricity production and waste treatment within an integrated sustainable farming system (Chará et al. 2000).

The two main bioenergy systems include digesters tied to (1) the pregnant sows' building; and (2) the dairy stable. The pregnant sows' building produces 912 m^3 wastewater per year. This waste is treated by two plastic tube biodigesters of 14 m^3 each and a channel of 64.5 m^2 of water hyacinth, complemented with plantain, banana, giant taro, and nacedero trees planted along the channel. Aquatic plants and sludge produced in the channel are used as fertilizer for the associated crops, and the water is pumped to irrigate adjacent grasslands. The biogas from this system is stored in a 49 m^3 bag and used for electric power generation in a diesel engine.

System 2 receives the wastewater from the dairy stable and from lactating sows and growing and fattening pig areas. It consists of two 75 m^3 plastic tube biodigesters and a storage tank that process a total of 12,448 m^3 of wastewater per year. The effluent from the digesters is stored in the tank, then pumped to fertilize 30.8 ha of pastures and crops on the farm, approximately 15,000 m^3 per year total. The biogas produced in this system is estimated to be 19,200 m^3 per year, used in 51 separate burners to heat the piglets from birth up to 60 days (14 hours/day). The remaining biogas is piped to the storage bag of System 1 to be used for electricity generation.

The system has been in continuous operation since 1986 and employs a staff of about 20 persons. The plastic for the biodigesters has been changed several times due to accidental damage. All maintenance has been carried out by the farmer. Economic and environmental benefits have accrued from reduced diesel consumption, improved waste treatment, elimination of chemical fertilizers, and improved soil quality through recycling of organic fertilizers. The innovative approach at the Pozo Verde farm demonstrated the key role of biodigesters in linking animal husbandry, agriculture/aquaculture, and energy production systems. The commercial success and environmental advantages revealed that the resulting integrated system was "more than the sum of its parts" and has led to similar efforts in other farms in Colombia.

Bioenergy Profile 7: Gasifier for Drying at Sidojadi Cocoa, Sumatra

PT Sidojadi, a cocoa-processing company located near Medan in North Sumatra, is engaged in growing and drying cocoa beans. Previously, they ran nine fixed-bed dryers, each fueled by an open firebox burning rubber tree wood. Each dryer handles 1,300 kilograms (kg) of wet cocoa beans in batches, reducing the moisture content from 60 percent to 7 percent in 48 hours of processing. In 1998, PT Sidojadi installed a gasifier run on palm nut shells, a waste product from its sister company, to heat three existing cocoa dryers using clean air at 70° C. As a result, both companies saved money, and the quality of the dry cocoa beans increased. The gasifier reduces drying time for a batch of cocoa beans from 48 to 14 hours, resulting in higher product value. The payback period was less than two years for the investment, although the gasifier manufacturer suffered losses because the gasifier had been priced in local currency shortly before a major devaluation in the Indonesian currency.

Gasifier at PT Sidojadi Cocoa Processor: Technical and Financial Summary

Rated Generating Capacity	290 $kW_{thermal}$ (250,000 kcal/hour)
Technical Design	BG-Systems™ (BG-100WT) downdraft gasifier
Fuel Supply	Palm nut shells
Annual Fuel Consumption	772 tonnes of palm nut shells
Feedstock reliability/accessibility	Available from nearby sister company (palm oil)
Rubber tree wood offset	9.2 kg for each kg of palm nut shells
Fuel Cost Savings	US$40,000 per year
Capital Cost	US$70,000
Generation + Distribution Cost	US$0.006 / $kWh_{thermal}$
Investment payback period	21 months

The BG-Systems™ gasifier was based on the Ankur gasifier originally developed by ASCENT in Baroda, India. The system components include a cyclone separator, gasifier blower, combustor, and air delivery blower to the batch dryers. In its first year of service from February 1998 to February 1999, the gasifier operated 70 percent of the time. BGT performed two scheduled maintenance inspections during the warrantee period and discovered that high moisture content in the nutshells was causing problems in the gasifier. Consequently, the shells are dried somewhat before introducing them into the gasifier, and the moisture problems have been resolved. Ample fuel for the gasifier was guaranteed through palm nut shells from PT Sidojadi's nearby sister company, engaged in palm oil production.

Multiple economic and environmental benefits were achieved through the fuel substitution along with the efficiency of biomass utilization. The use of palm nut shells solved an existing disposal problem (and environmental hazard). At the same time, deforestation in the region was addressed by replacing 9.2 kg of wood with 1 kg of palm nut shells, bringing savings in transport costs as well. By replacing three of the nine firebox furnaces with the gasifier, emissions of smoke and particulates have been reduced by one-third. The BG-Systems™ gasifier produces a low-calorie gas that is essentially free of tars and burns cleanly without measurable emissions. The main byproduct to be disposed of is ash, which can be compacted into briquettes using a wet ash recovery system integrated with the gasifier. PT Sidojadi now plans to replace the remaining six open fireboxes with gasifiers.

Bioenergy Profile 8: Philippines Dendrothermal Program

In 1979, the Philippine government initiated programs to develop and manage plantations for wood energy. As with many renewable energy programs of its era, it was a response to the oil crises of the 1970s, which were particularly acute in the Philippines where there was a great deal of oil-based electricity production. The energy needs of a growing population and the high cost of oil gave the program a somewhat urgent motivation as well as a high political profile. The program was spearheaded by the National Electrification Administration (NEA).

The dendrothermal program anticipated construction of 60–70 wood-fired electric power plants that would be supported by multiple energy crop plantations of 1,100 ha or more. These plantations would be grown by upland farmers recruited by NEA rural electric cooperatives, which would manage the projects locally. A report on the Dendro program covering the period 1980 to 1984 indicated that planting success improved during that time, but tree survival and plantation cost-effectiveness varied dramatically. Of 44 project sites, 13 had not yet established 100 ha of plantations, and five sites had tree survival rates below 10 percent. Managers suggested that the failures were caused by unfavorable soil conditions, reliance on a single tree species, free-roaming cattle, inadequate institutional support, and the discontinuation of the farmer loan program. Ultimately, only two out of nine power plants received adequate biomass supply.

A variety of other significant problems emerged. The lack of roads and trails at mountain sites complicated seedling distribution, silviculture, and marketing. Political factors often determined plantation location, and these sites generally produced poor results. Transportation costs were high due to the inaccessibility of many sites. Contracting problems arose with suppliers who sold wood to competing markets. Many *leucaena* plantations encountered serious insect infestations, but farmers were reluctant to invest in insecticides. Irregularities arose in the administration of project funds, and in some areas, civil unrest made it difficult or impossible to carry on the required activities. In the end, many plantations failed and overall the Philippine program would be judged to have been unsuccessful. For plantations that survived, yields and incomes were often less than expected. The program was discontinued in 1986 due to funding constraints and changes in the national government.

A number of lessons emerged from the Philippines dendrothermal program. First, the program was designed with a top-down approach, depending totally on government support for finance, administration, and technology. It could not respond to the specific market-related problems of decentralized power plants. Second, the program depended solely on the energy plantations and on one single tree species (*Leucaena leucocephala* or Ipil-Ipil), which proved to be very risky, with yields in some cases that were only 25 percent of the projected yield. Third, poor management and planning resulting from centralized decision making was not responsive to the decentralized implementation and operation, which aggravated the problems socially and economically. Finally, the inadequate and uneconomical supply of biomass fuel was the most important cause of the failure. The low yield led to competing needs and price increases. Transporting the wood in the mountainous areas using the installed aerial monocable system was so costly that it had to be substituted by manual labor.

The Philippines' initiative is perhaps the most infamous of all bioenergy failures, and it indicated the complexities of managing a dendropower system as an integrated operation. It demonstrated that securing a biomass supply through a well-developed biomass market is critical to ensuring the performance of dendrothermal plants. Alternatively, a reliable feedstock supply can be obtained from a strong, planned, efficiently managed, and dedicated biomass plantation system. In developing countries these conditions are difficult to achieve. Unless the markets and institutional infrastructure are firmly in place, dendrothermal programs in developing countries are likely to fail (FAO, 1997).

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Bioenergy Profile 9: Pacific Biodiesel, Maui, Hawaii

In 1995, landfill operators at the Central Maui Landfill complained that static pile fires from used vegetable oil were becoming more frequent and oil could leak into groundwater. Pacific Biodiesel, Inc., was born in 1996 as the answer to grave concerns over potential environmental and health problems resulting from restaurant grease clogging the Central Maui Landfill. Pacific Biodiesel produces biodiesel from used restaurant fryer oil. The company was recognized as one of the first commercially viable biodiesel plants in the United States. In 1997, Pacific Biodiesel began to attack an even larger problem for the landfill: grease trap waste. With the addition of a custom designed grease trap oil processor, PacBio was then able to supply its own boiler fuel, again while diverting 140 tons of grease trap oil from the landfill each month.

It is more economical for trucks to deliver used restaurant oil to Pacific Biodiesel than to landfill it, which results in a landfill diversion total of more than 40 tons of used cooking oil per month. Using a single-stage conversion process, the plant produces up to 150,000 gallons per year of premium biodiesel for diesel engines. The biodiesel produced by Pacific Biodiesel, Inc., is used to power its own transport vehicles, two boats, the generator, and the trucks used at Central Maui Landfill and Maui government vehicles, among others. PacBio also sells the biodiesel to local farmers, diesel car owners, boat tour companies, and hotels, which use the fuel to power landscaping machines.

A typical diesel car gets over 40 miles per U.S. gallon (some over 50 mpg), which means it would cost 6.1 cents per mile to drive on biodiesel at US$2.45 per gallon. A typical gas car gets about 25 miles per gallon, making it cost US$.078 per mile to drive on gasoline at US$1.95 per gallon. On Maui, petroleum diesel currently costs US$1.45/gallon.

The spent cooking oil on Maui was previously being landfilled, which created hot spots and fires in the landfill and composting piles and plugged air ventilation pipes in the composting piles; in addition, some of the oil was leaching into the ground. The glycerol byproduct of biodiesel production is used as a fertilizer enhancement in the composting facility located next to the biodiesel production facility

In 1997, Japanese businessman Soichiro "Sol" Yoshida contracted Pacific Biodiesel to design and build a similar plant for his Kentucky Fried Chicken franchise in Nagano, Japan. That plant now processes used cooking oil from 60 restaurants, producing biodiesel that completely powers one KFC restaurant as well as many cars, trucks, and industrial engines. Later, Pacific Biodiesel joined with the owners of Honolulu Disposal and the new partnership has begun construction on a biofuel plant in Honolulu on the main island of Oahu. A large-scale biodiesel plant is planned for the near future.

The Pacific Biodiesel project was undertaken without subsidies of any kind. It was based more on the need to address waste disposal problems than to pursue bioenergy on its own merits. It demonstrates the importance of addressing bioenergy as part of the solution to basic community resource issues. It is interesting to note that the biodiesel gained in popularity not only for economic and environmental reasons, but also for some aesthetic reasons. Some users said they preferred biodiesel because it did not give off the noxious smell that diesel does (Waste Age 2000).

2

Bioenergy Activities in India: Three Case Studies

2.1 India has one of the longest-standing and most developed national bioenergy programs in the world and also has a considerable amount of more dispersed activities outside the formal national program. This section contains three case studies highlighting three major bioenergy activities in India. The first case study is of an NGO-coordinated program that created an entrepreneurial cadre to develop and commercialize advanced biomass devices for entrepreneurs in the nonformal sector. The second case study relates a long-term experiment based on village-managed small-scale energy and water utilities. The third case study is an overview of the national bioenergy program of the Ministry of Non-Conventional Energy Sources.

Case Study 1: Marketing Bioenergy in the Nonformal Sector

2.2 This case study reports the experience of an NGO in setting up a network of entrepreneurs engaged in the commercial dissemination of biomass-fueled stoves, driers, and kilns for the nonformal industrial sector. The activity was funded by the India-Canada Environment Facility under the project "Diffusion of efficient biomass utilization technologies in non-formal industries in Karnataka and Kerala," which we call here the "Biomass Entrepreneurship" project. The implementing NGO, Technology Informatics Design Endeavour (TIDE), is a registered not-for-profit organization operating from Bangalore, Karnataka, India. TIDE was established with the objective of identifying working prototypes and concepts from research and development institutions and converting them into commercial products in the marketplace. TIDE has at any point of time a set of ideas in trial stage, demonstration phase, and commercial phase; it focuses on the areas of information systems, renewable energy, and waste management.

The Biomass Entrepreneurship Project

2.3 The Biomass Entrepreneurship project was an experiment in applying an entrepreneurial model to the diffusion of a set of technologies that were developed to meet social and environmental objectives. The Center for Application of Science and Technology to Rural Areas (ASTRA) at the Indian Institute of Science in Bangalore had developed a range of clean and efficient technologies for wood-fueled stoves, driers, and kilns over the period 1984-95. While the household cook stove was extensively disseminated (more than 1.5 million) by the government of Karnataka, the technologies for applications in nonformal industries were not promoted extensively. The Biomass Entrepreneurship project aimed to create self-sustaining markets for these highly promising technologies.

2.4 Prior to the launching of the Biomass Entrepreneurship project, the lead author of this case study had independently undertaken a small marketing effort of the designs developed at ASTRA on a strictly commercial basis. This effort, which extended from 1992 to 1997, was able to create an annual turnover of about US$10,000. The experience proved that there existed a considerable market potential for the devices being promoted, but that the significant initial investment and risk involved in developing

the market would be considered prohibitive by the typical private sector entrepreneur. It was also realized that although a commercial approach was possible, the financial return would not meet the profitability expectation of a private investor. This was due to the necessary market development costs and the competition that would result once barriers to entry were lowered by the initial market development activities.

2.5 TIDE developed the Biomass Entrepreneurship project with the aim of carrying out the market development activities and providing support to entrepreneurs in the initial phases of commercial dissemination of biomass technologies for nonformal, small-scale industry customers. The project activities were to be situated in the two target states of Karnataka and Kerala in southern India. These two states were chosen as there was existing experience on operations in the two states. The objectives of the project were:

a. To undertake a survey of the nonformal biomass utilizing industries in the two states to assess the viability of setting up entrepreneurship

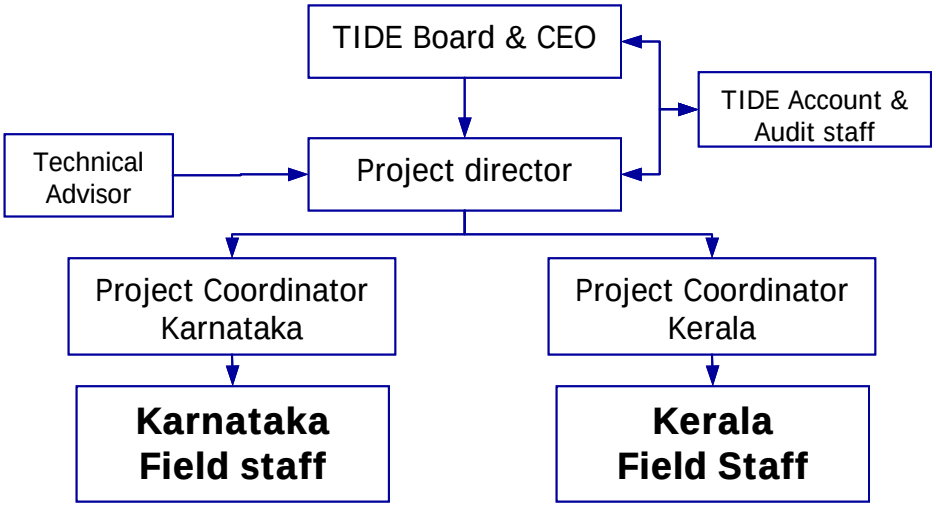
b. To demonstrate the devices developed at ASTRA with the objectives of training the potential entrepreneurs and further promoting the devices. A total of 270 devices were to be set up

c. To set up a network of 10 commercial entrepreneurs and support them during the initial phase so that a sustained entrepreneurship activity would be put into place.

2.6 TIDE obtained funding for the Biomass Entrepreneurship project from the India Canada Environment Facility in 1997 and commenced the five-year project in March 1998. The first year was for survey activities, the next two years were for demonstration activities, and the last two years were for entrepreneur support.

2.7 The structure of the organization for the project at the start is given in figure 2.1 below.

Figure 2.1: TIDE project organization



2.8 The Biomass Entrepreneurship project promoted three types of technologies: stoves, driers and kilns.

1) The stoves are clean and efficient devices for burning wood and other biomass feedstocks, using chimneys to provide draft for more efficient combustion and to remove the smoke from the working environment. The stoves are of masonry construction with a few metal components integrated into the construction. The range of costs of a stove promoted in this project varied from US$30 to US$150

depending on the application. The costs of the stove for similar types of application would vary by less than 20 percent across entrepreneurs. All stove constructions were new and no retrofitting of existing stoves was done.

2) The driers are biomass-fueled devices used for drying agricultural and other products. The driers are of masonry construction with metal supports for produce trays. These are more expensive devices with costs ranging from US$200 to US$1,000 and higher for larger applications. The project undertook both new installations and retrofits of existing driers with improved combustion and heat transfer systems. The major site-specific issue with the driers was the understanding of the protocol of drying for the various produce and its interaction with the drier parameters. The competence of the persons who could promote driers had to be higher than for those promoting the stoves.

3) The kiln technologies were designed for lime, pottery, and bricks. These devices were more complex and involved a very high level of technical competence in design and installation. The troubleshooting issues are also more complicated.

2.9 The project started with a survey of the biomass utilizing industries in the two states. TIDE decided to choose the survey staff from among the potential entrepreneurs in order to give them a good understanding of the field and the market conditions. TIDE also decided to work with engineers or diploma holders, as they would have the required level of technical competence and would have a longer-term interest in the project. The survey phase was completed within a year. It reconfirmed the presence of biomass consuming nonformal industries in the two target states and provided basic data on these industries as potential customers. The major conclusions from the survey were:

- Nonformal industries in Karnataka that were potential customers consumed approximately 2.9 million tons of biomass per annum. The industries were clustered in specific geographical locations and consisted primarily of agriculture products processing operations. Wood accounted for about 25 percent of the total consumption and the major portion of the consumption was with other biomass. A wide diversity of biomass was in use, and thus the technical solutions had to accommodate the correspondingly diverse requirements.
- Nonformal industries in Kerala that were potential customers consumed approximately 1.8 million tons of biomass per annum. The consumption was uniformly spread all over the state, with the exception of a few concentrated industries. Although the major consumption was still for processing agriculture produce, there were other operations also consuming biofuel. Wood accounted for the major source of the fuel accounting for over 70 percent of the consumption.

2.10 The survey phase was undertaken from May to December, during the major demand season for the biomass technologies. A quick demonstration was planned for a few devices to get user feedback in sectors where TIDE had no previous work in the field.

2.11 The subsequent two-year demonstration phase was adapted to account for the lessons learned during the survey phase. One lesson was that TIDE's selected technologies, although efficient and viable to the user, had to be further adapted to meet the various other expectations of the entrepreneur and client. During the very hectic year, TIDE devoted a significant amount of time to continual iteration and adaptation of the devices in the field. The ongoing need for technical development resulted in TIDE's creating a full-time technical support group and integrating it into the project's organization structure.

2.12 The devices demonstrated can be constructed either onsite, based on standardized design principles, or assembled from prefabricated components that are fitted together per a predefined design. A major issue in the design of well-functioning stoves is to account for site-specific factors, two main ones being the dimension of the vessel with which the stove is used and the type of fuel to be consumed. The onsite construction allows the construction team to maximize performance by making local design adjustments to these site-specific issues. The prefabricated systems impose constraints on such local

adjustments but require less expertise on the part of the construction team and thereby decrease the risk of technological flaws.

2.13 The original technology available was completely based on site construction. The different client requirements and the level of technical involvement necessary to carry out on site construction required that TIDE adapt these technologies for dissemination. TIDE attempted to shift its approach from onsite construction to fully prefabricated designs, but this was found inadequate as the transport became complicated and the site-specific client requirements could not be met. The project team continued to optimize this tradeoff through the first two years of the project. Ultimately, TIDE developed a strategy of prefabricating the critical components to ensure performance, with the balance being constructed locally and adequate training being provided within the project. TIDE found that while training on construction is important, even more important is troubleshooting competence.

2.14 The survey phase also reaffirmed TIDE's major decision to take an entrepreneurial approach by providing no device installations at zero cost to the user and by minimizing the number of installations providing even partial cost support to the user. Even in the demonstration phase, installations were "sold" to "clients," not "donated" to "beneficiaries." Intense marketing efforts were made to convince prospective users based on the merits of the device, rather than simply relying on users attracted by the availability of a free or heavily subsidized device.

2.15 At the end of the demonstration phase of the Biomass Entrepreneurship project, the field staff was offered the option of disassociating from the project or setting up their individual businesses with a one-year commitment of support from TIDE. All of the field staff took up the offer of creating independent businesses.

2.16 The next year of the project was the first year of the entrepreneur support phase and entailed the nurturing of the entrepreneurs as they established their independent ventures. The businesses they established in Karnataka and Kerala were significantly different. In Karnataka the business was in large clusters of units of a single type, while in Kerala it was based on a larger variety of devices to be delivered in different locations. Thus the entrepreneurs in Karnataka have a strong geographical focus, while those in Kerala operate in a larger geographical domain. In Karnataka, the business typically starts with a single product and then expands to include more products. In Kerala, the offer is for a large number of products and focusing on products is seasonal.

2.17 The staff members who had opted to start businesses were provided with one year of fixed support from TIDE. The extent of the support was equal to their last drawn payment at TIDE plus a fixed amount for travel costs during the first six months. In addition, support toward the promotion was provided at 10 percent of the sales value generated, to be paid against actual expenditures on promotional activities. Additional support was promised toward marketing costs based on 2 percent of the sales value generated. Working capital support was also provided to an extent of 50 percent of turnover. In one case, a facility for setting up the workshop was provided.

2.18 A formal agreement was drawn up with each of the entrepreneurs individually. The entrepreneurs themselves formed into groups for particular activities to obtain more efficient operations and to combine the marketing and construction skills. TIDE monitored each of the entrepreneurs' installations during the first year, held monthly monitoring and review meetings with them, and provided any needed technical support and trouble shooting. With this level of support, the first year of operations saw the entrepreneurs expanding business with a significant growth compared to what the Biomass Entrepreneurship project had done under TIDE the previous year.

2.19 In the second year of the entrepreneur support phase (and final year of operation of the project), TIDE did not provide any financial support directly to the entrepreneurs. It continued to provide the support toward promotion and additional support toward marketing-based costs, but the entrepreneurs were completely on their own for the marketing and construction activities. TIDE continued to monitor

the constructions and hold meetings with the entrepreneurs, providing guidance and support where required. The entrepreneurs did well once more during the fifth year, and continued a growth trend. During this year, the neighboring states were studied for potential for expansion of the market development activities. TIDE had also regularly received requests from prospective entrepreneurs who were willing to take up a venture if there were an opening available.

2.20 After the initial five years of the Biomass Entrepreneurship project, the funding agency allowed TIDE to use funds remaining from the original project with the objective of expanding the project concept into five other states. This activity is currently being undertaken with significant success. A cluster-based approach is being adopted for entrepreneurship development as the demand for the biofuel in nonformal industries is clustered geographically in the new target five states. The experience in these states is showing that any arising technical issues are rapidly sorted out and the entrepreneurship promotion can efficiently follow the sequence of identifying an entrepreneur, setting up a single-partly paid demonstration device at one location along with the entrepreneur, and using it as a training location and site for providing support to the entrepreneur. The entire process of establishing a cluster of entrepreneurs has proven to be approximately six months.

2.21 The entrepreneurs are managing the activity in the two states of Karnataka and Kerala. They continue to be viable, and in their own assessment the business potential is adequate to last for a minimum of three further years, although TIDE's assessment is that business can continue to expand for a longer period. We are still monitoring the constructions being undertaken by the entrepreneurs. There are very few requests from the entrepreneurs on the technical side this year, and most of them are sorted out by phone. The entrepreneurs are now focusing their requests for support on the identification of new devices and products for them to market to ensure their long-term survival. Table 2.1 below gives the number of entrepreneurs in operation over the years, and Table 2.2 gives the turnover achieved over the years.

Table 2.1: Entrepreneurs over the years

Year	Number	Notes
2001-02	17	All the existing entrepreneur associates started as entrepreneurs
2002-03	15	4 of the entrepreneurs withdrew and 2 new ones joined.
2003-04	14	Two have dropped out and one of the groups broke into two.

Table 2.2: Business turnover over the years

Year	Turnover in US$	Notes
1999-00	39,000	This was the first year of TIDE activity (Survey phase)
2000-01	76,000	This was the second year of TIDE activity (Demonstration phase I)
2001-02	119,500	This was the first year of entrepreneurs activity (Demonstration phase II)
2002-03	195,500	This was the second year of entrepreneur activity (Entrepreneur support phase I)
2003-04	195,500	This was the estimated business in 2004 (Entrepreneur support phase II)

Program Finances

2.22 Being an initial, somewhat untested endeavour that underwent considerable learning and evolution in thinking and design, the Biomass Entrepreneurship project required considerable financial support. The total investment on the project was US$733,000, most of which was provided by the funding agency and the rest by TIDE. These are the resources that went to the initial survey, further technology development, demonstrations, entrepreneur support, and funding for the TIDE staff involved. The project activities led to a turnover of US$695,000 over the project period. The turnover is expected to continue at ~US$200,000 for a minimum of five years. In addition, the value of the fuel cost saving that accrues to the clients of the devices is estimated at US$325000 annually.

Strategic Evolution of the Project

2.23 The approach of Biomass Entrepreneurship project arose from the earlier efforts to promote the devices as a business enterprise. TIDE's initial strategy was to select masons as the entrepreneurs; their primary undertaking would be to construct the devices with a modest amount of TIDE's marketing support. To enable the setting up of this network of entrepreneur masons, TIDE reasoned that a series of demonstrations would provide the necessary base for marketing the devices and training of the entrepreneur masons. However, as TIDE undertook the initial demonstrations during the survey phase of the project, it became clear that the existing devices could not be commercialized without continued technological iteration, and also that convincing the clients would require more than the demonstration of installed devices alone. The first change in strategy, thus, was to recognize that the need for further technological field development would require the entrepreneur to be an engineer rather than a mason. Furthermore, the need for a full-fledged technical support group to provide technical backup to the entrepreneurs was recognized, and then created and incorporated into the project strategy.

2.24 During the demonstration phase, TIDE learned a tremendous amount about the steps needed to promote entrepreneurial dissemination of biomass technologies. TIDE realized that the uncertainties faced by the technology, the required level of marketing effort, and the risks faced by entrepreneurs were so high that prospective entrepreneurs would require positive proof of the viability of the business concept. It was clear that entrepreneurship would not take off merely with technology demonstrations. TIDE would have to prove to the clients not only that the technology was functional, but also that the business was viable. In the second year of the demonstrations, TIDE took on the responsibility of proving the viability of the enterprise. TIDE decided to treat the two units at Karnataka and Kerala as separate profit centers and to independently evaluate the viability of their operations. The Karnataka unit, which was operating from within TIDE premises, was shifted out to increase its independence. Accounting was now incorporated into the individual units, and all business operations were handled by them. Further decentralization was undertaken in the cluster locations of demand in Karnataka and across the state in Kerala to get greater coverage.

2.25 TIDE undertook the necessary sales tax registration for the Biomass Entrepreneurship project so as to make the project more fully resemble an entrepreneurial venture rather than a nonprofit project. The field team was divided into marketing and construction teams and the process of business was established. All this was done as part of the project activity. Intense marketing and construction efforts were undertaken. This year there was significant attrition in the field staff that was intended to take over as the entrepreneur cadre, and it was necessary to introduce new entrepreneurs. By the end of the year, TIDE analyzed the business and confirmed it was viable. This analysis was shared with the field staff members, who were kept informed throughout the process to ensure that they had a realistic impression of the financial viability of the venture.

2.26 Thus the second year of demonstration was converted from a year of product demonstration to one focused on showing the viability of the enterprise. During this process the field staff

that could not successfully engage in the entrepreneurial process withdrew from the project. Most of the engineers left and TIDE selected as their replacements diploma holders trained in various trades and science and arts graduates, in an effort to identify a team that was more attuned to the entrepreneurship process and that was motivated to engage in a business possibility. Thus, over the course of the first two years of the Biomass Entrepreneurship project, TIDE's strategy evolved from selecting mason entrepreneurs competent in construction and providing modest marketing support, to identifying technically competent engineer entrepreneurs and providing substantial support for technical adaptation, and finally to identifying a relatively market savvy team capable of organizing the different components of a business and providing considerable entrepreneurial support. Another shift in the criteria for selecting entrepreneurs was to identify people who had realistic income expectations that matched the earning ability of the enterprise and were personally stable enough to handle the volatility of an entrepreneurial venture.

2.27 While these entrepreneurs were initially intended to take up the activity on their own with minimal support from TIDE, it required close interaction to motivate them to ambitiously undertake commercial activity during the first year. TIDE provided considerable support aimed at reducing the risk elements, which required an ongoing process of negotiation with the entrepreneurs. The forum for negotiation was provided through a formal monthly meeting between TIDE and the entrepreneurs, as the entrepreneurs learned how to engage in commercial activity and TIDE learned how best to train and support them. The meetings also helped in continuous monitoring of the activity undertaken by the entrepreneurs to minimize risks of failure.

2.28 By the end of the year, some entrepreneurs withdrew, having decided that the income potential wouldn't be sufficiently attractive after TIDE's support was withdrawn. The final year of the project had the remaining entrepreneurs setting their own goals and going ahead with the business, and the commercial activity was stabilized as TIDE had originally hoped. By the end of this year entrepreneurs who were unable to cope or compete were being edged out. On the other hand, new entrepreneurship had emerged outside the original set of entrepreneurs, and the existing entrepreneurs were forging new relationships. The entrepreneurs proved capable of identifying a mix of business size, quality, delivery mode, and follow up service that maximized their return, created new opportunities, and ensured a viable business. The whole idea of developing a market and supporting entrepreneurs had formed its own dynamics beyond the original thinking of the project proponents.

The Issues and Dilemmas

2.29 Other choices regarding various issues arose over the course of the Biomass Entrepreneurship project. While these cover a range of topics, we present them below in terms of issues relating to dissemination strategy, client, and technology.

Dissemination strategy

2.30 Conventionally, most new technology dissemination efforts have started with the development agency providing subsidy funding to early adopters of the technology. The expectation is that the subsidy can be progressively reduced, and when a critical threshold is achieved the subsidy can be withdrawn and entrepreneurship will take over. TIDE undertook the Biomass Entrepreneurship initiative with a different strategy. It eliminated the subsidy to the customers except as a marketing requirement and focused instead on measures involved in creating a self-sustaining commercial network of entrepreneurs. The cost to the entrepreneurs of initiating these ventures was subsidized by mitigating the risks and absorbing certain market development costs at the early stages.

2.31 A major component of the market development activity was advertising and awareness raising. TIDE used various methods for promotion depending on the product and the client profile. It undertook, for example, door-to-door campaigns, client endorsement, product display on vehicles, participating in trade fairs, promotional meetings among prospective clients, collaboration with trade

institutions, and paper advertisements. In successive stages, the entrepreneurs themselves proved able to expand marketing efforts and create new client bases once they had an established performance track record from which to build. Rather than the general marketing approaches, the entrepreneurs tended to rely more on one-on-one contact as a basis of building awareness and identifying clients—as might be hoped of entrepreneurs who are intimately familiar with their client base. TIDE was encouraged to find awareness and acceptance of the technologies spreading to areas that were not originally covered by the Biomass Entrepreneurship project's marketing campaigns.

2.32 The response to each type of promotion varied based on location and the client profile. In Karnataka, the direct interaction concepts worked very well and were the mainstay of the promotional campaigns. Other means were useful for awareness creation but rarely for creating sales. In the more literate Kerala, advertising was always the mainstay for creating sales. The costs of promotion were typically between 5 and 10 percent of the sales turnover. In the initial phase of entrepreneurship, a large effort was invested in creating name recognition for the entrepreneur organization. To capitalize on TIDE's name recognition and positive image among prospective clients, the Biomass Entrepreneurship project adopted a cobranding approach, wherein the entrepreneurs were allowed to present themselves as vendors of a technology that was developed and supported by TIDE. This was undertaken and successfully accomplished, even though it potentially posed a risk to TIDE in terms of being associated with entrepreneurs who might deliver substandard products.

2.33 In these early stages, TIDE's close hands-on approach placed it at the center of establishing the business venture, which it ultimately handed over entirely to the entrepreneurs. TIDE needed to adopt this hands-on approach in order to prove to the prospective entrepreneurs that the technology and business concepts were viable. Without direct evidence and without the risk-mitigating activities of TIDE, entrepreneurs could not be attracted to ventures such as the one created in the Biomass Entrepreneurship project, where there are high risks to investing in market development activities and low barriers to competitors entering once the market development investments are made.

2.34 From the onset, the product was sold to the client at or near full cost, but the client was not burdened with the additional costs of creating the marketing infrastructure. TIDE's experience was that this approach helped to reduce the time to set up a commercial network, but the client's expectations and demands remained high, ensuring that innovation and institutional agility would still be demanded of the demand-driven, entrepreneur-based process. If a subsidy were provided, experience had repeatedly demonstrated that clients would be unwilling to pass critical judgments or insist on value for their money. Under such circumstances, learning on the part of the entrepreneurs is curtailed or undermined, and as soon as the subsidy is withdrawn the level of demand declines significantly, to the detriment of the ultimate market development objectives of the subsidy. In contrast, the Biomass Entrepreneurship project found that once the market development phase was completed, the extension of market development to other target locations was rapid and straightforward. TIDE's experience suggests that this model is a vastly more effective framework for new product promotion than the subsid-based, supply-push route.

2.35 Within a market development approach, one question that arises is whether a nonprofit organization such as TIDE need be involved at all. In theory, the entire undertaking could be put in the hands of a private sector entity (or other actor) that would use external funding to fulfill the roles played by TIDE in the Biomass Entrepreneurship project, but as a profitable venture. This is possible in theory, but various issues arise:

2.36 *Profitability*: Incorporation of one more level of profit margin would have reduced the margins at the entrepreneur level. In the case of the Biomass Entrepreneurship project, margins at the entrepreneur level were not high enough to remain viable if they were reduced by a significant amount.

2.37 *Risk tolerance versus risk aversion*: TIDE pursued a range of technologies and client requirements based on many motivating factors other than the apparent commercial viability. This was arguably possible only with a not-for-profit motive.

2.38 *Proprietary concerns:* TIDE trained and supported entrepreneurs at local levels who in turn employed local staff. TIDE pursued prefabrication with the intention of building capacity within the entrepreneurial cadre, rather than retaining technical competence and making a profit through, say, licensing arrangements. Of necessity, a private sector entity would have had to interact with the entrepreneurs in ways that maximized (or at least preserved) its own profitability.

2.39 *Market-based activity versus aid-based activity:* Throughout the project, TIDE avoided projecting itself as a not-for-profit organization so as not to lead clients to expect subsidies typical of development projects. Instead, TIDE attempted to project to clients a private enterprise appearance with secondary focus on development. This balancing act might be easier or more difficult for an actual private sector entity, depending on the circumstances.

2.40 *Legal issues:* The process of applying for tax registrations for a not-for-profit organization is a complex affair, because of the need for a strict separation between the core nonprofit activities and semi-entrepreneurial revenue-earning activities. This can be difficult or impossible, depending on the perspectives and policies of the government agencies involved. Funding agencies as well have their own perspectives on the eligibility of market-based activities as eligible recipients of funds.

2.41 *Continuity:* In not-for-profit enterprises, skill retention post project is always a concern. The interests of the funding agency change over time, and there is no assurance that a similar activity relying on the same skills would continue into the future. To the extent that the skills required for this type of project are already typical of the skills available in private sector entities, this might not pose a problem.

2.42 As this discussion suggests, the relative merits of a nonprofit organization versus a private sector actor are subtle and will depend greatly on the context and intended objectives of the project and at what stage in the process of market creation the project is occurring. There are clear values to both types of actors.

Client

2.43 The choice of demonstration clients is important because it affects the likelihood of project success. The general strategy for identification had been to identify a well-known person in the area as the demonstration client. This attitude generally worked well, but TIDE also learned that it was necessary to consider the expectations of the client and his ability to take risks. TIDE realized that realistic expectations are important and learned that when a new technology is demonstrated and the front-end personnel provide a very rosy picture of organization backing the effort, the client may acquire an unrealistically high expectation of the product. When expectations are not met, even if they are unrealistic, there is invariably discord that affects further sales in the area. Also, if the client has low-risk tolerance and the device is adopted based on a feeling of being progressive, the discord can lead to more serious differences. TIDE learned that it is preferable to start with low client expectations and clients having hig-risk tolerance. The performance then gets accepted and the local expectation gets set on this basis.

2.44 The initial costs of clean and efficient devices are invariably higher than those of conventional devices. Prospective clients typically give the feedback that the cost should be reduced and subsidies should be provided. TIDE's experience has shown that a good product can sell purely on its merit and the associated facilities and services provided; it has sold devices at prices over 50 percent of the conventional options and found market acceptance. However, some degree of flexibility has to be shown, based on the social attitudes on payment for services or products. Provision of subsidies might be justified to those persons who cannot afford a device, but not to those who can afford it but feel it is expensive. In some areas the TIDE entrepreneurs receive prompt payment, in some it comes very slowly, and in others they've forgone the last installment. The pricing has to be adjusted accordingly.

Technology

2.45 The first technological strategy issue that TIDE had to address was whether to promote the device as a product or service. This was relevant more because the initial designs for the devices were completely based on site construction. The product approach would imply that TIDE takes the responsibility of procuring the various materials and labor components of the product and deliver a finished product to the client. The service approach required that the client brought the materials to TIDE's specifications and provided local labor; TIDE's role was restricted to providing the technical skill. The service approach had the advantage of minimizing the risk of the entrepreneur and taking advantage of the local presence of the client to reduce material and transport cost. On the other side was the uncertainty to the entrepreneur of delay in material supply by clients, reduced margins and becoming a labor contractor in a low-value business. TIDE decided to promote only devices and not service. This decision helped TIDE to standardize products and lower risks of untrained entrepreneurs entering the business and spoiling it by providing lower-quality solutions.

2.46 A second decision TIDE had to make was whether to undertake complete device construction onsite or deliver prefabricated devices. Prefabricated devices had a major advantage of being reliable and consistent in performance, but had the weakness of not allowing for adjustment to local site-specific conditions. This issue was particularly relevant for stoves, as the vessel sizes vary considerably from one site to another. TIDE's solution was an intermediate approach whereby some critical parts were prefabricated to ensure performance, but within an overall design that retained some scope for adjustment at the installation site to fit local requirements. When there was wide variability in the vessel size, onsite construction was preferred although the entrepreneurs had to be more technically savvy. Multiple solutions have been developed and provided to the entrepreneurs, and they choose the appropriate one based on their competence and client expectations. For example, the cheapest material for prefabricating, Ferro cement, cannot be exposed directly to fire, necessitating the use of a brick liner that must be constructed on site.

2.47 Although energy efficiency was TIDE's primary motivation for the whole project, it was not a prime interest of clients. Fuel efficiency may have been one factor in the purchase decision, but others often took precedence: quality of the product coming out of the process, time of the process, convenience of operation, portability, improvement in operational environment, appearance of the device, status symbol, and perception of technological progressiveness. Some factors seemed to be primarily psychological. The technology provided by TIDE had to ensure that a significant number of these factors were incorporated and highlighted in order to be successfully marketed. In fact, TIDE received negative responses in some cases for efficient devices because they lacked other features of importance to the client. TIDE and its entrepreneurs learned to identify and incorporate such features in design modification in such a way as not to compromise energy efficiency.

2.48 Energy efficiency can be improved by providing sophisticated controls to cover the various operating ranges. But every addition of a control makes the device sensitive and prone to misuse. The majority of the devices are not operated by the purchaser but by hired labor that is not particularly motivated to reduce fuel costs. TIDE thus decided to focus on robust solutions capable of handling misuse. The construction processes were made to make the system physically robust; the device was to be controlled only by firing rate alone, with no other controls; and devices were designed to be capable of handling a range of fuels prevalent in the target regions.

Conclusions

2.49 Establishing entrepreneurial ventures calls for activities that will obviously vary from one context to the next. In the context of the Biomass Entrepreneurship project, several of the key lessons that were learned may be transferable to other similar attempts to disseminate biomass technologies through market based entrepreneurial activities. Highlighting the main lessons brought out above are the following conclusions:

- A full lifecycle approach based on developing a commercial market and supporting entrepreneurs is more effective and sustainable than a subsidy-based, supply-driven approach. Given the proper support, entrepreneurs are able to build upon a business first established by an outside, donor-funded organization such as TIDE, benefiting from tangible investments (for example., fabrication facilities) but equally from the intangibles (for example., technical capacity building, marketing efforts, goodwill generated by TIDE). It is feasible for an NGO to develop a market, create a set of entrepreneurial ventures, and subsequently transfer them to a set of competing, independent, commercial business enterprises without compromising the institutional name, business quality, and size of operations.

- Any emerging technology, even one developed by institutions such as ASTRA that are highly sensitive to the social context of the end user, will inevitably face a phase of technological learning, iteration, and adaptation when the technology is first introduced to the market. To build a market for an emerging technological product, it must be completely vetted with the intended consumer base under realistic usage circumstances. Accomplishing this requires a fully funded phase of product and market that proves that is designed along quasicommercial lines, where the client pays a market price (or near market price) that preserves the incentive to expect high value. If this vetting process is neglected, technological problems will arise, resulting risks will outweigh the potential for rewards, and entrepreneurs will not take up the intended market activity. The conventional demonstration-oriented and subsidy-driven lab-to-land approach does not permit sufficient learning and innovation with respect to either the technology or the market. In the Biomass Entrepreneurship project, these initial technical issues were encountered and handled by TIDE, putting the entrepreneurs on a sound technological footing. Entrepreneurs were left with no substantive technological concerns, but merely the expected implementation problems linked to entrepreneur performance that are within the power of the entrepreneur to sort out. The lesson is that the major technical issues must be sorted out as part of a funded process that absorbs the technological risks of early commercialization, rather than passing them on to the entrepreneurs. This should be carried out up to the point that entrepreneurs can handle the remaining minor and operational technical issues.

- It may be useful to consider how market development in the energy field can learn from extensive experience of other industries, such as the computer software industry, which is accustomed to providing progressive versions of its products to end users. Obviously, this process requires a level of staying power that vastly exceeds the abilities of the software vendor and requires the backup and commitment of a promoting organization such as TIDE. In the Biomass Entrepreneurship project, this was possible only because of the financial support provided by the funding agency. Even when such resources are available, the iterative technology development process demands a flexible and adaptable internal institutional structure on the part of the promoting agency.

- Entrepreneurs require support and nurturing. The conventional approaches that rely on subsidy-based incentives and expect entrepreneurs to naturally come forward to undertake commercial activity are not feasible for establishing new product lines in rural markets. This

support involves a suite of services, such as technological backup, strategies, and resources for marketing and training for financial management of an enterprise.

- Identifying and attracting the appropriate sort of entrepreneur is important and can be difficult. The prospect of profitable work obviously plays an important role. In initial phases when attempting to attract entrepreneurs into an unknown and risky venture, the entrepreneurship arrangement may need to be fashioned so as to provide as much as twice the income of the alternative, known, relatively low-risk income opportunities available to the entrepreneur. At the same time, the entrepreneur development support process should not unrealistically raise the benchmark income higher than levels that can be sustained over a longer term. The process of product and market proving has to be based on realistic commercial lines that can provide the entrepreneurs a baseline for future operations. While the entrepreneurship development process can undeniably assist the entrepreneur, it cannot control all aspects of an entrepreneur's dynamics. The stability of the entrepreneur is crucial for success of the entrepreneur development process. It can be helpful to work with individuals who have a larger perspective of the business beyond the specific trade (such as masonry) on which the implementation most directly relies. There are many parallel dynamics operating in the entrepreneurship process, including personal and professional issues, not all of which can be managed within the entrepreneurship development process. Given these inevitable uncertainties, there must be adequate backup in any entrepreneurship activity. Dependence on a single person should be avoided, and competition among many entrepreneurs should be consciously encouraged as part of the market development process.
- While deep subsidies should be avoided, financial arrangements with the clients must be flexible. In the Biomass Entrepreneurship project, the extension of credit and the recovery of debts from clients by the entrepreneur was satisfactory and comparable to that achieved by TIDE during its operations. Interestingly, the payment terms have become more stringent with passage of time, but markets still expanded.
- The overall profit margins have grown higher under the entrepreneurs' operations. The entrepreneurs are continually assessing cost-saving options, including giving lower priority to some areas of work with lesser margins. Although concerns about product quality had risen, the market appears to put in place adequate self-corrective mechanisms in the form of maintenance costs and marketing concerns.
- Creating entrepreneurial activities that are viable for the indefinite future entails additional difficulties. The existing cadre of entrepreneurs, while successful at marketing the current line of biomass technologies, will eventually saturate the available market of nonformal industries. Whereas stable businesses are consciously looking at newer product options, the present set of entrepreneurs in the Biomass Entrepreneurship project does not have the capacity to identify and develop new options, and therefore continues to depend on TIDE for these services. If possible, a lifecycle approach should be developed for supporting entrepreneurship. As he matures, the entrepreneur requires a larger product range to survive and grow. If the entrepreneurship is based on an available product line only, the long-term survival of the entrepreneur may be in question. This will depend on factors such as the total population of potential end users, the lifetime of the product, and the need for servicing.

Case Study 2: Bioenergy Programs of the Indian Government

2.50 More than 60 percent of the people of India live in rural areas and depend primarily on biofuels such as firewood, agroresidues, and dung cakes for cooking and heating water and to provide energy for rural enterprises. An estimated 220 million tons of firewood and 160 million tons of nonfodder agricultural residues are consumed on a more or less sustainable basis every year to satisfy these energy service needs. In addition, 600 million tons of dung are produced from a cattle and buffalo population of about 288 million. However, the use of these large quantities of biofuels is associated with traditional devices and hence with inefficient conversion, pollution resulting from incomplete combustion, and the drudgery of fuel collecting, affecting especially women and children. It is thus a widely supported development goal to use the available bioresources more efficiently and cleanly and to produce modern energy carriers such as gaseous and liquid fuels and electricity in order to ensure sustainability as well as a better standard of living in rural areas. The Indian bioenergy programs, started in 1981 with the launching of National Program on Biogas Development (NPBD) under the Prime Minister's 20-point program, aimed at achieving the broad objectives of improved rural livelihoods. Considerable effort has been mounted in the past two decades in terms of funds spent, institutions mobilized, pubic outreach undertaken, and R&D carried out, to harness bioenergy resources efficiently. This case study reviews the various publicly supported bioenergy programs in Indian so far and discusses the results they have yielded on the ground.

The Various Bioenergy Programs of India

2.51 Table 2.3 below details a list of the various bioenergy efforts undertaken within the public sector bioenergy program, their starting years, and current status.

Table 2.3: Bioenergy efforts within the public sector bioenergy program

	Bioenergy project	Starting year	Current status
1.	National Program on Biogas Development (NPBD)	1981	Ongoing (revamped in 2002)
2.	National Biogas Management Program (NBMP)	2002	Ongoing
3.	National Program on Improved Stoves (NPIC)	1986	Terminated in 2002 (transferred to state gov'ts)
4.	Integrated Rural Energy Program (IREP)	1985	Ongoing
5.	Rural Energy Entrepreneurship and Institutional Development (REEID)	2000	Ongoing (pilot scheme)
6.	Women and Renewable Energy Development (WRED)	2000	Ongoing (pilot scheme)
7.	Biomass Power/ Cogeneration Program	1992	Ongoing
8.	Biomass Resource Assessment	1997	Ongoing
9.	Biomass Gasifier Program	1988	Action research projects closed in 2002
10.	National Program on Energy Recovery from Urban & Industrial Wastes	1995	Ongoing
11.	Bio Fuels	2003	Ongoing
12.	Biomass Briquetting	1981	Ongoing

2.52 The programs are usually initiated by the Ministry of Nonconventional Energy Sources (MNES) through a consultative process that involves expert committees and other governmental bodies such as the planning commission. The program consists of providing subsidies in the form of Central Financial Assistance (CFA) to the states, interest rate subsidies to distributors or purchasers of technologies, and funding for demonstration projects (either fully or partly financed by MNES). It further

conducts training and awareness programs, action research, and R&D and establishes Technical Backup Units (TBUs). As public money is involved, an elaborate arrangement for disbursal of subsidies and other monies is usually made in order to ensure accountability and to avoid malpractices. Physical targets are set up, both for a plan period (five years) and annually, and the magnitude of subsidies is pre-established so that government budget appropriations can be made in advance.

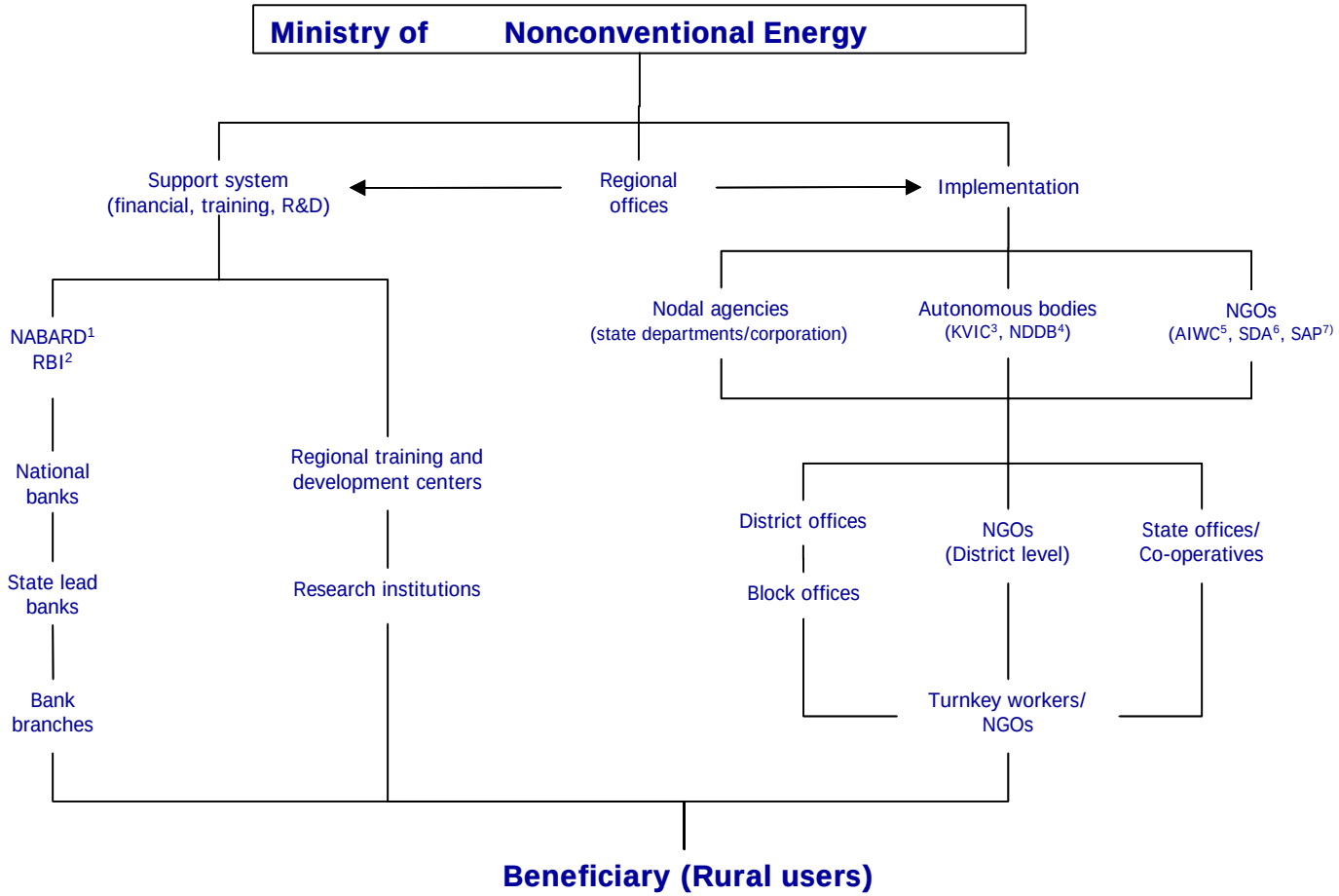
2.53 The flip side of such a method of program management is that the elaborate structural/institutional arrangement results in bureaucratic delays, diffused responsibilities, and incorrect reporting or overreporting of the achievements on the ground. It is important to understand the institutional arrangements before attempting a review of the various programs.

Structural/Institutional Setup

2.54 The worldwide awakening of interest in renewable energy following the oil crisis of the 1970s led to the establishment of the Commission for Additional Sources of Energy (CASE) in the Department of Science & Technology in 1981. The following year, a separate Department of Nonconventional Energy Sources (DNES) was created in the Ministry of Energy. A decade later, the DNES was upgraded and a full-fledged Ministry for Nonconventional Energy Sources (MNES) was established in 1992. India is possibly the only country in the world to have a ministry exclusively for renewable energy.

2.55 The administrative structure of the ministry consists of nine regional offices, three specialized technical institutions, and one financing agency (Indian Renewable Energy Development Agency, IREDA). At the state government level, several government bodies, such as the State Nodal Agencies (SNAs); State Electricity Boards (restructured currently in the wake of reforms;, State Councils for Science, Technology, and Environment; and state government-level ministries for agriculture and rural development are involved. Further down, district-level bodies such as District Rural Development Agencies (DRDAs) and local government bodies (panchayats) are involved. Several universities and technical institutes provide technical or R&D backup, and nongovernmental organizations (NGOs) are often involved in program implementation. The National Biogas Development Program, as the first bioenergy program to be designed and implemented, became the model for later programs, though such an elaborate program management structure was fully replicated for few other programs. The organizational structure of NPBD is shown in Figure 2.2 as an illustration.

Figure 2.2: Organizational structure of NPBD



[1]NABARD – National Agricultural Bank for Rural Development; [2]RBI-Reserve Bank of India; [3]KVIC-Khadi and Village Industries Commission; [4]NDDB-National Dairy Development Board; [5]AIWC-All India Women's Conference; [6]SAP-South Asia Partnership; [7]SDA-Sustainable Development Agency

Review of Various Programs

2.56 The review of the different bioenergy programs is based largely on published documents, some of which are not available to the general public, and discussions with people involved in various stages of project design and implementation. Details regarding annual targets, reported achievements, and amounts of subsidies are readily available from the annual reports of MNES, but evaluation reports, especially those based on field studies, are either rare or not made public. There are several independent critiques or studies by individuals or NGOs, but some of these might lack the vigor of field-based studies and hence are subjective to some extent. The involvement of one of the authors (V.V.N. Kishore) with many of these programs over the past 20 years has been the basis of this review.

The National Biogas Development Program

2.57 Generation of combustible gas (biogas or gobar gas) from animal dung is a long-established concept in India. Initial R&D was carried out by the Indian Agricultural Research Institute, Delhi, in the 1940s. The Khadi and Village Industries Commission (KVIC) took up the dissemination activities based on Jashubhai Patel's Gram Laxmi model biogas plant (presently called KVIC model) in the 1960s. The technology got a boost with the launching of NPBD in 1981–82, which was partly inspired by the Chinese biogas program. The so called Chinese models or "fixed-dome" plants were initially adapted for India by the Planning, Research and Action Division (PRAD) of the State Planning Institute of Uttar Pradesh in Lucknow and later by Action for Food Production (AFPRO), an NGO based in Delhi. The earlier fixed-dome model popularized was the Janata model, which later was substituted by the Deenbandhu model in the late 1980s. Several other models, such as Gobar Ganesh, Pragati Krishna, Jwala, and TERI, have been developed by various institutes, though not all have been sanctioned for promotion within NPBD.

2.58 The stated objectives of NPBD were to 1) provide clean and cheap source of biogas energy, 2) produce and use enriched manure, 3) develop management systems for production of value-added products, 4) improve sanitation and hygiene by attaching toilets to biogas plants, 5) mitigate drudgery of women and female children who collect fuelwood, 6) generate employment in rural areas, and 7i) set up biogas power station in cattle-based institutions.

2.59 The NPBD was centered on family-size biogas plants originally in the capacity range of 1–6 m^3/day, but in recent years standardized to 2m^3/day. The estimated potential for such plants is stated to be 12 million across all of India based on an estimate of the number of households owning enough livestock to support a biogas plant. To date, a cumulative total of 3.37 million plants have been installed, which seems at first blush to be a respectable penetration of nearly 30 percent. This has been accomplished through a central subsidy that varies from Rs. 1,800 for most farmers up to Rs.11,700 for farmers in the northeastern states.[17] In addition to this direct subsidy, which is the primary component of the promotion program, the NPBD provides further funding or incentives for a variety of biogas-related activities, such as job fees for construction teams for turnkey biogas plants, incentives for household toilet linked plants, repair charges of old nonfunctional plants, service charges and staff support, grants to biogas extension centers, training courses, communication and publicity, incentives for saving diesel, biogas development and training centers, and other incentives.

2.60 In addition to NPBD program for household biogas systems, a Community and Institutional Biogas Plant Program (CBP/IBP) was initiated in 1982–83. A cumulative total of

[17] In 2003, US$1 = ~Rs. 45.

3,487 plants, including 600 night soil-based biogas plants, were installed by 2000–01, at which point the community biogas program was effectively discontinued, with only a few plants built in the last few years. However, the institutional biogas and night soil-based biogas programs are continuing.

2.61 According to MNES estimates, the NPBD has saved 4.2 million tons of fuelwood as a result of the biogas plants. It is further estimated that 43 million tons of manure, equivalent to 950,000 tons of urea, is produced every year. Construction of about 180,000 plants every year is also estimated to generate 5.5 million person days of employment in rural areas.

2.62 Despite these apparent achievements, the success of the NPBD has been subject to public criticism, mainly concentrated on 1) poor functioning of the plants due to structural failures and other defects related to substandard construction, 2) disuse of plants because of a shortage of dung, and 3) sluggish and other corrupt bureaucratic implementation practices, for example, by those involved in local disbursement of funds. These problems have all dimmed the level of interest and motivation among rural households to install and maintain biogas plants. It is widely believed that if the subsidies are withdrawn, the program will collapse.

2.63 In recognition of these concerns MNES has commissioned occasional evaluation studies, which have helpfully drawn attention to the low rate of functionality of biogas plants and reasons for their nonutilization.

2.64 Among the most comprehensive of these was carried out by the National Council for Applied Economic Research (NCAER), which monitored 27,000 plants in 3,600 villages in 251 districts, constructed during the Seventh Five Year Plan (1985–86 to 1989–90). The NCAER has done three rounds of evaluation studies so far, including a socioeconomic cost-benefit analysis of the project. NPBD was also evaluated by the Comptroller and Auditor General (CAG) during the period 1985–93, and various shorter evaluations were done at a local or at the most regional level. Biogas programs implemented by NGOs have been evaluated separately. These various studies concentrated on the functionality rates or availability of dung but generated little information on the user perspectives on program effectiveness, program deficiencies, recommendations for capacity building, or field performance data and biogas usage statistics. Recently, the Programme Evaluation Organisation (PEO) of the Planning Commission undertook a comprehensive study to examine all the relevant aspects relating to design, implementation, and impact of the scheme. The major findings of this comprehensive evaluation are the following:

2.65 **Beneficiaries:** After two decades of implementation, the NPBD program seems to have affected a fairly small portion of rural households. Approximately 7 percent of the households in the sample villages were found to be using biogas, often as a supplementary source of fuel. A majority of these biogas-using households are well-to-do farmers who constitute a relatively small fraction of the rural population. The average number of cattle held by owners of functional biogas plants is greater than five, compared to a threshold of 3 used to estimate the national potential for biogas. In order to harness the potential of biogas, there is a need to bring a much larger proportion of rural households in the ambit of NPBD. The potential for reaching such households must be realistically assessed in light of factors such as the availability of alternate convenient fuels (LPG), distance of a village from the nearest town, availability of dung or other feedstocks, and inconveniences in handling and maintaining biogas plants. Though toilet-linked biogas plants increase the total potential, economic viability, and public health benefits, they have a lower acceptability rate due to sociopsychological inhibition with respect to routine operation.

2.66 **Functionality:** Properly functioning biogas plants undoubtedly benefit their owners. Approximately 75 percent of the owners of functional plants report substantial saving in the cost of cooking fuel, and 90 percent report that enriched slurry from the biogas plant reduces the cost of chemical fertilizers. However, despite the fact that the secondary data released by

MNES and state governments indicate impressive achievements and functionality rates, the primary data do not support such figures. This raises questions about the credibility of the reporting system and suggests a thorough review of the entire reporting system of NPBD scheme, for both accuracy and internal consistency. Primary survey data reveal that only 45 percent of the installed plants are working fully, with another 10 percent being used in part. A small proportion of households (3.4 percent, most of whom are disadvantaged groups among the scheduled caste/scheduled tribe category) do not have any dung to operate their plants. The assessment of institutional biogas plants run by welfare institutions and NGOs suggests they fare much better, with 90 percent of the plants being functional.

2.67 **Institutional arrangements:** The biogas staff is found to be overstaffed at the state level and understaffed at the district level. In all states, the district-level staff deficiency leads to inadequate supervision during construction and inadequate manpower for physical verification of plants, which enables corrupt practices in the distribution of subsidies and virtually ensures substandard biogas plant construction. Lack of district-level staffing also means that households get inadequate instruction; nearly 90 percent are not aware of government programs for repairing defective plants, and only 11 percent of households took advantage of the available financing programs.

2.68 **Community biogas plants:** The ultimate success of NPBD will depend largely on the ability to raise the use of biogas to several times its current level by bringing a large proportion of households within its ambit, by expanding nondomestic use of biogas in areas where commercial fuels are being used, by raising the potential of biogas through technology development efforts, and by making biogas sustainable without an unjustified level of budgetary support. The community biogas program (CBP), abandoned by MNES, is favored by Programme Evaluation Organizations as an important route toward accomplishing this in the larger rural context. Several suggestions were made to revive the CBP:

- The day-to-day operation of CBPs can be contracted out, rather than being managed by the community, given that management is often cited as a problem with CBP systems.
- It is possible to develop a market for dung, enriched slurry, and biogas in rural areas so that day-to-day operations can be commercialized and made financially self-sustainable for the operator.
- CBPs can further be made commercially viable by linking them to related programs such as rural water and sanitation, underground irrigation, rural street lighting, household electricity, and enterprise power, which provide high-value energy services for which there is an expressed demand in rural villages.
- Unsustainable subsidies currently being given to kerosene, diesel and electricity in rural areas can be redirected or reduced through promotion of CBPs.
- Technological improvement is ongoing for using biowastes (other than dung and night soil) as input for biogas, which expands the potential for viable biogas systems.
- Overall, CBPs are viable in the framework of social benefit-cost analysis as its social and environmental benefits are likely to far outweigh the direct benefits to individuals.

2.69 **Research and Development:** Another aspect of the NPBD is that it includes R&D support, but at a fairly meager level. The R&D allocation was about 2 percent of the program expenditure, which was spent primarily on microbiological studies for utilizing nondung residues and for developing bacterial consortia for low temperatures. None of these translated into field practices.

2.70 Several advantages of biogas utilization over fossil fuel utilization, such as local availability, supply of high-quality manure, green house gas reductions, and cost advantage over LPG and kerosene, are well established. In spite of such global and local gains, proven potential, and commitment of the government, it is important to identify the deeper reasons why the adoption of biogas is yet to take off in real sense. One such reason may be the difficulty of financing in the face of the fundamentally insolvent state of the agricultural sector in India, because of which biogas does not get priority for the limited investment funds available with the average farmer. Thus there seems to be a need to develop a holistic approach to include biogas as a component of sustainable rural infrastructure to revive agricultural sector and to evolve effective and efficient delivery mechanisms. (See the case study on the REWSU model of biogas-fueled water and electricity utilities.) In this regard, various measures might be considered in the future to strengthen the NPBD effectiveness, such as enhancing the involvement of NGOs with a proven track record for biogas dissemination as well as private sector actors, and to learn from a seemingly more successful dissemination model of the Nepal biogas companies.

National Program on Improved Stoves

2.71 The National Program on Improved Chulhas was initiated in 1986–87 with the objectives of 1) fuelwood conservation, 2) elimination/reduction of household smoke and reduction of smoke-related illness, 3) reduction in drudgery of women and children from cooking in smoky kitchens and collection of fuelwood, 4) environmental improvement and check on deforestation, and 5) employment generation in rural areas.

2.72 As per MNES statistics, a total of 33.8 million improved stoves have been promoted so far, compared with an estimated potential of 120 million. The implementation approach is similar to that of NPBD and consists of fixing targets and availability of subsidies. Subsidy disbursal is through state nodal agencies and departments and through NGOs such as All-India Women's Conference and BIOTECH in Kerala. KVIC is also involved in implementation. In addition to subsidy on different approved models of improved stoves, additional incentives are given to self-employed workers, Technical Backup Units, organizational infrastructure support entities, publicity and awareness building, training support, and dealership support.

2.73 As in NPBD, activities to monitor and evaluate the program are in place, with the emphasis again on ascertaining functionality of installed units. The most recent round of evaluation carried out by NCAER showed that 57 percent of the stoves are working and in use, 24.4 percent are working but not in use, and 18.6 percent are dismantled. Based on these figures, and various assumptions regarding the performance of improved and conventional stoves, MNES routinely publishes its estimates of the benefits of the NPIC, for example, fuelwood and financial savings.

2.74 An independent review of the NPIC indicates, however, that the calculated benefits are overoptimistic as they are based on certain unrealistic assumptions, particularly regarding the life expectancy of stoves. Making a realistic assumption of life of the stove, it was calculated that only about 4.07 million stoves were probably in the field as compared with the MNES estimate of 28.3 million in the year 1997–98. Calculations of fuelwood savings and monetary savings are similarly overestimated. The real benefit of NPIC, however, seems to be in removing smoke from the kitchen, resulting in less exposure to pollution and increased health benefits.

2.75 The NPIC was terminated at the central government level and the program transferred to state governments in 2002. This defunding at the central level has been interpreted by some observers to be the de facto end of the program. In the wake of serious concerns about the health effects of exposure to smoke, it is possible that interest in the program will grow within

the state governments, and they will take over and expand the program in the coming years. Evaluations, however, should be conducted to determine whether any measurable reduction in smoke-related diseases has in fact occurred in areas with active dissemination of improved stoves.

2.76 An apparent flaw in the NPIC program design was the large magnitude of the government subsidy and the infrastructure for disbursing it. Since government would bear half of the cost of the stove, the subsidy became the driving force rather than an instrument for further mainstreaming a product for which there was a latent demand. It suppressed efforts by private entrepreneurs to disseminate their own, often better, stoves because they were unable to compete with the subsidized stoves of the government program. The stove producers within the government programs tended to be concerned primarily with fulfilling the government's technical specifications (assuming there was adequate monitoring), rather than with responding to consumer preferences. Although the government invested substantial resources to subsidize the dissemination of improved stoves in rural India, the budget did not allot for sufficient supervision and assessment, which the subsidy-driven program would have required to ensure on the ground achievement. As a result, local stove construction was often hasty and technically faulty. Moreover, they were not geared toward the intended consumer. For example, many stoves did not accommodate the existing cooking pots. Since they stove producers were limited by their allotted quotas, they had no incentive to market aggressively to find new customers, and the market never flourished beyond the bounds of the NPIC program.

Bagasse Cogeneration Program and Biomass Power Program

2.77 This program started in the early 1990s with the objective of producing extra electricity from cogeneration of bagasse in sugar mills. It had already been standard practice in Indian sugar mills to produce thermal energy and electricity for self-consumption in a cogeneration mode, but with low conversion efficiencies and without export to the grid. Replacing old, low-pressure boilers with high-pressure boilers would result in production of excess, exportable electricity. To promote bagasse cogeneration and biomass power generation, MNES offered a package of incentives including subsidized interest rates (varying from 2 to 5 percent below market rates), concessional custom duties, exemptions from excise duty and sales tax (for high-pressure boilers and efficient steam turbines, for example), tax holidays, and accelerated depreciation. In addition, an attractive power purchase rate for the exported electricity was negotiated with state electricity boards (as with wind power). The exportable surplus from bagasse cogeneration was estimated to be 3,500 MW, out of which 43 projects with a cumulative capacity of 304 MW had been commissioned by 2003. Similarly, the potential for grid coupled nonbagasse biomass power was estimated to be 16,000 MW, out of which 164 MW has been established so far from 34 projects. MNES has set an installation target of 700 MW (450 MW from bagasse cogeneration and 250 MW from biomass power) for the tenth five-year plan (2002–07).

2.78 Most bagasse cogeneration projects are undertaken by the private entities in the agroindustrial sector and hence do not face the kind of problems encountered in rural energy programs. However, they do face problems typical to the Indian sugar industry. Because sugar mills run for only six to eight months per year, there is a problem of underutilization of the installed cogeneration capacity. The use of alternative feed stock during nonmilling season will alleviate this problem and is being attempted, though it has not yet been very successful. Sugar mills in many states are in the cooperative sector—as distinct from the private sector—and cannot avail themselves of incentives such as accelerated depreciation. Such mills are therefore much less motivated to undertake cogeneration projects. A further major barrier that applies to all project developers is that the state electric utilities are struggling to be financially viable and do not have the wherewithal or inclination to pay concessional rates to renewable electricity projects and especially bagasse cogeneration, which they assume to be a profitable venture, even when

such rates have been formally created by central government directives. In turn, prospective project investors are reluctant to rely on state electricity utilities, because they are seen as a risky source of project revenue.

2.79 Unlike the bagasse cogeneration projects, which can use captive biomass as feedstock, the biomass power projects depend on the acquisition of biomass from an external source, and hence the sustainability (both biophysical and financial) of biomass supply becomes critical. The experience to date demonstrates that mechanisms for ensuring feedstock sustainability are not yet in place. This has been the main problem faced by the biomass power efforts undertaken so far. Several biomass power projects have been undertaken based on sketchy and rather uncertain availability or price of biomass resources. In many cases, facility operators have had to procure different types of biomass feedstock or procure feedstock from other regions where the prices plus transport costs are lower. Many operators have had to operate the system at a lower capacity or for smaller number of hours, and have ultimately had to default on payments to IREDA. In recognition of this problem, IREDA has recently initiated a study on biomass availability issues for the projects sanctioned by IREDA. MNES is thus going slow on the biomass power projects at present.

Biomass Resource Assessment

2.80 Biomass has several competing uses, such as cooking fuel, fodder, roofing, pulp for the paper industry, and fuel in small and rural industries. Hence, a careful assessment has to be made regarding the availability of biomass for power generation to avoid disruptive competition for limited resources. Following a report from the State of Maharashtra (Rajvanshi 1995) that enough biomass would be available at the taluka level (the level of the subdistrict, of which India has roughly 3,000) to meet most of the power needs of the taluka, MNES initiated a taluka-level biomass resource assessment study program during the Ninth Plan. The program was implemented through a national focal point, five apex institutions, and a number of consultants to carry out field-level studies. A total of 495 studies were taken up in 23 states; 299 studies have been completed, and the remaining studies are likely to be completed by early 2005. The methodology consisted of collecting secondary data from agriculture records on crop production to derive agricultural residue resources, and data on forest cover (and other land types) from satellite images to assess fuelwood and other resources, and then excluding known biomass resources used for other known purposes based on agroeconomic analyses. Based on these studies, and using GIS techniques, a "Biomass Resource Atlas for India" is being prepared. No specific conclusions are available at this time, but the tentative observations indicate that there is a substantial potential for power generation through biomass in a large number of taluka. For more details, see discussion in Chapter 1 of this report.

Biomass Gasifier Program

2.81 The biomass gasifier program started in 1987 with the launch of a subsidy scheme for installing gasifier-based small irrigation pump sets. Nearly 1,000 systems were installed, but later evaluations showed that people purchased the systems because of high subsidy, which applied to both the gasifier and the irrigation pump set, and have not used the gasifiers. The subsidy structure was later corrected and the subsidy-based program is still active. According to MNES estimates, a total of 1,806 gasifier systems aggregating to 53.16 MW had been commissioned through 2003.

2.82 In order to support the gasifier program, Gasifier Action Research Centres was established and annual review meetings were held through the mid 1990s. Subsequently, Gasifier Action Research Projects (GARPs) have been established at IIT Delhi, IIT Bombay, IISc Bangalore, Madurai Kamaraj University, and Sardar Patel Renewable Energy Research Institute

(SPRERI) near Baroda. Several other institutes such as TERI and independent manufacturers such as Ankur have also been active in this the gasifier area.

2.83 Evaluation of the performance of systems installed in the field has been rare. An evaluation conducted in the state of Haryana in 1998 showed a very poor level of functioning. The survey results showed that of 36 gasifiers installed in the state, 24 were in government establishments, 4 were in the urjagram projects and 8 were in private enterprise. All of the gasifiers in the government units (many in the military) were either dismantled or were not operating. The four urjagram projects were not operating. Those in private enterprises seemed to perform better. One was operational, one worked for many months, and the rest were not functioning because of either technical snags or an increase in biomass prices.

2.84 Nonetheless, the gasifier program can arguably be credited with precipitating the emergence of several entrepreneurs outside the ambit of the MNES program. Nearly half a dozen of such entrepreneurs have independently sold as many gasifiers as those disseminated within the MNES subsidy program, mainly for thermal applications substituting diesel or furnace oil in small industries such as silk reeling, rubber drying, cardamom curing, and ceramic curing. The effort to perfect and commercialize gasifiers has apparently yielded results, but for thermal applications rather than power applications. A comprehensive and independent review of the performance and functionality of the gasifiers installed so far—in both thermal and power applications—would help elucidate the technical, financial, and policy barriers for promotion of gasifier systems, and provide lessons for updating the program.

National Program on Energy Recovery from Urban and Industrial Wastes

2.85 In order to use the potential of urban, municipal, and industrial wastes of India and address global environmental concerns, the Government of India is presently running two programs for recovery of energy from urban and industrial wastes: the UNDP-GEF project launched in 1994 to develop high rate biomethanation applications, and the National Programme on Energy Recovery from Urban, Municipal and Industrial waste started in 1995.

2.86 The National Programme on Energy Recovery from Urban, Municipal and Industrial Waste was intended to 1) create favorable environment with financial support to promote, develop and demonstrate the utilization of waste for energy recovery, 2) advocate best management practices for processing and treatment of waste prior to disposal using renewable energy technologies, and 3) promote demonstration projects for urban, municipal, and industrial wastes. The UNDP-GEF program aims to reduce greenhouse emissions using high-rate biomethanation technologies through institutional building; capacity building; promotion through demonstrations, outreach (through seminars, workshops, and training), and the development of a national master plan to promote high-rate biomethanation technologies.

Institutional arrangement

2.87 The national program is implemented through state nodal agencies, government departments, and urban local bodies. Thirty nodal agencies and eleven financial institutions are involved for coordinated execution of program at the state level. The target projects are very large compared with the household or institutional scale, with the minimum capacity limit of waste to energy project to be eligible under this program being 15 tonnes/day for fuel pellets, 300 m^3/day for biogas, 2.5 tonnes/hr for steam, and 25 kW for electricity generation. The maximum capacities have been specified as 5 MW for MSW-based demonstration and 2 MW for industrial waste-based demonstration.

2.88 The UNDP-GEF program is implemented by the National Bioenergy Board (NBB), a body created solely for management and implementation of this program that provides

policy guidelines and oversees implementation of this project. NBB involves representatives of related ministries and departments such as the planning commission, departments of biotechnology, economic affairs, scientific and industrial research, science & technology, and urban affairs. These institutions assist NBB in various stages of the program execution, including technology assessment, technology absorption, and translation of designs to Indian conditions.

Financial incentives

2.89 The UNDP-GEF program is a jointly financed program with financial assistance of Rs 158 million by GEF, Rs 235 million by MNES, and Rs 190 million by the beneficiary organizations.

2.90 This program supports both demonstration projects based on innovative technologies as well as commercial projects based on established technologies. For commercial projects, the program offers an interest subsidy up to 7.5 percent subject to a maximum of Rs. 20 million/MW. For demonstration projects, the program offers fairly comprehensive support covering the project development phase, project implementation, feedstock (waste) procurement, and monitoring. The program provides 50 percent cost sharing incentives for design and preparation phase (up to Rs 200,000) and implementation phase (up to 30 million/MW). Municipal bodies receive up to Rs 1.5 million/MW for site clearance and facilitation, and state nodal agencies receive up to Rs 0.5 million/MW for coordination and monitoring.

Current status

2.91 A total number of 12 waste to energy projects have been commissioned under the National Bioenergy Project, and 9 have been implemented under the UNDP-GEF project. The total installed capacity under the national program is 21.7 Mweq, and the total aggregate power production from UNDP-GEF implemented project is 4.0 MWeq. These activities comprise projects based on a wide range of wastestreams Nonetheless, it can be concluded that the program has not taken off to the degree intended, particularly given that the major objective of these programs was the creation of an environment that would foster wide replication. There have been several individual demonstrations, but these haven't met the expectations that the programs would foster widespread replication. Because of nonutilization of all the appropriated funds, the UNDP-GEF program has been extended beyond the original project period by another five years

2.92 Among the apparent reasons for the inability to catalyse more market activity have been a failure to promote technologies appropriate to the local circumstances and small-scale enterprises and lack of parallel R&D efforts to develop such technologies. A bureaucratic structure for implementation is the main reason for lack of achievement.

Biofuel programs

2.93 MNES attempted to develop technologies for production of ethanol through various processes, converting different nonedible oils to biodiesel and developing retrofit kits capable of using biofuels with conventional fuels in blends of 10 percent and greater. A recently completed policy study will inform the drafting of a long-term policy on biofuels. A soft loan scheme based on interest subsidy was launched in 2003 for producers of ethanol and other biofuels and the manufacturers of modified engines and retrofit kits to enable the use of biofuels in engines.

2.94 A project called SuTRA (Sustainable Transformation of Rural Areas) was launched at the Indian Institute of Sciences in Bangalore for promoting the use of Honge (pongamea) oil—a locally produced nonedible oil that is suitable for conversion into a biodiesel or for blending with diesel. The project was funded by MNES and Rural Development and Panchayat Raj Department (RDPR) of the state government of Karnataka. Though several

engines have been modified to run on this oil, and other activities such as biogas production from seed starch have been initiated, the final outcome of the project seems to be inconclusive. Several questions remain to be answered relating to engine operation and maintenance, availability of seeds, sustainable yields of pongamea seeds, costs and logistics involved in collection of seeds, and cost of pongamea oil. RDPR has recently initiated an evaluation study of the project, but the results are not yet published.

2.95 A major biofuel promotion recently commenced when the central government issued a directive to promote the blending of ethanol in transport fuels for air quality and energy purposes. In the first phase, blending of 5 percent ethanol with petrol became mandatory in several regions starting January 1, 2003. Nine states (Andhra Pradesh, Goa, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu, and Uttar Pradesh) and four Union Territories (Chandigarh, Dadra & Nagar Haveli, Daman & Diu, and Pondicherry) were to introduce the ethanol additives. The second phase would expand this to the entire country. In the third phase, the ethanol additive content would be increased to 10 percent. The ethanol requirement was calculated to be 320–350 million liters per year for the nine states and 4 UTs and about 500 million liters for the whole country.

2.96 Oil companies have issued letters of intent to procure anhydrous alcohol from distilleries in various states, but unfortunately bureaucratic and other problems have slowed down this ambitious program. Ethanol manufacturers in Maharashtra, Gujarat, and Goa have a surplus of ethanol (a total of 280 million liters compared to their local requirement of 140 million liters at present), but they are waiting for oil companies to take delivery, while the oil companies are awaiting clearances from the Income Tax Department. In other states, the program has not taken off because of a shortage of ethanol, although various incentives have been put in place. An excise duty relief of Rs. 0.30 per liter was announced for blended petrol, which would decrease its price by Rs. 015–020 per liter. The government of Andhra Pradesh has reduced the sales tax from 20 percent to 4 percent. Tamil Nadu has yet to resolve issues of the price of ethanol; in addition, problems remain regarding the impact of a sales tax (12 percent) and surcharge (5 percent), and administrative fee of (Rs 1 per liter).

2.97 Supply should be adequate to meet this target, providing that the various financial and policy incentives are implemented in a manner that facilitates ethanol production and interstate trade in ethanol.

Integrated Rural Energy Program

2.98 The IREP is an ambitious program that aims at developing the planning and institutional capabilities at the state, district, and block levels to formulate and implement area-based microlevel energy plans and projects for promoting the utilization of an optimal mix of various energy sources. The IREP envisions large-scale participation of the people in the planning and implementation process through involvement of Panchayats, NGOs, and other institutions. It seeks to set up and strengthen the mechanisms for linking micro-level planning for rural energy with national and state-level planning for energy and economic development.

2.99 The IREP has national-level and state-level components. The central component provides grants-in-aid for the support staff in the IREP project cells at the state level and in IREP blocks. Financial support is also given for training and extension work, primarily though the four regional training and R&D institutions at Bakoli (Delhi), Chinhat (Lucknow), Jakkur (Bangalore), and Anand (Gujarat). These institutions have been given several interrelated tasks related to local energy planning. They are tasked to:

1) Impart training to planning, implementation, and administrative manpower at the village, block, district, state, and national levels

2) Develop course material for various training programs for different levels on IREP

3) Establish a database on rural energy demand and supply for different microregions of the states and subregions

4) Monitor rural energy and development projects and develop a suitable computer simulation model

5) Establish facilities for documentation, information dissemination, and mass communication in the areas of rural energy, appropriate technology, and efficient uses of water

6) Establish a demonstration center for appropriate rural technologies

7) undertake research and development on rural energy systems and appropriate technology, including draught animal power resources, manual labor, energy-efficient practices utilizing conventional and nonconventional energy in agriculture, forestry, and rural industries works

8) Undertake research and development on program implementation and management methodologies, including the use of various organizational and institutional alternatives, voluntary agencies, and NGOs9) Carry out economic, social, and environmental impact assessments and other related studies.

2.100 A total of 860 blocks have so far been sanctioned for implementation of IREP, covering 16 percent of the total number of blocks in the country. At this early stage, the block-level project documents have been prepared for most of these blocks. The major conclusions that have been made from these block-level studies are that there is a wide variation in energy consumption in different agroclimatic zones, ranging from 830 to 2,868 kilo calories/capita/annum. Of total energy consumed for cooking, 90 percent is fulfilled by nonconventional energy sources, and there is similarity in the amount and type of energy used, particularly for cooking. However, there are significant variations in quality and quantity of energy across the various agroclimatic zones and energy consumption levels for the agriculture, transport, and industrial sectors. Ultimately, the outputs of these analyses will provide baseline data on which integrated rural energy plans will be designed.

Biomass Briquetting

2.101 In India, materials such as sawdust, coffee husk, ground nut shells, mustard stalks, and rice husk have been the most suitable locally available biomass for briquetting. The resulting briquettes have been used successfully in small-scale boilers of various small industries, and furnaces such as brick kilns, though they have they been marketed minimally as a household cooking fuel. Approximately 500 briquetting machines have been installed since the 1980s by indigenous manufacturers, of which 300 are estimated to be operational. These were primarily with ram and piston machines that employed a binderless briquetting process using high pressure (1,500 kg/sq.cm) and temperature (200° C). As a result, roughly 1 million tons of biomass is briquetted annually at present, which is a small portion of the projected potential of 100 million tons.

2.102 In part, the failure to diffuse more broadly in India is because biomass briquetting technology requires some further advancements. In particular, there are several operational problems related to wear and tear and downtime for repairing. Also, most briquetting machines require that saw dust be added (at ~50 percent) to the main biomass feedstock, which itself generally must be dried and pulverized. Briquetting is thus viable in contexts where the necessary combination of suitable materials is available. A practical problem is that, since biomass handling

machinery and briquetting machinery relies on electrical power, the frequent power outages in rural areas inhibit the smooth and continuous operation of plants.

2.103 The growth of the briquetting industry in India has occurred largely through entrepreneurial efforts over the last decade and half. Initially, IREDA gave soft loans to entrepreneurs to install briquetting plants, but it has since discontinued loan disbursement because of poor loan recovery. There are cases, however, in which entrepreneurs took commercial loans and successfully repaid them, suggesting that briquetting enterprises can be profitable ventures. This, coupled with the fact that a large potential exists for biomass briquetting, and that it is suitable as a rural enterprise, suggests that a comprehensive national program involving financial, R&D, and policy support for biomass briquetting could make a significant impact.

Rural Energy Entrepreneurship and Institutional Development

2.104 This REEID pilot scheme was initiated in 2000–01 with the objective of creating entrepreneurship in the rural energy sector. The program intends to strengthen entrepreneurship development centers in different states with linkages to renewable energy industries, IREDA, state nodal agencies, and NGOs. Although the program supports renewable energy generally, a major thrust is expected to be on bioenergy because of its importance in rural areas. The central government provides financial assistance for outreach activities such as Entrepreneurship Awareness Camps (of which 96 were organized in 2001–02) and Entrepreneurship Development Programs (33 in 2001–02). This program is still modest but expanding, and a budget of Rs. 10 million was provided for the year 2002–03.

Women and Renewable Energy Development

2.105 The WRED scheme was initiated in 2000–01 with the objective of empowering rural women through promotion, marketing, utilization, and management of renewable energy systems and devices. The program establishes Renewable Energy Sales and Servicing Outlets (RESSOs) and Renewable Energy Women Self-help Groups (REWSHGs) to foster energy related activities that can be undertaken at the local level. These activities include, for example, construction and maintenance of renewable energy devices and generation of energy plantation in wastelands for fuelwood production. The scheme is implemented by state nodal agencies and departments, the Khadi and Village Industries Commission, academic institutions, and NGOs. During 2001–02, 140 orientation and training courses were organized, and 58 RESSOs and 79 REWSHGs were established (compared with program targets of 200, 120, and 122, respectively).

2.106 The objectives of the two programs above have been focused on capacity-building activities, rather than tangible results such as setting of targets and the installation of specified numbers of units. Once sufficient time has elapsed to allow the capacity-building activities to bear fruit, an evaluation should be carried out to assess the indirect achievements of the programs.

Conclusions

2.107 The government of India has mounted perhaps the world's largest effort to develop bioenergy technologies and promote their dissemination. A range of measures, including provision of capital subsidies, packages of incentives, provision of R&D support, and creation of institutional arrangements, have been undertaken for a variety of national programs. However, the general feeling is that the results obtained on the ground are not commensurate with the efforts.

2.108 The program as a whole has lacked a holistic, integrated, and missionary approach. There has been a strong emphasis, especially in the earlier and larger projects, only on meeting quantitative dissemination targets. In the target-driven, bureaucracy-heavy programs, there is an elaborate and complicated structure for disbursal of subsidies and dissemination of

systems, and a diffused responsibility among the various institutional partners. This structure discourages earnest efforts to learn from failures to achieve the established targets, and blunts incentives to identify alternative ways to satisfy the needs of the intended consumers.

2.109 This target-based approach is overreliant on government machinery and underreliant on nongovernmental and private institutions. The program has correspondingly not focused its efforts on market development or leveraging the efforts of the private sector.

Case Study 3: Rural Electricity and Water Supply in Karnataka

2.110 This case study examines the Rural Electricity and Water Supply Utilities (REWSUs) implemented in Pura and the other villages in India. These utilities provided lighting and pumped water to village households. These services were made based on biogas-generated electricity that was produced from cow dung delivered by the village residents. These systems were managed and operated by village residents, with the technical support of outside academic or development organizations. The REWSU implementation emphasized both "hardware," in terms of infrastructure for power generation and distribution and water supply, and "software," in the form of institutional arrangements to implement, manage, and maintain the village scale utility. This case study examines the experience with REWSUs and discusses the scope and challenges faced for large-scale replication in the Indian context.

Background

2.111 The delivery of clean and affordable household services such as lighting, water, and cooking to rural areas is one of the most significant challenges for sustainable development. Among the array of national and multinational efforts to meet this goal, such as grid expansion, the marketing and financing of solar home systems, and the dissemination of efficient cookstoves, community-based initiatives that rely on local renewable resources such as biomass are of special interest for at least two reasons. First, the use of local resources, especially biomass, can provide participating users greater control and avoid the losses inherent in delivery from centralized systems to dispersed consumers. Furthermore, as described elsewhere in this report, in addition to the sustainability benefits inherent in the use of decentralized, renewable energy sources, there may also be income-generating opportunities associated with both the supply and end-use segments of such systems, especially in the case of biomass. Second, in contrast with programs and projects that target individual households, community-based initiatives tend to focus on cooperation, building social capital, empowering women, and improving access for all members of the community rather than simply for those who can afford to pay for individual devices or systems. Within the broader development context, women's self-help groups and cooperatives have been successful in improving living standards across social and economic groups by developing networks of exchange and cooperation to complement conventional business models of individual entrepreneurship, which would otherwise benefit only whose who are relatively affluent and upwardly mobile (Mayoux 1995). Such organizations have developed their programs on the pretext that empowering women within poor communities is a worthy development objective in itself, because doing so creates opportunities and builds institutions to give women voice and thereby provides them supplementary tools to address their human development needs in otherwise patriarchal environments.

2.112 The commonly found forms of biomass in most rural areas are animal dung, woody biomass, and crop wastes. Biogas is a mixture of methane and carbon dioxide (in the ratio 3:2) produced by the anaerobic fermentation of biomass such as animal dung. Where cattle are commonly kept as draught animals and for dairying, a biogas-fueled system may be suitable. Biogas has a calorific value of 23 megajoules (MJ) per cubic meter and can be used directly as a fuel for cooking or as a partial replacement for diesel in dual-fuel systems generating electricity for other services. The sludge from biogas plants typically has higher nitrogen content than manure, which provides an additional benefit.

2.113 In India, biogas systems have been promoted quite aggressively and with some success by various government agencies since the early 1970s (see the MNES case study in this report). The thrust of these programs has been on family-size plants to produce biogas for cooking as a replacement for fuelwood. At the community scale, however, there have not been many successful community- or village-level biogas plants. Fateh Singh ka Purva (a hamlet in the

Etawah district of the north Indian state of Uttar Pradesh) had the first community-based plant constructed in 1979; it provided households with biogas for cooking and also powered a dual-fuel engine genset to generate electricity for domestic and street lighting, water pumping, and other electric services (Bahadur and Agarwa, 1980). A community-scale biogas diesel plant, which began generating electricity in 1987 for household lighting and water supply, was established in Pura (a village in the state of Karnataka, Southwestern India) by the Center for the Application of Science and Technology to Rural Areas (ASTRA) at the Indian Institute of Science (KSCST 1987; Reddy and Balachandra 1990; Rajabapaiah, et al., 1993). In 1995, under a Rockefeller Foundation grant, the International Energy Initiative (IEI) launched a program to replicate the Pura experience in nine pilot villages in Karnataka and explore mechanisms for broad replication of REWSUs. The systems deployed in these pilot villages comprised both "hardware," in terms of power generation and distribution and water supply, and "software," in the form of institutional arrangements to implement, manage, and maintain the village scale utility.

2.114 The model explored in IEI's REWSU project sought to provide village households unserved (or poorly served) by public water and power utilities with an alternative means of meeting these basic needs. In the absence of these services being provided by the respective utilities, this project took the approach of creating local community-managed utilities. As in the case of many public investments in rural areas, such as road extension, grid extension, medical care, and education, the REWSU model attempts to provide services to customers who are obviously unable absorb the upfront investment costs, (see the discussion on economics below). The REWSU model is not intended to absolve the public sector from providing basic services, but to provide a mechanism through which local community institutions can leverage a relatively small public sector investment to provide vitally important basic services at lower total costs and with greater local benefits, including the ability to build social capital and empower women, than alternative options such as public water works and grid extension.

2.115 This case study examines the REWSUs in Pura and the other villages where they have been implemented, and discusses the scope and challenges faced for large-scale replication in the Indian context.

Technology

2.116 The technology at the core of a typical REWSU is one or more floating drum biogas digesters, with the minimum capacity required for producing enough biogas per day to meet the basic daily water supply and lighting demands of all households in the village. The digesters are generally capable of producing additional biogas to energize a few devices and systems during off-peak demand to improve capacity utilization of the system and provide opportunities for income generation. For a typical 100-household village and a human-to-cattle population ratio that is slightly lower than 2:1, there is enough dung available to produce the equivalent of about 42.5 cu.m. of biogas per day, or roughly 1 GJ of fuel. The optimal plant design with these parameters corresponds to a digester capacity of 40 cubic meters. The biogas demand for cooking is significantly higher than that needed to produce electricity for drinking water and electricity, implying that without a much higher cattle population or a biodigester suitable for additional feedstocks such as agricultural residues, REWSU villages would not be able to support the entire community's cooking needs.

2.117 The floating drum employed in the REWSU uses low-cost construction techniques and can be built onsite by a skilled welder. The digester pit is constructed using local labor. The inverted drum, whose diameter is very slightly less than that of a cylindrical digestion pit (usually but not necessarily below ground level), serves as a gas tank that is anerobically sealed while floating up and down, depending on the amount of biogas stored. The digester is divided by a wall separating the inlet and outlet portions. Feeding the pit through a gravity flow

channel is an inlet tank where dung and water are mixed in a slurry. Waste slurry, at the end of the digestion period of about six weeks, is fed through an outlet channel to a tank, from which it flows into sandbed filters where it is dried into a sludge.

2.118 Gas from the digester is directed to a dual-fuel diesel engine, where it is mixed with about 15–20 percent diesel fuel to run an alternator that can generate up to 5 kW of electricity. The electricity is distributed through village streets to feed fixed 15 W lighting connections in every house that opts for one. There is also a water distribution network that comprises individual household tap connections, fed by water pumped from a borewell. A switch at the power plant determines whether the water or lighting system is to be energized at any given time. The typical REWSU generates electricity only for about four hours a day, split equally between lighting and water supply. It is also common practice to provide water for community-managed vegetable gardens or lighting to meet special needs for private parties.

Institutional Arrangements

2.119 As a community-scale project, the REWSU is critically dependent on an overlapping set of local and regional institutional arrangements, requiring especially active village-level cooperation and the ongoing commitment of political and administrative bodies. Such arrangements are important at every stage of the project, including conceptualization, design, financing, construction, and implementation. Beginning with Pura, REWSU project supporters (ASTRA and, later, the International Energy Initiative) held extensive consultations with villagers, especially women, to assess local needs, biomass availability, and the ability to pay for services. They also sought the endorsement of local and state government officials for building village-level infrastructure and the involvement of local NGOs and academic institutions for conducting surveys and gauging the interest of village leaders and the general populace in participating in the enterprise.

2.120 The lynchpin of the REWSU is its local governance structure, which consists of a micro-utility board known as a *Gram Vikas Sabha* (GVS) or "Council for Village Advancement." The GVS is typically composed of about 15 adult members of the village, and with IEI's recommendation, having strong representation by women, that is, generally more than a third and in some cases a majority. GVS selection is primarily through local nomination during consultations, although NGOs have also had to play a role in urging individuals to join. The presence of other village-level institutions, such as women's self-help groups and microfinancing organizations, has been very effective in bringing responsible and socially responsible individuals to the GVS. The main task of the GVS is plant management, which comprises the following duties: identifying and setting an appropriate tariff; employing a plant operator; sanctioning repairs and other maintenance expenses; and developing ways to improve the capacity utilization of the plant and thereby increasing revenue.

2.121 The tariff determined by the GVS is expected to cover the operational expenses of the plant, including the operator's salary, diesel bill, engine and other component maintenance, and future replacement costs. The typical REWSU is expected to collect at least Rs. 20 (about US$0.45) per month from each household to cover these costs under conditions where about two hours each of water and lighting supply are provided. There is no expectation of recovering the capital costs through household tariffs at such low levels of capacity utilization. However, improved levels of capacity utilization are conceivable if commercial demands for electricity

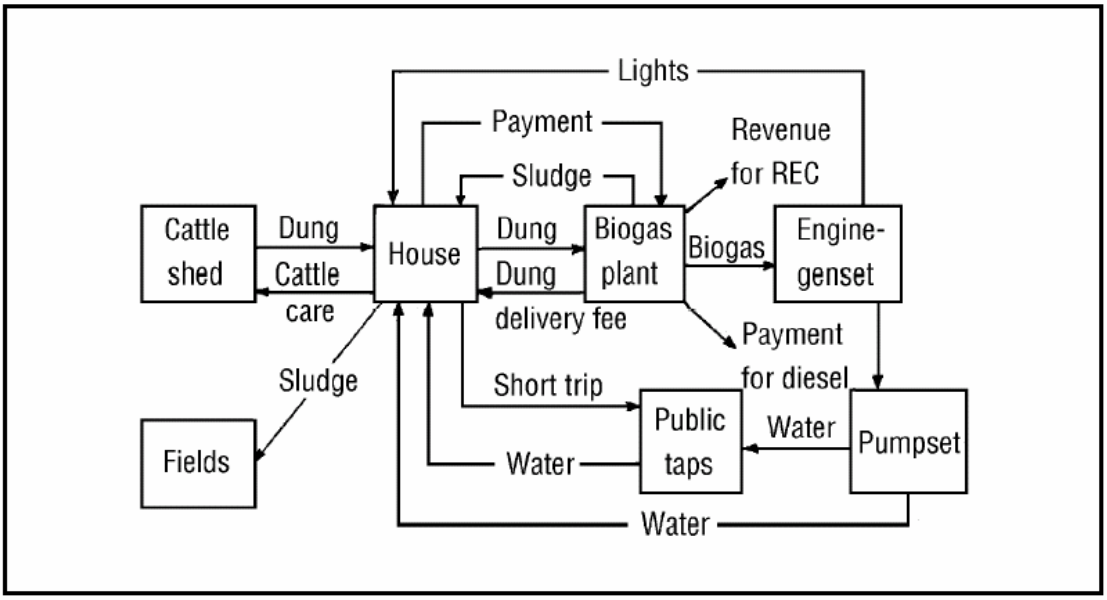
services (for example, flour mill, irrigation) are locally present or if energy exports to the grid are feasible.[18]

2.123 The operator, who tends to be a young unemployed or semi-employed male, has several duties, including collecting dung, charging the digester, maintaining the sand bed filters and the engine, returning the digester sludge to dung contributors, and, perhaps most important, maintaining accounts and collecting tariffs. Dung collection is a less trivial matter than might be imagined, because rural residents in much of India place a high value on dung, which has multiple uses as fertilizer, insecticide, and fuel. The main incentive to provide dung to the plant, in addition to the benefits of lighting and water,[19] is that nitrogen rich digester sludge will be returned for use as fertilizer. Initial charging of the plant is often a major hurdle, and some REWSUs have even needed to resort to importing bulk quantities from outside after unsuccessful attempts to persuade villagers to make their own sizeable contributions in the face of an uncertain future concerning the plant's success. During full-fledged plant operations, dung contributions are typically just enough to keep the plant running to operate at the current capacity utilization; there is rarely excess dung available to produce more gas than necessary. In other words, feedstock supply is somehow collectively regulated according to the needs of the utility's operations. Figure 2.3 is a schematic of the web of material and financial flows associated with the typical REWSU.

[18] In one instance, the GVS in the village of Kalgudi made arrangements to share the proceeds of a high-yielding export crop (dill cucumber) with a farmer who purchased irrigation water. Such innovations were directed toward maintaining adequate cash flows for operational needs rather than to pay back the capital, which was secured as a grant.

[19] In Pura, a "dung delivery fee" was also recorded; associated with a small amount per kilogram of dung delivered to the plant, but this practice of providing a monetary incentive for dung was discarded for the other REWSUs. At any rate, the "fee" may not quite have captured the value of dung, since as discussed below it has a variety of alternative uses that villagers may not be willing to forgo easily. Rather, it can be seen as a means through which the developers sought to generate villagers' trust and assure them that the dung would in fact be put it to good use and returned to them as fertilizer sludge.

Figure 2.3: Schematic of REWSU



Source: Batliwala and Reddy, 2003.

2.124 As long as plant operations are smooth, tariff collection tends to be correspondingly straightforward. The operator makes monthly rounds of all the households to collect tariffs and makes entries in a passbook. Expenses such as diesel and maintenance are also recorded. The operator prepares a balance sheet and presents it to the monthly meeting of the GVS. The GVS may also hold periodic community meetings to hear complaints and suggestions in a public forum. Local government officials and NGO representatives may be present in these meetings to provide new perspectives and to take heed of the local developments that might be relevant to replication efforts in other villages.

Experience with Replication

2.125 Following about seven years of successful operation of a REWSU in Pura, IEI—with funding from the Rockefeller Foundation—sought to replicate the effort in nine other villages in Karnataka (see Table 2.4 for a summary). The idea was to transfer the technology and institutional experience to local NGOs, academic institutions, and a government agency that would replicate, with suitable adaptations, the Pura experience. These efforts would, along the way, provide a better understanding of the challenges and opportunities associated with REWSUs in multiple circumstances and prepare for subsequent, wider phase of replication. The shift from demonstration to pilot was also intended to identify alternative pathways for improving the financial viability of the system.

2.126 IEI employed several criteria for selection of site villages:

- The villagers should express a clear desire for the REWSU; that is, they should express a felt need for the services and a willingness to take responsibility for operations and maintenance.
- Sufficient resources should be available in the village, including dung, an existing water source (well/borewell), and a small plot of land that villagers are willing to donate for the REWSU.

- There should be clear communication regarding the obligations of villagers toward the REWSU, including average dung requirement, costs (diesel, operator's salary, repairs), tariff per household, GVS participation, recordkeeping, periodic meetings, and so on.
- Villagers should make a commitment to contribute resources, including tariff and dung, toward continued operation of the REWSU.
- Women should be involved in the decision as to whether or not to establish the REWSU.
- Local and state government officials should be completely aware of the project goals and make commitments to provide official support for its implementation.
- They should also place the REWSU officially on par with government-sponsored schemes for providing services and offer support from administrative machinery.

2.127 Based on consultations with local NGOs and staff from engineering colleges and government agencies, seven organizations ("implementing agencies") were selected in early 1995 to implement the REWSUs in nine villages that met the above criteria. Three years later, eight REWSUs were constructed, with six in full-fledged operation. The ninth was abandoned altogether because extended delays in construction led to a total loss of confidence in the project by the villagers, who decided to withdraw support. Subsequently, however, none of the REWSUs was functional for a while, and only through IEI's unrelenting and close support did one REWSU in the village of Mavinekere continue functioning. This painstaking process resulted in considerably less self-sustaining REWSU activity than initially hoped for, but also generated a wealth of lessons regarding the barriers to community-based supply of energy services and the prospects for further replication. The following subsections relate some of the relevant lessons from the replication experience.

Table 2.4: Summary data from REWSU villages in 1998

Village →	Basavanahalli	Doddagollahalli	Kalgudi	Mailanahatti	Mavinakere	Nayakanahoolikatti	Sunkadahalli	Yeladahalli
Number of households	41	130	97	83	149	96	85	84
Number with lighting connections	41	130	97	83	149	96	85	84
Number with water taps	41	130	97	83	149	96	85	84
Total construction cost (1996 $)	14,061	20,753	17,660	17,417	21,164	17,594	17,881	17,205
Construction cost/hh	343	160	182	210	142	183	210	205
Monthly operating cost	43	51	43	48	59	40	48	43
Monthly household operating cost	1.04	0.39	0.45	0.57	0.40	0.42	0.56	0.52
Monthly household collection	0.58	0.58	0.58	0.58	0.58	0.72	0.58	0.58
Total monthly income#	45	75	56	48	86	70	49	49
Total monthly surplus or deficit	3	25	13	0	27	30	2	5

Source: Shivakumar et al., 1998.
Includes a subsidy from the implementing agency and a fee paid by a single large consumer of gas for cooking.

2.128 *Training.* IEI organized three different types of training programs for REWSU implementation: overall orientation, construction, and operations for implementing agencies; technical operations for the REWSU operator; and administration for the GVS members. IEI and ASTRA prepared training materials for construction, the GVS, and the operator, some of which were prepared in English and in the local language, Kannada (Shivakumar et al., 1998). In addition, there were routine meetings with implementing agencies and GVS representatives as well as a few public meetings in villages where IEI staff and technical consultants attempted to motivate the local participants, answered technical questions and provided operational support. Clearly, though, even this level of training seemed inadequate in a number of instances, where implementing agencies, the operator, or GVS members themselves encountered preventable technical and operational problems (for example, motor burnout, poor recordkeeping) or errors in judgement (for example, unreasonable penalty or poor communication about account keeping) in realms where operational factors had been earlier agreed upon. Close followup by IEI helped sort out many of these problems, but a fundamental difficulty of institutional sustainability seemed to persist in the overall project, although other issues like competition from free government-sponsored schemes may have influenced this strongly (see below).

2.129 *Management*. While IEI had initially planned to play a relatively hands-off role in implementation of the project, it frequently found itself having to micromanage several aspects of construction and operation. Often during construction, several technical problems largely relating to specifications not being followed required IEI's efforts to get the project back on track. When the REWSUs were in operation, IEI's close involvement was again necessary to ensure that the GVS and implementation agencies were broadly following procedures that IEI had developed following several years of experience in Pura. For instance, IEI repeatedly needed to insist that operators maintain records of important parameters such as dung collection and income and expenditure. Interestingly, though, implementing agencies that had taken on a second REWSU seemed to require much less of a helping hand from IEI the second time around, suggesting that these organizations were effectively "learning by doing" and improving their own management skills over a relatively short period of time.

2.130 *Implementing agencies*. The character of the implementing agency seemed to have some bearing on the way in which the project was implemented. Although it is difficult to make broad generalizations based on the small sample of organizational types and the host of confounding factors affecting implementation, IEI gleaned some broad lessons from the close interactions with these agencies. It seemed that large local NGOs with extensive previous experience in implementing rural development programs and close contact with villagers were effective in ensuring timely project implementation. However, their close involvement could also imply paternalism, which hinders self-reliance among the beneficiaries and raises expectations of ongoing support from the outside. While staff from engineering colleges provided excellent technical support for the project, they tended to be positioned exactly opposite large local NGOs in terms of their ability to build motivation and remain sensitive to local needs. Similar problems afflicted NGOs that had little or no local base and were interested in one-off asset creation rather than sustained operation. On the other hand, there are some distinct advantages associated with such organizations: their large network and sizeable resources could help transfer experience and replicate the project quickly across different regions; their distance from local residents could potentially create a greater sense of responsibility within the community for sustaining the project. Notwithstanding its extensive experience with local development programs, the enormous backing of government institutions and policymakers, and ability to leverage other resources, local government implementation of the REWSU seemed to be the least effective

approach, in large part because bureaucratic inability to mobilize the local community. In all these cases, though, local institutions need to be built up whose habits, informal rules, and practices are strengthened to maintain the REWSU's "virtuous cycle" (Mayoux 1995).

2.131 *Economics* While total project expenditures varied widely among the eight REWSUs, capital costs were directly determined by the plant size and the number of light and water connections. Because of the mistakes in construction and longer construction times, significant underestimates of labor and material costs, and some minor design changes, the total cost turned out to be about 20 percent higher than the initial estimate. In 1996 terms, the average construction cost per household for the plant, lighting, and water distribution systems was US$199. The actual lifecycle cost of electricity in the project turned out to be about US $0.104/kWh. This could have been brought down by about US$0.01/kWh if all eight REWSUs had been built at the cost of the most efficiently built plant. Given the effects of higher capacity utilization (6,000 hours per year) and improved engine technology to remove the need for diesel entirely, the cost would reduce to about US$0.78/kWh. This is considerably less than the electricity price that households routinely pay for batteries, or the price of electricity from solar home systems. Note also that the capital cost, if amortized (10 years at 15 percent per year), amounts to about US$40 per household, or about 2 percent of the absolute poverty income of one dollar per day per capita.

2.132 *Financial Sustainability*. Soon after construction, it became quite clear that monthly management of expenses and income was a delicate balancing act that the GVS found hard to sustain (see also Table 2.4, which is based on estimated rather than actual income in 1998). The largest fixed items in the expenditure were the operator's salary (about US$20 per month) and diesel costs (about US$10–15 per month), which were typically more than covered by the monthly fees recovered from the households (typically set by the GVS at less US$0.50 per month for each water or electricity connection). In addition, there were unexpected repairs, which together with maintenance costs would average out at about US$3–5 per month, but would typically appear as lumpy costs of US$20 or more. This seemed to present a significant problem of monthly fee collection for the GVS, which faced the unfortunate problem of having to maintain consumer confidence in the system while ensuring that persistent defaults on monthly payments did not lead to plant shutdowns. To the extent that IEI or the implementing agency was able to provide some capital inflows, the REWSUs remained viable. But in 1998, at the end of the funding period for the overall project when IEI had to withdraw financial support from the six functioning REWSUs that were already in operation, the local institutions found it increasingly difficult to remain financially viable after a few months. By 2000, when IEI resumed support for Mavinekere, it seemed it was too late to garner sufficient public support to try to help bootstrap the remaining REWSUs. Meanwhile, the state government had itself begun a counterprogram of providing free piped water to the villages, which further undermined the confidence and interest of even those villagers who were otherwise vocal champions of REWSUs.

Future Prospects for Replication of REWSUs

Lessons from REWSU replication experience.

2.133 The project revealed several important lessons about replication:

1. The overall technical and operational features of the Pura REWSU could be replicated, to the extent that support for operational wrinkles continues for some minimum period of time during early replication efforts.

2. It is essential for there to be either a strong local stake on the part of the village or a durable desire and capability within an implementing agency to build local confidence.
3. Democratic and transparent institutional arrangements and clear communication are crucial for sustained operation; this includes maintaining proper records and accounts, holding routine GVS meetings, and placing public accountability as an constant operational target.
4. Parallel operation by government agencies to provide equivalent services that compete with the REWSU could be disastrous; on the other hand, government support for the project is vital.
5. While government involvement and support are essential, implementation by the government seems ineffective.
6. Financial sustainability in operations is difficult to achieve and requires broad long-term outside support in the form of risk sharing with lenders or other financial institutions in a manner that does not undermine local self-confidence in maintaining the system.

2.134 To a large degree, it appears that the REWSU may also be an instrument for improving gender inequity and building local networks of cooperation. Traditional patriarchal arrangements in rural areas tend to limit women's opportunities to secure livelihoods through education and employment, through a vicious circle that reduces their prospects for advancement. Poor access to energy services within such a social context has meant also that they bear the burden of numerous associated health and economic problems (they eat poorly, carry large loads of water and fuelwood, suffer the consequences of indoor air pollution, and reduce the time available for productive activity). To the extent that governance arrangements in REWSUs are tilted toward helping women produce and make use of energy services more effectively, some (although not all) of these problems may be dissipated (Batliwala and Reddy 2003). By intentionally addressing women's empowerment as part of REWSU objectives and operations with explicit institutional arrangements for forming formal (GVS) and informal associations (self-help groups), women may be better able to change prevailing social norms within the community. The converse may also be true; that is to say, where women's social capital is already significant or on the rise because of other developments in a region (as is the case in many parts of southern rural India through the proliferation of small savings schemes organized by self-help groups), it seems more likely that community-based initiatives like REWSUs will flourish. In the final analysis, it may be that resource availability is much less of a constraint than robust institutional arrangements, and support from outside organizations for finance, administration, and technology.

Future Replication Schemes

2.135 One possibility for large-scale replication of the REWSU is to use a concessionary approach that has long been applied to natural gas and oil and is being explored for some renewables like wind. The main steps of this approach would be:

1. Conducting a regional survey and identifying the prospective area for development
2. Delineating the resource area into license areas or concessions
3. Inviting bidders under published terms and conditions
4. Licensing to successful bidders under a Build/Train/Operate/Transfer model.

2.136 The specified conditions would have to account for the need for appropriating adequate public funds and leveraging adequate private funds for the financing of the building, training, operation, and transfer of REWSUs. Due to the inevitable need to treat widespread REWSU replication as a public infrastructure undertaking, it might be appropriate to design concession areas based on administrative units with full government support. Given that one of the primary limiting factors on REWSU's financial independence is their need for higher capacity factors, agreements with larger utilities to buy back excess power from the REWSU at reasonable rates could contribute great to the financial viability of a large network of net-exporting REWSU's. This options could be particularly promising in regions with a large population of cattle or where biogas digester technology can be employed to consume agricultural residues. It will also be important to develop work obligations in concessions or other contractual arrangements to ensure that public benefits are preserved and institutional arrangements arranged so that women are involved in governance organizations and the plant operations remain transparent. Finally, the transferees could be the GVS or a private sector Energy Services Company (ESCO) that relieve the developer from the long-term responsibility of distribution of the outputs from the REWSU.

Conclusion

2.137 REWSUs comprise a remarkable mix of hardware (technology, capital, bioresources) and software (financing, governance, resource collection, billing, and existing social arrangements) that need to work in harmony in order for the system to remain sustainable. When they do, it appears that the potential for benefits to the community are substantial, in terms of the provision of energy services and human development. Local assistance in the form of technology support, finance, and institution building may be necessary for some period beyond construction, although it is conceivable that these may be established by committed long-term partnerships among civil society organizations, private contractors, and the government.

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The World Bank

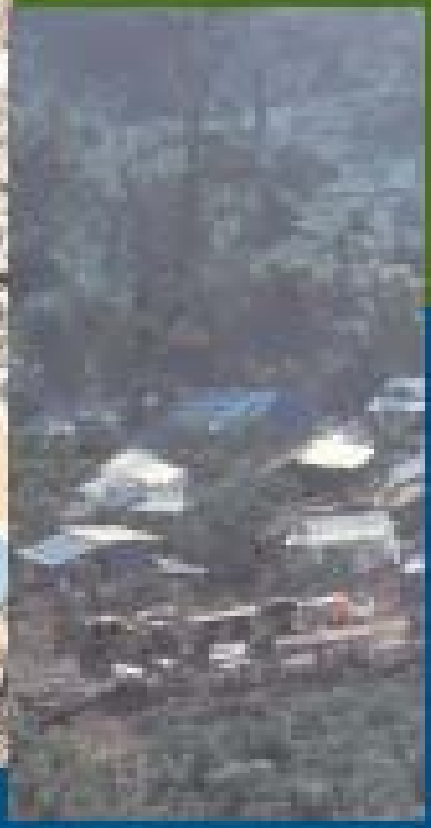
1818 H Street, NW

Washington, DC 20433 USA

Tel.: 1.202.458.2321 Fax.: 1.202.522.3018

Internet: www.worldbank.org/esmap

Email: esmap@worldbank.org



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