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Symposium on Development and Utilization of Biomass Energy Resources in Developing Countries

Vienna, 11–14 December 1995

Proceedings

Volume I

Thematic Papers

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Explanatory notes

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Preface

The present publication consists of papers and results of case studies submitted to the Symposium on Development and Utilization of Biomass Energy Resources in Developing Countries, held by the United Nations International Development Organization (UNIDO) at Vienna from 11 to 14 December 1995. The objective of the Symposium was to facilitate a dialogue between technologists, technocrats, scientists, decision makers and potential donors, in order to promote and identify biomass energy technical assistance and investment projects. The Symposium was convened under the overall direction of A. Tcheknavorian-Asenbauer, Managing Director, Industrial Sectors and Environment Division of UNIDO.

Volume I of the publication presents the opening statement and keynote addresses of the Symposium, and includes 21 papers. Fourteen countries are represented thus giving a broad perspective on the development and utilization of biomass energy resources. The papers are organized into six parts, each dealing thematically with the topic of the Symposium. The last part summarizes the outcome of a round-table discussion held at the conclusion of the Symposium. The contents of each part are outlined below.

Part one, consisting of six papers, provides an overview of the development and utilization of biomass energy in the following six regions: Africa; Asia; Asia-Pacific; Central America; central Europe; and eastern Europe. Particular emphasis is given to identifying regional biomass energy resources, establishing the extent to which the resources are utilized and determining the technologies currently applied to the enhancement of biomass resources and their conversion into energy. The papers further discuss the policies and strategies governing, as well as the barriers limiting, the development and utilization of biomass energy resources.

Part two, consisting of six papers, deals with technologies for the enhancement and conversion of biomass resources. The first three papers focus on issues related to the enhancement of biomass energy resources. Problems associated with the lower energy density of biomass and its lower concentration relative to fossil fuels are discussed, and situations in which advanced technologies for the enhancement of biomass resources should be developed are identified. Those situations are then assessed from a pragmatic perspective on resource enhancement. Finally, technology options are critically reviewed.

The fourth paper examines the main existing and innovative technologies for converting biomass into electric power or heat. The status of conventional versus advanced technology in a few developing countries is reviewed. Finally, major technology options are covered in detail, and criteria for their effective application in developing countries are discussed. The next paper provides detailed coverage of two biomass conversion technologies: circulating fluidized-bed combustion and circulating fluidized-bed gasification, both designed and developed by Lurgi. In addition, criteria for the selection of either technology are discussed, and a procedure for transfer of the technologies to developing countries is proposed.

The last paper in the section deals with the issue of technology transfer. A new perspective on this complex process is presented, involving a systematic approach to establishing a complex technological capacity in a given field. A successful project in East Africa is described to support the arguments for the new perspective.

Part three, consisting of two papers, covers funding sources and mechanisms. The first paper examines the technologies and fuel risks that are unique to biomass energy projects, and summarizes the public financing sources and support that are available to assist in dealing with the unique risk profiles. The paper also presents potential strategies that the developer of a biomass project could apply in seeking the involvement of, and negotiating with, local governments and public financing agencies.

The second paper discusses financing hurdles and other problems facing biomass utilization in developing countries. In order to promote market penetration by technologies designed to achieve widespread and efficient use of biomass, the paper emphasizes the need for intervention by Governments or by the Global Environment Facility. To accelerate the flow of private capital, the paper proposes joint implementation of biomass technology projects by industrialized and developing countries.

Part four, consisting of four papers, is concerned with the environmental economics of biomass energy utilization. The first paper focuses on the environmental, social and economic benefits of sustainable development and utilization of biomass energy. The second paper gives a perspective on the role of biomass energy in the ecosystem, and discusses the technical, institutional and social barriers that must be overcome.

The third paper presents a cost comparison between biomass and coal as feedstocks for production of electricity and liquid fuels using advanced conversion technologies in developing countries. The last paper looks at the external costs of electricity generation-costs not included in the market price mechanism. Those costs are divided into two categories: environmental external costs; and non-environmental external costs. The paper details environmental and non-environmental externalities, and discusses various strategies for internalization of external costs of conventional forms of energy, including emission taxes and tradable emission permits.

Part five contains three special papers. The first presents a historical overview of fuel oil from Jatropha plants in Africa, focusing on the approach used to overcome problems during the implementation of a pilot project in Mali. In addition to information on the use of plant oil as fuel, the paper provides a perspective on the positive environmental, social and economic effects of such use, and describes a technology transfer approach that encourages the local production of the required equipment, and concentrates on training and dissemination of the relevant know-how. The second paper explores the potential for the utilization of oil crops as an energy source, focusing on the use of untreated vegetable oils, particularly rapeseed oil, for that purpose. It then reviews the process feasibility aspects and future possibilities for the use of vegetable oils. The last paper reviews the current and future role of biomass energy in the pulp and paper industry. It further considers the likelihood of the pulp and paper industry serving as an important early market for advanced biomass-based cogeneration technology.

Part six provides a summary report on the consensus and conclusions reached during a round-table discussion, held at the conclusion of the Symposium, on the need for, and identification of, technical and investment projects in the field of biomass energy.

Volume II of the publication presents the results of three UNIDO-sponsored case studies conducted in Brazil, the Philippines and Romania. The results were presented at the Symposium.

Contents

Page

PART ONE

PART FIVE

Tables

Figures

Page

Opening statement and keynote addresses

OPENING STATEMENT

M. de Maria y Campos
Director-General
UNIDO

Ladies and Gentlemen,

On behalf of UNIDO, I would like to warmly welcome you to the Symposium on Development and Utilization of Biomass Energy Resources in Developing Countries.

As you may have heard, UNIDO has just concluded a somewhat difficult General Conference, and the management is preoccupied in setting a course for the Organization in the circumstances it will encounter over the next bienniumWhile UNIDO has encountered difficulties, we are happy to report that despite those difficulties, our Member States approved the Organization's programme of work for the next two years.

For the past two years, UNIDO has been engaged in a reform process. We are the first United Nations agency that has taken up the challenge of responding to the new global situation and have accordingly reformed the organization to concentrate on a focused programme with greater impact. As a result of our reform process, it is clear that we have to exercise our mandates in support of the industrialization of Africa and the LDCs. In that context, you would agree with me that one of the important elements is the supply of energy in support of the industrialization in those countries. Not only must the supply of energy be ensured, but it must be done in a manner that is both economically viable and environmentally sound.

Countries such as the LDCs have seen a lot of deforestation and degradation of landscapes and the environment as a result of a lack of energy that led people to act without considering the technological alternatives or the consequences for ecosystems. This in itself is quite alarming, and we cannot remain silent, knowing that to improve the quality of life for the people, countries require energy to facilitate industrialization and, thus, economic growth.

The major evolution in recent industrial development patterns is that industrialization is placed in the context of several parameters such as environment and social issues. Today, environment is quite a complex issue. Therefore, UNIDO is obviously needed more today, especially by those regions and countries which plan to be industrialized in the twenty-first century. By providing them with the necessary information and technological know-how and also assisting them in building capacities, UNIDO could support their efforts to achieve industrialization in harmony with their environment and social requirements.

In the light of this, UNIDO's mandate in the next decade will be sustainable industrial development. This would encompass not only environmental concerns but also energy supply systems that are harmonious with the environment. As industry is one of the major consumers of energy, the first step to be taken is to generate energy that is environmentally sound, so that industry can be sustainable. This is why we are holding this symposium on the utilization of biomass energy. We are very happy that you have responded positively to our invitation to participate. This will provide us with the benefit of your experience and your know-how in determining to what extent and how we could introduce this energy source into the development patterns of developing countries.

Many people will ask why UNIDO is now involved in energy and why we were not so much involved in energy 10 or 20 years ago. We have come to realize that while many institutions and organizations were looking into energy matters, they were not really looking into energy for industrialization. Most organizations were involved in energy-related infrastructural issues, but very little attention was devoted to energy for industrialization. Therefore, my organization has decided that, if we are to have success in industrialization, we have to emerge as a player in the field of energy.

In support of the intent just stated, UNIDO participated in the First Conference of the Parties to the Framework Convention on Climate Change at Berlin in February, and we are preparing, at the request of the Group of 77, a very important study to identify, inventory and assess technologies that are conducive to reducing emissions of greenhouse gases in energy-intensive industrial sectors. Your contribution to this symposium will also help us prepare that study.

So with these observations, ladies and gentlemen, I would like to conclude my remarks and wish you fruitful and spirited discussions during the following days. Thank you.

KEYNOTE ADDRESS

A. Tcheknavorian-Asenbauer
Managing Director, Industrial Sectors and Environment Division
UNIDO

Mr. Director-General, distinguished experts, participants, colleagues from United Nations agencies and UNIDO,

In addressing you this morning, it is my pleasure to provide you an overview of the substance of this important symposium.

The world's growing energy demands are by now well understood. Most projections indicate that world energy demands will triple over the next decades. It is also common knowledge that over the same period, developing countries will account for about 40 per cent of world energy demand, as opposed to their current share of 25 per cent.

Against this backdrop of demand, we will have to confront global and local environmental stresses posed by fossil-fuel-based energy supplies. Were increases in demand to be met by fossil-fuel-based resources and the current technology, we could face a significant increase in emissions of global greenhouse gas from present-day levels. In all likelihood, that situation would cause severe disturbances in the planet's ecosystems.

Yet again, we have to consider that the growth in energy demand in developing countries, if based on current patterns of resource utilization, would perpetuate their dependence on imported energy. That dependence would diminish the prospects for investment in other sectors of their economies.

UNIDO efforts on environmentally sustainable industrial development cannot be divorced from the question of environmentally sustainable energy supplies. With industry being a large consumer of energy, industrialization patterns could exert a profound influence on the economics and the ecological effects of growth in energy supplies.

Against this context, UNIDO regards this symposium as a new beginning- a beginning in the sense that we wish to initiate a long-term global programme in the field of energy and industrialization based on consideration of the economics, technologies and environmental sustainability of energy supply systems.

The use of biomass energy lends itself as a particularly interesting point of departure in this respect. Biomass resources are both varied and abundant in developing countries, technologies for the utilization of biomass are evolving, and if properly managed, biomass-based energy systems could demonstrate significantly better environmental results than fossil fuels. We could significantly increase energy self-sufficiency and reduce environmental stress if biomass resources could play a more important role in the global energy mix.

However, the realization of the full potential of biomass-based energy is inevitably conditioned by the quality and type of energy resources available, the compatibility of technologies with different fuels and the resultant financial or economic viability of the biomass energy system.

Broadly stated, UNIDO sees the biomass-energy system as having three components. The first is the resource supply component, the second is resource enhancement and the third is the utilization of biomass in energy generation. UNIDO can assist developing countries in the choice, assessment, adaptation and demonstration of technologies for each of the components.

Regarding the question of resource supply, the sheer variety of biomass resources presents important and varied problems, whether in relation to the trade-off between food and energy in agricultural sectors or the sustainability of forest resources. To the extent possible, we must develop and generate biomass resources that support the sustainability of agriculture and natural ecosystems.

The enhancement of biomass resources, the second component of the system, is crucial insofar as enhancement technologies will determine the cost/energy yield ratios of those resources. While technologies are developing at a fair rate, there is a need to assess and match technologies to different resources and also to the economic and environmental factors that prevail in different countries and sites.

Thirdly, the utilization of biomass resources presents an amazing diversity of applications, ranging from household energy to large-scale commercial generation of electricity. Here we need to capture and enhance energy yields in each application. Measures in this respect range from improving the efficiency of domestic stoves to adopting higher energy conversion technology for commercial generation of electricity.

All three system components offer great scope for international cooperation among actors such as UNIDO, governments, technological institutions and the private sector.

In recognition of the scope for cooperation, our symposium has been segmented into distinct themes to be dealt with in seven sessions:

- In sessions 1 and 2, we hope to provide a foundation for our discussions by reviewing regional and national opportunities for, and constraints on, enhancing the utilization of biomass energy.
- Session 3 is intended to deal with the state of the technologies that can best capture the energy potential of various biomass resources.
- In sessions 4 and 5, we will review key issues in the financing and environmental economics of biomass resources.
- Session 6 will deal with the potentials of selected special fuel sources in various regions of the world.
- Session 7 is intended to identify strategic areas in which UNIDO could support the development of biomass energy projects.

While I had earlier mentioned that this symposium is a new beginning, I would hasten to add that biomass energy is not an entirely new topic for UNIDO. We have had several individual projects assessing or demonstrating various technologies in several countries, and recently we launched a biomass energy programme for the African region.

Our new beginning means a difference in our approach. We hope, in this symposium, to launch a strategic programme based on an overview of energy systems on the one hand, and on the other, on a recognition of the global imperative to mitigate climate change and reduce greenhouse gas emissions. Thus the difference is one of perspective.

In closing, I wish to express my personal thanks to all the high-level experts and to you, the participants, for accepting UNIDO's invitation to join in this endeavour. I wish you all success in this symposium. I am confident your deliberations will enrich UNIDO's understanding of the issues, as well as guide us in our work in the years ahead.

Thank you for your attention.

KEYNOTE ADDRESS

Heinz Kopetz
Director, Landeskammer für Land- und Forstwirtschaft Steiermark, Graz, Austria
Chairman, European Biomass Association, Paris, France

It is an honour for me to be invited by UNIDO to present my ideas on biomass as a source of energy. I thank you for this invitation.

I work at the Chamber of Agriculture and Forestry in southern Austria. For one year now, I have also been Chairman of the European Biomass Association (AEBIOM).

Fifteen years ago, the Austrian Chamber of Agriculture, with the support of the Ministry of Agriculture, started to focus on green energy-biomass energy. Today, many organizations, as well as individuals and public institutions such as municipalities and federal governments, pay more and more attention to the development and utilization of biomass energy.

Figure I shows the potential for the development of biomass energy in Austria. Presently, the contribution of biomass energy to the Austrian energy mix amounts to about 13 per cent, which is the third highest contribution in Europe, after Finland and Sweden. It is AEBIOM's objective to double this contribution within the next 20 years.

On the European level, however, biomass energy does not play a significant role (table 1). AEBIOM has just prepared a report, "Strategies for biomass", analysing the possibilities and potentials for the role biomass energy can play in the European energy supply. The results indicated that possibilities exist for increasing the contribution of biomass energy to the energy mix in the European Union from the current 3 per cent level to 20 per cent within 30 years, by raising production and the sale of heat, electricity and biofuel (figure II).

Why is it imperative to increase the biomass energy contribution to the energy mix in Europe?

The urgency arises from the following:

- The energy system in Europe is not sustainable-84 per cent of the energy supply comes from non-renewable energy sources such as fossil fuels. Deposits of non-renewable sources are finite, and they will be exhausted, be it in 40, 50 or 60 years.

- The use of fossil fuels is harmful to the environment. For each tonne of oil burned, 2.8 tonnes of carbon dioxide (CO_2) are discharged to the atmosphere. In the European Union, the annual CO_2 emission amounts to approximately 3,300 million tonnes. Thus, without doubt, the increase of greenhouse gases in the atmosphere and the expected global warming are mainly due to the present energy system. Concerning the climatic evolution, it is of no consequence whether CO_2 emissions stem from a house heated with gas, a coal-fired plant or a car using petrol. There is no question that maintaining the present energy systems will endanger the living conditions of future generations.

Figure I. Development of renewable energy

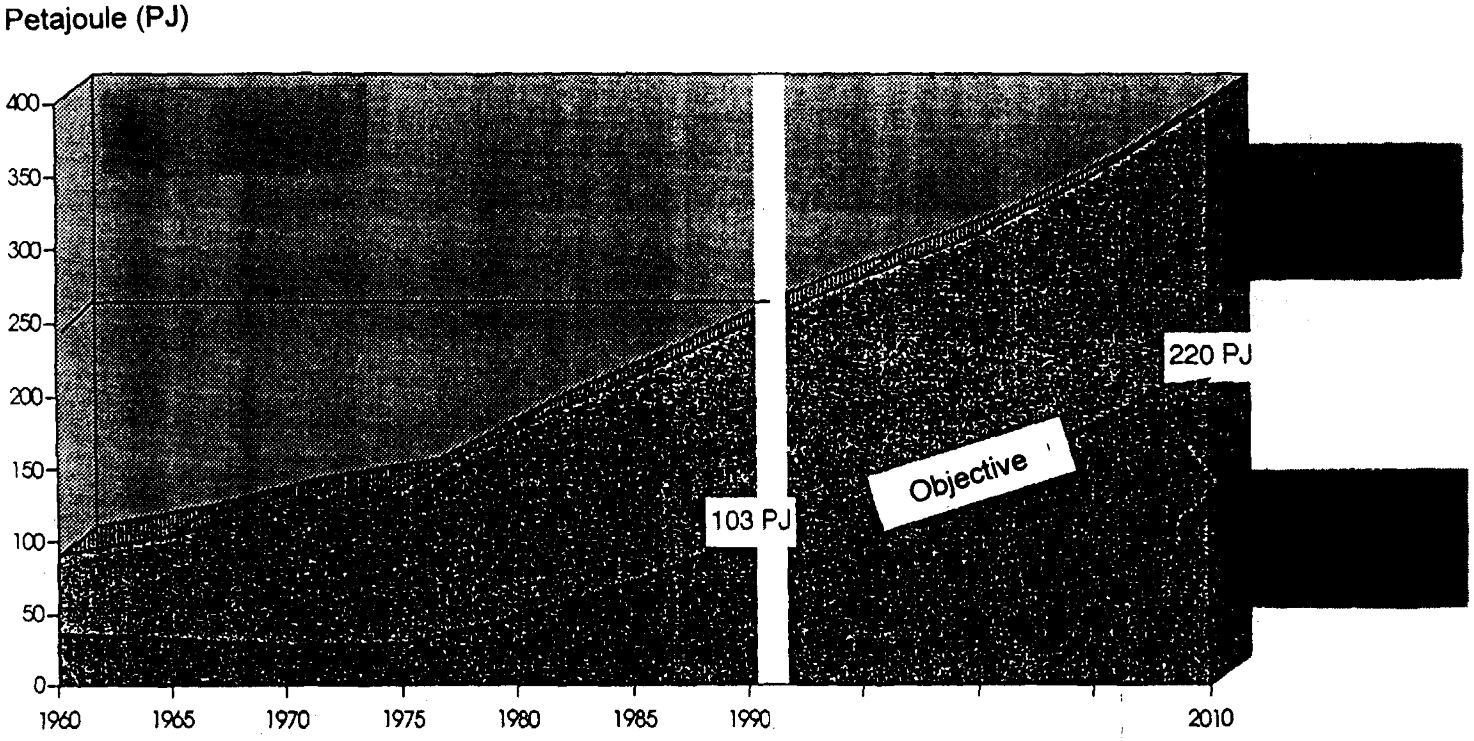
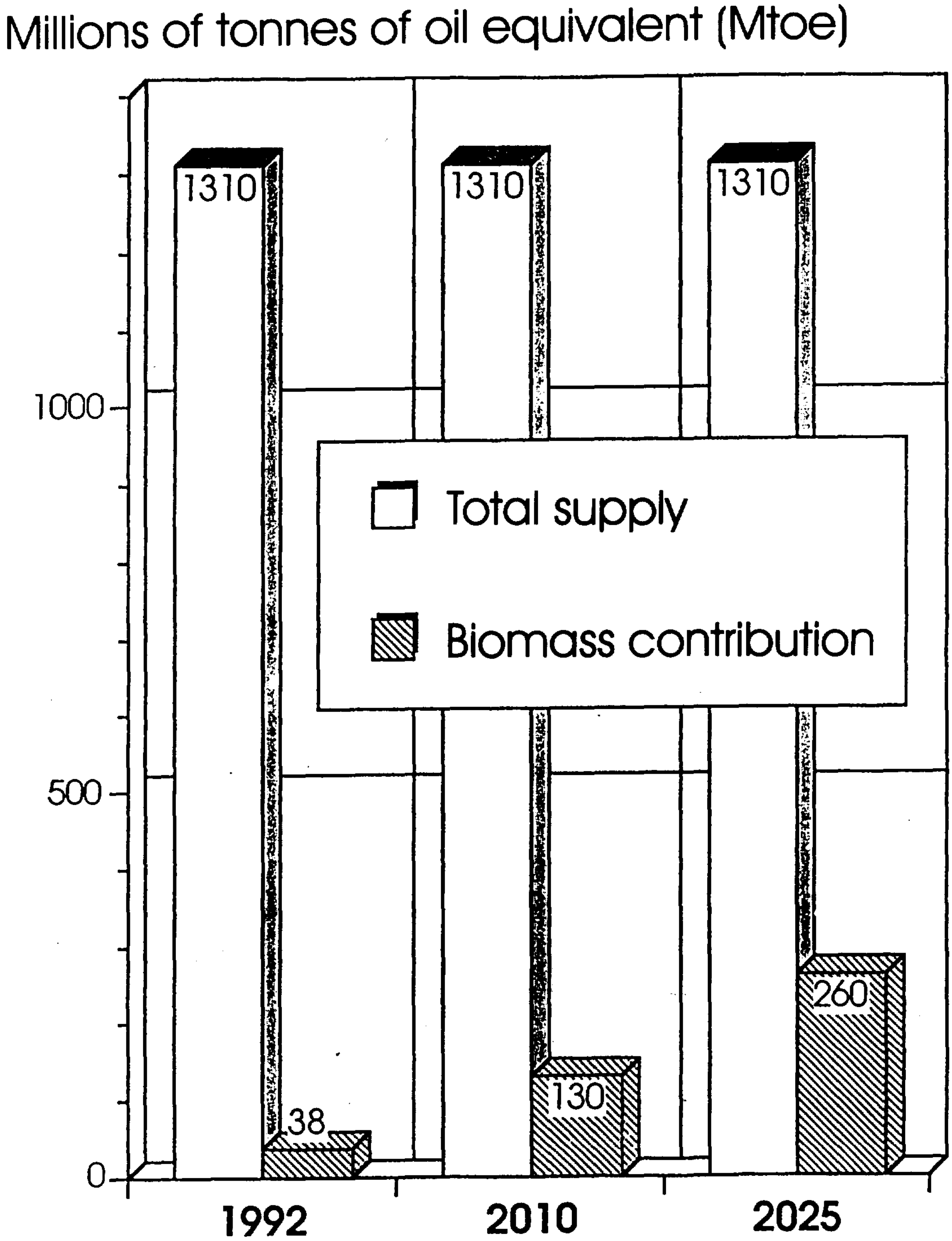


Figure II. Possible development of biomass in the 15 countries of the European Union



Source: AEBIOM.

Table 1. The supply of biomass

	1992	2010	2025
Supply (Mtoe)			
Present contribution of biomass	38	38	38
Additional use of demolition wood etc.	-	3	7
Additional use of agricultural and municipal waste, including biogas	-	12	24
Additional contribution from wood coming from conventional forests, residues, bark, thinning etc. to the energy market	-	30	56
Energy crop for biofuels	-	9	11
Energy crop for biocombustibles	-	38	124
Total	**38**	**130**	**260**
Land needed (Mha)			
Agricultural land		6.8	22.2
Total		**12.5**	**29.2**

Source: AEBIOM.

The alternative to the present situation resides in a more efficient use of energy and in the gradual replacement of fossil fuels by renewable energy sources. In summary, the main reasons for the promotion of biomass energy are limited deposits of fossil fuel resources and the harm to our environment resulting from their use.

How to promote biomass energy?

Our energy system has to be changed from a fossil fuel system into a solar one. The sun is the source of almost all the renewable energies, be it in a direct way (e.g. the solar captors of photovoltaic cells) or in an indirect way (e.g. hydroelectric, wind and biomass). Among all renewable sources, biomass energy has by far the most promising potential for future development.

In order to promote the development and utilization of biomass energy, one has to undertake an in-depth analysis of the energy demand/market as it relates to biomass transformation and biomass production.

Biomass transformation

Societies and economies do not need biomass but do need heat, electricity and fuel for cars. Biomass can be transformed into heat, electricity and biofuels. Effective channels must be developed for the penetration of biomass into these potential markets.

For the conversion of biomass into heat, the following methods can be identified:

- Single wood-fired heating systems: traditional boilers, modern turbo boilers, earthenware stoves and automatic boilers.

- Integrated heating systems: effective boilers with a heat network.

Electricity production from fossil fuels is one of the main sources of CO_2 emissions. Four schemes can be used to convert biomass to electricity:

Pig and cow manure
↓
Biogas
↓
Gas engine
↓
Generator
↓
Electricity

Oleaginous plants (rapeseed for example)
↓
Oil
↓
Diesel engine
↓
Generator
↓
Electricity

Solid fuel (wood, wood products, straw etc.)
↓
Steam generator
↓
Steam turbine
↓
Generator
↓
Electricity

Solid fuels
↓
Gasification
↓
Gas turbine
↓
Generator
↓
Electricity

In Austria, the processes described in the first three schemes are already installed and operating, and the fourth scheme, gasification, is at an experimental stage.

For biofuels, two schemes can be identified:

Starch
↓
Sugar
↓
Ethanol, ETBE

Oleaginous plants (rapeseed)
↓
Esterification
↓
Biodiesel

Biomass production

Most of the raw material comes from plants which, through photosynthesis, absorb CO_2 from the atmosphere. All plants contain chemically accumulated solar energy.

The main biomass energy resources available to us are in the form of agricultural residues (crop residues and animal waste), waste from forests and the wood industry (sawmill residues, forest residue and bark), municipal waste and annual or perennial energy crops, including oleaginous plants, cereals, maize, beet-root, sorghum, grass, miscanthus and short-rotation thickets.

So far, our discussion has mainly concentrated on technical questions, such as the analysis of market, transformation and production. In addition, however, to promote biomass successfully, favourable economic and political conditions must be created. A reorientation of policies in various areas is necessary as well as the realization of specific programmes. A brief outline of major policy and economic issues is provided below.

Information and education

The majority of the population is not aware of the necessity to change the present energy system. The link between the use of fossil fuel, the increase of CO^2 concentration in the air, the progressive warming of the planet and the associated climate change is not understood or, at least, taken as seriously as it should be. It is imperative to inform people at all levels of society of the advantages of renewable energy and the drawbacks of fossil energy. Such an information campaign has to focus on the communities, regional and local policy makers, administrators and agricultural organizations.

Ecological tax reform

For broader development and utilization of biomass energy, a surcharge must be imposed on fossil fuels (oil, gas and coal). One such surcharge scheme is proposed below:

Case	*Surcharge, ECU/toe*
Fossil fuels for heat production	260
Fossil fuels for electricity production	80
Liquid biofuels	650

Financial assistance

Substantial capital is required to extend the production of heat and electricity from biomass. In the initial phase of an extension programme, 50 per cent of the required investment should be financed by public funds.

Requirements for electricity

For profitable production of electricity from biomass, provisions must be made for its purchase, at a competitive price, by the electric utility. Currently, the possibility for this only exists in certain countries.

Choice of channels

We have talked about many channels to enhance the production and utilization of biomass energy. The choice is country-specific and must be made in consideration of the prevailing economic, energetic and social conditions. The following criteria are applicable:

- *Energy balance*. The conversion of solid biofuels to heat provides for a better energy balance than their conversion to liquid biofuels such as ethanol or biodiesel. The land needed for the production of 1 Mtoe of liquid biofuel is 636,000 ha, whereas the area needed for production of 1 Mtoe of solid biofuel is around 179,000 ha. Energy balance as well as energy output per hectare favour the production of heat and electricity from solid biofuels rather than liquid biofuels.

- *Competitiveness*. The competitiveness of biomass, in the context of a free market, depends on several parameters such as the form of the energy produced (heat, electricity, biofuels) and the nature of the raw material used (by-/co-product, forestry residues, energy crops). Heat production is more competitive than electricity production, which in turn is more competitive than biofuel production. In most cases, the use of residues or co-products is more economical than the use of energy crops.

- *Sustainability*. The supply of biomass must be sustainable. This means that in a given period of time, the market demand for a biomass energy resource should match the supply of that resource.

- *Balance between energy and agricultural policies*. Currently, agriculture in the European Union suffers from overproduction. With the entrance of the central European countries into the European Union, the problem of overproduction will become even more important. However, this oversupply of agricultural products may create a potential market for biomass energy. On the other hand, in countries where agricultural production is not even sufficient for feeding the people, the potential for biomass energy is small and is restricted to animal waste and some by-products. Even though biomass energy resources are not restricted to agricultural by-products/waste, care should be exercised to assure a balanced use of arable land, taking advantage of any potential synergism between energy and food production.

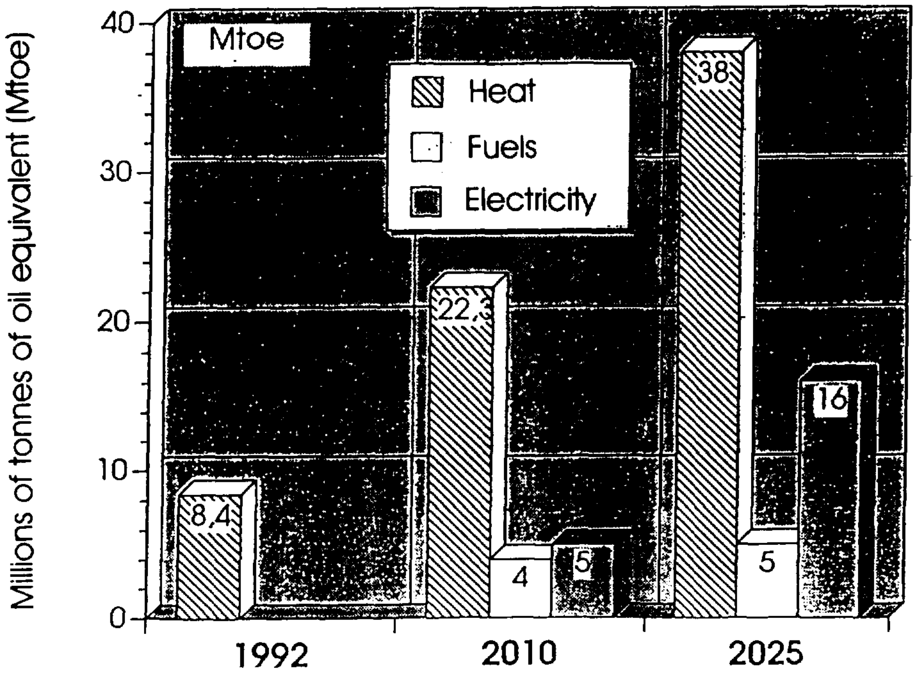
Considering these criteria, AEBIOM has elaborated a strategy for the further development and utilization of biomass. In accordance with our conviction, the contribution of biomass energy to the European energy mix should be raised substantially; at the same time, energy issues should play an important role in European agricultural and forestry policies. Further, the European strategy should focus on increasing the contribution of biomass energy to 20 per cent of the total energy consumption, with 38 per cent of it going to the heat market, 16 per cent to the electricity market and 5 per cent to the fuel market (figure III). The advantages of this strategy would be:

- Annual reduction of 550 million tonnes (17 per cent) of CO_2 emissions.
- Creation of approximately 2 million new jobs, particularly in rural areas.
- Annual investment of about 30 billion ECU, with the implication of additional new jobs in the industrial supply sector.
- The proposed increase in biomass energy contribution would require 29 million ha of land, which could result in less idle land and new income possibilities in agricultural and forestry sectors.
- More economic activities in rural areas, better air quality and less dependence on energy.

To achieve these benefits, however, much work remains to be done in the future.

I wish you all success in your work with biomass energy, an energy system of the future. Thank you.

Figure III. Share of biomass in different energy markets



Part one

Biomass energy: regional overviews

I. OVERVIEW ON THE DEVELOPMENT AND UTILIZATION OF BIOMASS ENERGY IN AFRICA AND ASIA

Stephen D. Joseph
Biomass Energy Services and Technology Pty. Ltd.
Saratoga, New South Wales, Australia

Abstract

In developing countries, biomass is the main source of energy for rural communities and industries and is often a source even for urban households. A pressing concern is the rapid rate of deforestation, brought about by two factors: land clearing for agricultural production and for dwellings and the growing demand for biomass as an energy source. The production of agricultural and forest residues has also been increasing. Much of this residue is disposed of by burning it on the fields or is used in highly polluting stoves and furnaces for cooking or other food processing or industrial activities. Air pollution from inefficient combustion of biomass residues is severe in a number of places, leading to increases in eye and lung diseases and in greenhouse gas emissions.

In this overview paper, the following information will be provided:

- Summary of the available data on biomass resources from Africa and Asia and indication of its reliability.
- Description of the current technologies used to convert biomass to energy.
- Discussion of the current research and development (R and D) on the efficiency of these technologies.
- Examination of the barriers impeding the adoption of new, more efficient technologies.
- Identification and evaluation of the policies and strategies being used to improve the efficiency of biomass as an energy source and to increase resource availability.

Biomass will continue to be the main fuel for most households and many rural industries in Asia and Africa for the next 10 years. In many countries, the biomass, especially wood, is being used on an unsustainable basis. A wide range of more efficient and less expensive conversion and production technologies have now been developed and are in use in Africa and Asia. The rates of adoption of these technologies have varied considerably, however, between and within countries of the region.

For effective dissemination, governments, non-governmental organizations (NGOs), commercial organizations and end-users must cooperate. Governments must establish an effective policy environment and support R and D programmes to ensure that commercial organizations can sell these technologies to households. Energy pricing policy must enable farmers to get an attractive rate of return if they grow trees and other biomass. Environment policy and regulation must encourage the use of existing biomass residues as a non-polluting energy source.

Introduction

In developing countries, biomass is the main source of energy for rural communities and industries and is often a source for urban households. A pressing concern is the rapid rate of deforestation, brought about by two factors: land clearing for agricultural production and dwellings and growing demand for biomass as an energy source. The production of agricultural and forest residues has also been increasing. Much of this residue is disposed of by burning it on the fields or is used in highly polluting stoves and furnaces for cooking or other food processing or industrial activities. Air pollution from the inefficient combustion of biomass residues is severe in a number of places, leading to increases in eye and lung diseases [1] and in greenhouse gas emissions.

In this overview paper the following information will be provided:

- Summary of the available data on biomass resources from Africa and Asia and an indication of its reliability. Approximate figures on the utilization of these biomass resources for different industries and for domestic use will be given, along with estimates of the potential availability of biomass.
- Techniques used to increase biomass production will be briefly outlined and some current technologies used to convert biomass to energy will be described:
    - Combustion devices to provide process heat for households and industry.
    - Combustion devices to provide power and combined heat and power (CHP).
    - Gasification to provide process heat and power.
    - Biological methods of producing gas for process heating or power from wastes.
    - Production of liquid fuels from biomass using either biological or thermal processes.
- Discussion of current R and D on the efficiency of these devices or techniques, including work on improving the yield of biomass from forests and farms. Examination of how improved agricultural and forestry practices can be integrated with energy production.
- Examination of the economic, political, social and technical barriers impeding the adoption of these new practices, including case studies in Africa and Asia.
- Identification and evaluation of the policies and strategies that are being used to improve the efficiency of biomass as an energy source and to increase the amount of biomass available.

A. Biomass resources and utilization in Africa and Asia

1. Background

Biomass is basically solar energy converted into plant form. From the perspective of human use, it includes food, fodder, timber and biofuels. From an ecological perspective, it includes trees, shrubs, grasses and other plants that are, in total, crucial to global ecosystems: they recycle gases and moderate the climate, and they recycle water and essential nutrients.

Although biofuels supply a far smaller proportion of global energy than fossil fuels, they meet the direct fuel needs of most of the world's people, principally in the less developed countries and principally in the rural areas of those countries. For example, India, despite its large industrial sector, still relies on biofuels for nearly half its total energy supply and more than 80 per cent of its residential energy consumption. Poor countries such as Bangladesh, Botswana and Nepal rely on biofuel for close to 90 per cent of their total energy needs [2]. Most of this fuel is used for cooking, some for heating and perhaps as much as one fifth for industry. Fuelwood is the most important biofuel and it will remain so for the foreseeable future.

Considerable research has been undertaken to try to quantify the biomass resource base and biomass use. Hall [3] has shown that most of these data are inaccurate and that it is only possible to give an overview at the continental and regional levels. Foley [4] has suggested that consumption figures are often overestimates. Furthermore, the gap between sustainable wood fuel consumption and supply need not imply a wood fuel crisis: economic forces lead to substitution by less scarce fuels, more efficient use of scarcer resources and the production of additional supply. This view has received some support from studies in Ethiopia, where there has been a dramatic increase in kerosene usage in urban areas since 1982 [5].

Within individual countries and within individual sectors, more detailed and accurate information is sometimes available. However, it is difficult to interpret this information as the energy content of the fuel depends on its moisture and ash content, which are rarely known. This paper summarizes the regional data and examines a small number of local, in-depth studies.

2. Asia

In Asia, biomass comes from three main sources: natural forests and plantation forests, agricultural residues and animal and human waste. The chief agricultural residues are bagasse, rice husks and straw, with local concentrations of oil palm and coconut residues and, where there is large-scale forestry activity, sawdust, bark and chips. Another biomass resource that is sometimes included in the figures is municipal solid waste (MSW).

Data from the Food and Agriculture Organization of the United Nations (FAO) and the Biomass User's Network (BUN) indicated that the total biomass resource potential of Asia could be as high as 40,000-50,000 petajoules (PJ) a year (1 PJ = 10^{15} joules). However, other sources give more worrying figures: the Asian Development Bank and Aditech, a French company associated with the Centre for Technology Forecasting and Assessment, in Paris, both estimate a current fuelwood use for China 30 per cent higher than that estimated by FAO [6]. Estimates of current biomass utilization and resource potential are given in table I.1.

Table I.1. Estimates of current biomass utilization and resource potential: Asia
(Petajoules per year)

Biomass use	China	India	Indonesia
Plantation fuelwood	950		
Other fuelwood	950		
Fuelwood and charcoal		2,600	1,400
Bagasse	1,200	300	107
Biogas (animal, human wastes)	50	14	NS
Other agricultural and forest residues	6,150	NS[a]	NS
Total biomass used	**9,300**	**3,000**	**2,700**[b]
Biomass used/energy currently consumed	0.27		
Biomass resource potential	9,200	10,100	2,300

[a] NS = not specified.
[b] Approximate figures.

Energy consumption throughout Asia is growing considerably faster than the population. Deforestation is also accelerating in most Asian countries. Both India and China have extensive reforestation and energy forestry programmes to try to reduce this deficit and to ensure a sustainable supply in the future, but it is difficult to determine whether these programmes are slowing the rate of deforestation. Indications from remote sensing and from agricultural statistics are that the sustainable potential of the wood resource is decreasing, the utilization is increasing and efforts to increase the resource base are inadequate.

In most Asian countries the greatest consumption of biomass is for domestic cooking. In Nepal 90 per cent of all domestic energy is derived from biomass, whereas in Malaysia the comparable figure is probably less than 20 per cent. The amount being used is related to both the wealth of households and the availability of cheap alternatives such as gas, kerosene and electricity. In deforested areas or in areas where people need to sell the available wood for cash, much of the energy for households is supplied by residues (dung, straw, leaves and twigs). Many industries throughout Asia (except for China) use biomass as their main fuel source for heating. Biomass is also used to generate electricity in the sugar and palm oil industries.

In some countries, virtually all of the available biomass residues are used as an energy source, as a soil conditioner or fertilizer, as a material for handicrafts or as a constituent of animal food and other industrial products. In other countries, considerable quantities of residues are burned on the fields, disposed of in landfills or dumped into waterways. Within any one country, there are areas where there is a surplus of residues and areas where there is a deficit. In China and India most of the available wood and agricultural residues are fully used, although in some areas there is a surplus of rice husks.

Recently the author studied residue availability and the potential for energy production in industry in south-east Asia (table I.2). He found that most industries (except the sugar and palm oil industries) either burn or dump their biomass residues. Only a small proportion of the residues are used by other industries or by poor people for food, cooking, building materials, livestock feed or bedding. Most of the industries (again, except sugar and palm oil) use grid electricity and gas- or oil-fired process heat [7].

Table I.2. Summary of Association of South-East Asian Nations (ASEAN) market information

Industry	Number of mills	Waste type	Amount of wastes (tonnes/yr.)	Power required in mill (kW)	Heat required (kW)
Rattan furniture	300	Sawdust and off-cuts	3,200,000	150-300	500-1,000
Sugar refining	>200	Bagasse	2,000,000 (excess)	1,000-10,000	5,000-50,000
Coconut processing	123	Shell/fibre	>3,000,000	NS[a]	NS
Palm oil mills	<500	Shell/fibre/ bunches	>15,000,000	400-1,000	2,000-5,000
Sawmills	>15,000 <5,000	Sawdust/ chips/ slabs	40,000,000+ 20,000,000-30,000,000	50-200 300-1,500	3-1,000 1,000-4,000
Rice mills	80,000 2,000	Husks	40,000,000 12,000,000	50-300 300-2,000	3-1,000 1,000-5,000

[a] NS = not specified.

In south-east Asia, biomass may be more abundant than in China and the Indian subcontinent. The FAO Regional Wood Energy Programme Expert Meeting (1992) [8] concluded that if they had comprehensive wood energy national policies, biomass countries in the region could harvest resources sustainably to meet the future demands of households and industries.

3. Africa

Detailed studies on availability in certain areas have been carried out over the past 10 years. Much of this has been compiled by the World Bank [9]. Other than in equatorial Africa, the demand for fuelwood far exceeds the supply. However, in many African countries data on resource potential and on utilization are scarce. Table I.3 summarizes data from countries where reasonably comprehensive biomass energy surveys have been carried out.

Table I.3. Estimates of current biomass utilization and resource potential: Africa
(Petajoules per year)

Biomass use and potential	**Kenya**	**Botswana**	**Sudan**	**Ethiopia**
Plantation fuelwood	55			
Fuelwood and charcoal	300	10	250	500
Bagasse	NS[a]	..	Very small	small
Dung	NS	<1	NS[a]	50
Other agricultural and forest residues	15	<1	NS	45
Total biomass/used	**>380**	**<12**		**>600**
Biomass used/energy currently consumed	0.7	0.5	0.84	>0.8
Biomass resource potential	350-400	>12	500-550	NS

[a] NS = not specified.

Between 70 and 90 per cent of the people in most African countries use wood, cow dung or agricultural residues for cooking and, in cooler areas, for heating. People use, on average, 1-2 kg of wood or dung/person/day for cooking. In urban areas, charcoal is more likely to be used: approximately 0.3-0.5 kg/person/day of charcoal is used for cooking. One of the main causes of deforestation in a number of countries has been the considerable increase in the production of charcoal for use in urban areas.

In many countries, agricultural residues, especially from processing plants, have not been utilized, and they are often burned or dumped.

A study carried out in Ethiopia in 1984 by Newcombe [10] indicated that potential residue availability was 0.07 PJ and that it could be as high as 0.3 PJ. Based on that indication, the World Bank designed a large briquetting project. Then, when detailed studies of availability were carried out, it turned out that much of the available residue was being used as a fuel for other purposes: there had apparently been a rapid increase in the use of residues, especially dung, as a result of increasing population, political upheaval and war and the increasing price of alternative fuels. This example suggests that it may be dangerous to extrapolate from older data, as fuel substitution can occur quite rapidly.

Biomass use in larger scale industry (except for sugar production) is much lower than in Asia owing to the lower level of industrial activity. Most small-scale industries that process food use wood and sometimes charcoal or agricultural residues. Detailed studies carried out by FAO in 1986 [11] and, in Sudan, by Ahmed and others in 1986 [12] provide some indication of the extent of biomass use by industry in Africa. In Khartoum alone, 174,000 tonnes/yr of wood were consumed in the brick-making, bakery and other food-processing industries. By far the largest consumer was brick-making (55 per cent). Wood makes up only 10 per cent of the production costs of the bricks and the food, and at the time of the study there appeared to be little incentive to save. FAO noted that, in parts of Africa, the following food-processing industries were the largest industrial user of wood: smoked fish (100,000 tonnes/yr), tea (300,000 tonnes/yr), tobacco (1,000,000 tonnes/yr) and coffee (1,000,000 tonnes/yr).

Although some equatorial African countries currently have a surplus of biomass, most countries are in a deficit situation, in some cases a severe one.

B. Description of the current technologies that use biomass as a fuel input

1. Combustion devices for heating for households and industry

Most biomass is converted to energy by direct combustion in stoves, furnaces, ovens and kilns. At the household level, most people use a simple mud stove (Asia) or an open fire (Africa). Charcoal, rice husks and sawdust are usually burned in simple ceramic stoves. The thermal efficiencies of these devices are very low, from 5 to 20 per cent. Emissions of particulates, toxic organic compounds and carbon monoxide (CO) are much higher than those recommended by the World Health Organization (WHO) [1].

In industry, combustion devices range from large mud stoves to furnaces with a sophisticated grate system. In the sugar and palm oil industries, steam is generated by burning the fuel on a simple step grate. A series of bars or strips are placed at an angle to the bottom of the furnace with the fuel rolling down as it is burned. In most sawmills, a horizontal grate is used, with wood being placed on this grate and burned in batches. Both types of furnace are relatively inefficient and can generate high levels of pollutants. Wood, sawdust and rice husk are used extensively in the mineral processing and ceramics industries. Most of the kilns do not have a grate: wood is burned on the floor of the kiln or rice husks and/or sawdust are intermixed with the materials being processed and burned *in situ*.

Over the past 10 years, high efficiency, low pollution furnaces have been introduced into Asia and Africa. Most of these were designed in Europe, North America, Australia or New Zealand. The combustion in these furnaces is staged. The fuel is decomposed at the bottom of the furnace and then secondary air is added to burn the volatiles. A typical example of this is an underfed stoker. Another method that has proved popular involves turning the biomass into gas in one chamber and burning the volatiles in a second chamber by introducing highly turbulent secondary air.

2. Power and combined heat and power systems

Wood and agricultural residues are also being burned to produce electricity and to produce CHP. There has been a long history in the sawmilling, rice milling and sugar and palm processing industries of using steam engines and steam turbines. In Thailand, for example, a small number of steam engines are manufactured each year. These engines, designed about 80 years ago, are large and their efficiency is only 3-5 per cent. The cost for a 50 kW unit is about US$ 60,000. Later on, many mills that traditionally used steam engines converted to grid electricity or to diesel engines. Recently, however, there has been a renewed demand for modern, high-speed steam engines that could replace diesel engines, particularly in the Philippines. This demand will be discussed in the next section.

Well over a hundred small steam turbines are sold to the agricultural and wood processing industries throughout Asia and Africa each year. Most of the turbines are manufactured in Europe, India or China. The output of these turbines ranges from 150 kW to 1 MW. Most of the units use high-pressure boilers, which are locally manufactured for Asian markets. In many cases, the fuel is produced on site. The waste steam from the turbines is often used in processing timber or crops. Much larger steam turbines are sold to the sugar industry, and there has been a push to improve the efficiency of the furnaces and boilers to allow excess power to be fed into the grid.

3. Gasification and pyrolysis

Pyrolysis involves the thermal degradation of biomass in the absence of air to produce charcoal and a volatile gas consisting of tar and combustibles such as CO, methane and hydrogen (H_2). Most of the charcoal production in Asia and Africa is carried out in simple earth or brick kilns. The volatiles are released to the atmosphere without being converted to energy and/or condensing the tars for use as a chemical feedstock. In some countries, such as China, there are vertical retorts in which the tars are condensed and the volatile gases are used to heat the kilns. Agricultural residues can be turned into charcoal via a process of briquetting and then carbonizing, or, alternatively, the residue can be carbonized and then briquetted using a binder.

An alternative route to producing both heat and power is through gasification. This technology involves breaking the wood down to a gas that consists of CO_2, CO, H_2 and methane. It was originally developed 100 years ago and was widely used in the early twentieth century and during the two world wars to power automobiles, to provide gas for cooking, to provide electricity and to fuel CHP systems in Africa and Asia. Over the past 20 years there has been a renewed interest in using agricultural residues, wood and wood chips for fuelling gasifiers. The initial development work took as its starting point designs developed during the Second World War. The main type of gasifier that was promoted was a down-draught unit. In these units, a limited supply of air flows from the top of the bed of fuel and the gas and ash come out at the bottom of the unit. In the process, tar is formed, and the gases must then be cleaned and cooled before they can be passed into a diesel or a petrol engine.

For process heating, up-draught or cross-draught gasifiers have been most commonly used. In this application, the gas is not usually cleaned except that large particles are removed in a cyclone. The gas is then taken to a specially designed gas burner, where oxygen is added and the gas is burned.

Many demonstration programmes were carried out in Africa and Asia, and over 20 firms started to market gasifiers. Very few of these companies are still in existence and the penetration of gasifiers into the market-place has been small in relation to the amount of money that has been spent. There are some success stories, however. A Chinese manufacturer has been able to sell about 100 small rice husk gasifiers with outputs of 60-100 kW. A company in South Africa claims to have sold over 100 units with outputs ranging from 10 to 100 kW.

4. Biological methods of producing gas for process heating or power from wastes

(a) Biogas

The technology for converting liquid biomass to produce methane and CO_2 was developed in the first half of this century. The initial production occurred at sewage treatment plants. In the absence of oxygen, bacteria will decompose biomass into methane and carbon and leave a residual sludge.

Biogas has been used as a fuel for cooking, for driving engines and for providing process heat. The feedstock for biogas plants can be animal dung, human waste, effluent from abattoirs and starch processing plants or finely chopped biomass. Two size ranges of reactors have been built: those suitable for use by families or small farmers and those that are suitable either for an industry or a community. The most popular digester in China has a fixed dome made from brick, and the digester used in India and Africa has a moving steel dome. In some countries, polymer bags have been used; in others, long cement tanks with plastic tops have been built.

(b) Landfill gas

When MSW is buried in the ground, it is starved of oxygen; bacteria decompose the biomass in the waste to form methane and CO_2. For many years now, this gas has been tapped and used to fire brick kilns or provide heat for other industrial processes. More recently, it has been used to generate electricity for industry. A particular landfill site is surveyed to assess how much methane is being produced, its quality (the percentage of methane and the amount of contaminants such as hydrogen sulphide) and the possible lifetime of the source. An economic analysis is then carried out to assess whether or not to proceed with tapping the gas. The landfill plant consists of a series of pipes sunk into the ground and a pumping station to bring the gas to a gas cleaning plant. Once the gas has been cleaned, it is fed to a spark ignition engine and the power is then fed to the grid. A small number of plants have now been installed in China and in Thailand.

5. Production of liquid fuels from biomass using either biological or thermal processes

The production of liquid fuels from sugars and starch is a well-proven technology, and there are plants in both Africa and Asia. The most common raw materials are sugar cane and molasses, although grains, tuber crops and liquid waste streams have also been used to produce alcohol. Zimbabwe and South Africa have developed their own technology and now have a mature industry.

For alcohol (ethanol) production from molasses, the following process steps are necessary. The molasses is fermented and then the resulting mash is distilled to produce an alcohol and an effluent (vinasse). CO is also produced and can be used for other chemical and food processing. The 10 per cent ethanol solution is then dehydrated before being blended with petrol or with diesel.

When grain is the biomass input, it must be milled and converted to sugar before fermentation. There are two types of processes used, dry milling and wet milling. In the dry milling process, all of the grain is milled and then turned into sugars using enzymes. The residues from the distillation are sold as distillers dry grains. In the wet milling process, gluten meal and oil are taken from the grain before it is turned into fermentable sugars.

C. Improved biomass energy conversion technologies: directions in research and development and implications for the dissemination of the technology

The overriding priorities in Africa and Asia are to improve the fuel efficiency of existing devices and their level of particulate and toxic gas emissions, to develop more cost-effective technologies and to increase the reliability of the proven technologies and reduce their production cost.

1. Combustion

(a) Domestic and institutional stoves

The earliest R and D effort was carried out in India in the 1950s and produced some improvement in stove designs. However it was not until the 1980s that the R and D efforts in Asia and Africa resulted in the development of stoves that use significantly less fuelwood than traditional cooking methods. These stoves have carefully designed fireboxes made from ceramic or metal. They are able to heat two pots at once, with the first pot receiving most of the heat and the second pot extracting heat from the flue gases.

A number of institutional stoves have now been developed that consume less fuel and produce less smoke. To gain these improvements, pots have been sunk into the stove, thereby increasing heat transfer. Complete combustion is achieved by burning the wood on a grate, air being introduced above and below the grate.

(b) Industrial furnaces, kilns and ovens

There have been some real successes with the development and initial commercialization of improved industrial furnaces, ovens and kilns. In Africa, the Bellerive Foundation, with technical input from Eindhoven University [13], has developed an improved wood and residue-fired oven for baking bread. The unit uses an improved firebox with a larger heat transfer area around it, which reduces the amount of wood used to bake bread by over 50 per cent and also reduces smoke emissions. In Asia, universities and private companies have developed fuel-efficient ovens that are now being manufactured and sold by the private sector. In some cases, such as the German Agency for Technical Cooperation (GTZ) refugee programme in Pakistan, researchers optimized the dimensions of the traditional oven to reduce fuel consumption. In India, new ovens have been designed based on modern wood stove practice (they have a grate, primary and secondary air inlets and effective insulation).

Similar work has been carried out to improve the efficiency of tobacco-curing barns and brick kilns. To reduce energy consumption, changes have been made both to the furnaces and to the driers, to reduce heat losses and better distribute the air. Programmes in Kenya, Malawi and Thailand have developed improved kilns that reduce wood consumption by 30-50 per cent. Many of these demonstration programmes have been funded by organizations of the United Nations system, including the World Bank, and by countries of the European Union. Although the literature suggests that many of these programmes have been successful, there are few cases where the technology was disseminated after the donor organization and its advisers departed.

2. Power and combined heat and power generation

A number of programmes are now being undertaken to introduce state-of-the-art power and CHP systems in developing countries. In the Asian and African sugar industries, improved wet bagasse-burning furnaces have been successfully introduced, reducing the need for firewood. Pulverized fuel burners are being used to increase the efficiency of bagasse burning so that sugar mills can now export excess electricity to the grid. A number of these improved burners and boilers have been built in Indonesia and in Thailand. Other programmes have focused on improving the performance of existing furnaces with grates and replacing aged steam turbines with more efficient modern turbines. These improvements have improved the viability of the sugar industry and led to grid electricity that is more environment-friendly.

A new initiative has been undertaken in ASEAN countries to introduce high-efficiency fluid-bed combustors with modern, high-speed steam engines or turbines. This technology is to be used in both small and medium-sized processing mills where residues are available. The steam engines use the latest in materials technology to ensure that they can run without lubrication at high speeds, and their efficiencies are double those of conventional engines and turbines. This considerably reduces the capital and running costs as the boilers are much smaller and therefore cheaper.

Considerable effort is going into the development of Stirling engines, which are externally heated and use air as the working fluid to move a power piston. Approximately a hundred 5 kW engines based on a design developed in the United States have been built and are undergoing field trials in India. The head of this engine is heated in a biomass combustor. In theory, these engines have efficiencies of over 30 per cent, and since they do not require a boiler, they should be more cost-competitive than fossil-fuel-powered engines. Although no official report has been made, information obtained from the field indicates that many technical problems must be overcome before the engine is commercially viable.

3. Gasification

The quest for low-cost reliable gasification technology is being pursued. Work funded by GTZ has resulted in the development of a low-cost producer gas unit (ferrocement, 10 kW (shaft), open-core, down-draught) that runs on charcoal. Initial field trials in Thailand, carried out under controlled conditions, indicated that the unit, when fuelled with charcoal, could be cost-competitive with fossil-fuelled generation and pumping units. A number of units were constructed, and longer-term tests were carried out in the field. The unit did not perform as expected, apparently due to cracking in the reactor. In the past five years, universities and private companies in India and Thailand have developed more reliable and lower cost gasifier units. These designs range in output from 5 kW to 100 kW. The units still use either down- or up-draught technology.

4. Biological gas (biogas) production

The technologies developed to convert animal and human wastes at the household and village levels have reached maturity. Various projects are under way to improve the quality of materials used in the manufacture of the digesters and to reduce the costs. The emphasis of R and D has been on the development of larger, more efficient units and more efficient bacteria. However, the author could not find any examples of these different strains of bacteria being used at the village level. Considerable effort is being made to develop low-cost digesters for the production of methane from grasses, weeds, factory waste and MSW. A small number of pilot plants have been built in Asia, and further research is under way.

5. Liquid fuels

The technology to convert sugars and starches to ethanol is mature. A number of different processes have been developed to reduce the energy requirements and the amount of effluent needed. The technology to convert other lignocellulosic materials such as cotton stalks, straw and sawdust is still being developed at universities in Asia. The plants involve the breaking down of the cellulose structure using enzymes or acid hydrolysis, followed by fermentation.

6. Production and processing of biomass

Over the past 20 years a great deal of research has been undertaken to utilize degraded land and agricultural land to produce biomass for energy. One of the main strategies used is to plant fast-growing eucalyptus tree varieties and to coppice the trees on a sustainable basis. This strategy has worked in countries such as Ethiopia but is not without critics, as eucalyptuses can degrade the soil very quickly. To overcome these criticisms, some researchers have successfully established mixed plantations of species such as leucaena (a nitrogen-fixing tree) and eucalyptus. The leucaena is used as a source of fuel and fodder and the eucalyptus as a source of construction timber and fuel. This strategy has been successfully applied in India and in Thailand.

D. Economic, political, social and technical barriers to the adoption of new technologies and practices

Rates of adoption for innovations in biomass energy technology and biomass production techniques have differed from country to country and technology to technology. For example, although fuel-efficient cookstoves have been adopted in most countries, very few gasifiers are operating in a commercial environment, despite considerable inputs of government and private capital. China has been very successful in disseminating improved biogas, stove and kiln technologies, whereas in Thailand the dissemination of such technologies has been relatively slow. Barriers to dissemination for each technology will be examined.

1. Combustion devices

During the 1980s the main barriers to the adoption of improved stoves were technical and social. Most of the designs that were being produced were developed by scientists and engineers working in the laboratory or by volunteer workers based in villages. Most of the stoves did not meet user criteria for speed of cooking, fuel flexibility, portability, cost, ease of use and fuel savings, and most were owner-built or built by artisans in the household. However, once designers started to develop stoves with input from users and private sector manufacturers, whether they were artisans working in the informal sector or manufacturers working in the formal sector, stoves started to be purchased by large numbers of people.

The rate of adoption then became dependent on the type and amount of government support. The programme in China, as reported by Smith and others [14], was initially very successful, because it was targeted at families that could afford to pay for most of the cost of the stove (subsidies were kept to a minimum); small commercial companies manufactured the stoves; the bureaucracy that ran the programme was lean; the government programme was independently monitored; and policies had been established to encourage use of the stove. These policies allowed households that adopted the new stove to cut timber at a preferential price, set rewards for townships, village leaders and artisans who promoted or made the most improved stoves and removed the licences of those artisans who kept on manufacturing the old stoves; they also withheld permission to build a new house unless a new stove was also to be built and allocated steel and brick supplies to enterprises making the new stove. The programme has slowed as it tries to disseminate the technologies to poorer households in more remote areas.

The programme in India has been less successful. In the 1980s it emphasized the introduction of mud stoves built by extension workers at the household site. Most of the extension workers were employed by the government and were relatively unskilled. Very poor families received the greatest subsidy and were often the focus of the stove programme. Independent monitoring was carried out but was of variable quality. Each local authority and state was given yearly targets to meet, but the money to carry out the programme often did not arrive until half way through the financial year. Extension workers, who had a number of other tasks to carry out, could not meet the targets unless they rushed their work, so the quality of construction and training of the users was poor, and there was no time to see if the women had problems using the stoves.

In Africa, after the failure of a number of programmes to introduce owner-built mud stoves, the focus was switched to artisan-built improved charcoal stoves. Rates of adoption were slow at first owing to the high cost of the stove and the lack of government support. The high cost was due to the lack of competition (only a few artisans were producing the stove) and the inefficient method of manufacture (most stoves were being manufactured by artisans in the informal sector). At various points, governments tried to shut down these production units, as they had often been established on public land. As soon as more artisans were trained to build the stoves and governments supported the programme, rates of adoption increased. However, no resources were allocated to monitoring, so the quality of the stove declined and, although initially fuel consumption decreased substantially, it has begun to rise again.

The barriers faced by industries wanting to purchase new furnaces are considerable. The greatest barrier is lack of cash. In particular, small industries have very small capital works budgets. Money to purchase new technology comes from savings on fuel or from special grants from the government or aid agencies. Often operators are used to a particular type of combustor and they may be reluctant to use the new device properly. Often the factories are not suitable for a new combustor, or, in some cases, the management of the institution wants to build a new factory or extend an existing one before introducing a new combustor. In small industries competition is high and margins often very small, so they may be unwilling to adopt unproved innovations, that is to say, they are risk-averse.

Potential private sector manufacturers of combustors also face considerable difficulties in making a profit from producing and selling the new stoves. These include a lack of capital for tooling, training and R and D, as well as unfamiliarity with the product and the market. In some countries, private sector manufacturers successfully started stove manufacture only to find that NGOs, whose overheads are paid by aid funds, had decided to compete: because the NGOs were subsidized, they were able to undercut the private sector manufacturers.

2. *Combined heat and power*

Many industries have used their residue as a fuel for heat and power production. Most of the technologies were developed between 1920 and 1950 and they are relatively polluting and inefficient. There were a number of constraints on the adoption of new technology during the 1980s:

- Lack of awareness on the part of end-users as to the benefits of the technology.
- Low cost of electricity.
- Low price of fossil fuels.
- Lack of stringent environmental legislation on the dumping of waste and the emission of particulates and CO from small biomass-fired boilers and furnaces.
- Lack of cheap, highly efficient steam engine technology.

3. *Gasification and pyrolysis*

The diffusion of producer-gas-fuelled electricity generation units has been extremely slow, even though considerable effort has been expended on R and D and on demonstration programmes. Evaluation of programmes carried out by the World Bank and FAO [15] and commercial information gathered by the author indicate that the following factors account for the poor acceptability of power gasification systems in Asia and Africa:

- High capital cost.
- Low petrol, diesel, kerosene and electricity prices.
- High cost of charcoal and the increasing scarcity and cost of wood.
- Problems of maintaining the units.
- Large quantities of water required for cleaning and scrubbing, and the need to clean up this water.
- High level of skills needed to run the units effectively.
- Need for engines to be specially designed to withstand the harsh operating conditions.

The most acceptable and reliable power gasifiers in developing countries use simple, low-cost open-core down-draught gasifiers and low-speed diesel or petrol engines. The overall efficiency of these units is very low (about 5 per cent). These simple units are socially acceptable, technically reliable and have positive returns on investment when used in very remote areas. However, where cheap electricity or subsidized fossil fuels are available they are not commercially viable.

The main barrier to the use of improved charcoal kilns is the dispersed and informal nature of the production. Much charcoal production is carried out by villages to supplement income from agricultural activity.

4. Biological gas (biogas) production

Although there have been successful small pilot projects in Africa, biogas technology has been widely disseminated only in China and India. These projects were evaluated by Daxiong and others in China [16] and Bhatia in India [17].

Biogas technology began to be introduced in China in the 1950s and was heavily promoted in the 1970s. Probably fewer than half of the digesters disseminated at that time were used for more than a year, owing to poor construction and maintenance. In the 1980s, further R and D was carried out to improve the construction materials, a set of standards was prepared and a heavily subsidized campaign was launched. Quality was emphasized and considerable technical and financial assistance was given to both the manufacturers and the users. Special service companies were organized to ensure that the farmers and the owners did not have to spend too much time cleaning and repairing the unit. By 1986, over 5 million households and 10,000 factories and larger farms had purchased biogas digesters. There were 8 MW of installed electricity-generating capacity at factories and farms.

In 1983, subsidies were reduced from two thirds to one third of the capital cost and the central Government reduced its subsidy to local governments for promotion, R and D and follow-up and extension activities. There was a threefold decrease in the number of units installed. With further economic liberalization, more peasants decided to leave full-time agricultural work and to pursue business activities. Households also started switching to coal. To counter this trend, the Government started to establish centralized biogas plants to which human and animal wastes were pumped. The gas from these plants was piped to households. The Government also started to sell biogas plants as part of an integrated package of income-generating activities for households. Although there are no published recent evaluations, government officials in the Ministry of Agriculture have confirmed that there still is a market for biogas. However, this market continues to shrink as more people leave for urban areas and as rural incomes increase.

In India, over a million units have been installed with the help of a highly subsidized State-run extension programme. Evaluation of the various State programmes shows variable results. In some areas, over 70 per cent of the units were in operation after three years, whereas in other areas only 20 per cent remained in operation. The capacity utilization of a biogas unit depends on the number of animals that are owned by the household, the quality of the construction, the effectiveness of the training and the extent of follow-up after the unit has been installed. The rate of adoption is also a function of the level of subsidy and the degree to which people value the liquid manure that is produced.

5. Liquid fuels

Although liquid fuels based on either sugar or grain fermentation are being successfully produced in Zimbabwe and South Africa, the low cost of petroleum products has made these industries unattractive in most countries. Some researchers feel that the production of liquid fuels from biomass will be viable only once the technology for conversion of wood waste and for high yielding plants has been perfected.

6. Production of biomass fuels

The Expert Group Meeting on Biomass Energy Technologies (Bangalore, 1992) [18] identified the following constraints on the greater availability of biomass fuels in Asia and African countries. The participants particularly emphasized socio-political constraints:

- Unequal distribution of income and land holdings.
- Insecurity of land tenure.
- Lack of popular participation in the design and implementation of forestry programmes.
- Lack of political will to correct these problems.

Technological constraints include the following:

- The problem of producing and delivering to conversion facilities large enough quantities of biomass.
- Inefficiency in the harvesting, handling and storage of biomass.

7. Summary

Demand-side constraints that are largely economic in nature include a high initial cost for the technologies, the fact that many of the technologies do not generate income and the complexity of the procedures for obtaining loans and subsidies. Social constraints include the fact that cooking, because it is considered a task for women, has low priority, and many people are unaware of the problems or of how they could help to alleviate them. On the supply side, there is often inadequate funding and poor training, with concomitant poor manufacture, maintenance and quality control. Many potential investors and manufacturers are ill informed about the market potential. An infrastructural constraint is the lack of information and experience on the potential of the technologies, as well as inadequate R and D. It may also be very difficult for planners to rectify distortions in the pricing of fuels, which adversely affect investment in biomass technologies, and there are often political difficulties in achieving such rectification.

E. Policies and strategies for the development and utilization of biomass energy resources

Macro- and micro-policy initiatives and strategies are required to ensure that biomass resources are utilized more efficiently and that the large number of innovations in biomass energy technologies can compete effectively in the marketplace.

1. Energy and environment policy, gender issues and pricing

Planners and policy makers must firstly recognize that most of the collectors and users of biomass are women and children. In many countries, they undertake most of the planting of trees and crops. In urban areas, it is the women who often purchase fuel and stoves. In industries, many of the workers who are affected by the smoke from inefficient kilns, ovens and furnaces are women. It is essential, therefore, that women play a major role in the design of programmes that disseminate new technologies and techniques. In any case, at the local level it is often the women and children who are more receptive to innovations than men.

However, at the political level, it is often men who must be convinced of the need to undertake such projects, and there must be effective dialogue between decision makers, those who control the resources and the end-users of the technology.

In many countries, the pressure must be taken off existing resources to allow the regeneration of forests. Recent experience in Africa and Asia shows that by providing cheaper alternative fuels such as gas and kerosene and restricting the availability of charcoal and wood or increasing their price the consumption of the latter can be significantly reduced.

Increasing energy prices can also motivate people to purchase appliances that are more fuel-efficient. For this strategy to work, sufficient resources must be made available to develop and test fuel-efficient devices and then promote their use. Most households and small industries find it difficult to purchase sufficient fuel for their needs, so any increase in fuel prices must go hand in hand with a reduction in fuel usage to ensure that the strategy is cost-neutral for the end-user.

Raising the price of energy can also give farmers an incentive to plant more trees, as long as they are able to harvest them and sell in the local market. Care must be taken in changing prices if the objective is to increase biomass supply. Species must be chosen that will be able to produce a range of income streams so that risks to the farmers are minimized.

2. *Increasing the resource base*

In both Asia and Africa, populations are still growing rapidly, although the rate of growth is beginning to decline. Almost everywhere the biomass resource base is being used for human needs on an unsustainable basis. It is essential that the amount of biomass available for energy be increased. One strategy for achieving this involves the large-scale planting of trees and fast-growing biomass crops. Another strategy is to use the resource more efficiently, which implies continual product development and the participation of both producers and consumers in all stages of this. It is also crucial that local people should have an interest in growing and conserving biomass, which implies the more equitable distribution of resources within and between communities.

The FAO Expert Group Meeting in 1992 suggested that, for the Asian and African regions, specific policy initiatives needed to be judged according to the principles of sustainable development, which include the reduction of social and economic inequalities. Growth that excludes the disadvantaged creates social and economic problems in the long-term and will not be sustainable. This is particularly true of the use of non-renewable resources such as fuelwood. Sustainable development policies recognize the need to devolve control over resources and decision making as widely as possible among the people affected, since they know better than anyone their problems, priorities and potential for development.

Policies for increasing the fuelwood supply must address the following:

- Securing property (including customary and communal) rights, particularly for the most disadvantaged groups.

- Improving access to, and management of, local land resources.

- Eliminating market distortions, internalizing externalities through pricing policies and reducing uncertainties.

- Creating institutional structures to give local people control over the decisions directly affecting them.

Soussan [19] has identified the following general policy directions:

- Improve the information base on which policies are developed. Much conventional energy and forestry planning reflects a failure to understand the forces driving biomass fuel production and use. Policies have often been based on highly aggregated data and faulty assumptions. Effective monitoring is rare; the available information often does not allow even a crude assessment of likely future mixes of modern and biomass fuels or of the economic benefits and costs associated with different forms of fuel provision and consumption.

- Correct market failures and improve market functioning. At present, benefits are often disassociated from costs, prices from scarcity, rights from responsibilities and actions from consequences. "The key market and policy failures are inappropriate property rights, incorrectly priced resources, policy-induced price distortions in capital, labour and commodity markets and overvalued currencies" [20]. Price distortions act as disincentives to improved efficiency and conservation.

- Develop strategies for the fuelwood sector.

3. *Improved combustion and biogas technology for domestic, institutional and small industry applications*

A number of different procedures can be used to develop, produce, promote and install higher performance combustion devices and biogas plants in households, small industries and institutions in Africa and Asia. In some programmes, the technologies have been developed in the institutions, by government and non-governmental development agencies. The stoves have either been given away or sold at a subsidized price. Many of these stoves have been built by the owners of the institutions themselves. There are considerable problems with this strategy.

An alternative is the commercialization strategy, by which the private sector advertises, manufactures, distributes and sells the combustion and biogas technologies. A number of elements are involved:

- *Production*. Includes quality control, information about the materials, machines and tools required, equipment development, the establishment of costing systems, the selection of appropriate producers, training, repair and maintenance, and coordination with marketing networks.

- *Marketing strategy*. Entails developing techniques for promoting the technology to different market segments, establishing channels to distribute the stoves and setting up after-sales service.

- *Monitoring and evaluation*. Requires marketing research staff and skills, a methodology for feedback, time and money. Monitoring and evaluation must relate to the programme objectives and deal with the loss of quality as the number of manufacturers increases.

- *Financing*. Pertains to funding for the marketing programme, R and D and the production systems. Manufacturing companies also need sufficient cash flow and business acumen to maintain a viable business [21].

It is important to carefully define the roles of the different agencies in this strategy. In the experience of the author, government and voluntary agencies play a key role in helping to establish the market, in establishing a network to ensure communication between all actors in the commercialization process, in organizing training and in ensuring that the necessary product development work and monitoring and evaluation take place.

Governments and NGOs need to work together to set targets for reaching poor users. They need to establish programmes that do the following:

- Develop and test market new designs.
- Modify products as the need arises.
- Eliminate features that consumers do not want.
- Ensure after-sales service, replacement and repairs.
- Pay special attention to the quality of the materials used, shapes, styles, colours, attractiveness and safety of the technology, especially stoves.

Governments must establish policy and priorities, help with funding and coordinate the stove programmes of different agencies. Sufficient funds must be allocated to R and D, the exchange of information, managerial and technical training, testing in the field and dissemination. Stove builders and users need effective training and follow-up assistance.

In general, having a number of smaller decentralized programmes is more effective than having a single large, centralized programme. For stove programmes to become self sustaining, the new technologies must have economic and social benefits for both producers and users. Users and local producers must be involved in making decisions on the design and use of the technologies and the implementation of programmes: the targets must be realistic and timetables must be flexible. When local people are involved in implementation, they become committed to ensuring that the technologies are built and maintained after the external agents leave. The quality of construction, the attention to maintenance and the fuel savings are all higher. The social benefit of a stove programme is greater if metal and ceramic stoves can be manufactured by small local enterprises [22]; however, such enterprises need technical and sometimes managerial support.

Subsidies are controversial. Most programmes have subsidized the cost of R and D, pilot programme implementation, training and monitoring of the dissemination programme. One difficulty with subsidies is that many of the programmes fail once the subsidies are withdrawn. However, because low-income people must have access to improved technologies if a reduction in fuel usage and other national priorities are to be achieved and because many rural consumers are unable to pay the full cost of improved stoves, large dissemination programmes will continue to require subsidies.

4. Generation of electricity and heat for industries

It is apparent that the main policy issues driving the use of residues and waste as an energy source in Africa and Asia are environmental concerns, forestry policy, energy pricing policy and the changing pattern of energy use in the domestic sector. Where households are switching from biomass fuels to electricity and fossil fuels and where there is rapid economic development two phenomena are occurring:

- A shortage or an unreliable supply of electricity.
- Pollution from the wastes being generated by industrial and domestic activity.

To overcome these problems, governments need to make industries pay for the removal of waste and need to provide incentives for the use of these wastes as an energy source. This may involve paying a price high enough to make it attractive for industry to invest in new technology.

Where there is considerable land degradation, farmers and industry need to be encouraged to grow trees to provide construction material, fuel, food and fodder. The thinnings and the residue from the processing of the wood can then provide a reliable supply of fuel for process heat and/or power. Over the coming five years either steam or producer gas power technology in the 50-500 kW size will have to be demonstrated to convince potential end-users of the benefits of this technology.

5. Liquid fuels

As long as petroleum fuels remain relatively cheap and most economic analysis does not consider all the externalities (the environmental impact of petroleum fuels, import substitution, employment), the market for liquid fuels will remain small. In countries that are land-locked and have no indigenous supply of oil (Zimbabwe, for example) growing sugar cane to provide feedstock for ethanol plants can be justified on national security grounds.

F. Conclusions

For the next 10 years, biomass will continue to be the main fuel used for most households and many rural industries in Asia and Africa. In many countries the biomass, especially wood, is being used on an unsustainable basis. A wide range of more efficient and low-cost conversion and production technologies have been developed and are now in use in Africa and Asia. The rates of adoption of these technologies have varied considerably between and within countries of the two regions.

Effective dissemination requires the cooperation of governments, NGOs, commercial organizations and end-users. Governments must establish an effective policy environment and support R and D programmes to ensure that commercial organizations will be able to sell these technologies to households. Energy pricing policy must enable farmers to get an attractive rate of return if they grow trees and other sources of biomass. Environment policy and regulation must be designed so that existing biomass residues are used as a non-polluting energy source.

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II. THE DEVELOPMENT AND UTILIZATION OF BIOMASS ENERGY RESOURCES IN CHINA

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Abstract

Biomass energy resources are abundant in China and have reached 730 million tonnes of coal equivalent, representing about 70 per cent of the energy consumed by households. China has attached great importance to the development and utilization of its biomass energy resources and has implemented programmes for biogas unit manufacture, more efficient stoves, fuelwood development and thermal gasification to meet new demands for energy as the economy grows. The conclusion is that the increased use of low-carbon and non-carbon energy sources instead of fossil fuels is an important option for energy and environment strategy and has bright prospects in China.

Introduction

1. Status of biomass energy resources

There are abundant biomass resources in China, including crop residues, firewood and various kinds of organic wastes. Biomass is the main source of household fuel. Generally speaking, annual biomass production is about 5 billion tonnes, of which about 600 million tonnes can be used for energy purposes. It accounts for about 70 per cent of the energy consumed by households in rural areas, and in some remote areas, it may account for as much as 100 per cent. Table II.1 shows biomass energy resources in China in 1993.

Table II.1. Biomass energy resources in China (1993)
(Million tonnes)

Biomass resource	Annual production
Crop straw	450
Rice husk	15
Sugar cane	67
Forestry residue	15
Garbage	73
Municipal sewage	146
Waste water	18,250

Crop residues are of three main kinds:

- Straw.

- Sawdust from timber processing plants.

- Residue from agricultural and forestry product processing, such as rice husks from rice mills, bagasse from sugar mills and sawdust from furniture manufacturers.

- Firewood is one of the main sources of energy in rural areas, accounting for about 70 per cent of the total biomass used by households for energy. However, it is in short supply, since there is limited land on which to plant trees. In 1993, about 5.5 million hectares of firewood land supplied about 30 million tonnes of firewood.

2. Main characteristics of the use of biomass energy resources

The use of biomass for energy has three characteristics:

- *Low energy density and extensive distribution.* The total output of grain in China was 442.7 million tonnes in 1992 and the total amount of wheat, rice and corn straw collected was about 478.6 million tonnes, or 232.5 tonnes of coal equivalent (tce). Although the quantity of straw is quite large, its energy density is much lower than that of coal. The average calorific value per kilogram of biomass energy resources is 3,500-4,000 kcal, whereas that of coal is 5,000-7,000 kcal.

- *Small-scale, decentralized and low-efficiency utilization.* The total consumption of biomass energy is 230 million tce, accounting for 40 per cent of total energy consumption in rural areas. The use of energy from biomass is mainly in households, where a very low efficiency, 10-20 per cent, is achieved.

- *Direct burning, without conversion to secondary energy.* In rural areas, the excessive use of biomass has led to serious ecological damage such as deforestation, soil erosion and loss of soil fertility. Moreover, agricultural residues are mostly burned directly, which causes serious air pollution, especially during harvest.

A. Current technologies for the use of biomass energy resources

With current technologies there are four ways of using biomass energy in China:

- Direct combustion.

- Bioconversion (anaerobic digestion to produce biogas).

- Mechanical conversion (gasification or densification).

- Hydrolysis (to make alcohol).

1. Direct combustion

Direct combustion is an important way to utilize biomass in rural China nowadays. Since 1980, to improve energy efficiency, protect the environment, promote the well-being of women and improve living conditions in rural households, the Government of China has promoted the National Improved Stoves Pilot County Programme (NISPCP) throughout the country. The aim of the programme is for more than 90 per cent of all rural households in a pilot county to use stoves with a heat efficiency of over 25 per cent within three years of the contract period and to establish a system for training, marketing, selling and maintaining the stoves.

By the end of 1993, 732 counties had carried out NISPCP contracts, which means that 150 million rural households had replaced traditional stoves with improved stoves; in other words, over 70 per cent of the households in rural China were using improved stoves.

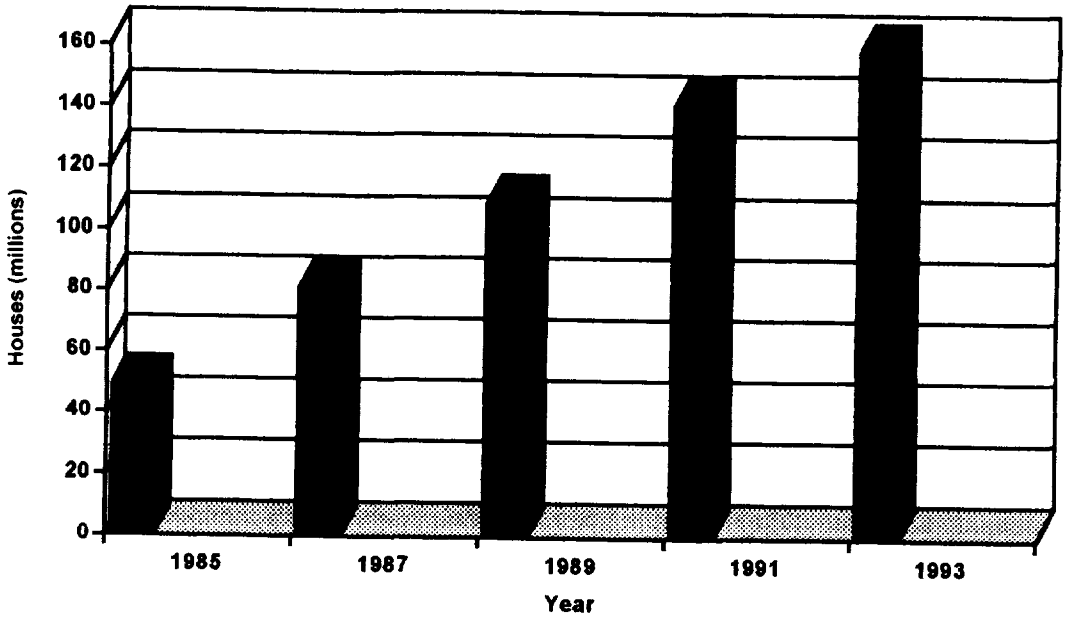
To achieve a complete burning of the fuel in the stove chamber and a conversion efficiency over 25 per cent, the stove must be designed in accordance with the fuel characteristics and combustion theory. Compared with traditional stoves, improved stoves (always installed with chimney, grate, air chute and surplus heat recovery system) had efficiencies that were 10-30 per cent higher. Table II.2 shows the basic specifications of some improved stoves.

Table II.2. Basic specifications of improved stoves

Factor	Unit	Specification
Heat efficiency	%	> 25
Rate at which temperature is raised	°C/min.	> 5
Evaporation rate	kg/min.	> 0.08
Cost	Y/stove	60-100
Firewood savings	tonnes/stove/year	1

Each stove can save 1-1.5 tonnes of firewood annually. To build a new, improved stove costs 60-100 yuan renminbi (Y), and the cost of the firewood saved every year amounts to over Y 100-200, which indicates that the investment costs for new stoves are recovered in one year. According to preliminary estimates, energy savings reach about 50 million tce and 30 million tonnes of CO_2 emissions are avoided annually in China owing to the use of improved stoves. Figure II.1 shows the proliferation of improved stoves in China.

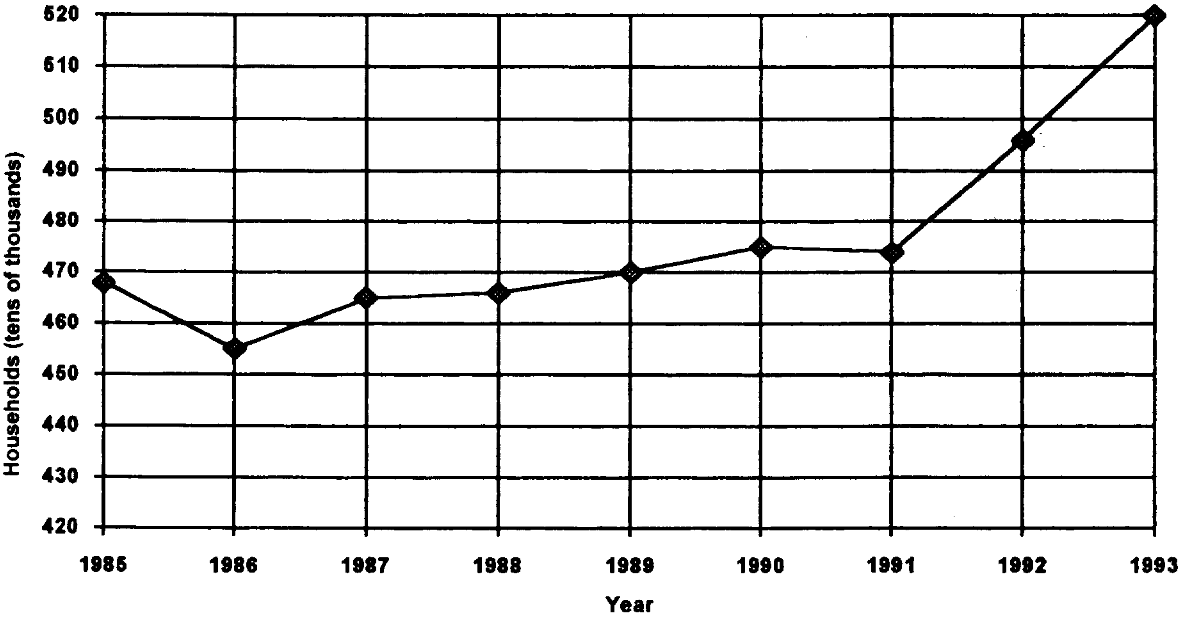
Figure II.1. The proliferation of improved stoves in China, 1985-1993



2. Anaerobic digestion (biogas technology)

Anaerobic digestion is a bioconversion technology that has been widely adopted in China. In recent years, the promotion of biogas technology, especially in rural areas, has achieved remarkable progress and has accumulated a great deal of experience in China. By the end of 1993, there were 5.2 million rural household biogas digesters in normal operation for cooking and lighting and, in some areas, for electricity generation. Generally, household biogas digesters work by anaerobic digestion at ambient temperatures and have a gas production rate of over 0.2 m^3/m^3 digester. Figure II.2 shows the progress of household biogas digesters from 1985 to 1993. Annual biogas output from households is over 1.2 billion m^3.

Figure II.2. The proliferation of household biogas digesters, 1985-1993



To improve the technology for anaerobic digestion, scientific research institutes, colleges and universities, as well as institutions promoting rural energy, have worked extensively on raising gas production, reducing the cost of maintenance and extending the biogas digester's operational life as well as on integrating use of residues from the digesters to maximize benefits. Researchers have called for the comprehensive utilization of the biogas system by integrating the use of residues from livestock production and crop production.

Large and medium-scale biogas projects total 84,000 units, of which more than 600 have a capacity of 100 m^3. The large and medium-size biogas digesters are used to treat highly concentrated organic wastes from factories and livestock farms. Most of them make use of the anaerobic contact process, an up-flow anaerobic sludge blanket, an anaerobic filter or a combination of these.

In the mid-1980s, the anaerobic contact processing of detained-type sludge was introduced along with additional equipment for mixing and sludge recovery; the digesters were above-ground and were insulated. Because the solid sludge remained mixed with anaerobic fermentation microbes for a long time, the rate of gas production rose rapidly. When a pre-processor, an up-flow sludge bed and a sludge bed plus filter are used together in biogas plants, the gas production rate increases substantially, and over

85 per cent of chemical oxygen demand (COD) is eliminated. This combination is so successful that environment protection standards can be met and the waste materials can be recycled.

In addition, post-disposal processing has recently been introduced. It produces organic fertilizer and fodder from the digested material left after anaerobic fermentation, increasing the economic viability of the biogas plant.

3. Biomass gasification

A biomass gasifier is a reactor that converts biomass such as agricultural and wood processing residues to gas in a high-temperature chemical reaction. Although biomass gasification had been studied in several institutes and universities in China, it was not commercialized until the end of the 1980s. Nowadays, about 10 manufacturers in China produce between 500 and 800 biomass gasifiers every year, with most of them having been used for drying and gas supply.

Gasification has a number of advantages:

- It can convert biomass wastes to high-grade fuel without producing pollutant wastes.
- Energy conversion efficiency is as high as 70-75 per cent. The overall heat efficiency is 1-2 times greater than that of direct combustion. Fuel savings can be 30-50 per cent.
- There is less corrosion in the gasifier because biomass materials contain less sulphur and other minerals.
- The gasifier has a simple structure and low cost.

The status of biomass gasification technology in China is shown in table II.3.

Table II.3. The status of utilization of biomass gasification technology in China

Type	Diameter of gasifier (mm)	Intensity (kg/m^{2}h)	Efficiency (MJ/hr)	Application
Up-draught	1,100	240	2.9	Heat for production
	1,000	180	1.6	Heat for boiler
Down-draught	400	200	0.3	Power (10 kW)
	600	200	0.66	Wood drying
	900	200	1.490	Steam for boiler
	600	200	0.66	Gas for household
Stratified down-draught	2,000	150	160 kW	Power generation
	1,100	150	60 kW	Power generation
	200	398	2-5 kW	Power generation
CFB[a]	400	2,000	4.2	Steam for boiler
CFB with medium thermal value	150	2,000	0.67	For use by 400 households

[a] CFB = circulating fluidized bed.

4. Biomass briquetting

Biomass briquetting is a mixture of biomass shaping and charcoal-making technologies. Biomass can be shaped by continuous extrusion or by moulding. The former technique makes use of an open container in which the raw materials are pressed from one side and come out from the other side continuously; the latter technique uses a closed container in which the raw materials are pressed between the top and bottom. Most of the briquetting machines developed in China are of the screw-extrusion type (see table II.4).

The particle diameter and the moisture content of the raw materials influence the efficiency of the briquette-making machines and the quality of the moulded products. The diameter and moisture content can be controlled by grinding and drying the raw material before briquetting, although this preprocessing increases the product cost. Up to now, there has been no production in China of moulded fuel using agricultural straw and stalk as the raw material, because of the poor transportation infrastructure, the low calorific value and high energy consumption of the straw and stock and the high cost of its preprocessing.

Table II.4. Main specifications for different models of screw press biomass briquette equipment in China

Characteristic	Unit	Model			
		OBM-88	JX-7.5	MD	SZJ-80A
Motor power	kW	11	7.5	11	5.5
Electric heater	kW	6	3	3	3
Main shaft	rpm		20		270
Weight	kg	700	350	750	330
Dimensions	m	1.7 x 0.7 x 1.6	2.2 x 0.8 x 1.55	2 x 1.5 x 1.7	1.25 x 0.56 x 1.1
Power consumption	kWh	8.3	10	10	14
Average productivity	kg/hr	120	110	120	85

B. Prospects for the development and use of biomass energy resources

China is rich in biomass energy resources. More than 570 million tonnes of biomass from agricultural fields and 150 million tonnes of firewood were produced in 1992, and this is expected to reach 610 and 200 million tonnes, respectively, by 2000. In timber processing, about 25 per cent of the wood is residual and could be used as fuel. Excess wood and straw that are usually burnt in the field can also be used instead of firewood, returned to the fields as fertilizer or used as fodder or as a raw material for industry. If all the above-mentioned biomass resources could be turned to higher grade bioenergy and put to use, a huge amount of energy would be realized, bringing economic as well as environmental benefits. It could be the basis for sustainable development in rural areas.

Waste manure and other organic materials from livestock farms and municipal areas could be another important source of biomass for energy production. It is estimated that about 22 billion tonnes annually of waste water will be discharged from households in cities and towns by the end of the century, and industrial waste water will amount to about 50 billion tonnes, of which 230 million tonnes are manure, 14 billion tonnes are industrial organic wastes and 1.93 billion tonnes are livestock manure. If the anaerobic digestion technology is adopted to treat those organic materials, biogas output would be 250 billion m^3 annually, or 180 million tce.

Based on the present economic situation and policies, different technologies have different prospects:

- *Improved stoves.* Although the current type of improved stove has reached an efficiency of 20 per cent, higher efficiency, about 40 per cent, could be reached with various kinds of materials. It has also been suggested that improved stoves should be standardized to facilitate their marketing.

- *Biogas technology.* To increase efficiency, the technology for small digesters has to be improved. In addition, medium-size and large digesters will have to be developed, particularly for urban areas.

- *Biomass gasification.* For the time being, this technology mainly provides gas for cooking and heating in rural households; in areas with a shortage of electricity, it can be used for power supply.

- *Biomass briquetting.* The key problem with briquetting technology is the short life of the screw, which generally lasts no more than 100 hours; the lifetime of the driving parts is also very short. Another constraint is competition from coal.

Biomass conversion offers a significant potential for increasing energy production and replacing conventional fuels. Such a transition could have significant environmental and socio-economic benefits since biomass is a renewable energy resource. Although it is difficult to predict the amount of energy from biomass that will be used in the next century, it is clear that biomass conversion technologies will be further commercialized. Meanwhile, suitable services, monitoring and management systems should be established to encourage energy from biomass, which in turn will contribute to sustainable development in China.

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III. BIOMASS AS AN ENERGY SOURCE: AN ASIAN-PACIFIC PERSPECTIVE

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Economic and Social Commission for Asia and the Pacific

Abstract

Biomass is the most commonly used renewable source of energy in the region covered by the Economic and Social Commission for Asia and the Pacific, making up an average of 50 per cent of energy supplies in the developing countries. However, experience over the past one and a half decades in rural energy supply in the ESCAP region suggests that biomass resources are unlikely to compete with conventional supplies in meeting expanded rural energy needs for fuel, electricity and fertilizers. Nevertheless, biomass, especially wood and agricultural residues, will remain the main energy source in most countries of the region for the next two decades.

The development of biomass energy systems in the ESCAP region is at different stages for different types of biomass resources. Efforts have been concentrated in six areas: direct combustion, gasification, co-generation, anaerobic digestion, densification and dendrothermal processes. Among the biomass technologies presently being promoted in the region, biogas and cooking stove programmes are the largest in terms of scale, operations and coverage. Co-generation is promising as its economic advantages make it attractive to industrial consumers, particularly the booming food and fibre production and processing industries, which produce enough biomass feedstock to warrant installing co-generation facilities. Despite its potential, the production of liquid fuel from energy crops is presently taking place in only a few countries.

The major constraints on extending the use of biomass include the difficulty of assessing resources, poor local acceptance of technology (mainly for social and economic reasons), lack of financial resources and manpower, environmental concerns, the absence of up-to-date local technology and the lack of after-sales services.

Appropriate technologies to develop and harness the region's vast biomass resource base to augment energy supplies, particularly in rural areas, has been a major issue in the developing countries of the ESCAP region. This paper analyses resources and issues in the development and diffusion of biomass technologies and environmental concerns. Since biomass is moving from a technology-dominated phase to a market-led phase, future directions in biomass development should be market-driven rather than technology-oriented. Efforts should be devoted to the commercialization and marketing aspects of biomass technologies. Intercountry cooperation through regional groups working in new and renewable energy sources and in rural energy planning is needed to diffuse these technologies. ESCAP's approach to the issues is briefly presented.

Introduction

Biomass is all the organic matter that can be derived from photosynthesis. It encompasses wood and agricultural residues, animal discharges (dung), municipal wastes and refuse from the food and manufacturing industries. It is geographically widely distributed. It can be converted into three fuel forms: solid, liquid and gaseous. Biomass is the world's fourth largest energy source today. Given its enormous potential as an energy source, biomass will be the most important renewable source of energy in the twenty-first century.

In the ESCAP region, biomass is the most commonly used renewable source and is the principal source of rural energy supplies. Over the past decade, countries in the region have devoted efforts to the development and wider use of biomass to augment existing energy supplies, particularly in rural areas [1-9].

The aim of this paper is to present an overview of the regional biomass programme and the leading issues and constraints, with a view to contributing to the discussion at the Symposium of regional and international policies and strategies that will reinforce national endeavours in the exploitation of biomass resources for energy purposes.

A. Share of biomass in world energy supply

Biomass provides 14-15 per cent of the energy used worldwide and 35-38 per cent of the energy used in developing countries (figure III.1) [1-3, 10-12]. The world's biomass consumption, as estimated by the International Energy Agency (IEA) and the World Energy Council, is shown in table III.1. The annual growth rate of world biomass consumption is estimated at 2.8 per cent [13]. Table III.2 shows the IEA projection of world biomass consumption up to the year 2010 [13]. In 1990, the biomass consumption in developing countries was equivalent to 900 million tonnes of oil equivalent (Mtoe). About 45 per cent of this biomass (400 Mtoe) was wood [11].

Table III.1. Estimates of world biomass consumption
(Million tonnes of oil equivalent)

Source of estimate	Consumption
IEA Statistics	610
World Energy Council (1990)	1, 051
IEA *World Energy Outlook* (1995)	838

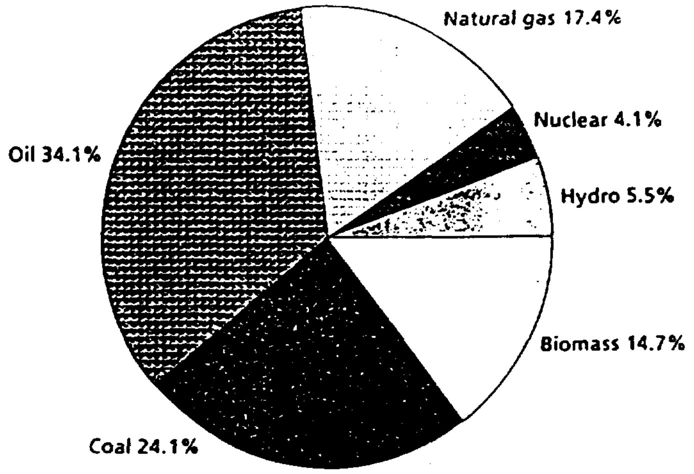
Source: *World Energy Outlook*, 1995.

Table III.2. Estimates and projections of world biomass consumption
(Million tonnes of oil equivalent)

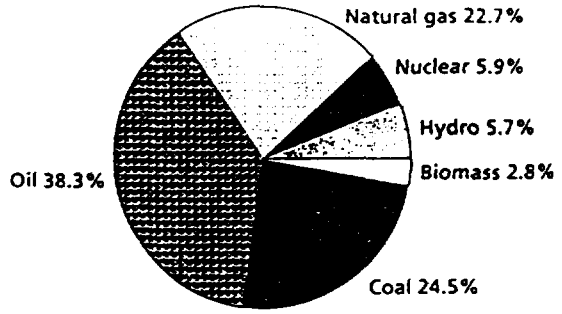
		2010	
Region	**1992**	**Capacity constraint scenario**	**Energy saving scenario**
OECD	161	224	233
Africa	150	235	209
China	182	122	122
South Asia	155	176	159
South and Central America	86	93	96
Other	104	104	104
Total	**838**	**954**	**923**

Source: *World Energy Outlook*, 1995.

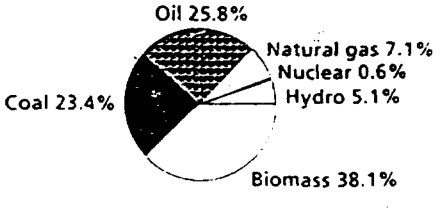
Figure III.1. Primary energy use for the world (top), industrialized countries (middle) and developing countries (bottom) in 1985



World
Total = 373 exajoules
Population = 4.87 billion
Energy use per capita = 77 gigajoules



Industrialized countries
Total = 247 exajoules; 66 percent of world total
Population = 1.22 billion; 25 percent of world total
Energy use per capita = 202 gigajoules



Developing countries
Total = 126 exajoules; 34 percent of world total
Population = 3.65 billion; 75 percent of world total
Energy use per capita = 35 gigajoules

Source: D. O. Hall and others, "Biomass for energy: supply prospects", *Renewable Energy Sources for Fuels and Electricity*, T. Johansson, ed. (1993).

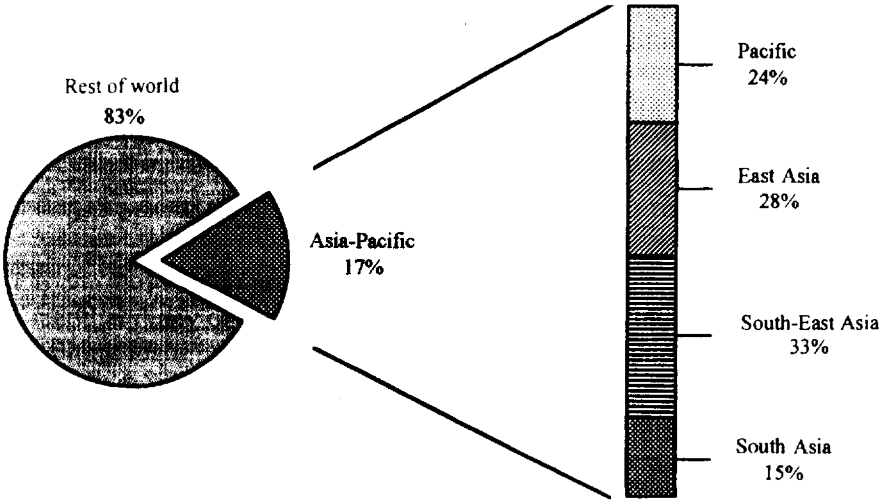
B. Resources: availability and utilization

The main biomass resources in the region are wood and agricultural residues, energy crops and animal wastes (dung).

1. Fuelwood

Fuelwood, the most popular and traditional biomass resource in the region, contributes the greatest amount to the energy supply in rural areas. It is obtained from numerous sources, ranging from forest plantations and common woodlands to on-farm tree plots. Forests and woodland in the Asia-Pacific region occupy approximately 662 million ha, about 17 per cent of the world's total. On a subregional basis, South-East Asia has the largest forest area, followed by East Asia, the Pacific and South Asia (figure III.2) [14]. Another source puts the total forested area in Asia at 440 million ha, about 42 per cent of the total land area (table III.3) [15].

Figure III. 2. Distribution of forest in the Asia-Pacific region



Source: FAO, 1994.

Table III.3. Forest area in relation to land area

Region/country	Area (million ha)		Proportion of forest (%)
	Land	Forest	
South Asia	442	84	19
Continental South-East Asia	196	68	35
Insular South-East Asia	286	194	68
Central tropical Asia	75	54	72
Papua New Guinea	46	40	87
Total/average	**1,045**	**440**	**42**

Sources: *Natural Resources of Humid Tropical Asia*, UNESCO, Paris, 1974; *Forest Resources of Tropical Asia*, FAO-UNEP (GEMS), 1981.

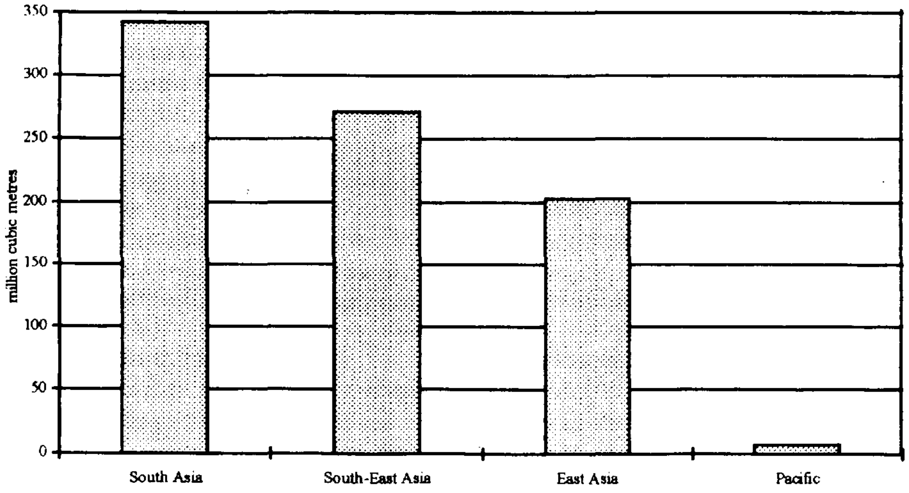
Three countries, Australia, Indonesia and China, have more than 100 million hectares each under forest cover, constituting about 52 per cent of the total forest area in the region. Most of the other countries have at least 20 per cent forest cover [16] (table III.4). Indonesia has one of the largest tropical forest areas in the world, and natural forests are one of its most important assets.

Table III.4. Forest area in the Asia and the Pacific region, 1992

	Forest and woodland	
Country/area	**Area (thousand ha)**	**Proportion of total land (%)**
Large area of forested land (100 million ha)		
China	130,495	14
Indonesia	108,600	60
Australia	106,000	14
50% forested land		
Solomon Islands	2,560	91
Papua New Guinea	38,200	84
Vanuatu	914	75
Democratic People's Republic of Korea	8,970	74
Japan	25,230	67
Cambodia	11,600	66
Republic of Korea	6,404	65
Fiji	1,185	65
Malaysia	1,352	59
Lao People's Democratic Republic	12,500	54
Bhutan	2,560	54
20-50% forested land		
Myanmar	32,387	49
Western Samoa	134	47
Nepal	5,350	39
Philippines	1,000	34
Sri Lanka	2,100	32
Viet Nam	9,650	30
New Zealand	7,380	28
Thailand	13,500	26
India	68,500	23
20% forested land		
Bangladesh	1,890	15
Tonga	8	11
Islamic Republic of Iran	18,020	11
Mongolia	13,915	9
Pakistan	4,050	5
Maldives	1	3

In terms of fuelwood and charcoal production, the Asia-Pacific region experienced an annual average growth of 2.1 per cent (compared with world average growth of 1.8 per cent) over the 1982-1992 period. The production of fuelwood and charcoal has remained high in South Asia, followed by South-East Asia and East Asia, with comparatively low production in the Pacific (figure III.3). With the exception of Japan and the Republic of Korea, the production trend of fuelwood and charcoal either increased or remained constant over the 1982-1992 period [14].

Figure III.3. Fuelwood and charcoal production in the Asia-Pacific region, 1991



Source: FAO, 1993.

The Asia-Pacific region is by far the biggest consumer of fuelwood; its share in world consumption is 48 per cent, and about 1.5 billion people depend on fuelwood or charcoal to meet their daily cooking/heating needs [6].

2. Agricultural residues

The agricultural sector plays a dominant role in the national economies of most developing countries in the Asia-Pacific region. Increasingly large quantities of agricultural residues are being produced every year as by-products or wastes on farms or agro-processing installations. Most Asian countries are rice-growing countries, and rice husk is by and large the most abundant crop residue that can be used for process heat, shaft power and/or electricity generation.

Rice husks, bagasse, palm oil, coconut and wood residues production in the ASEAN region, as reported by Tanticharoen and Wibulswas at the ESCAP-organized Asia-Pacific Renewable Energy Symposium in Australia, July and August 1995, is shown in tables III.5-8 [17]. Rice straw, maize stalks, cassava stalks, corn-cobs etc. are also extensively used in the ASEAN region [18].

The total supply of these agricultural residues is more than 13 million tonnes per year in Malaysia and 35 million tonnes per year in Thailand [19, 20]. Table III.9 shows the utilization of rice straw in ASEAN countries. Better utilization technologies are being identified or developed.

Certain types of industrial waste water are utilized for biogas production. Several breweries in Thailand now generate biogas from their liquid wastes. Liquid wastes from sugar mills and palm oil mills are also being considered for biogas generation. In Malaysia, the annual production of palm oil mill effluent is more than 10 million m^3 [17].

Table III.5. Husks production and energy equivalent in the rice sector in ASEAN countries

Country	Husk (million tonnes)	Primary energy content (Mtoe)	Potential energy (GWh)
Indonesia	11.3	3.6	4,500
Thailand	3.8	1.2	1,500
Philippines	2.5	0.8	1,000
Malaysia	0.3	0.1	120
Total ASEAN	**17.9**	**5.7**	**7,120**

Source: *Report of ASEAN-EC Programme*, AIT-Bangkok, July 1993.

Table III.6. Bagasse production and energy equivalence in the sugar sector in ASEAN countries

Country	Bagasse (million tonnes)	Primary energy content (Mtoe)	Potential energy (GWh)	Maximum power generation (MW)
Thailand	11.8	2.1	4,000	1,600
Indonesia	9.0	1.6	3,000	670
Philippines	5.9	1.1	2,000	440
Total ASEAN	**26.7**	**4.8**	**9,000**	**2,710**

Source: *Report of ASEAN-EC Programme*, AIT-Bangkok, July 1993.

Table III.7. Biomass residues from palm oil mills in ASEAN countries, 1989
(Thousand tonnes)

Country	Bunches	Fibres	Shells
Indonesia	2,352	1,840	716
Thailand	253	198	77
Malaysia	7,047	5,515	2,145
Philippines	-	-	-
Singapore	-	-	-
Brunei	-	-	-

Source: *Report of ASEAN-EC Programme*, AIT-Bangkok, July 1993.

Table III.8. Coconut and wood residues in ASEAN countries, 1989
(Thousand tonnes)

Country	Coconut husks	Coconut shells	Wood residues
Indonesia	3,530	1,890	11,760
Thailand	483	220	752
Philippines	5,926	2,540	966
Malaysia	440	236	6,580
Brunei	..	..	70
Singapore	..	..	273

Source: *Report of ASEAN-EC COGEN Programme*, Malaysia, April 1992.

Table III.9. Use of rice straw in selected ASEAN countries
(Percentage used)

Country	Feed	Paper	Fuel
Indonesia	..	Nil	..
Malaysia	..	-	..
Thailand	50	30	10

Source: Country Reports on Rice By-Product Utilization.

C. Biomass energy systems and market opportunities

The development of biomass energy systems in the ESCAP region is at different stages for different types of biomass resources. Efforts have been concentrated in seven areas: direct combustion, gasification, co-generation, biological conversion of biomass, densification, dendrothermal systems and fuel alcohol.

1. Gasification

Gasifiers ranging in size from small (less than 3 kW) through medium (300-500 kW) to large (larger than 500 kW) have been developed for electricity production in the region [8]. However, some technical problems such as type of fuel (rice husk, corn-cobs, coir dust, wood chips), tar removal and gasifier design limit the widespread application of this technology. Technological improvements have, however, been achieved during the last decade, resulting in new designs that address the above-mentioned technical problems [1, 2].

In rural areas, the ability to produce small amounts of mechanical power using locally available renewable fuels is extremely valuable, regardless of the production efficiency. Of all alternative sources for rural areas, producer gas from the gasification of biomass appears to have the greatest potential in small-scale power production.

Gasification systems operated on charcoal that produce less than 5 kW of power have been reported [1, 2, 8]. They are particularly suitable for rural applications. The use of wood, coconut shell and corn-cob for gasification is possible only in large-scale applications, where qualified personnel are available to service the system [1-8].

Direct heat gasifiers are becoming popular for industrial applications, particularly in processes that can be operated efficiently with gaseous fuel. Up to now the only practical use of pyrolysis has been carbonization or charcoal production [1, 2].

2. Co-generation

A promising application of biomass in the region is the co-generation of electricity and heat for on-site needs and electricity for export to the local electric utility. The significance of this market is clear from the amount of electricity generated from three agro-industries in Asia: sugar, palm oil and rice mills [1-8, 17-20]. These three types of mills have the potential to produce saleable electricity in excess of their normal heat and power consumption. For example, Thai agricultural industries supply about 10 per cent of the power generation capacity of the country [19, 20].

A joint European Union-ASEAN co-generation programme was established in 1991 [17]. From 1991 to 1994, the programme identified significant potential for the transfer of proven technologies for generating heat and/or power from wood and agro-industrial residues. The use of rice appeared promising in the Philippines and in Thailand. The capacities of Indonesian and Malaysian rice mills were, however, too low to envisage power generation from rice husks. The sugar sector as well was promising in the Philippines and in Thailand, but despite the potentially high profitability of investments in these power generation systems, sugar and rice mills in the Philippines might be reluctant to adopt these technologies due to the lack of investment funds. The privatization of the sugar industry in Indonesia, now envisaged, could offer scope for the European Union-ASEAN programme in the future [17].

In the wood sector, Indonesia and Malaysia were top world producers; in the Philippines and in Thailand, logging bans have decreased near-term opportunities. In Indonesia, the tariff for the purchase of power from independent power producers has been approved and will provide opportunities for installing industrial-scale biomass energy equipment and will benefit the wood and agriculture industries. The opportunities for selling excess power generated from palm oil wastes were limited in Malaysia and Thailand.

3. Biological conversion of biomass

Biogas technology can be applied at different levels: on farms, in industries and on landfill. In the Asia-Pacific region, the use of biogas technology ranges from rural applications, aimed at the hygienic disposal of animal manure and the production of energy for cooking, to the larger scale production of biogas from agro-industrial wastes with a view to reducing pollution and increasing energy recovery. Industries that could benefit from biogas technology include pineapple canning factories, tapioca starch factories, pulp and paper factories, palm oil mills and alcohol distilleries. In the ASEAN region, biogas is being increasingly produced from industrial wastes [1-9, 17-20]. Biogas from tapioca starch waste water, palm oil mill effluent, pineapple cannery waste and banana waste has been the subject of intensive study under the auspices of the Working Group on Food Waste Materials of the ASEAN-Australian Economic Cooperation Programme [17]. Under this cooperative programme, the waste water from the processing of tapioca (Thailand's production accounts for half of Asian production and 15 per cent of the world total) is being treated and used in Thailand to produce biogas and cultivate algae using the digester effluent [17].

Biomethanation is a marketable biotechnology, but success requires sustained confidence and profitability. In Thailand, about 20 industrial biogas plants have been built using imported technology [17]. Fewer than half of these plants are active, mainly for technical and economic reasons. This has given anaerobic digestion a bad image among Thai industries, and few new plants have been built [1, 2, 17].

While landfilling is generally regarded positively as a means of reclaiming spoilt land, pressures on land use make it unattractive in countries such as Japan. The future of landfill gas as a fuel is tied to a number of issues of global significance. Unless much more waste is recycled or materials reclaimed, disposal to landfill will not be a popular option in the region or elsewhere [1, 2, 17-20].

4. Densification of biomass

Densification has been used in some countries of the region. Densified fuels based on agro-industrial residues are used as a substitute for fuelwood in small-scale industries and for household cooking [3].

South and South-East Asia and China have a large potential supply of residue for briquetting. The most promising residues for briquetting are sawdust, cotton stalks, groundnut shells, rice husks and coconut pith. In some places, these residues have little or no alternative use.

A survey of briquetting activities in Thailand, India, Nepal, Sri Lanka, Malaysia and the Philippines by the University of Twente in the Netherlands indicated that private investments in briquette production had exceeded US$ 15 million over the past 10 years (mainly in India and Thailand) [21]. Success was limited, for a number of reasons:

- Mismatch of technology, raw materials and prospective market.
- Unsuitability of the briquettes for the intended market.
- Technical difficulties.
- Excessive operating costs (mainly electricity and maintenance).

Briquetting can only compete in a monetized fuel economy. Uncarbonized briquettes have to compete with fuelwood, coal or lignite, whereas carbonized briquettes compete with lump charcoal.

Today, the most likely market for uncarbonized briquettes is in energy-intensive, fuelwood-using industries, where fuel costs are substantial relative to product value (e.g. in brickmaking, potteries, lime kilns). This industrial sector is a major employer and currently faces wood shortages and high fuel bills.

The Twente University study [21] also identified another market for carbonized and uncarbonized briquettes: institutional kitchens (restaurants, schools, hospitals, barracks, camps).

5. Dendrothermal systems

Biomass grown for energy purposes on dedicated energy plantations is considered as having good potential in the long term and has recently received attention. The dendrothermal programme of the Philippines aims to promote self-reliance and to reduce the country's dependence on oil for the production of electricity. A typical dendrothermal power system consists of a tree plantation of 1,100 hectares, a 3 MW wood-fired power plant and a transport subsystem using cableways and trucks [10]. At present, five systems with a total generating capacity of 17 MW have been commissioned [10]. Several Thai feasibility studies based on *Eucalyptus camaldulensis* indicate that a dendrothermal power system with a generating capacity of between 20 and 50 MW would be economically feasible under Thai conditions. Pilot systems have been recommended for proper evaluation [1, 2, 8, 17-20].

6. Fuel alcohol

Several countries (Australia, India, Indonesia, Japan, Philippines, Sri Lanka and Thailand) already have fuel alcohol programmes. Because the technology has good prospects, some of them have been encouraging R and D on new technologies for the production and utilization of fuel alcohol as part of their energy policies. For example, under its National Energy Research, Development and Demonstration Programme, Australia has spent some $7 million on ethanol R and D [22, 23], allowing the technology to be used to power vehicles. The Philippines has been implementing a programme for alcogas, a blend of alcohol with gasoline. Several other countries have conducted engine trials of hydrated ethanol.

D. Trends and issues in biomass development and utilization

1. Trends

Two trends have been noted in the Asia-Pacific region. The first is the noticeable decline in recent years in the share of traditional biomass in rural energy supplies in several countries of the region, owing partly to a lowering of oil prices and partly to an increase in demand for commercial fuels owing to rapid growth of the industrial and agriculture sectors [1-9]. Nevertheless, the majority of the rural population will continue to depend on traditional supplies to satisfy basic household requirements and to support rural productive activities.

The second trend is the increase over the past decade in the use of biomass, especially in the industrial sector, owing to environmental concerns, better efficiencies and lower costs (see the preceding section on biomass energy systems and market opportunities). The increased availability of technology and capital from the developed countries would allow for a substantial increase in the modern use of biomass. However, the prospects for this use depend on oil prices, environmental factors and technological improvements [12].

According to IEA projections [13] of biomass use under the two scenarios (capacity constraints and energy savings), biomass use in China, which is the largest user of biomass in East Asia, is projected to decrease by 2010 under both scenarios, whereas biomass use in South Asia (where India is the largest biomass user) is projected to increase by 2010 under both scenarios (table III.2).

The importance of traditional sources of energy for developing countries of the region cannot be overemphasized: these sources still contribute about 50 per cent of the energy supplies in these countries. Quite often they are the only energy sources available to the rural people. But experience over the past one and a half decades in rural energy supplies in the ESCAP region also seems to suggest that biomass resources are unlikely to compete with conventional (fossil fuel) supplies in meeting growing rural needs for fuel, electricity and fertilizer. Nevertheless, biomass, especially wood and agricultural residues, will remain the main energy source in most countries of the region for the next two decades.

2. Issues and constraints

Many of the countries in the ESCAP region are potentially rich in biomass resources. These resources can be exploited for farm operation, rural electrification and use in vehicles. Their better exploitation to augment energy supplies, especially in rural areas, has therefore become a major issue in developing countries of the region. Appropriate methods and technologies to harness biomass resources efficiently are important, and the introduction and diffusion of successful biomass-conversion technologies continues to be a priority [1-9].

The main constraints on extending the use of biomass include the difficulty of assessing resources, local hesitance to accept the technology, mainly for social and economic reasons, lack of financial resources and manpower, environmental concerns, the absence of up-to-date local technology and the lack of after-sale services [1-9].

Constraints on resources and on the development and diffusion of biomass technologies are discussed in the ensuing sections, as are environmental impacts. Technical difficulties associated with the available biomass technologies will not, however, be dealt with in this paper. A wealth of information in this area is available in the current literature.

3. *Resource constraints*

When considering the development of biomass fuels, the availability of the fuel resource and competing uses for it become determining factors. For example, in parts of China and in the plains of northern India, Bangladesh and Pakistan, fuelwood is scarce but crop residues and dung are abundant. The development of fuelwood-based technologies in these regions has, accordingly, not been so successful, but biogas production from crop residues or dung is a viable option.

When there is competition for resources from established industries that utilize biomass for food or fibre, biomass becomes very expensive for energy production. Wood resources, for example, are finding greater application in new and profitable products. Asian pulp producers have begun using products from cultivated forest (rather than rainforest) to produce better quality, short-fibre pulp, which is becoming established on the world market, and eucalyptus is being discounted for producing eucalyptus pulp, which is the benchmark short-fibre quality (*Bangkok Post*, 11 November 1995). An organization of wood product producers in Thailand has announced schemes to expand production of particle board and fibreboard in the near future (*Bangkok Post*, 9 November 1995).

Nevertheless, the fast-growing food and fibre production and processing industries in this region produce a range of residues for which there is generally no demand and for which there is a disposal cost. However, not all the residues can be utilized for energy. Their scattered nature and low bulk density sometimes make recovery, transport and storage too costly. In certain cases, the residues are more valuable when recycled into the soil to restore nutrients or reduce erosion or when they are burnt in the fields as is done with rice residues in Indonesia, Malaysia, Myanmar and Thailand to prevent the spread of pests and plant diseases [24].

Biomass plantation has received some attention. However biomass is unlikely to be used as a fuel in units above 25-50 MW, mainly because of the large growing area required. For example, 400 ha of eucalyptus trees, one of the favoured species in some areas, are needed for each megawatt of power (assuming trees take seven years to mature) [1, 2, 8, 22, 25]. A programme on an *ipil ipil* plantation in the Philippines also fell far short of expectations. A central problem for the plantation part of the programme was that the cost of the fuelwood produced was typically higher than the price of wood purchased on the open market [25].

Although animal dung is a potentially large biomass resource in regions with many animals, cow dung is readily recoverable only for confined livestock or where the labour costs associated with gathering dung are modest, as they are in the rural areas of LDCs in the ESCAP region. Furthermore, dung often has an alternative use as a fertilizer.

4. *Socio-economic constraints*

As with all renewable technologies, the main social constraints on biomass technology are micro in nature and directly related to user attitudes and limitations. These social or user-related constraints include a lack of information, of motivation and of skills, the social and cultural unacceptability of the technology and low literacy levels. These factors, plus the normal resistance to change of villagers, combine to make biomass technologies unpopular. If a new system is tried out, minor technical problems tend to discourage its further use.

The main economic constraints on the use of biomass energy systems are associated with the relatively high cost of acquisition, inadequate (financial) incentives and lack of purchasing power on the part of potential users. Moreover, the non-monetary character of the returns from adopting the innovation cause them not to be perceived as a benefit. Rural people may not understand macro benefits and may not be able to internalize them. The small subsidy to the user and the non-cash equity on the part of prospective users are the main stimulants for the diffusion of technology, particularly domestic biogas systems and improved cookstoves.

The lack of after-sales services is a serious issue in rural areas where innovative technologies for new and renewable sources of energy (NRSE) have been diffused. This predicament has caused installed units to become non-operational after some time, resulting in a dwindling number of operational units, particularly biogas units (see section on the biological conversion of biomass). The most damaging effect, however, is the tarnished credibility of the technology, which spreads to neighbouring areas and discourages potential users from adopting the system.

In the face of the prevailing socio-economic constraints, governments in the region have nevertheless had some degree of success in diffusing these technologies. Of the biomass technologies being promoted, the biogas and cooking stove programmes are the largest in terms of scale, operations and coverage. China and India are the largest users of biogas and improved cooking stoves [1, 2, 7]. The Maya Farm in the Philippines is a successful commercial undertaking that produces biogas from agricultural wastes [1, 2, 7].

Government efforts at diffusion are motivated mainly by the energy crisis and the dwindling fuelwood supply in rural areas. However, the adverse impact of the energy crisis on the national and rural economy seems not to be understood by the villagers: they do not appreciate the need to switch to efficient technologies as a means of abating energy problems and optimizing resource utilization.

5. Environmental impacts

Although biomass conversion processes are effective in the disposal of organic wastes, especially in rural areas, they also generate vast quantities of pollutants, thus turning one pollution problem into another. The environmental impact of NRSE will depend on the technology being used and on whether dispersed or centralized systems are adopted. In general, NRSE are considered to be environmentally benign when compared with most conventional energy sources. Most of the renewable technologies currently in use do not result in net greenhouse-gas emissions if they are properly deployed. For example, fuelwood combustion leads to no net increase in CO_2 emissions as the CO_2 has already been absorbed from the atmosphere in photosynthesis [13].

Major causes of deforestation and desertification include fuelwood and fodder demand, unsustainable exploitation for industries, various land use policies and population pressures. FAO found [16] that the annual average deforestation rate in the region had increased from 2 million hectares in 1976-1981 to 3.9 million hectares in 1981-1990. Of the tropical regions in the world, the Asia-Pacific region has the fastest rate of deforestation (1.2 per cent per year), the fastest rate of commercial logging, the highest volume of fuelwood removals and the fastest rate of species extinction. FAO estimated that, at the current rate of deforestation, an area of about 50 million hectares would be deforested in the next 10 years. The countries with the largest areas of deforestation are India, Indonesia, Myanmar, the Philippines and Thailand [16]. The deforestation of tropical forests in the Asia-Pacific region is becoming an increasingly serious phenomenon, affecting the region's ecology and fuel supplies and the livelihood of hundreds of millions of forest dwellers. It is being realized that the environmental issues surrounding biomass use need to be taken into account when considering energy supplies.

6. Marketing constraints

As discussed in the preceding sections, there are market opportunities for most of the biomass conversion technologies. However, the markets in which renewable energy technologies, including biomass, are trying to establish themselves are complex, dominated by well-established technologies and influenced by the existing supply networks. There is also a skepticism about using a new form of energy supply. Public policies work against renewable sources of energy by heavily subsidizing conventional sources, especially in rural areas. Despite technological achievements in the past decade, many renewable energy applications are too expensive to compete with fossil fuels, and for some applications, even if the cost of energy from renewable sources is reduced, institutional barriers would still prevent decision makers from responding to price signals. In the current commercial environment, renewable energies find themselves being judged less on their long-term potential as contributors to diversification and more on short- to medium-term economic criteria in competition with well-established conventional sources. If to these market-place problems are added the socio-cultural and manpower constraints as well as the environmental concerns that are being encountered, the challenge facing the marketing of renewable sources is indeed formidable.

E. Policies and strategies for industry development

Generally, governments in the region have attempted to popularize the use of biomass-conversion technologies in response to the scarcity of fossil fuel and the degradation of the environment in rural areas brought about by the use of biomass.

Appropriate measures should be taken to solve the growing problem of deforestation, which is causing serious degradation of the environment. Government policies should recognize the trade-off between biomass development for energy production and biodiversity issues. Attempts at managing the ecosystem have yet to be successful, so the issue of deforestation should be given renewed emphasis in national energy supply and demand planning.

The diffusion of biomass conversion technologies appears to target the socio-economic needs of the whole rural sector. For instance, domestic biogas systems and improved cooking devices are not meant to solve the energy problems of rural areas but to reduce the drudgery of women (cooking and collecting fuelwood). Bringing women's perspectives to rural energy planning is emphasized in ESCAP's rural energy programme [1-9, 26-28].

Governments are trying to integrate the applicable technologies into rural development programmes to achieve greater penetration. This would include developing cluster schemes (like a communal biogas plant) wherever practical. Accordingly, community-scale biogas plants are being pursued in China and India, where their potential is substantial. Because the initial costs of these systems can be shared among the beneficiaries and the cost constraints posed by prospective individual users can be minimized, ESCAP has organized activities involving integrated rural energy planning and environmental development [28], biogas dissemination [29] and rural energy technologies [30, 31].

Policy directives are needed to achieve the integrated use of agricultural residues of different kinds and from different sources to produce energy. When agricultural residues are systematically used as energy sources they become a by-product, reducing production costs. Thus, the diffusion of technologies for new and renewable energy sources would be a good means of achieving rural development goals.

Village entry tactics should centre on demonstration rather than on seminars or lectures, because rural people tend to believe what they actually see. Better results are attained if potential users are given the chance to operate a system with trainers. To address these issues, ESCAP has applied the Participating Action Research Systems approach for the dissemination of biogas units, cooking stoves, charcoal-making technologies and afforestation programmes in three LDCs in South Asia (Bangladesh, Bhutan and Nepal).

Using this approach, pioneered by a team from Chulalongkorn University in Thailand, the East-West Centre in Hawaii and FAO, teams of facilitators established themselves in villages and were able to motivate rural residents to participate in the planning, organization and management of biomass schemes, thereby mobilizing indigenous resources and using existing ecological systems. For example, biogas was used for lift irrigation in areas where families had many animals and where agricultural residues were scattered around the huts. Power was generated for agricultural processing using the energy of the water in the numerous streams and canals flowing through the villages.

Since inadequately trained manpower has been widely considered one of the main reasons for the slow progress in NRSE diffusion, a large number of technicians are being trained to disseminate biomass and other renewable technologies in many countries of the region. ESCAP has organized in-country training courses for the training of trainers in China, the Lao People's Democratic Republic and Viet Nam.

The biomass industry is moving from a technology-dominated phase to a market-dominated phase, and future studies on regional biomass potential should be market-driven, with efforts devoted to the commercialization and marketing aspects of biomass technologies. Towards this end, ESCAP has been identifying appropriate niches for NRSE technologies and improving the linkages between research institutions, industry and end-users, which is vital for the wider dissemination of NRSE. ESCAP has also organized regional exhibitions and conferences and in-country promotion activities. For example, the Asia-Pacific Renewable Energy Symposium in 1995 and, before that, Asia-Energy in 1991 contributed to commercialization of renewable technologies in certain countries, and its renewable energy activities in China, Sri Lanka and Viet Nam promoted local entrepreneurial participation in renewable industry.

Intercountry cooperation in the form of regional working groups on NRSE and on rural energy planning is needed to promote the development and use of biomass. ESCAP has worked with countries in the region to establish such working groups. By doing so it has managed to maximize regional and donor resources and improved the implementation of rural energy planning in the region considerably.

F. Conclusions

The energy potential of biomass is being increasingly recognized by the countries of the region. R and D on biomass production, conversion and use increased over the past decade [1-9].

Biomass is the principal energy source in the rural areas where the vast majority of the region's population lives. Traditional biomass (fuelwood, crop residue and dung) constitutes a substantial proportion of rural energy supplies. While experience over the past decade and a half in rural energy supplies indicates that biomass resources are unlikely to compete with conventional sources of energy in satisfying growing rural energy needs, biomass will remain a key renewable energy source in the region for the next two decades.

The main constraints on extending the use of biomass include the difficulty of assessing resources, local reluctance to accept the technology, mainly for social and economic reasons, lack of financial resources and manpower, environmental concerns, the lack of local technology and the scarcity of after-sales service.

Better exploitation of the region's vast biomass resource base to augment energy supplies, particularly in rural areas, has been a major issue in developing countries of the region. Appropriate methods and technologies to develop and harness biomass resources in an efficient manner remain a major concern. The introduction and diffusion of successful biomass conversion technologies continues to be a priority.

The biomass industry is moving from a technology-dominated phase to a market-dominated phase; future studies on biomass should be market-driven. Intercountry cooperation through regional working groups on NRSE and rural energy planning are needed to promote the development and use of biomass.

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IV. POLICIES AND PROGRAMMES ON NEW AND RENEWABLE ENERGY IN THE PHILIPPINES

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Abstract

The New and Renewable Energy Programme aims at accelerating the promotion and commercialization of new and renewable energy systems. In pursuit of this goal, the Programme has the following policies: (a) pursue the large-scale use of new and renewable energy sources (NRSE), (b) enhance energy self-sufficiency through continuous exploration, development and exploitation of indigenous energy sources and (c) encourage greater private sector investment and participation in all energy activities.

The strategies to be implemented include the intensification of R and D and the demonstration of technologically feasible and socio-environmentally acceptable NRSE; the institutionalization of area-based energy planning and management for NRSE; the encouragement of a favourable market environment for manufacturers, suppliers and users of NRSE; the promotion of commercially viable energy sources such as solar and wind energy, and continuing applied R and D for less-advanced technologies such as ocean thermal and wave energy conversion, fuel cells and municipal wastes.

The subprogrammes of the New and Renewable Energy Program are as follows:

- The technology subprogramme aims at developing economically viable NRSE to levels of technical maturity at which NRSE can compete commercially with conventional energy.
- The commercialization subprogramme envisages the creation of a favourable market environment to encourage private sector investment and participation in NRSE projects and activities.
- The promotion subprogramme attempts to heighten public awareness of NRSE.
- The area-based energy subprogramme is a mechanism for accelerating the promotion and commercialization of new and renewable energy systems at the regional and subregional levels using a decentralized, area-based approach.

Introduction

The Department of Energy of the Philippines has been mandated under Republic Act No. 7638 to coordinate, supervise, control and prepare an integrated plan for all efforts, programmes, projects and activities of the Government relating to energy exploration, development and utilization. In executing the mandate, the Department is stepping up efforts to achieve the long-term goal of energy sufficiency, reliability and affordability within the context of environment promotion and protection:

- Formulation of clear policies and responsive plans and programmes.

- Intensive development of indigenous energy sources.
- Effective coordination of downstream energy activities.
- Provision of subsidies to host communities.
- Promotion of private sector participation in energy projects.
- Close coordination and cooperation with other government agencies and private sector entities.

A number of the policies and strategies are specific to new and renewable energy:

- Pursue the large-scale use of NRSE.
- Enhance energy self-sufficiency through continuous exploration, development and exploitation of indigenous energy sources.
- Encourage more private sector investment and participation in all energy activities.
- Intensify R and D and the demonstration of technically feasible and socio-environmentally acceptable NRSE.
- Institutionalize area-based energy planning and management for NRSE.
- Encourage a favourable market environment for manufacturers, suppliers and users of NRSE.
- Intensify the promotion of commercially viable NRSE such as the sun and the wind.
- Continue applied R and D on some less-advanced technologies such as those for ocean thermal energy conversion and wave energy conversion, fuel cells and municipal wastes.

A. The New and Renewable Energy Program

Through its 1996-2025 New and Renewable Energy Program, the Non-Conventional Energy Division of the Department of Energy is accelerating the promotion and commercialization of NRSE in coordination with other energy-related agencies such as the National Power Corporation; the Philippine National Oil Company, Energy Research and Development Centre; the National Electrification Administration; and the Department of Science and Technology and its associated agencies, which include the Philippine Council for Industrial Energy Research and Development and the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development.

Its new programme has four subprogrammes:

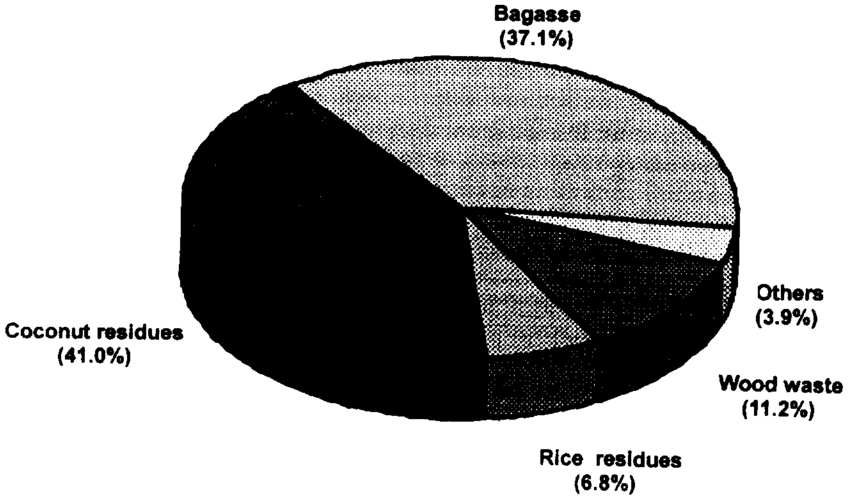
- The technology subprogramme aims to develop economically viable NRSE to technical maturity, at which point they can compete commercially with conventional energy.
- The commercialization subprogramme envisages creating a market environment favourable to private sector investment and participation in NRSE projects and activities.
- The promotion subprogramme attempts to heighten public awareness of the use of NRSE.

- The area-based energy subprogramme is a mechanism to accelerate the promotion and commercialization of new and renewable energy systems at the regional and subregional levels using a decentralized, area-based approach.

B. Historical consumption profile

In 1973, indigenous sources of energy accounted for about 8 per cent of the total energy mix, with new and renewable energy sources contributing a meager 3 per cent. Because of the country's heavy dependence on imported oil, the New and Renewable Energy Program was launched to increase the contribution of such sources to total energy consumption. In 1994, imported energy (oil and coal) accounted for 15.06 Mtoe, or 71 per cent, of the total energy mix, while indigenous energy accounted for about 6.14 Mtoe, or 28.9 per cent. Of the indigenous energy sources, conventional energy (oil, gas, coal, hydro and geothermal) had the largest share, 4.11 Mtoe, or 19.4 per cent. The remaining 9.6 per cent, or 2.03 Mtoe, was attributed to new and renewable energy sources (see figure IV.1), a 1.9 per cent increase from the preceding year's figure of 1.99 Mtoe. Bagasse and agricultural wastes were the major contributors, providing about 1.95 Mtoe of the total renewable energy share. Other new and renewable energy sources - solar, wind, micro-hydro, biogas and black liquor - contributed about 0.08 Mtoe of the country's total energy requirement. This is a 15.7 per cent increase from the preceding year's contribution of 0.07 Mtoe.

Figure IV.1. New and renewable energy consumption in the Philippines



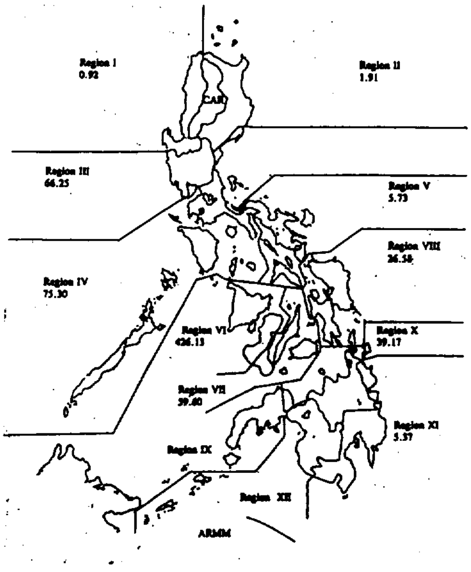
C. New and renewable energy supply potential

Data and statistics from various government agencies paint an optimistic picture of new and renewable energy in the next decade. Based on the projections of the Department of Agriculture and the Department of Environment and Natural Resources, the aggregate biomass supply potential in 1996 is equivalent to 19.2 Mtoe and is expected to exhibit modest growth through 2025, increasing to 41.7 Mtoe (see table IV.1). Contributors to this aggregate biomass supply potential are wood wastes, bagasse, coconut and rice residues, animal wastes and municipal solid wastes (see figures IV.2-IV.4).

Table IV.1. Philippine new and renewable energy supply projections
(Million tonnes of oil equivalent)

Biomass	1996	2000	2005	2010	2015	2020	2025
Rice	1.0	1.2	1.5	1.8	2.2	2.7	3.3
Coconut	2.7	2.9	3.2	3.5	3.9	4.3	4.7
Bagasse	1.6	1.9	2.3	2.7	3.3	4.1	5.0
Wood/wood waste	11.6	12.7	14.4	16.4	18.8	21.8	25.3
Animal waste	1.7	1.8	1.9	2.0	2.1	2.2	2.3
Municipal waste	0.6	0.6	0.7	0.8	0.9	1.0	1.1
Total biomass	**19.2**	**21.1**	**23.9**	**27.3**	**31.3**	**36.0**	**41.7**

Figure IV.2. Philippine biomass resource potential for bagasse (MW)



Weather data show that the country has good potential for wind energy. The average mean wind power density is 30.8 watts per square metre (W/m^2). Region I has the greatest potential for wind energy, with an annual wind power density of 88 W/m^2 (see figure IV.5). It has also been estimated that the country's average power density from solar radiation, based on sunshine duration, is 161.7 W/m^2, with a range of 128-203 W/m^2 (see figure IV.6).

Data from the National Electrification Administration show that the country has an aggregate micro-hydro power potential of about 27.8 MW (see figure IV.7).

Figure IV.3. Philippine biomass resource potential for coconut residues (MW)

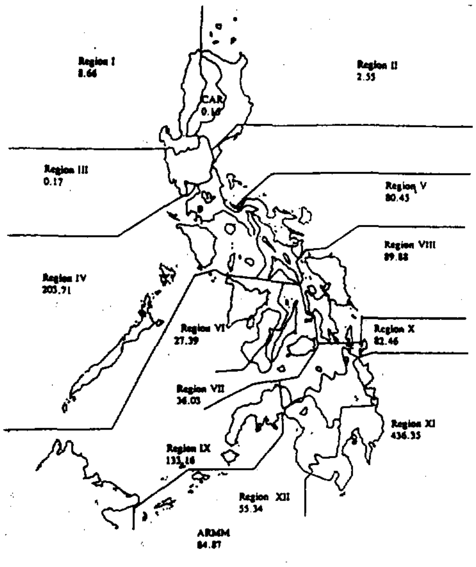


Figure IV.4. Philippine biomass resource potential for rice residues (MW)

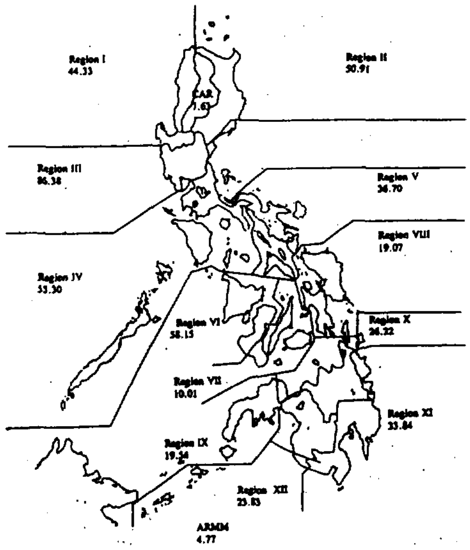


Figure IV.5. Philippine wind energy resource potential

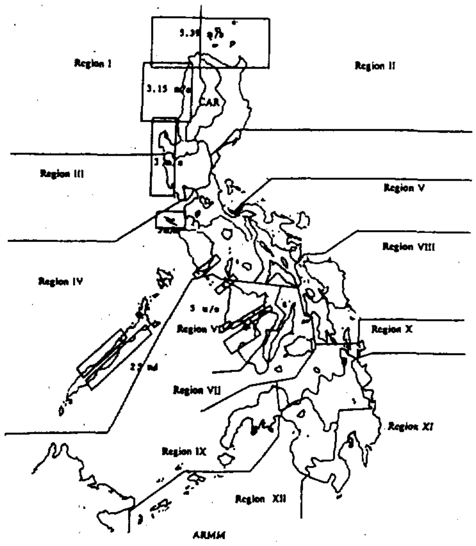


Figure IV. 6. Potential areas for solar energy installations in the Philippines (average daily insolation approximately 5 kWh/m^2)

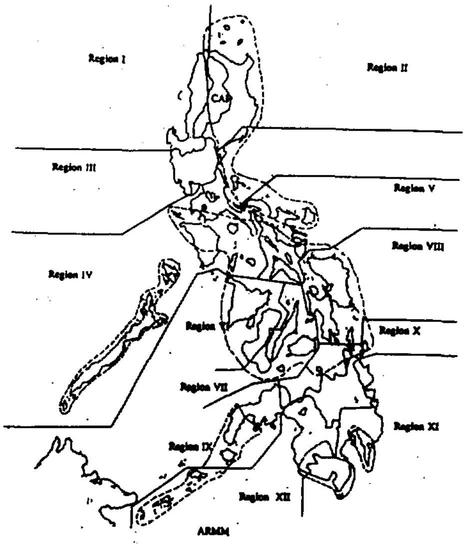
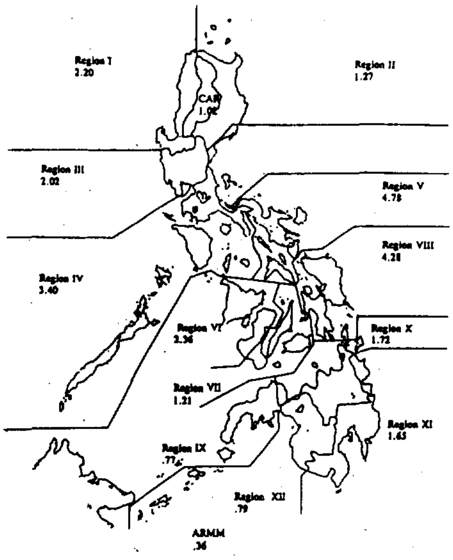
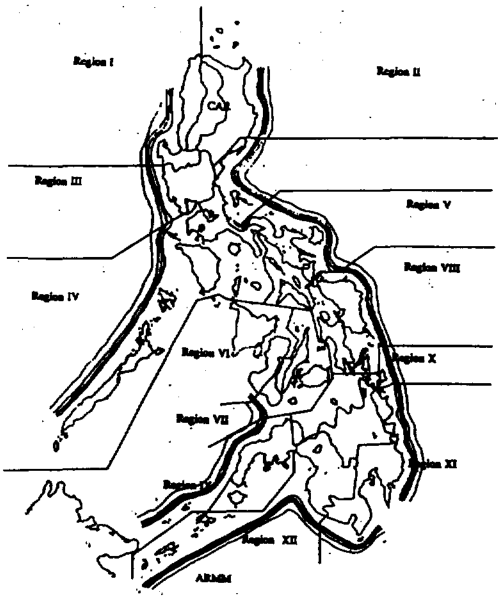


Figure IV.7. Philippine micro-hydro power potential (MW)



The country's ocean resource area is 1,000 km^2. It has a potential capacity of about 265 million MW (see figure IV.8). Although little information is available on the potential of ocean energy, it is considered to be a significant resource.

Figure IV.8. Potential areas for ocean energy applications



D. Projected demand for new and renewable energy

In 1996, the consumption of new and renewable energy is estimated at 8.94 Mtoe and is expected to have increased to 30.95 Mtoe by 2025 (see table IV.2). Biomass resources are the major contributors (99 per cent), with wood wastes giving the largest share (6.79 Mtoe, or 76 per cent). By 2025, biomass will account for 26.17 Mtoe, or 84 per cent, of the total renewable energy share. Other NRSE (solar, micro-hydro and wind) have a negligible contribution in 1996 but will grow to 4.78 Mtoe in 2025.

Table IV.2. Philippine new and renewable energy consumption projections
(Million tonnes of oil equivalent)

Energy sources	1996	2000	2005	2010	2015	2020	2025
Biomass	**8.94**	**10.07**	**11.97**	**14.70**	**17.76**	**21.40**	**26.17**
Wood/wood waste	6.79	7.18	7.98	8.95	10.15	11.68	13.67
Municipal waste	0.00	0.00	0.00	0.42	0.63	0.74	1.05
Bagasse	0.85	1.07	1.43	1.89	2.48	3.24	4.21
Coconut residue	0.83	1.06	1.38	1.76	2.20	2.72	3.32
Rice residue	0.37	0.49	0.69	0.95	1.28	1.72	2.29
Animal waste	0.08	0.24	0.46	0.71	0.98	1.28	1.60
Black liquor	0.02	0.02	0.03	0.03	0.03	0.03	0.03
Others	**0.00**	**0.05**	**0.17**	**0.25**	**0.44**	**2.06**	**4.78**
Micro-hydro	-	-	-	0.01	0.01	0.01	0.03
Wind	-	0.05	0.16	0.22	0.37	1.00	1.97
Solar	-	-	0.01	0.02	0.06	0.20	0.67
Ocean	0.00	0.00	0.00	0.00	0.00	0.84	2.11
Total	**8.94**	**10.12**	**12.14**	**14.95**	**18.20**	**23.46**	**30.95**

Biomass consumption will grow at an average annual rate of 3.8 per cent for a 30-year period. Wood waste will continue to be the biggest contributor to new and renewable energy, but its rate of use will grow at only 2.4 per cent. Other NRSE will grow faster, at 32.2 per cent annually.

From 1996 to 2000, about 85 per cent of new and renewable energy use will be for non-power applications such as process heating, mechanical driving and cooking. After the year 2000, however, there will be a substantial decrease in the share of non-power applications.

The application of new and renewable energy for power production will take a giant leap from the 1996 level of 524 MW to 5,960 MW in 2025, capturing a sizeable portion of the country's power requirement. Of that amount, 3,947 MW will be connected to the major grids. The difference, 2,014 MW, is intended for in-plant utilization and small-scale applications. Most of the new and renewable energy will come from biomass (specifically, bagasse, municipal wastes and wood wastes), the wind and the ocean.

E. New and renewable energy projects and activities

1. Technology subprogramme

(a) Biomass

In 1992, the Department carried out the Pre-Investment Study on the Commercial Potential for Power Production from Agricultural Residues under the auspices of the World Bank Energy Sector Management Assistance Programme. The salient conclusions of the study are as follows:

- The biomass projects examined are cost-effective and present attractive investment opportunities.
- A relatively large number of individual plants are involved, but only a small fraction of the potential can be developed in the near term to help alleviate the power shortage.
    - The sugar sector can be conservatively described as having the potential to contribute 60-90 MW to the grid supply in the near term.
    - A realistic estimate of the rice sector's potential contribution is not more than 40 MW.
    - The coconut sector is estimated to have a potential contribution of 20 MW.

The Department of Science and Technology and its associated agencies have also actively pursued the development of technologies for agricultural and forestry residues, including a rice-hull gasifier/combustor for drying agricultural products, the fluidized-bed gasification of wood and agricultural residues for power generation and the design and development of a continuous rotary kiln for carbonizing sawdust and other particulate agri-forest residue material to make charcoal briquettes and the like.

Similar studies, as well as installations of biomass-fired briquetting machines and improved cookstoves, have also been undertaken by the affiliated non-conventional energy centres (ANECs).

Biogas systems are considered a mature and developed technology. Several training courses and seminars have already been conducted by ANECs, particularly on the construction and management of biogas systems.

Recognizing the need for consumer protection and product reliability, the Department plans to pursue the establishment of product standards and testing procedures for biomass energy conversion systems. It also plans to demonstrate the viability of modular rice-hull power plants to be supplied by a cluster of rice mills. Sites identified for this project are Nueva Ecija, Bulacan and Isabela.

Another activity is the demonstration of biogas systems in rural communal slaughterhouses by the National Demonstration Project on Biogas Technology, a collaboration between the Department of Energy, ANEC at Don Severino Agricultural College and the Department of Agriculture.

(b) Solar energy

There have already been many solar energy projects. The Department continuously supports the operation of the Solar Laboratory at the University of the Philippines, National Engineering Center, where there is R and D on solar energy. To date, the Laboratory has prepared and submitted to the Bureau of Product Standards draft photovoltaic component product standards and the test procedures.

Similarly, the Department supports the Philippine-German Photovoltaic Water Pumping Project through the Water Resource Center at the University of San Carlos. The Project has installed a total of 15 photovoltaic pumping systems with a total capacity of 21 kWp for pumping potable water in remote villages of Cebu Province. Rural water and sanitation associations were organized to manage these systems.

The Department will push for the local assembly of solar photovoltaic panels, which will eventually lead to their local manufacture. This activity is geared towards reducing overall system cost to make the technology more affordable to the local end-users.

(c) Wind energy

There is growing interest on the part of foreign investors in wind energy for power generation. In 1992, the Department, with assistance from UNIDO, conducted a feasibility study on wind energy (Assessment of Technical, Financial and Economic Implications of Wind Energy Application for Electricity Generation). The study revealed that, at a conservative estimate, about 250 MW of wind power could be tapped and integrated into the Philippine Power Development Program.

Following on this study, the National Power Corporation, with funding support from the Philippine Council for Industrial Energy Research and Development, is monitoring the wind energy profile at seven potential sites. The wind energy data that will be collected by this monitoring are vital in designing future projects on wind. The Corporation is also implementing a 10 kW pilot wind turbine generator power project in Romblon.

Recently, the Renewable Energy Programme Support Office, the local affiliate of Winrock International, proposed a Philippine wind energy mapping project, which will produce a wind resource atlas for the country based on comprehensive analysis of existing and new international and local wind data sets. With the results of this mapping, the Department will embark on a follow-up project, to be supported by Denmark's Development Assistance Programme, that will produce, among other outputs, site-specific wind energy statistics and economic and financial assessments and an implementation strategy report.

(d) Micro-hydro

Six demonstration units of micro-hydro systems with an aggregate capacity of 114 kWp have been installed. Micro-hydro systems, one of the oldest technologies, have been used for mechanical applications (e.g. rice and corn milling), to generate power for lighting and to run electrical machines. A future project on micro-hydro will focus on demonstrating other applications, particularly for hybrid installations.

(e) Ocean energy

Foreign investors are pressuring the Department to undertake exploratory activities on ocean energy, an emerging technology. To systematically examine this possibility, the Department convened a national committee on ocean energy development and utilization. The inter-agency committee has been given the task of formulating guidelines and regulations for the exploration, development and utilization of ocean energy.

At present, the National Power Corporation is implementing a tidal current assessment project with assistance from the Council for Industrial Energy Research and Development. The project aims to create a resource profile for four potential sites: Gaboc Channel in Surigao, San Bernardino Strait in Samar, Hinatuan Passage in Surigao del Sur and Basiao Channel in Bohol.

With support from the United Nations Development Programme (UNDP), a project on wave power potential in the Philippines is being proposed that will prepare a wave map for the country. This information will be used to prepare an ocean energy development plan and to identify sites for resource assessments.

2. *Commercialization subprogramme*

Complementing these developments, the Department has launched a number of projects to accelerate the commercialization of new and renewable energy sources.

(a) Isang Libong Bahay: Pailaw Mula sa Araw

Popularly known as Prosolar, the Pailaw Mula sa Araw project (literally: light from the sun) is an extension of the Special Energy Programme of the Government of Germany, which will reimburse private manufacturers/sellers for their pre-commercialization expenses. A commercialization fund facility in the amount of one million Philippine pesos (P) has been established, and roughly one thousand solar heating systems are expected to be installed by the private sector. Project sites include Nueva Ecija, Tarlac, Palawan, Mindoro, Batangas, Quezon, Davao del Sur, Davao del Norte and South Cotabato.

To date, the project has developed a policy manual to guide project implementation. Other activities, such as consultation with possible end-users and accreditation and solicitation of proposals from the private sector, were intensified.

(b) Renewable Energy Power Program

Launched in 1990, the project Renewable Energy Power Program seeks to create a market environment that will attract local and foreign investments by making available funding support, information and financial incentives relative to the commercialization and utilization of new and renewable energy technologies. The money comes from GSIS and SSS and is passed through three government banking institutions, the Philippines National Bank, the Development Bank of the Philippines and the LBP.

(c) Financing Energy Services for Small-Scale End-Users

The project Financing Energy Services for Small-Scale End-Users (FINESSE) seeks to provide financial assistance for the commercialization of mature and market-ready NRSE. The medium-term investment requirement is about US$ 430 million. Before putting together the financing package for each technology, scheme-specific technical assistance will be provided. The FINESSE project is expected to be operational at the earliest by 1998.

(d) Environmental improvement for economic sustainability

In cooperation with the Government of the Netherlands, the project aims to install 15,000 solar heating systems in three years by subsidizing 40 per cent of the total project cost. It further envisages a mechanism for marketing such systems in remote areas by ensuring a reliable supply of spare parts and developing local expertise to solve any operational problems.

Another large-scale commercialization project is being coordinated by the Department of Interior and Local Government for implementation of the Australian-supported municipal infrastructure solar project. This project seeks to identify applications of photovoltaic systems in rural health centres, schools and other community facilities.

3. *Promotion subprogramme*

To promote new and renewable energy and disseminate information on it, two kinds of activities were undertaken.

(a) Provincial forums

Provincial forums are considered to be the most effective means of spreading information on the various technology options to local government units, non-governmental organizations and local private sector groups and of identifying project opportunities oriented to users and their needs.

(b) Organization of the Renewable Energy Association of the Philippines

To mobilize private sector participation, the Department organized the Renewable Energy Association of the Philippines, which is composed of private manufacturers, importers and distributors of various NRSE products and devices. The Department continuously provides financial assistance for the Associations' projects and activities.

Other activities of the subprogramme include the conduct of training courses/seminars/workshops, participation in trade fairs and exhibits and the development, production and dissemination of various promotional and information materials on new and renewable energy.

4. *Area-based new and renewable energy subprogramme*

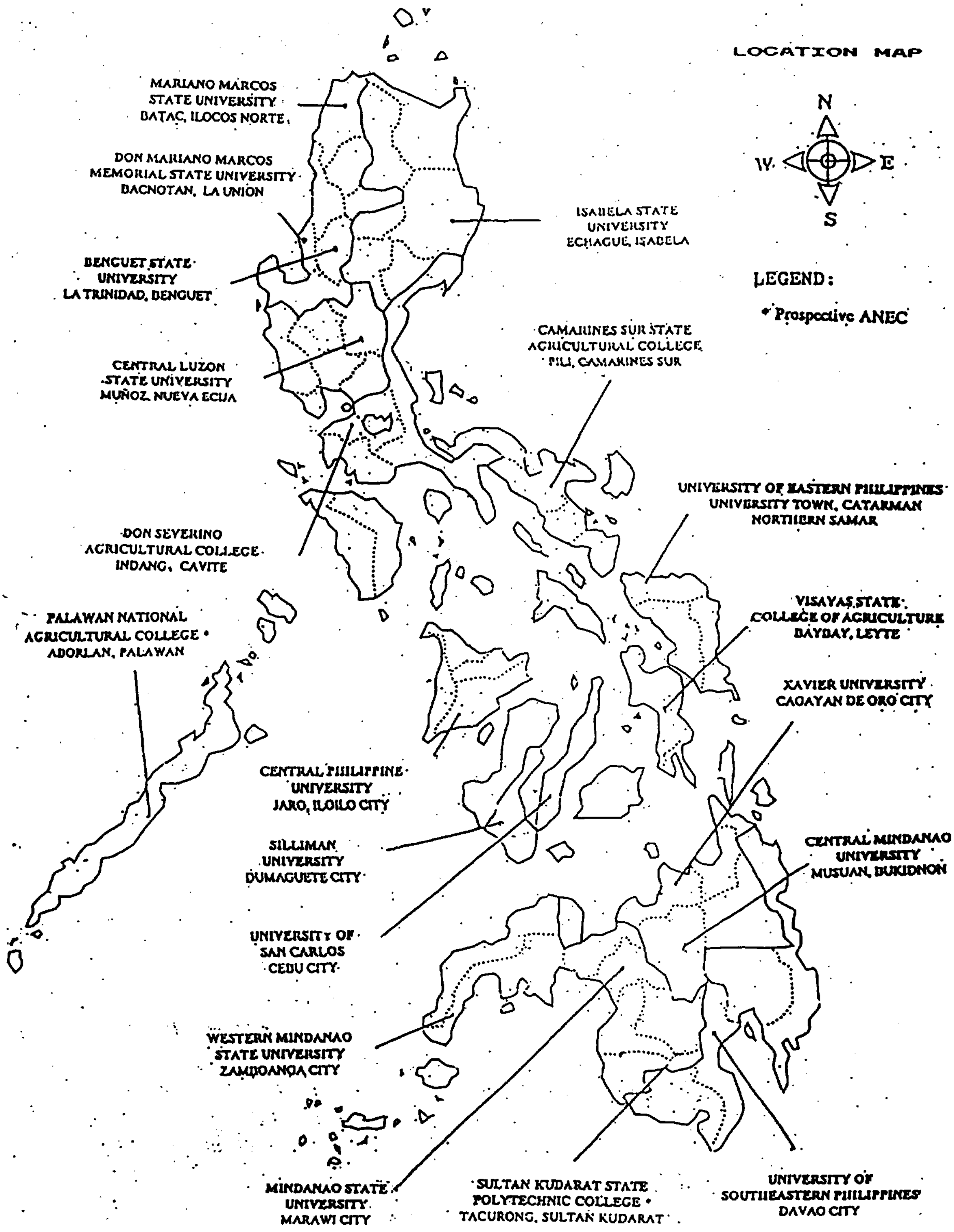
(a) Establishment and maintenance of affiliated non-conventional energy centres

In response to the increasing demand for rural energy, the Department established ANECs, which serve as the extension arm of the Department at the regional and provincial levels. As the link between the national and local structures, ANECs aim at improving the local energy situation through the judicious and efficient use of NRSE in the locality. Their activities include the formulation of rural energy plans and programmes; the installation of NRSE demonstration units; the rehabilitation of non-operational demonstration units; and the conduct of training courses, seminars and workshops for potential end-users, manufacturers and other key players on NRSE.

At present, the Department manages and supervises 19 ANECs at various public universities and colleges in the country (see figure IV.9).

One of the important achievements of the ANECs was the inventory of NRSE installations in 1994 in the 12 regions of the country. The data gathered estimated the actual contributions of NRSE to the national energy mix and serve as baseline data to determine the nature of assistance that should be given to NRSE owners and operators. The Department expects to rehabilitate all inoperational NRSE, to improve the image of NRSE.

Figure IV. 9. Philippine Department of Energy: 19 regional ANECs



(b) Area-based energy technology for sustainable development

Recently, the Department piloted a new strategy to strengthen local participation in identifying, prioritizing and implementing energy projects that will directly address their needs. Tried out in Mountain Province, the project was able to consolidate and maximize the efforts and resources of local government, NGOs and the private sector in bringing about the desired level of energy sufficiency in their local communities.

(c) Wood energy development programme

Recognizing the dominance of wood wastes and fuelwood as a traditional fuel in rural areas, the Department collaborated with the Regional Wood Energy Development Programme of FAO to develop a wood energy programme that will contribute to the sustainable production of fuelwood and its processing, marketing and rational use by households, industries and other productive enterprises.

The Department initiated the creation of the National Advisory Committee and the National Wood Energy Working Group, composed of government and non-government agencies. These groups were to formulate a project proposal and ensure its orderly and timely implementation. A series of consultations was undertaken to frame the proposal, which was eventually presented and submitted to the Regional Advisory Committee Meeting at Bangkok.

F. Capital investment requirements

The 1996-2025 New and Renewable Energy Programme will require funding of almost P 627.6 billion, or of 8.0 per cent of the total energy programme requirements. Of this, the local private sector will shoulder almost 43.7 per cent (P 274 billion) to implement commercialization activities for the different renewable energy systems and products. Foreign investors will provide P 314.5 billion, or 50.1 per cent of the total requirement, to upgrade new and renewable energy technologies and increase system efficiency and reliability. The private sector will provide the bulk of the capital (P 482.3 billion), principally for commercializing various renewable energy systems and products, while the Government takes the lead in the technological upgrading of product/system efficiency and reliability. The Government will also finance the installation of large-scale wind power systems and incineration plants for power generation. The participation of private research groups is also considered important as it would complement Government-led R and D.

V. BIOMASS ENERGY IN CENTRAL AMERICA

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Abstract

The objective of this paper is to introduce the concept of biomass to energy issues and opportunities in Central America. In this region, made up of seven countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama), the biomass sector has the potential to play a crucial role in alleviating the environmental and development predicaments faced by all economies of the region.

This paper assesses the available biomass resources at the regional and country levels and gives an overview of the current utilization of biomass fuels. It also describes the overall context in which the biomass-to-energy initiatives are immersed.

At the regional level, biomass energy consumption accounts for more than 50 per cent of total energy consumption. In regard to the utilization of biomass for energy purposes, it is clear that Central America faces a critical juncture at two levels, both mainly in rural areas: in the productive sector and at the household level. The absence of sustainable development policies and practices has jeopardized the availability of biomass fuels, particularly wood. Firewood is an important source of energy for rural industries such as coffee processing, which is one of the largest productive activities in the region.

This paper comments on some of the most successful technological innovations already in place in the region, for instance, the rapid development of co-generation projects by the sugar cane industry, especially in El Salvador and Guatemala, the substitution of coffee husks for firewood in coffee processing plants in Costa Rica and El Salvador and the sustainable use of pine forests for co-generation in Honduras.

Only one out of every two inhabitants in Central America now has access to electricity from the public grid. Biomass fuels, mainly firewood but also, to a lesser extent, other crop residues such as corn stalks, are the main source of energy for cooking and heating by most of the population. (It is foreseen that by the end of the century an even lower proportion of the population-only one out of three Central Americans-will have access to the national grid).

Finally, the paper recommends some actions to enhance alternative options for the conversion of biomass resources to energy in order to address the ever-increasing demand for power in the region. A key recommendation is a biomass technology assessment initiative that would facilitate the effective transfer of technology within the region.

Introduction

Biomass is the organic product of agriculture and forestry systems used to provide food, fuel and fibre. It finds great potential for exploitation in the world's tropical zone, and in developing countries it is the main indigenous source of primary energy. However, in some regions this important resource has been inappropriately managed and exploited, causing severe land and watershed deterioration as well as deforestation, with negative effects for the low-income population, especially in rural areas.

The objective of this study is to introduce the concept of biomass to energy issues as well as give an overview of different technology opportunities in Central America. In this region bordered by Mexico on the north and Colombia on the south and comprising seven countries- Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama-energy from biomass may play a crucial role in alleviating the environmental and development predicaments faced by the region's economies.

The social, economic, political and ecological consequences of the shortage of biomass fuels needed by rural households and poor urban households and by some industrial processors (primarily rural industries) are becoming critical for all countries in the region. The shortage is directly due to the weaknesses or inadequacies in integrating and deploying appropriate biomass-to-energy technologies. Some of the technologies that are already in place and succeeding in other regions could provide short-term and long-term environmentally sound energy alternatives. This paper discusses the conversion of biomass to energy as well as the need to select biomass technology for an effective technology transfer within the region and from other countries around the globe.

A. Availability and use of biomass resources

Central America is much affected by biomass mismanagement. A hundred years ago, it was covered by tropical forests and wetlands. As the population increased, more and more trees were indiscriminately cut down to provide energy and land for human settlements, pastures and the extraction of timber. These practices resulted in serious deforestation, a problem that continues to worsen. In vast regions of El Salvador and Nicaragua all the land has been deforested; in Costa Rica, the Central Valley is practically deforested. Honduras is the only country with substantial remaining pine forest, but even there local farming techniques and slash-and-burn cultivation threaten this resource. In Belize, Guatemala and Panama, tropical forest survives only in places such as the highlands of Petén and along the northern coast of Panama and in Darien.

Table V.1 shows biomass consumption in the seven countries. Panama has the lowest consumption per capita (0.54 tonnes of wood equivalent (twe)) while Nicaragua has the highest (0.93 twe). In Guatemala, biomass generates 72 per cent of the total energy consumed.

Table V.1. Biomass and commercial energy utilization in Central America

	Biomass energy utilization				**Commercial use (Mtoe)**	**Biomass share of total energy (%)**
	Per capita		**Total**			
Country	**twe**[a]	**toe**[b]	**Mtwe**	**Mtoe**		
Belize	..	..	..	..	0.06	..
Costa Rica	0.79	0 28	20.1	0.74	0.97	43.0
El Salvador	..	..	..	..	..	..
Guatemala	0.87	0.31	7.01	2.50	0.97	72.0
Honduras	0.85	0.30	3.65	1.30	0.61	68.0
Nicaragua	0.93	0.34	3.13	1.11	0.71	61.0
Panama	0.54	0.19	1.15	0.41	0.92	31.0

Source: Biomass Users' Network, "Why biomass matters", *Energy and the Environment*, vol. 5, No. 4 (July-August 1991).

[a] twe = tonnes of wood equivalent.
[b] toe = tonnes of oil equivalent.

As was mentioned before, firewood is the main biomass resource. Table V.2 examines the consumption of electricity, oil, firewood and other biomass residues by sector. It shows that oil is an important energy source and is used for transportation, industry and thermal power generation, even though the region imports almost all of its fossil fuels. Biomass, especially firewood, and hydroelectric plants are the two largest indigenous power sources in the region. From Table V.2, it can be seen, first of all, that most firewood is consumed by the household sector. Secondly, over two thirds of the electricity is consumed by households and about 30 per cent is consumed by the industrial sector. Lastly, agricultural residues (coffee husks, rice hulls, corn stalks and bagasse, among others) are another potential source of energy in Central America that is being used without attention to sustainable management, mostly by industries in the rural sector that do not require large amounts of energy. This enormous biomass energy potential must also be subject to better exploitation practices. Agricultural residues represent about 10 per cent of total energy supply and about 5 per cent of total energy consumption in the region as a whole [1].

Table V.2. Fuel energy consumption by sector in Central America, 1989
(Percentage)

				Fuel
Sector	**Firewood**	**Electricity**	**Oil**	**Biomass residue**
Transport	-	0.7	57.6	-
Industrial	6.6	29.9	23.6	100.0
Household	93.4	69.4	18.8	-
Total	**100**	**100**	**100**	**100**
Share of overall consumption	48.8	6.6	33.0	4.7

Source: J. Blanco, ed., *Commercially Successful Biomass Energy Projects in Developing Countries*, San José, 1994.

B. Conversion of biomass resources to energy

1. Regional issues

The Central American countries face similar situations that limit the use of biomass resources for power generation. Some of these situations are discussed below.

(a) Economic constraints

In Central America, as in most developing regions, the behaviour of the energy sector is conditioned by the fact that demand for energy is growing faster than the economy. This fact compelled public utilities to invest heavily, in the 1970s and 1980s, in centralized means of generation, with an emphasis on large hydroelectric projects, fossil-fuel-based thermoelectric plants and extension of the conventional grid.

Such investment was possible thanks to foreign funds to finance the construction of large power generation facilities, the maintenance of the existing State-owned systems and extensions of the grid as well as to pay for the imported oil needed to operate the existing thermoelectric plants. The foreign debt of the energy sector accounts for a significant portion (as much as 45 per cent in some countries) of the overall external debt for most countries in Central America. In the 1990s, the ability to meet growing demand by conventional means has decreased in the face of open markets, structural adjustments in the public sector, the privatization of public services and sharp reductions in public investment.

As a result, several new players–private power producers and regional and community utilities–have entered the traditional energy monopoly. These new players have helped to diversify the supply of power to the national grid by developing technologies such as small and mini-hydroelectric plants, stand-alone photovoltaic panels and biomass-based co-generation plants.

(*b*) *Rapid growth in energy demand*

In the wake of peace in Central America, the region has experienced rapid economic and social growth since 1990. As the national economies recover and pressure mounts to improve social conditions, the demand for power is increasing, to deliver basic energy services and to cope with the increasing stock of electrical appliances.

Even though there are significant differences in the availability of energy services from country to country (for example, the electrification index varies, from 40 per cent in Guatemala to 90 per cent in Costa Rica), demand for electricity in the region grew by over 7 per cent in 1994. At that rate, the region will probably have to double its installed electric capacity by the year 2000, a difficult task in the face of the economic constraints mentioned above.

(*c*) *Environmental considerations*

The demand for resources and services and the resulting environmental damage tend to increase more rapidly than the physical and financial ability to satisfy the demand and remedy the damage. The population, currently 46 million inhabitants, is expected to double in less than 30 years. In that short time, resources and services must also at least double from present levels, which have been achieved only at great expense in both monetary and environmental terms.

Under the energy pattern that prevailed before the 1990s, the energy establishment has not appraised the long-term availability of power from renewable energy sources, in particular biomass resources, nor has it taken measures to ensure this availability. Severe droughts, which have affected the major reservoirs, and the lack of appropriate planning and maintenance have led to serious power shortages in Honduras, Guatemala and Nicaragua. In Honduras, in 1994, blackouts lasting up to 10 hours a day were common.

The hydrological basins, too, have been deteriorating rapidly. Forest destruction due to overgrazing and intensive farming of the surrounding slopes without attention to appropriate soil conservation practices have caused erosion, which together with the disposal of urban wastes along the rivers, affects the operation of the reservoirs and the quality of the water for the production of electric power.

(*d*) *Social considerations*

The situation in the energy sector in Central America has social impacts. Firstly, only half of the population currently has access to electricity services, so there is a very large unmet demand, especially in rural areas. In Guatemala alone, 6,000 villages wait to be linked to the grid, something that will probably not happen for the next few decades.

Secondly, as was shown in table V.2, firewood consumption accounts for almost 50 per cent of total fuel consumption in the region, with most of it used for household cooking in rural areas. The third aspect associated with the quality of life is the role of the Central American woman in energy use.

Women and children spend a great deal of time gathering, transporting, preparing and burning firewood for cooking, leaving them less time for education, impairing their health and limiting their opportunities to earn additional income for their families.

(e) Need for new or underutilized biomass fuels

Two of the most readily available and underutilized sources of biomass are crop residues and agro-industrial waste. Although in countries like India and Nepal crop residues and animal wastes are being used as domestic fuel and for the production of biogas to make electricity for lighting, irrigation, supply of drinking water etc., in most Central American countries the residues are simply spread on the fields as fertilizer, burned off or used as fodder.

This situation contrasts sharply with the way in which agricultural residues are used as a source of domestic energy in other places around the world. In exceptional situations (when there is no wood available or when the labour to gather wood is scarce), residues or animal waste are resorted to. These fuels, used directly, do not burn well and necessitate long preparation times for meals. Neither of the above situations has been common in Central America until now.

2. The industrial sector

The preceding sections have presented different issues that encourage the sustainable utilization of indigenous energy resources. Two major developments are occurring in the region that deserve some mention here: one is the use of bagasse to diversify the supply of power and the other is the use of coffee husks to alleviate the pollution of rivers around coffee processing plants.

(a) Potential for electric power production in the sugar industry

Sugar cane is cultivated in all Central American countries. Traditionally, the sugar industry has been able to survive in these countries thanks to its self-sufficiency in power production. The bagasse, which is a by-product of the juice extraction process and represents 25-30 per cent of the sugar cane weight, becomes the fuel for the production of the steam that is used to generate the mechanical and electrical power required in the process.

The great majority of the sugar mills in Central America started operations long before the 1973 oil crisis and were designed when no thought was being given to alternative energy sources in a monopoly energy market. Thus, they recovered just enough energy from the bagasse to meet their needs, and the leftovers were disposed of in nearby fields.

However, the energy picture has changed radically since 1990, and at present most of the countries, especially El Salvador and Guatemala, are passing new laws to promote private participation in schemes such as the one where bagasse from sugar cane is used to supply not only internal power for the operation of the plant but also power to be sold to the grid. An average sugar mill in the region produces 12-15 kWh per tonne of processed sugar cane and uses approximately the same amount of energy. However, technology innovations that are being introduced may raise the energy production to 50 kWh per tonne.

The Salvadoran case illustrates the potential for these technologies. For example, if all the mills in the country could be brought up to date technologically with standard low pressure systems, about 3.8 MW could be connected to the national grid. If upgrading to high-pressure boilers and other energy efficiency improvements were carried out in all the mills, up to 100 MW of power could be connected.

Such improvements make use not only of high-pressure steam but also of condensed turbogenerators instead of counter-pressure turbogenerators and equipment that reduces steam requirements.

Usually, sugar mills that sell power to the grid generate power all year round, mixing power generation from bagasse during the season and thermal power generation during the off-season. An interesting case in El Salvador is the San Francisco sugar mill, which will be the first thermoelectric plant in the region, and will have an installed capacity of 5 MW. It aims to rely completely on biomass resources (primarily bagasse and other agricultural wastes).

(b) Coffee husks

Coffee husks are another abundant biomass residue that can be used for process heat. In Central America nearly 25 per cent of all agricultural land is dedicated to this crop. Normally, about 44 per cent of coffee husks are used as a biomass fuel. In El Salvador, an interesting technology, the combustion of firewood and coffee husks, generates enough heat to increase the air temperature directly for drying coffee [2], alleviating the need to buy firewood, which is expensive owing to its scarcity; this innovation is being introduced and adapted to some of the coffee processing plants in Costa Rica.

3. The household sector

In Central America, the most widespread method of cooking in rural areas is the rudimentary and inefficient open-hearth stove, which loses most of the energy produced by the combustion of fuelwood. An average rural family uses approximately 7 m^3 of fuelwood per year, and 100,000 families would use approximately 700,000 m^3, which represents a loss of almost 6,000 hectares of forest area each year. More efficient use of fuelwood would lessen the pressure on forest resources and improve living standards by reducing the time needed to gather fuelwood (labour usually undertaken by women) and minimizing the exposure to hazardous fumes. Several small-scale projects in Central America have taught people to build and use the innovative, energy-efficient stoves, including the dissemination of Lorena stoves, developed in Guatemala, and Finlandia stoves in the Trifinio area, where El Salvador, Honduras and Guatemala come together.

In El Salvador, where 58.3 per cent of primary energy is from fuelwood and about 60 per cent of households burn firewood for cooking, such initiatives to introduce stoves would have great potential. The potential would be even greater in rural areas, where 86 per cent of the households use firewood for cooking (table V.3).

Table V.3. Use of fuelwood by households in El Salvador
(Percentage)

Category	Share of fuelwood used for cooking
Rural	86.1
Urban	28.3
National average	54.6

Source: National Census of El Salvador: 1992.

C. Recommendations to enhance development opportunities for biomass-to-energy projects

A number of areas in which action is needed are briefly mentioned, along with the names of institutions involved in such biomass activities in Central America.

1. Sustainable utilization of biomass fuels for rural industries

Biomass fuels, predominantly wood, are the main source of energy for rural industries and are integral to processes such as baking, tobacco curing, coffee drying, brick and lime making and pottery making. As these industries pay cash for fuel from wooded areas, forests or fuelwood plantations, they have a dramatic impact on deforestation. PROLENA, a Honduran development organization, estimates that in that country about 7 million cubic metres of timber are cut for firewood each year, a leading factor in the high rate of deforestation [3].

Much like urban biomass fuel demand, rural industry demand tends to be concentrated, and it therefore distorts the local supply and creates a focus for depletion of forests. Rural industries, unlike households, purchase wood-based fuels, so it is likely that they will view with favour improvements in efficiency or technologies that allow switching to biomass fuels that are cheaper than firewood.

2. More efficient use of agricultural wastes and residues

Timber operations in developing countries are very inefficient converters of biomass into marketable products. In the vast majority of commercially planted forests, less than 20 per cent of the biomass is converted into marketable products. The remainder is either burned off in the field after harvesting, incinerated at the sawmill or left to rot.

Disposal of residual biomass in this manner results in significant environmental and economic problems. Projects in this area focus on the use of forest wastes to provide the electricity and heat for processing logs into lumber. One example is a 15 MW project in Honduras that uses the remains of the pine forest to generate power that is sold to a local utility. Such an approach can mean a more economical use of the resource and has environmental and other benefits.

3. Biomass technology assessment

The Biomass Users' Network regional office in Costa Rica has proposed a model for the sustainable exploitation of biomass resources that would avert total deforestation in the present decade and provide new development opportunities. If the rational use of biomass resources is enforced by having a proper regulatory framework, if information campaigns and training on sustainable biomass exploitation methods are carried out and if the diversification of agricultural crops is fostered, soil and water will be conserved, employment will increase in rural areas and farmers will have better living standards, helping to stop migration to urban areas.

All countries in the region have undertaken biomass-related projects with specific goals; however, none of them has a complete list and description of the project opportunities in this area, to share among themselves and with other regions. An activity such as the one being suggested would assess current and potential biomass technologies in the region, classifying them by end-use into four major categories: energy, forestry, agriculture and industry.

4. Policy dialogue

The assessment exercise discussed above would also stimulate a dialogue on policy and dissemination of information, since these are two of the primary constraints on the application of biomass-to-energy projects.

Energy policies must be formulated in the context of national development and social needs, so biomass-to-energy projects have to involve consensus building. Developing policy for domestic and rural industrial end-uses, to which little attention has so far been devoted, spans various ministerial portfolios, from energy, agriculture and forestry to natural resources, and is likely to be a complex task.

5. Financial and legal frameworks

Financing for biomass-to-energy projects will have to come from foreign sources because the indigenous financing systems are unable to meet the capital investment requirements of medium and large projects, particularly those in the range 1-20 MW.

The need to develop appropriate legal frameworks in each country to support the implementation of biomass projects must be a priority. A transparent and consistent regulatory framework will facilitate technology transfer, will attract foreign investment and will build confidence and interest in biomass as a source of power.

The financing of small-scale biomass projects, especially those associated with households or small-scale enterprises, faces other constraints, such as high transaction costs and small loan amounts.

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VI. POTENTIAL OF FORESTRY BIOMASS FOR ENERGY IN ECONOMIES IN TRANSITION*

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Abstract

A rapid increase in the world's population, the gradual exhaustion of fossil fuels and serious ecological problems are making developed countries more attentive to the utilization of renewable energy sources, mainly biomass, which should form part of the global energy mix during the twenty-first century.

The economies in transition have been experiencing a transformation of their political, economic and social systems and a modernization of their industry, including the energy industry. Energy supply in the transition economies is based on coal, oil, gas and nuclear power. Of the renewable sources, only hydroelectric power is utilized to any significant extent. The forest biomass resources of these economies are quantified in this paper.

The economies in transition have a big potential for biomass from forestry and timber industry wastes and agricultural wastes that are not being utilized and could become a source of energy. So far, biomass is used as a source of energy in only small amounts in the wood and pulp industries and as fuelwood in forestry. The governments of some countries (the Czech Republic, Hungary and Slovakia) have energy plans through the year 2010 that aim to develop renewable energy sources. Economic, institutional, technical and other barriers to the development of renewable sources and their utilization are analysed in this paper and some remedies are proposed.

In cooperation with countries such as Austria, Denmark, Sweden, Finland, the United States of America and others, which have achieved remarkable results in the utilization of biomass for energy, it would be possible for the transition economies to quickly develop the technological know-how needed to satisfy the demand for energy of approximately 350 million inhabitants.

Introduction

In the face of the rapid increase (more than 80 million people per year) in the world's population, the exhaustion of fossil sources of energy, the risks of nuclear energy (Chernobyl) and ecological problems such as the pollution of soil, water and air and forest destruction, which together with the production of greenhouse gases may cause climatic changes, the developed countries are turning their attention to the use of renewable sources of energy including biomass, which should account for a larger share of the global energy mix during the twenty-first century.

Of all renewable energy sources, biomass has by far the biggest potential for further development. In a few countries, like Austria and Sweden, biomass already contributes more than 10 per cent to the

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*"Economies in transition" is a term applied to the following countries: Albania, Armenia, Azerbaijan, Belarus, Bulgaria, Czech Republic, Estonia, Georgia, Hungary, Kazakstan, Kyrgyzstan, Latvia, Lithuania, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Turkmenistan, Ukraine and Uzbekistan.

primary energy supply. In the future, the share of biomass in the energy supply could be even more significant.

Bioenergy as a substitute for fossil energy may also be able to reduce CO_2 emissions to the atmosphere, because the carbon that is set free during biomass combustion is taken up again by growing plants, closing the carbon cycle of bioenergy. The carbon balance of bioenergy has to take into account both the reduction in carbon emissions from fossil fuels and the reduction in carbon stored in the biosphere (plants, litter and soil) [1, 2, 3].

Using biomass as a source of energy also allows the utilization of wastes and agricultural overproduction, reduces unemployment and assists sustainable rural development. The economies in transition have seen the transformation of their political, economic and social systems and the modernization of their industry, including the energy industry. There are more than 20 countries at different stages of transition from a centrally planned to a market economy.

Energy supply in the economies in transition is based on coal, oil, gas and nuclear power. Of the renewable sources, only hydroelectric power is utilized to any significant extent. The industrial structure in these economies (smelting of iron, aluminium and other non-ferrous metals and the manufacture of heavy machinery and armaments) has a high requirement for energy and a low energy efficiency. This low efficiency also persists in other applications such as the heating of buildings, transport and electric power production and use.

The potential renewable energy sources, mainly biomass, are considerable but have not been tapped until now. This paper has three aims:

- To provide basic information about the potential of forestry biomass for energy.
- To identify barriers to the use of biomass as a renewable source of energy in the transition economies and to propose means of eliminating them.
- To contribute to a proposed international programme on biomass as a renewable energy source for economies in transition.

A. Basic facts on the economies in transition

Classified on the basis of their progress in transition and privatization, there are three groups within the economies in transition:

- The Czech Republic, Hungary, Poland and Slovakia have made the best progress. In 1994 and 1995, they showed growth in gross national product (GNP). These countries are oriented towards the solution of ecological problems and the use of renewable energy sources. They accept the concept of environmental preservation and have established institutions for it. Ministries of the environment and environmental offices at regional and municipal levels have been given the right to impose penalties (to be paid into an eco-fund) on those who violate ecological standards. There is, however, a lack of funds to finance projects that deal with important ecological problems. Ecological awareness has been raised at all levels of society, and a programme on renewable energy sources has started to build demonstration projects with the assistance of Austria, Denmark, the United States and others. While a number of programmes and foundations support the transition economies and the scientific community in these countries is involved in programmes and projects of the European Union such as Phare and JOULE I-II, still more assistance is needed.

- Albania, Belarus, Bulgaria, Romania, the Russian Federation and Ukraine lag behind the first group in the transformation of their economies. This delay can be minimized by the systematic removal of barriers.

- The remaining transition economies show no real evidence of transformation, but they possess significant natural resources, so the transfer of information, know-how and new technologies is of interest to them.

Basic data on forestry and biomass sources in these countries can be found in tables VI.1-VI.4 and figures VI.1-VI.4. The assessment included forests, which covered slightly more than 3,443 million ha, or 27 per cent of the land area. The total growing stock was 384,000 million m^3, and growing stock/ha was 114 m^3.

Forests and other wooded land cover more than 977 million ha in the economies in transition, which is 25 per cent of the estimated global total and up to 50 per cent of forest land in the temperate zone. The former Soviet Union has 942 million ha, followed by North America with 749 million ha and Europe with 195 million ha [4].

The volume of growing stock in exploitable forest in the developed countries is estimated at 112 billion m^3, of which 45 per cent is in the former Soviet Union and 34 per cent in North America [4]. The volume of growing stock per hectare varies widely, between 125 and 300 m^3. In areas with less favourable growing conditions, it is below 100 m^3/ ha.

Since the first energy crisis in the 1970s, interest has grown in the use of biomass in general and wood in particular to supply energy. In future, total wood removals for energy production purposes will be significant. Estimates of the above-ground standing volume of biomass are as follows: Europe, 12,000 million tonnes; the former Soviet Union, 94,000 million tonnes; North America, 52,000 million tonnes; and other, 5,000 million tonnes. The total in developed countries is 117,000 million tonnes.

The net annual increment is estimated at 2,400 million m^3 in the developed countries, of which 968 million are in North America, 700 million in the former Soviet Union, 577 million in Europe and 163 million in Australia, Japan and New Zealand.

In all developed regions and countries, fellings have remained below the net annual increment. Fellings in 1990 on exploitable forest in the developed countries were an estimated 1,780 million m^3 (for comparison, the estimate net annual increment was 2,400 million m^3). Fellings were thus 26 per cent less than the increment (20 per cent in North America, 26 per cent in the former Soviet Union and 29 per cent in Europe).

Besides the managed forests in the transition economies, there are huge areas of natural, unmanaged old-growth forests in Siberia and the Far East. There are large timber, wood processing, pulp and furniture industries in these countries, but they are generally outdated and inefficient compared to world standards. The price of wood in Ukraine, Belarus and the Russian Federation is lower than elsewhere in Europe.

These estimates, which are from 1990 [4, 5] demonstrate that the transition economies, especially the Russian Federation, possess forest biomass of world importance that have not been sufficiently utilized as renewable sources of energy until now. It may be noted that the estimates vary from source to source.

Table VI.1. Population and classification of forest and other wooded land

Country/region	Population (10^3)	Forest and other woodland					
				Forest			
		Total (10^3 ha)	Per capita (ha)	Total (10^3 ha)	Per capita (ha)	Exploitable (10^3 ha)	Unexploitable (10^3 ha)
Albania	3,250	1,449	0.45	1,046	0.32	910	136
Bulgaria	9,010	3,683	0.41	3,386	0.38	3,222	164
Czech Republic and Slovakia	15,660	4,491	0.29	4,491	0.29	4,491	0
Hungary	10,550	1,675	0.16	1,675	0.16	1,324	351
Poland	38,180	8,672	0.23	8,672	0.23	8,460	212
Romania	23,200	6,265	0.27	6,190	0.27	5,413	777
Yugoslavia	23,810	9,453	0.4	8,370	0.35	7,768	603
Former USSR[a]	288,590	941,530	3.26	754,958	2.62	414,015	340,943
Belarus	10,200	6,256	0.61	6,016	0.59	5,392	624
Ukraine	51,700	9,239	0.18	9,213	0.18	5,820	3,393
Total/average transition economies	**412,250**	**977,218**	**0.68**	**788,788**	**0.58**	**45,603**	**343,186**
Canada	26,520	453,300	17.09	247,164	9.32	112,077	135,087
United States	249,970	295,989	1.18	209,573	0.84	195,596	13,977
Total/average North America	**276,490**	**749,289**	**2.71**	**456,737**	**1.65**	**307,763**	**149,064**
Total/average	**688,740**	**1,726,507**	**1.36**	**1,245,525**	**1.12**	**353,366**	**492,250**

[a] Including the Byelorussian Soviet Socialist Republic and the Ukrainian Soviet Socialist Republic.

Table VI. 2. Estimate of amount of forest biomass[a]
(Millions of tonnes)

	Mass (absolutely dry)		
		Forest	
Country/region	**Total forest and wood resources**	**Exploitable**	**Unexploitable**
Albania	..	..	..
Bulgaria	..	..	..
Czech Republic and Slovakia	..	..	..
Hungary	197	147	38
Poland	839	896	23
Romania	690	620	58
Yugoslavia	..	..	..
Former USSR[b]	52,419	31,117	20,384
Belarus	..	..	..
Ukraine	..	..	..
Total transition economies	**54,145**	**32,780**	**20,503**
Canada	25,568	12,334	13,234
United States	22,329	18,393	1,314
Total North America	**47,897**	**30,727**	**14,548**
Total	**102,042**	**63,507**	**35,051**

[a] Excluding roots.

[b] Including the Byelorussian Soviet Socialist Republic and the Ukrainian Soviet Socialist Republic.

Some of these economies suffer from severe industrial pollution and radioactive contamination of forests. The "black triangle" area where Poland, Germany and the Czech Republic meet is so called as a result of SO_2 pollution. More than 4 million ha of forests in Ukraine, Belarus and the Russian Federation are contaminated as a result of the Chernobyl nuclear power plant disaster in 1986.

The huge amounts of fossil fuel resources in the economies in transition, especially in the former Soviet Union, and low prices that consumers paid for energy were not conducive to developing renewable sources of energy. Now, technical management and research are progressive and efficient, but rigid economic policies in this sector have prevented the needed changes.

All forests in the transition economies were public property at one time. This is now changing, with privatization having taken different forms in different countries and having occurred at different rates. Large numbers of small holdings emerged in the Czech Republic, Estonia, Hungary, Latvia, Poland and Slovakia, which had always had many forest owners in the past. However, most forest land in the majority of transitional countries remains in State hands (the Russian Federation, Albania, Lithuania and Romania).

Forest industry production, including that of the wood industry, in the transition economies has fallen 30-40 per cent in the past five years. The main reasons for this sharp decrease include the following:

Table VI.3. Summary of forest sources statistics by region for developed countries

	Forest and other woodland			Forest					Exploitable (production) forest				Net annual increment (NAI)		Annual fellings	
Country/region	Total (10^6 ha)	Share of total land (%)	Per capita (ha)	Total (10^6 ha)	Share of forest and other wood-land (%)	Exploi-table (prod.) (10^6ha)	Unex-ploitable (non-prod.) (10^6 ha)	Other wood-land (10^6 ha)	Total (10^9 m^3 o.b.)	Per hectare (m^3 o.b)	Share of conifer-ous (%)	Above ground (oven dry) (10^9 tonnes)	Total (10^6 m^3 o.b.)	Per hectare (m^3 o.b.)	Total (10^6 m^3 o.b.)	Share of NAI (%)
Former USSR	942	44	3.26	755	80.1	414	341	187	50	122	74	94	700	1.7	518	74
North America	749	40.8	2.71	456	60.9	308	148	293	38	123	64	52	968	3.2	771	80
Europe	195	35.4	0.35	149	76.4	133	16	46	19	139	64	12	577	4.3	408	71
Australia, Japan, New Zealand	178	21.7	1.24	72	40.4	43	29	106	5	117	47	5	163	3.8	83	51
Total/average	**2,064**	**38.6**	**1.62**	**1,432**	**69.4**	**898**	**534**	**632**	**112**	**125**	**68**	**163**	**2,408**	**2.6**	**1,780**	**74**

Note: o.b. = over bark.

- Rising electricity, fuel and wage costs.
- Sharp increase in the prices of raw materials on the domestic market.
- The collapse of the Council of Mutual Economic Assistance bloc.
- A lack of investment in new technologies.
- The inability, owing to poor quality, to compete on the world market.

GNP in the transition economies in the past five years has been lower than in 1989 and continues to be so. In 1993-1994, certain signs of economic recovery appeared, including the wood products sector in the Czech Republic, Slovakia, Hungary, Latvia and Poland [6]. Despite the many problems in the forestry industry, a number of positive factors bode well for biomass as a potential source of energy in these countries:

- A strong forestry tradition and education system (universities for forestry and the wood industry).
- A network of research institutes for forestry and the wood industry.
- Longstanding forest plantation policies in Bulgaria, the Czech Republic, Hungary, Poland and Slovakia).
- Relatively low labour costs.

Table VI.4. Main forest statistics of economies in transition

Country	Total land area (10^3 ha)	Forest land share of total land area (%)	Per capita (ha)	Growing stock[a]	
				Total (10^3 o.b.)	(m^3 o.b./ha)
Armenia	329	11.0	0.09	39	119
Azerbaijan	992	11.5	0.14	8,128	129
Belarus	6,256	30.1	0.61	921	147
Croatia	2,458	43.5	0.53	298	121
Czech Republic	2,637	33.4	0.26	617	234
Estonia	1,915	42.5	1.24	243	127
Georgia	2,758	39.6	0.51	422	153
Kazakstan	9,643	3.5	0.57	366	38
Kyrgyzstan	729	3.7	0.16	23	32
Latvia	2,757	42.7	1.05	439	159
Lithuania	1,959	30.0	0.52	321	164
Republic of Moldova	315	9.3	0.07	35	111
Russian Federation	771,109	45.2	5.2	81,644	106
Slovakia	1,989	40.6	0.38	360	181
Slovenia	1,077	53.2	0.54	207	192
Tajikistan	410	2.9	0.08	6	15
Turkmenistan	4,127	8.5	1.12	14	3
Ukraine	9,239	15.3	0.18	1,320	143
Uzbekistan	1,909	4.3	0.09	11	6

[a] o.b. = over bark.

Figure VI.1. Distribution of forest and other woodland in the world, 1990

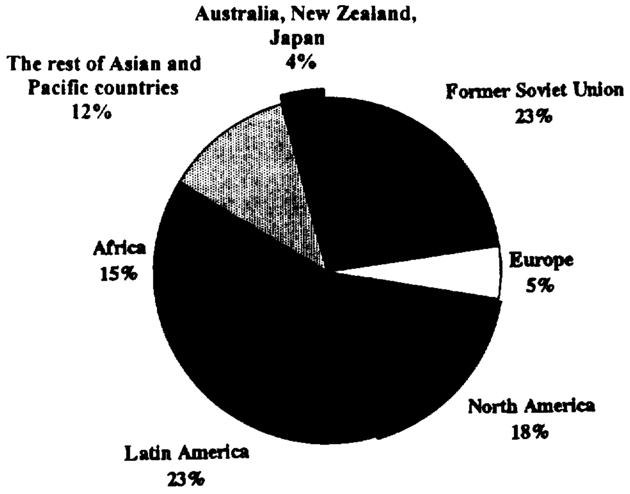


Figure VI. 2. Distribution of forest and other wooded land in temperate climates

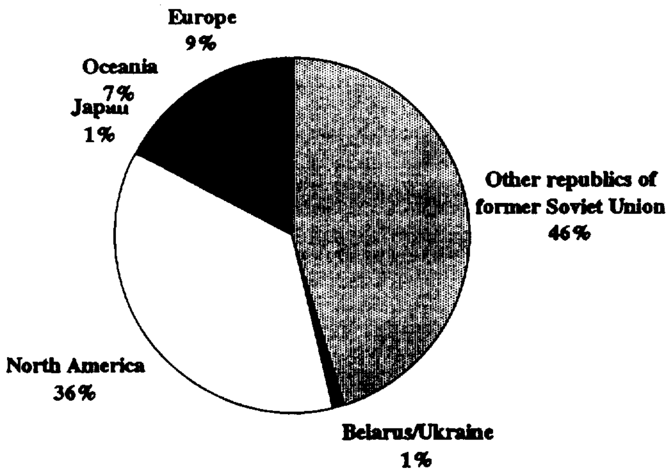


Figure VI. 3. The share of forest and other wooded land in all dry land

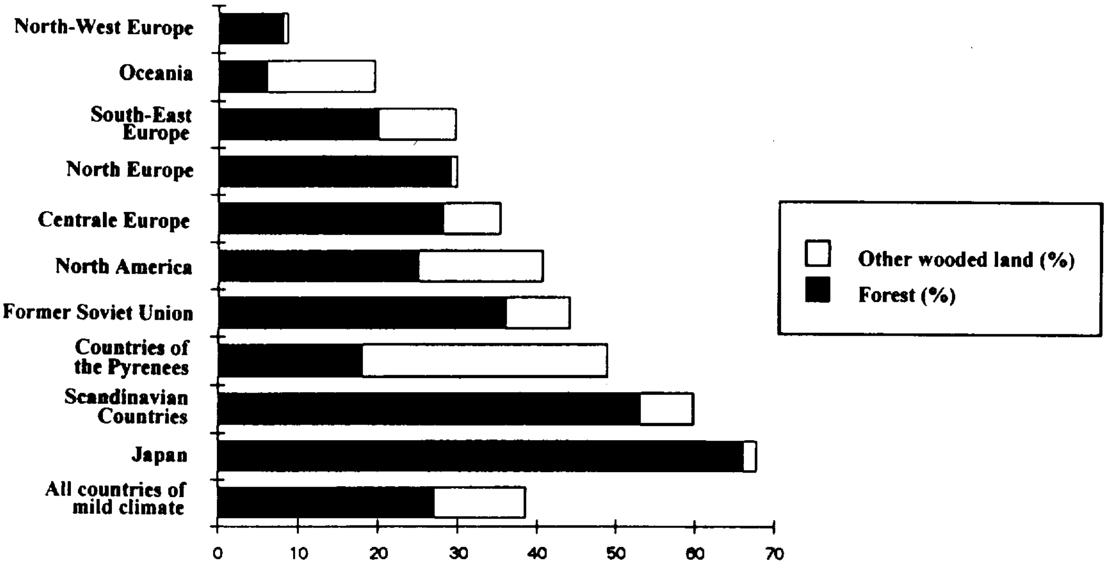
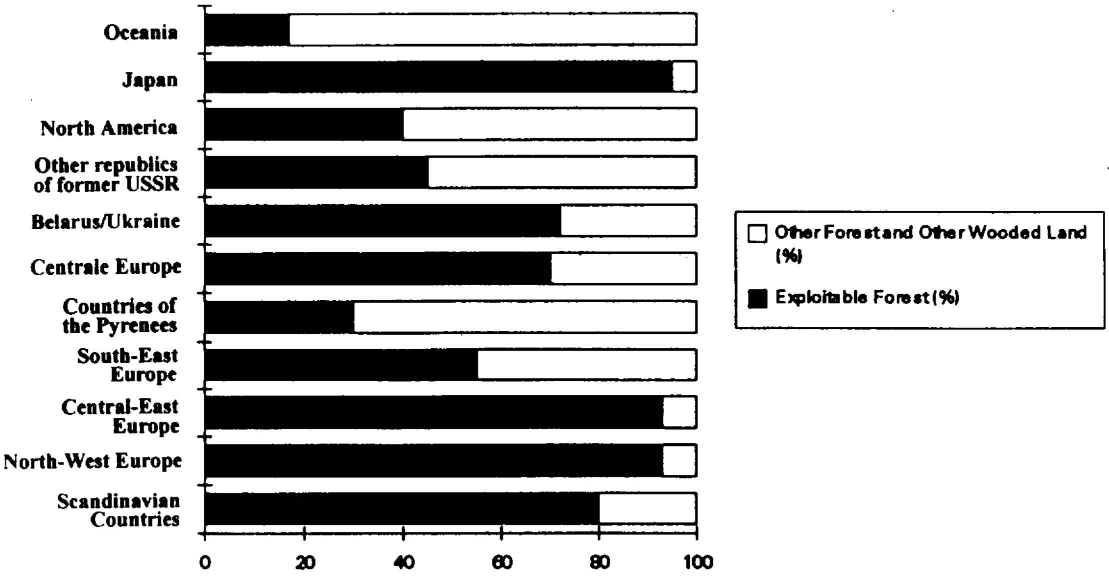


Figure VI. 4. Distribution of wood resources in exploitable forest in temperate climates



B. Problems to be solved and need for assistance

While there are some differences between the various economies in transition, for the most part similar things need to be done before renewable sources of energy can be developed:

- Dissemination of high quality professional, technical and economic information on renewable energy sources to ordinary citizens, businessmen, decision makers (the mayors of villages and towns and the chairmen of agricultural cooperatives), farmers and government officials.

- Creation and support of institutions that will be able to transfer information, know-how, new technologies and feasibility studies on renewable sources of energy on a professional level.

- Financial assistance for the organization of meetings, workshops and conferences about renewable sources of energy, especially in the languages of the transition economies.

- Training in the commercial management of renewable sources of energy and in marketing and computer skills for project evaluation.

- Initiation, creation and acceptance of new laws to support renewable sources of energy and to overcome the disadvantages they suffer relative to fossil fuels, which up to now have received more subsidies.

- Support for R and D and for NGOs and their activities in environment protection and renewable energy sources.

- International cooperation, exchange and transfer of information, and opportunities for experts from the transition economies to participate in R and D programmes and projects of the European Union and IEA.

- Financial assistance for projects to demonstrate renewable sources of energy.

- Overcoming price competition from developed countries by cooperating in the production of equipment for renewable sources of energy and taking advantage of idle industrial capacity and the low cost of labour in the economies in transition.

- Using the experience and assistance of countries such as Austria, Denmark, Finland, Sweden, the United States and other countries, which have achieved good results in developing a market for biomass energy, together with the relevant know-how and technologies.

C. Conclusions

In the transition economies, especially in the Russian Federation, there are forest biomass resources of world importance whose potential as a renewable energy source has not so far been realized.

The estimates of resources [4, 5] are trustworthy and objective because they were gathered in 1990, a time of economic stability in these countries. Now, gathering objective information is difficult, especially without knowing the Russian language.

Forestry and wood industry production has fallen 30-40 per cent during the past five years, as shown in the tables and figures. Data on fellings of wood in 1990 are an indication of the potential that could soon be achieved again or even exceeded.

Information about biomass as a renewable source of energy is inadequate, but it might be possible to fill in the gaps directly in the individual countries to estimate data with the help of the software "Biomass-toolkit for modelling of production and utilization of forest biomass as a renewable source of energy in a mild climate". The author has participated in software development in the European Union project JOULE II. Regardless of the present state of the transition economies, it is proposed to create a programme on biomass as a renewable source of energy, especially for the countries of the former Soviet Union, which will lay the groundwork for the use of biomass in these countries when their economies finally rebound.

This paper does not evaluate in depth the internal economic situation, especially in the former Soviet Union, where biomass resources are significant. It might, however, be possible to carry out the evaluation based on the current technical literature available in Russian and personal contacts with experts.

The Slovak Biomass Association, which is a member of the European Biomass Association, could serve as a mechanism for transferring information as its personnel have experience with biomass programme development in the former Czechoslovakia and a knowledge of the Russian, English, German and French languages.

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Part two

Technologies for biomass resource enhancement and conversion

VII. BIOMASS SUPPLY MANAGEMENT FOR ADVANCED ENERGY: APPLICATIONS IN DEVELOPING COUNTRIES

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Abstract

Advanced biomass energy systems, including new biomass resource enhancement technologies, should be developed only where compelling situations for investors or communities exist to economically do so. These situations, or minimum viable operating conditions, are assessed from a pragmatic perspective. They are determined by specific circumstances and divergent interests that take time to define and integrate. Customized solutions are necessary and can change quickly with geography and market circumstances New technologies offer more options but are not necessarily the best.

The example of energy crop technology is used to demonstrate the interdependencies that exist between new resource enhancement technology and biomass energy systems operations. The ability to genetically increase the energy density of energy crops is compared to other enhancement measures such as increasing the number of tonnes grown per hectare-year, reducing costs per tonne and improving other characteristics. Issues that need to be considered include significant knowledge gaps, lack of commitments in R and D, specificity of conversion system requirements, handling capabilities and opportunity costs.

Broader biomass procurement strategies, which may be more important than resource enhancement technologies, are discussed. Biomass cost-supply is utilized as a strong analytical feature to evaluate the effectiveness of biomass procurement strategies and new biomass production technologies. Some past experiences are reviewed. Cost-supply is assessed from the perspective of the whole biomass energy system to expose the interdependencies between production operations, conversion scale and technologies, and community markets and service. Investment limits, for example, may be as important a determinant as the cost-efficiency of a new technology, which, in turn, affects biomass cost-supply-quality requirements. The cost of new technologies can then be compared to the changed performance of the overall system.

Introduction

Biomass supplies must be evaluated, managed and improved to make advanced energy systems as profitable as possible. Supplying the biomass may account for more than half the costs of biomass energy projects. This means that the supply end of a project is at least as important as the conversion technology end. It is important that supplies be rigorously assessed for availability, quality, cost and risk when determining project feasibility. Minimum performance standards can be set, although much will depend on the site.

Enhancement of biomass does not simply mean producing more biomass. It also takes into account many facets of the overall energy system performance, especially profitability and service to communities. Several measures of performance may be used. The main ones are cost per unit energy (cost/kWh), profit margins and services rendered (both energy and non-energy services for fulfilling community needs).

This paper first discusses the implications of meeting overall measures of performance for energy projects through biomass supply management. Some of the important issues and some of the analytical approaches are summarized to address these implications. Most notable are cost-supply curves and fuel cycle evaluations. Logistics and handling are also addressed. This is followed by a pragmatic review of the role of energy crops in enhancing the performance of a biomass energy project. A prioritization process for selection of plant characteristics is reviewed to demonstrate the importance of maintaining an overall energy system perspective in the enhancement process. A set of general recommendations concludes the paper. Results are based on research and on project experience in North America, western and central Europe, India, southern China, Latin America and sub-Saharan Africa. Throughout the paper, financial and biological phenomena are presented as intermingled factors.

A. Effect of biomass supply on meeting customer requirements

The primary objective for developers of biomass energy projects is to profitably compete in an energy market on the basis of low cost, high market share, acceptable profit margin at a given level of risk and/or low transaction costs. To achieve this objective, three issues must be taken into consideration:

- Security of biomass supply (°minimize biomass costs, control and optimize supply).
- Realization of valued services and products (raise income and gain support for the project).
- Respect for the opportunity costs in a community (reduce negative community relations).

These issues were inferred from the benefits and challenges for biomass projects summarized in table VII.1. From these it is easily seen that most of the perceived benefits are related to the production of biomass and are difficult to value in the context of an energy project. Most of the perceived challenges, by contrast, involve markets, costs and the design and operation of systems.

Table VII. 1. Perceived benefits and challenges of advanced biomass projects

Perceived benefits	Perceived challenges
Return on marginal land	Hard to compete with fossil fuel
Meet soil stabilization needs	Hard to compete with food for land
Utilize wastes (revenue rather than cost)	Alternative values for biomass
Reduce net greenhouse gas emissions	Small cost reductions not much help
Rehabilitate/remediate soil	Small scale in national/regional planning
Locally produced (indigenous) fuel	Immature markets and infrastructure
Base-load capability	Local determinants and restrictions
Assist rural development goals	Industry/technology not coalesced

An evaluation of successful biomass energy projects around the world reveals the characteristics they generally have in common:

- They take advantage of some local circumstance or service needed by the community but unrelated to the energy market.

- They are located in places where energy services were unavailable, frequently disrupted or very expensive.

- A sizeable amount of very cheap biomass is available.

These characteristics, in combination with the benefits and challenges listed in table VII.1, suggest that purposeful and imaginative biomass supply planning tailored to local circumstances is essential for a successful project. Going one step further, it appears that to make biomass energy competitive, the project must co-produce some non-energy service that a community, government or industry is willing to pay for.

The implications of these conditions and objectives are strong and direct: if biomass energy is to compete in existing and future energy markets, the selling price of a unit of energy must be low.

In terms of biomass supply, this means that:

- The price per tonne of biomass must be lower per unit of usable energy than that of competing fuels and higher than that of competing biomass uses, and the biomass must be available in the quantities needed and at scales that attain desired conversion efficiencies.

- The supply must be continuous to enable full use of the conversion capacities (risks of supply disruption are low or consequences of disruption minimized).

- The biomass should be as homogeneous as possible to optimize conversion efficiency, preparation and handling and minimize cost.

- Costs and losses associated with biomass handling, transport and storage must be minimal.

- The quality of the biomass must meet minimum standards to be suitable for a particular kind of conversion equipment.

- A non-energy service must be involved for which someone will pay or that will in some other way make the biomass system more economically attractive.

Biomass markets and supplies can be controlled and enhanced using a number of tactics, some of which enhance the economics of the biomass supply and others of which address technical considerations. This combination approach is needed to convince investors that the system is both sustainable and profitable.

1. Economic enhancement measures

A number of tactics will enhance the economics of a project:

- Offer a price and delivery system that attracts biomass producers.

- Maintain control over enough biomass (for example, buy land and grow energy crops rather than buying them on the spot market) to minimize price fluctuations and disruptions from strikes and natural disasters.

- Apply pricing and procurement methods that minimize supply risks and flatten the cost-supply curve.
- Strive for improved homogeneity and the more profitable utilization of biomass supplies (implement standards in quality and measurement).
- Satisfy local, regional, national or international demand for non-energy services (waste disposal, environmental improvement, development objectives etc.).

2. Handling enhancement measures

The handling of biomass can be enhanced in a number of ways:

- Moisture reduction.
- Densification (baling, bundling, pelletizing etc.).
- Proper pre-sizing.
- Continuous harvesting and delivery (minimize storage).
- Homogenization and minimum fuel switching (minimize variation).
- Screening, separation and cleaning.

3. Biological enhancement measures

Biomass can also be enhanced by biological means:

- Energy content can be improved.
- Productivity per unit land area can be increased to minimize land requirements and reduce the cost per tonne.

B. Analytical approaches

Methods for analysing and enhancing the supply of biomass for energy are difficult to glean from the literature. One reason for this is that methods and their results quickly become proprietary for reasons of competition and profit. Another is that the economic, land use and biological conditions are so localized when it comes to biomass supply that analytical methods are quickly adapted to local conditions. In most cases, the need for very specific geographic information adds significantly to the cost of evaluations, leading sponsors to pool their efforts to acquire such information.

1. National and regional approaches

National and regional methods for analysing and enhancing the supply of biomass [1, 2, 3, 4, 5] involve integrating data from very diverse sources into geographic information systems [6]. These methods are used for biomass inventory, renewability, cost and logistical considerations. Satellite and remote imagery, maps, biomass business statistics, market information on energy and land use and computer software for analysing transportation systems are used for larger scale analyses. For such analyses, the challenge is to get up-to-date, accurate information at the appropriate resolution and scale.

Because biomass supply is largely determined by local factors, national and regional analyses must be seen only as broad indicators of supply and cost.

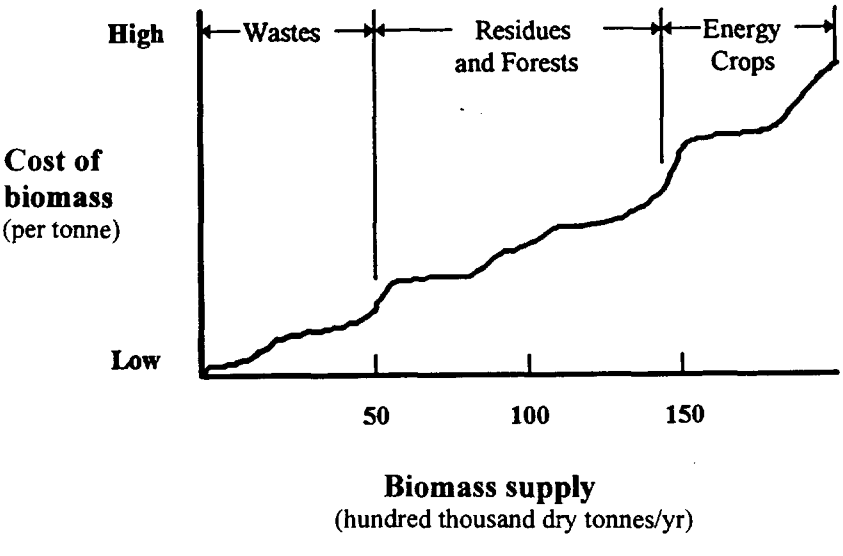
Such analyses allow the application of coarse criteria for identifying areas where evaluations should be carried out. They may also allow estimating the potential for biomass energy, although the margin of error can be quite large. The reasons for such error are that biomass usually cannot be economically hauled long distances, making it difficult to capture biomass resources, and information is scarce on providing biomass for advanced biomass energy systems and on opportunities to provide non-energy service that would be of value in a particular locality.

2. Biomass cost and supply

Local or site-specific methods are the focus of this review: cost-supply curves [3], sensitivity analyses [7], evaluations that recognize opportunity costs [8] and supply logistics methods [3].

Usually the cost of biomass increases as the amount of biomass needed increases (see figure VII.1), because the cheapest biomass is used up before purchasing progressively more expensive biomass to meet demand. On-site wastes are purchased first, then wastes from other nearby industries. If more biomass is needed, it may be collected from fields and forests as residues in connection with other operations. Finally, standing forests and dedicated crops or portions of crops may be purchased.

Figure VII.1. Hypothetical cost-supply curve with likely position of various categories of feedstock



The cost-supply cost relationship can help to determine the effects of various supply strategies and tactics on the overall cost of biomass. For example, the payment of transportation costs on delivery gives the closest supply of biomass no advantage over a more distant supply. Such a tactic maximizes the area for purchasing biomass, reduces disruptions in supply and makes it easier to force suppliers to compete and keep prices down.

Using the same cost-supply relationship, the cost of special conditions imposed on the collection of biomass, such as environmental requirements or transportation taxes, can be quantified. Other imposed conditions may include biomass standards or limits on the number of suppliers. These conditions recognize quality limits (or incentives) and transaction costs, respectively. Cost-supply curves can also help to quantify the financial benefits of various government-support programmes in several sectors (e.g., energy, agriculture and the environment).

Some variations of the cost-supply approach are necessary to accurately assess the value or quality of the delivered biomass. For example, some biomass may require special handling equipment, an expense that must be taken into account. High-quality biomass (with a low moisture content, high energy content and low ash content) will bring a higher price.

3. Integrated assessment framework

An integrated assessment framework such as the ones discussed by Perlack and Ranney [6] and others [9, 10, 11] is needed to capture the local intersectoral dynamics (e.g. energy, agriculture, environment and development) that determine the feasibility of a biomass energy project. This framework must be able to assess a biomass energy system as an integrated whole system with three components: biomass production, logistics/transport and biomass conversion. The framework must also be able to address implementation and sustainability issues, including energy/economic issues, institutional/social issues and environmental issues. Tables VII.2 and VII.3, modified from Perlack and Ranney [7], identify the general areas of assessment. Each area has a specific set of analytical tools, which cannot, for lack of space, be described in this paper. The conclusion, however, is that the application of such analytical frameworks requires multidisciplinary teams with expertise in agriculture, forestry, economics, energy and the environment.

Nearly every component listed in the two tables in some way affects biomass supply, through either management practices or costs. The improvement of energy crops as a dedicated fuel supply is discussed next.

Table VII.2. Components of a framework for assessing an integrated biomass energy system

Biomass production	Logistics/transport	Biomass conversion
Accessible land base and land uses	Biomass access	Local and regional demand, use and timing for energy
	Road conditions	
Existing supplies of suitable quality and availability	Hauling distances	Choice of technology (efficiency, scale, cost, availability of equipment, repairs)
Assessment of site qualities (rainfall, soils, elevation, slope)	Storage and storage losses	
Productivity	Fuel preparation and quality	Operational aspects (capacity factor, assurance of supply, local control and management)

Biomass production	Logistics/transport	Biomass conversion
Environmental benefits (afforestation, soil stabilization, CO_2 and warming, biodiversity, soil rehabilitation) Species improvement Vegetation management practices	Co- and by-products Vegetation management practices and adjustment with hauling distances Alternative supplies Cost-supply dynamics Methods/equipment	Grid integration

Table VII.3. Components of a framework that addresses implementation and sustainability issues

Energy/economic	Institutional/social	Environmental
Minimum financial and economic returns Food and fuel competition Power sector/energy resource planning issues Integration of energy into distribution systems Constraints to deployment Arrangements (financial, land tenure and extension) to procure biomass Integrating activities based on fuel cycle to achieve best benefits Financing Biomass purchasing tactics	Amount of change required due to interactions among resources, technology, policies, markets and culture Identification of lead institutions Assisting institutional development Examination of regional and local development and environmental programmes Obtaining support at national, regional and local levels Role of NGOs and donor organizations Specific assurances and data required by investors Procurement system	Soil stabilization Use of diverse plant materials to aid environmental resiliency and diversity Nutrient depletion and conservation Chemical use Biodiversity and habitat conservation Non-point source pollution Protection of existing habitat Land restoration and soil habilitation Waste treatment and disposal

C. Enhancing energy crops for improved supply and system performance

In 1991 and 1992, international experts, principally tree geneticists experienced in wood energy crops, participated in IEA workshops on feedstock quality [12]. The output of the workshops involved developing a systematic approach to identify the most important ways in which biomass characteristics might be modified. Many considerations were involved, such as the ability to change a characteristic, the extent to which it could be changed, the effort required to do so, the probability of transferring unwanted characteristics in the process and the net improvement to the overall performance of the biofuel system.

Table VII.4 lists desired performance-related characteristics at different stages of the biofuel system. To simplify the evaluation, some social and community benefit issues were not included. The specialists had already reviewed the potential to alter the characteristics of short-rotation woody crops at previous meetings [13]. These are listed in table VII.5. Their estimates of the extent to which some of these characteristics could be changed are presented in Table VII.6.

Table VII.4. Desired performance-related characteristics at different stages of the biomass energy production and conversion system

Stage	Characteristic	
Propagation	Ease/cost	Vigorous material
	Disease-resistance	Accurate genetics
	Freedom from disease	
Land acquisition	Fair to good agricultural quality land	
Establishment	Fast growth	Low chemical emissions
	Drought tolerance	Low erosion
	Soil structure tolerance	Competition control
	Improved water quality	
Maintenance and growth	Low chemical emissions	Low cost
	High site quality	Wildlife habitat
	Fast growth	Pest resistance
Harvest, handling, field storage and procurement	High harvest index	Low storage losses
	Residue management	Low moisture content[a]
	High density	Long harvest window
	Straight boles	Few, small limbs
Facility storage, delivery and pretreatment	Low storage hazard	Low abrasion
	Constant supply	Clean material
	High density	
Conversion treatment	Homogeneous material	Low alkali metals
	Low ash content	Low water requirements
	Low heat requirement	High wood qualities[a]
	Low pesticides	Minimum/usable nutrients
	Low sulphur, nitrogen, VOCs	
Waste disposal	Low non-CO_2 emissions	Inert solid wastes
	Small waste quantity	Liquid treatment ability
End-use	Low S, N, Cl, VOC emissions	Low CO emissions
Financing	Substantiated performance data	Accurate cost data

[a] Objectives will vary for thermal, thermochemical and biochemical conversion processes.

Table VII.5. Wood characteristics that can be changed by genetic manipulation to realize an improved biofuel system performance

Characteristic	Linked qualities
Moisture content	Specific gravity
Specific gravity	Moisture content, lignin content
Lignin content	Moisture content
Cellulose content	Lignin content
Hemicellulose content	
Hemicellulose quality	
Ash content	Ash quality
Ash quality	Ash quantity
Bark content	Ash quantity, volatiles
Limb architecture	Bark quantity, nitrogen content
Nitrogen use efficiency	
Nitrogen content	
Heavy metals	Ash quality
Drought tolerance	
Wetness tolerance	
Pest resistance	
Herbicide tolerance	
VOC emissions	Bark content
Fibre length	

Table VII.6. Summary of the ability to genetically modify selected characteristics of woody energy crops listed in order of their priority for attention

Characteristic	Existing condition	Estimated change	Best methods
Specific gravity[a]	0.37	0.03	Breed/selection
Lignin quality[b]	100%	7%	Genetic engineering/breeding
Hemicellulose quality[b]	100%	7%	Genetic engineering/breeding
Bark content[c]	5%	1%	Silviculture/breeding
Hemicellulose content[d]	23%	2%	Species selection
Physical properties[e]	100%	4%	Selection/silviculture/breeding
Moisture content[f]	115%	15%	Selection/breeding
Ash content[g]	1.6%	0.3%	Silviculture/breeding
Extractives[h]	4%	1%	Selection/breeding/silviculture
Uniformity[i]	100%	10%	Silviculture/breeding
Lignin content[j]	20%	1%	Breeding
Cellulose content[j]	48%	1%	Species selection/silviculture/ breeding
Calorific value (kcal/kg)[k]	3,500	50	

Note: The characteristics in this table have qualities that can be numerically estimated. These numeric qualities are listed under the columns "Existing condition" and "Estimated change". Existing conditions refers to the qualities of that particular characteristic as it exists today. Estimated change indicates what geneticists and wood technologists believe they can accomplish in desirable change before diminishing returns are reached in the desired wood quality, before the survival and health of the tree is threatened, or before the cost of achieving the change becomes prohibitive.

[a] The present average specific gravity of *Populus* grown in plantation conditions is about 0.37. Through breeding and genetic selection, this can be raised to 0.40 relatively easily. This is an estimated change of 0.03 in the specific gravity of the wood.

[b] Lignin and hemicellulose are made up of many component chemicals whose contribution to energy content are significant. Lignin is energy-rich compared with cellulose and hemicellulose. Hemicellulose is more energy-rich than cellulose. One would want to change these to either have more energy or to have a larger component convertible to fermentable sugars. Based on energy research on lignin and hemicellulose qualities, it appears that for energy purposes both may be genetically changed by about 7 per cent up or down (depending on the quality in question) over what is found today in hybrid poplar. This is a change in chemistry, not quantity. The table uses 100 per cent as today's number.

[c] Bark is energy-rich because of the various extractives it contains. It also contains much ash. Research is looking at how to reduce bark content. Assuming plantation-grown trees as a basis, the bark content may run about 5 per cent of total materials by volume with mature short-rotation trees. By developing better tree architecture, selecting trees with thinner bark and using careful silviculture methods, the bark content might be reduced to 4 per cent. This is a reduction of 1 per cent by volume, or a 20 per cent reduction in bark.

[d] Hemicellulose is a varied group of materials that is neither lignin nor cellulose but something in between. It appears possible to increase hemicellulose content at the expense of cellulose to increase energy content. Using a base for wood of 23 per cent hemicellulose, it seems likely that hemicellulose could be raised to 25 per cent, an increase of 2 per cent.

[e] Wood density, porosity and cell structure affect the way wood reacts in being converted to energy. This is especially important in the biochemical processes. Through classical genetic processes and silviculture, these physical properties may be modified to improve conversion reaction processes by perhaps 4 per cent over existing levels.

[f] Moisture content in trees is highly variable but also genetically controlled to an extent. On a dry weight basis, wood may be more than half water (more than 100 per cent). Since this is an added useless weight for transport, any reduction is desirable. Through breeding, geneticists believe a 15 per cent reduction in moisture content is possible.

[g] The amount of ash in wood is somewhat consistent at 1.6 per cent. Genetic alteration of trees may be able to reduce this to 1.3 per cent, which is a physical reduction of 0.3 per cent, or a relative reduction of about 18 per cent. Since ash represents a disposal problem, 18 per cent less ash is a significant help.

[h] Extractives are a series of chemicals in wood and bark that can be removed (extracted) by water or selected chemicals. It would be helpful to either reduce or increase these depending on the energy conversion process. The present level of extractives is about 4 per cent, and geneticists believe this could be reduced or increased to 3 per cent or 5 per cent, respectively, depending on objectives. This is a 1 per cent change in the actual content of extractives in the wood, or a relative change of 25 per cent.

[i] Wood is not wood. It varies with respect to moisture content, ash content, amount of rotten material, dirt, ash quality and several other qualities. These vary by season, source of wood, storage method etc. Through careful management, this variability can be reduced. Homogeneous wood over time allows conversion technology to be geared for greater efficiency. All practical issues considered, homogeneity may be improved by perhaps 10 per cent over existing situations. In the table, the existing condition is taken as 100 per cent for lack of a better unit.

[j] The amount of lignin and cellulose in wood is about 20 per cent and 48 per cent, respectively. A lot of work has gone into changing these because of their importance to the fibre industry. However, it appears that a 1 per cent change is about all that is likely. That is, lignin and cellulose could be changed to 19 per cent and 49 per cent, respectively.

[k] The energy value of wood is quite consistent at about 3,500 kcal/kg. For combustion technologies it would be desirable to raise this number. However, the outlook is that an increase of 50 kcal/kg is possible, which is only about a 1.4 per cent change.

Several objectives stand out:

- Low storage losses.
- High productivity.
- Increased pest resistance.
- Adaptability to dry sites or wet sites.
- Reduced erosion hazard.
- Less chemicals used (fertilizers/pesticides).
- Improved harvest efficiency (stem architecture).
- Higher ethanol yield (components capable of being converted to fermentable sugars).
- Improved thermal efficiency (high energy content, low oxygen, low ash).
- Reduced emissions of nitrogen oxides (NO_x), volatile organic compounds (VOC) and sulphur oxides (SO_x).
- Sustained productivity at a site.
- More biodiversity.

It is important for the evaluation that the biofuel system should be characterized by stages, that the objectives for each stage should be fairly detailed and that any particular activity subject to change should be assessed against all objectives, not just the objectives of the stage of immediate concern. Although the manipulation of short-rotation woody crop characteristics was chosen as the example, the activity could just as easily have dealt with biomass receiving equipment, procurement tactics, storage techniques, biomass pretreatment or any one of a number of activities in a biofuel system.

The framework for biomass supply enhancement can thus be reduced to the following: (a) a detailed characterization of the stages in a biofuel system, (b) a set of specific objectives for all stages and sub-stages, (c) an assessment of the potential to change particular activities or conditions along the biofuel system (and the cost of doing so) and (d) an optimization process to improve the performance of the entire system.

Table VII.5 shows how biomass qualities can be changed by the management and/or selection of plant materials. Table VII.6 goes on to estimate the change that can be achieved by directed efforts. It does not compare the time and expense of genetic engineering, for example, with that of classical plant selection to achieve changes in characteristics. This can be quantified and was considered when prioritizing characteristics for change.

Each of these characteristics was compared to each of the objectives in table VII.5 to ascertain its contribution to meeting overall performance requirements at a given cost, given the expected level of improvement in the characteristic. The priorities will vary somewhat with the specific conversion technology, especially between biochemical and thermochemical technologies.

From this evaluation of supply enhancement, it could be seen that the dominant performance issues for both thermochemical and biochemical conversion systems were the transport limitations of the system. If biochemical technologies are involved, the chemical qualities of the biomass become extremely important. If other technologies are involved, the energy content and the bark content are most important.

From experiences in developing countries, issues other than energy qualities may be the most important concern, especially for meeting the subsistence needs of farmers. In India, the use of agricultural residues [14] and the production of energy crops for advanced biomass energy systems [15] was less important than meeting the farmer's need for fodder and for household fuel. The livestock were the means of cultivation and a source of energy (from dried dung), milk products and hauling power for farm produce. Any production of energy crops or utilization of residues had to respect the need to meet fodder requirements. In Armenia, where farms are very small, a family's livelihood is dependent on gaining practically every living requirement from those few hectares. Dedicating land to energy crops made little sense from the farmer's perspective. In Armenia and China [8], government land (large consolidated landholdings) could be devoted to energy crops, but in some places in India the landholdings were too small and the opportunity costs too high.

These issues of landownership are mentioned to demonstrate the importance of socio-economic circumstances to biomass supply enhancement. Variations of these concerns emerged with respect to municipal waste disposal in Armenia, China, India and the United States, but only in specific locales. Such waste could be used as a fertilizer for growing energy crops, which would at the same time solve the problem of satisfactory treatment or disposal. Any evaluation of biomass supply enhancement will need to include development (socio-economic) and environmental objectives in the evaluation process [16, 17].

D. Summary and conclusions

A framework for enhancing biomass supplies for energy is loosely presented from the perspective of overall biofuel system performance, not just enhanced quantities of biomass. The framework is quite complex, but it can be simplified to meet the needs of specific projects, which usually depend on the anticipated scale of operations and associated investment requirements. This framework involves (a) a characterization of the entire biofuel system (i.e. the identification of stages and sub-stages) and aspects of affected sectors (e.g. energy, agriculture, the environment and development), which are listed in the paper, (b) the development of the main performance requirements or desired conditions for each stage and sub-stage and (c) an evaluation or optimization process in which each contemplated change in the biofuel system is assessed against multiple objectives. The methods for doing this have not been clearly spelled out and can vary substantially by region, conditions, level of detail desired to satisfy investors and professional discipline. Biomass cost-supply curve analyses are suggested as a place to start, although it is realized that biomass qualities may also need to be assessed.

The potential modification of short-rotation woody crops is considered in order to demonstrate the analytical framework: the biofuel system is first characterized, the objectives at different stages in the biofuel system are identified and the ability to change wood qualities is assessed. In the example, expert opinion was relied on to simplifying the optimization process. However, economic and operations research techniques exist to conduct more rational evaluations.

Although the framework continues to evolve, its specificity is hampered by the need to keep it adaptable to specific projects and circumstances. Cross-disciplinary expertise is essential, as is a perspective that looks at the performance of the whole biofuels system.

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VIII. BIOMASS ENERGY RESOURCE ENHANCEMENT: THE MOVE TO MODERN SECONDARY ENERGY FORMS

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Abstract

Income growth and industrialization in developing countries is driving their economies towards the use of secondary energy forms that deliver high efficiency energy and environmentally more benignend-uses for biomass. Typical of these secondary energy forms are electricity, distributed gas systems and liquid fuels. This trend suggests that the hitherto separate pathways taken by biomass energy technology development in developing and industrialized countries will eventually share common elements. While in the United States and the European Union the majority of the bioenergy applications are in medium- and large-scale industrial uses of self-generated biomass residues, the characteristic use in developing countries is in rural cook-stoves. Increasing urbanization and investment in transportation infrastructure may allow increasing the operational scale in developing countries. One factor driving this trend is diminishing individual and household biomass resource demands as rural incomes increase and households ascend the energy ladder towards clean and efficient fuels and appliances. Scale increases and end-user separation from the biomass resource require that the biomass be converted at high efficiency into secondary energy forms that serve as energy carriers. In middle-income developing country economies such as Brazil, secondary energy transmission is increasingly in the form of gas and electricity in addition to liquid transportation fuels.

Unfortunately, the biomass resource is finite, and in the face of competing food and fibre uses and land constraints, it is difficult to substantially increase the amount of biomass available. As a result, development must emphasize conversion efficiency and the applications of bioenergy. Moreover, as a consequence of economic growth, biomass resources are increasingly to be found in the secondary and tertiary waste streams of cities and industrial operations. If not used for energy production, this potential resource needs to be disposed of in some other manner owing to its negative environmental impacts.

The development cycle for biomass thus moves in a stepwise fashion. The first step is the gathering of wood and agricultural residues by families for cooking, heating and lighting. Next, investments are made in anaerobic digesters, which simultaneously address energy, environmental and hygiene needs, and in efficient wood- and straw-fired stoves, which improve the indoor air environment and reduce the depletion of forests for fuelwood. The final stage is the village-scale operation of digesters and gasifiers that provide distributed gas to households and enterprises not necessarily associated with agricultural or forestry activities. At this stage, industries that process biomass into pulp, paper, lumber and sugar (from sugar cane) can move from being merely self-sufficient in process heat needs to becoming significant exporters of electrical energy into the regional and national grids. The key to all these advances is the availability of highly efficient, environmentally sound and economically viable conversion technologies.

Introduction

In industrialized countries that are members of OECD, the use of biomass as a direct fuel in the household has diminished considerably, while the use of residues generated in biomass-based industries such as pulp and paper by the industries themselves has increased significantly. The former decrease in use has resulted from the increasing urbanization of OECD societies and the latter increase in use from economic and environmental pressures. A recent trend has been the production from biomass of electricity and liquid fuels that are marketed into the general energy economy. In the United States, for example, 9 GW of grid-connected electricity are being generated from a variety of biomass resources, ranging from sawdust and wood residues from lumber mills in CHP (also known as co-generation) installations, to the use of agricultural residues and the clean fraction of the urban solid waste stream in stand-alone generating stations. Since 1980, the production of ethanol from maize in the United States has increased to 5.3 million m^3 (1.4 billion United States gallons per year). It is used in gasoline blends to mitigate air pollution in urban areas. Around the world, CHP systems are increasingly being installed in biomass-residue-generating industries. Thus, rice husks, sugar cane bagasse and wood and pulping residues are used to generate electricity. Animal wastes and industrial process effluents are increasingly being used to generate methane in anaerobic digestion. The resulting secondary energy forms–electricity, methane and liquid fuels–are then marketed into end-user sectors distant from the biomass resource.

As the use of secondary energy forms increases and more efficient, less environmentally damaging conversion technologies are developed, there is a general appreciation that conversion technologies are the key link in the management of integrated biomass materials flow in modern economies. The biomass resources are energy crops, crop residues process residues and the clean, biomass-derived residue streams from mankind's urban activities. Modern conversion technologies facilitate the production of secondary energy forms that can be used in rural, urban and industrial end-use sectors. An integrated biomass materials management system such as that just described pertains predominantly to urbanized countries in North America and Europe.

In developing countries, where the population is mainly rural, another system of biomass materials management prevails. In these countries, the household and the village are the management unit for their own fuel needs, which usually involves the direct combustion of biomass in cooking and heating stoves. However, the demand for secondary energy forms in developing countries is increasing rapidly. At the same time, there is an ever-increasing need to conserve the biomass resource in the face of pressure for wood and fibre products, food and energy.

This paper explores the application of advanced biomass conversion technologies to socio-economic development. These technologies allow the production of secondary energy forms with much higher end-use efficiencies. This, in turn, enables finite biomass resources to be used more efficiently to generate energy as well as to play their traditional role, as sources of food, fibre and materials.

Several modern, efficient and environmentally sound biomass conversion technologies are becoming available. These include advanced combustion systems, gasification and pyrolysis, and bioconversion to ethanol and to methane. For the purpose of this paper, one technology, biomass gasification, will be examined in the context of socio-economic development, at both village and industrial scales. This will facilitate discussion of the linkage between practice in developed countries and the application of that practice in developing countries. The examples herein describe applications that can be foreseen in the near term. We describe in some detail the technological evolution proposed, since it is paramount, in the course of developing bioenergy, that end-use services (i.e. heat, light and power) should be as economical as possible.

A. The village scale

In many developing countries electricity is in short supply. Peak demand deficits of 10-20 per cent are common, and significant fractions of the population are not served with electricity at all. Recent data [1] show that while more than 80 per cent of the urban population in developing countries have access to electricity, less than 60 per cent of those in rural areas have access. Even though many rural towns and villages are connected to the electricity grid or are served by stand-alone diesel generating systems, the supply of electricity is intermittent, unreliable and of poor quality. As a result, the villages still rely on dry cell batteries for radios, kerosene for lighting and biomass fuels for cooking. In most rural areas, there is an apparent deficit of biomass; fossil fuels must be obtained to satisfy even daily living needs. However, if more advanced technologies were applied, the biomass supply in many areas (from agricultural residues and sustainable fuelwood) would be adequate not only to satisfy these daily living needs but also to provide excess energy for labour-saving appliances, telecommunications and light industry. Unfortunately, this is not yet achievable.

1. Plotting a rural energy trajectory to demonstrate the potential of advanced technologies to serve all energy needs

China and India have the world's largest rural populations, 70 per cent of their combined population of 2.2 billion. Most of these people depend on biomass for the bulk of their daily living requirements. To show the role that advanced technologies could play in such a setting, the following section outlines a series of incremental investments that could bring a typical village from being a net energy importer with a low level of energy services to one that uses its biomass resource base to become energy self-sufficient, satisfy modern expectations of energy service and perhaps even export energy.

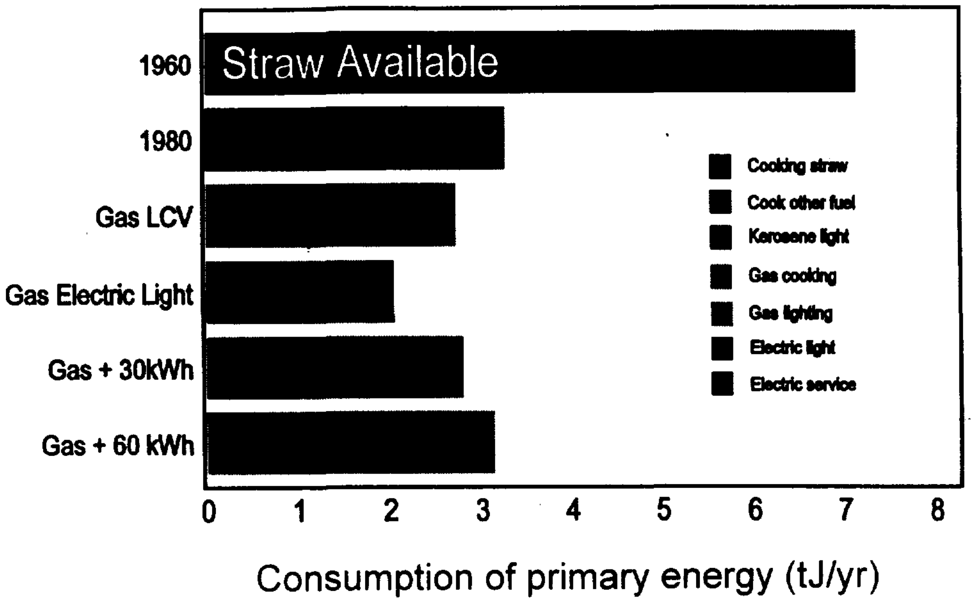
2. Jincunzhuang village: high conversion efficiencies at small scales

To illustrate both the current situation and the potential of biomass at the village scale, this section discusses a hypothetical village situated in south-eastern China in a region of double cropping (winter wheat and summer maize), a situation typical in the provinces of Shandong and Jinan. The hypothetical village of Jincunzhuang has 97 households (about 300-350 population) and access to approximately 20 ha of arable land. In this highly productive region the annual straw production (wheat straw and maize stover and cobs) is about 15 tonnes per ha, leading to an annual energy supply capability of 4.66 TJ. Today, the bulk of this residue is used for cooking and some surplus is burnt in the fields owing to the lack of effective conversion technologies. This was not always the case. The development of the biomass energy system for Jincunzhuang will be described in terms of its evolution starting in 1960 to its projected status in the year 2000.

(a) Jincunzhuang in 1960

In 1960, the available conversion technology was essentially an open fire (the three-stone stove) or a primitive cook stove with an efficiency of 10-12 per cent in delivering fuel energy to the cooking pot. As a result, the daily demands for cooking energy (approximately 19 MJ per household) could not be met from indigenous resources, and the village had to gather fuelwood, purchase coal or do without cooked meals. This last option was common; it is estimated that many households were short of fuel for as much as three to four months per year [2]. This can be seen in the first bar of figure VIII.1, which shows that, because of the low efficiency of cooking, as much as 25 per cent of the annual cooking fuel demand had to be satisfied by another fuel. It is assumed that lighting was provided for 6 hours per day by four kerosene wick lamps consuming about 0.75 l of kerosene per household each day. This level of lighting service would deliver only about 1,200 lumens (lm).

Figure VIII.1. Technology makes for better energy service: Jincunzhuang village



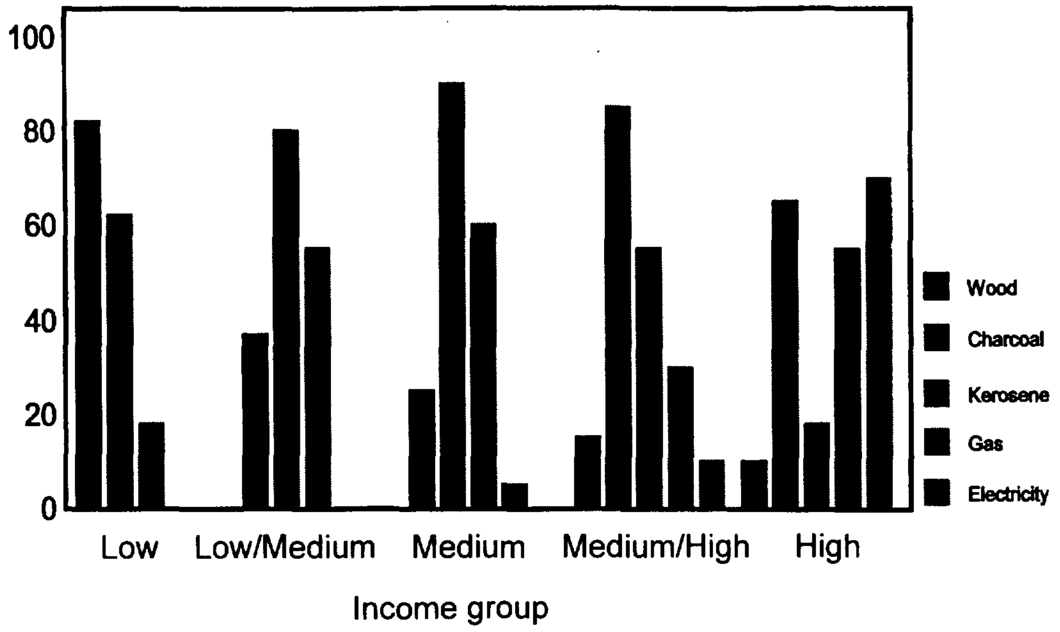
(b) Jincunzhuang in 1980

The chronic fuel shortage in developing countries and the rural population's inability to purchase fuels spurred governments and NGOs throughout the 1960s, 1970s and 1980s to develop improved cook stoves and the social structures and systems for their rapid diffusion. Though this development was not without its set-backs, it eventually succeeded in many countries through the efforts of women's groups and government and non-governmental organizations [3]. In China, a little known stove programme developed the most extensively diffused stove model of all, the Chinese improved cook stove, which has an efficiency of 20-40 per cent. This stove has been distributed to over 140 million households, or more than 70 per cent of all rural households in China [4]. Most of them were installed in the 1980s, as shown in figure VIII.1, where a look at the data for 1980 shows that the entire annual cooking demand for Jincunzhuang could be satisfied by 50 per cent of the annual straw production, leaving a surplus and eliminating the need to purchase fuels or take fuelwood from the surrounding regions. In regions with less arable land per household or limited biomass productivity (e.g. lack of irrigation, short season), supplementary fuels would still be required.

(c) Jincunzhuang in 1995

It is well known that as incomes rise in developing countries, the cooking fuel preference quickly changes from self-gathered wood and straw to purchased charcoal or kerosene. Increasing affluence, especially among urban dwellers, leads to the use of liquefied petroleum gas (LPG) and natural gas or, where electricity is ample, electric cook stoves. While this transition is very complex and poorly understood, the factors that affect a household's shift to modern stoves and clean, efficient secondary fuels include household income, fuel-producing assets such as woodlots and animals (anaerobic digestion), reliability of access to modern fuels, the relative costs of not only the fuels but also of the appliances, the educational level of the household, cooking habits, division of labour and the control of finances [5, 6]. Figure VIII.2 quantifies the anecdotal knowledge base for five medium-size towns in Kenya in the 1980s. A survey by the Surrey Energy Economics Centre shows that high-income households have the choice of several different fuels and cooking appliances.

Figure VIII.2. Ascending the energy ladder: Kenyan fuel use by income

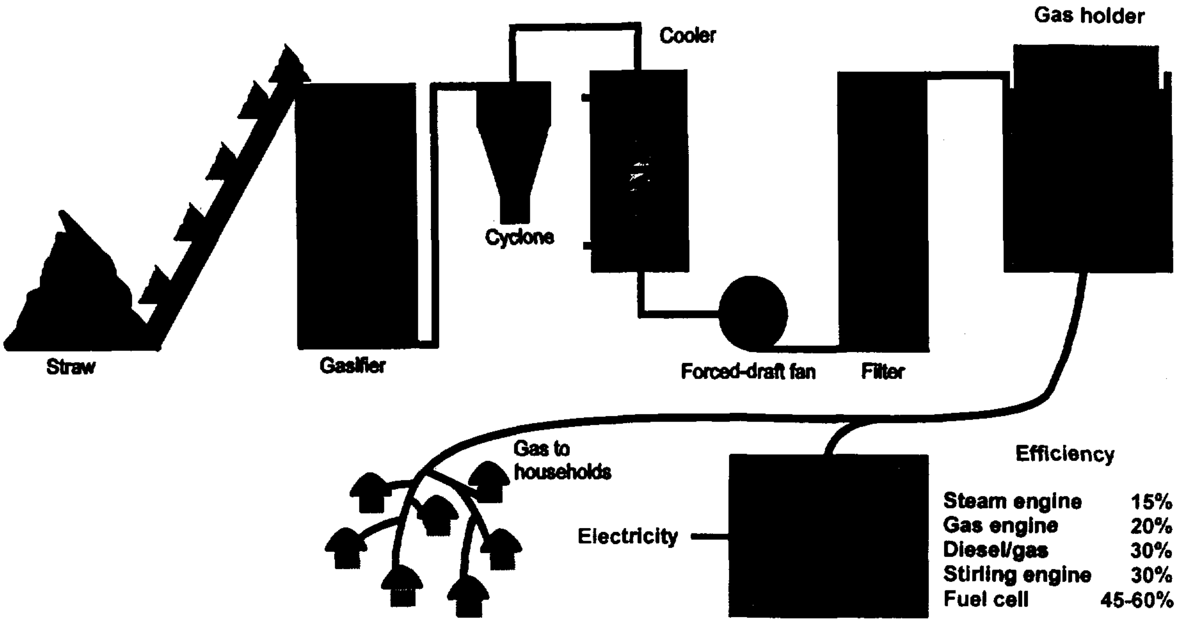


Source: OTA-E-486.

The rural user rarely has access to natural gas pipelines or LPG distribution, making the use of these clean, efficient energy sources unlikely. Such a user would benefit most from more efficient straw conversion through thermochemical gasification and the production of a gas that is distributed through a local grid to each household. Such a gasification scheme has been demonstrated by the Shandong Energy Research Institute at Huntai village in Zebo County. The XRF-1 gasifier (figure VIII.3) furnishes gas to 97 households [7]. It uses agricultural residues such as maize stover and operates on a continuous basis with chopped stalks, typically, for about 4.5 hours per day, since the operating rate of the gasifier is high. The gas is stored in a large gas-holder so that the peak demands at the three mealtimes each day can be satisfied. Though in the current demonstration project straw gasification meets only the cooking demand, the third bar of figure VIII.1 illustrates an option in which agricultural residues are gasified to produce gas for both lighting and cooking, allowing the village to become independent of kerosene lamps.

Typically, mantle lamps operating on gas or pressurized kerosene give 1.5-2 lumens per watt of energy input [8, 9], making them 10 times more efficient than a kerosene wick lamp: for half the energy input of the kerosene wick lamps, approximately 6 times the lighting service can be obtained. In this example case, Jincunzhuang would be able to use about 60 per cent of the straw and eliminate the majority of the kerosene purchases.

Figure VIII.3. Village thermal gasification system in a Chinese village



(d) Jincunzhuang after 2000

The availability of distributed gas and of an efficient and proven gasifier for the conversion of agricultural residues such as maize stover and cereal straw could solve the problem of producing electricity at the village scale and allow the very efficient use of the biomass resources. Figure VIII.1 contains three entries (bars 4-6) for the production of electricity from the village gas system. The first of these is based only on replacing gas-fired mantle lamps by energy-efficient fluorescent lamps in each household. It is estimated that fluorescent lamps would demand 300-400 Wh of electricity per household per day. A six-hour period of lighting demand would be satisfied by an electrical generator of 5-6 kW. Thus, the generator output would provide electricity to all of the households, would reduce the straw demand for lighting by about 70 per cent as compared with the gas-mantle case, and provide each household with 30 per cent more lighting service. The generator could be a spark ignition engine, which has already been demonstrated on low-energy-content gas in China [7]. The overall efficiency in going from gas to electricity is assumed to be 20 per cent. To satisfy community needs at a minimum level, including some lighting and a television set, a radio and perhaps a refrigerator, about 30 kWh per month per household would be needed (figure VIII.1, bar 5). At a gas-to-electric conversion efficiency of 20 per cent, this load increases the straw demand to 2.8 TJ, a level similar to the gas mantle lighting option. Increasing the level of service to 60 kWh per month per household would require a more efficient prime mover having a capacity of 30-40 kW and an efficiency of 30 per cent or better from gas to electricity (bar 6).

3. Prime movers for the village scale

The efficient conversion of low-energy-content gas to electricity must take into account the characteristics of the gas and its effect on the functioning of the engine. Although gasifiers were used on vehicles during war-time fuel shortages [10], gasifier engine combinations have not been very successful [11]. A notable exception is the 160 kW Chinese system based on rice husks, which, however, has not been commercially available in recent times [12]. Most gasifier engine combinations have been close-coupled and have used the engine to provide a vacuum to pull the air-gas mixture through the gasifier. In the village energy system proposed, the gas would be cleaned and cooled prior to storage and the prime mover would be coupled to the gas system after storage. Since it would no longer be close-coupled to the gasifier, the engine could be installed where the energy in the exhaust could be used to heat water for households and industries.

The efficiency of the prime mover will have a significant effect on the biomass demand as the use of electricity grows. At a small scale, systems with better than 30 per cent efficiency are desirable. If possible, these systems should not use fossil fuels for pilot ignition although, as an interim step, the use of modified diesel engines would allow dual fuel operation as well as efficient gas use.

New technologies offering high efficiency in going from a low-energy-content gas to electricity include both Stirling engines and fuel cells. At present, these technologies are both expensive and just completing their development cycles. Both would be cheap if the fixed costs of establishing manufacturing facilities could be spread over a large number of mass-produced units, either for the developing country village electricity market or, in the case of fuel cells, for transportation use. This last application is close in power output to the suggested village energy system, since small passenger automobiles are often in the 30-40 kW power range.

B. Industrial-scale biomass-fuelled combined heat and power production

Efficient bioenergy production schemes can also be used in the major agricultural commodity sectors and the pulp and paper sector. In tropical and semi-tropical latitudes the sugar industries represent a significant potential source of export electricity if advanced technologies are adopted, and the Industry and Energy Department of the World Bank has supported such modernization in the sugar sector. The adoption of advanced technologies promotes diversity in the utility sector since most of the sugar mills are in the private sector, promotes energy and material efficiencies because of the inherent efficiencies of CHP and, of course, utilizes a renewable energy resource.

1. The sugar industry

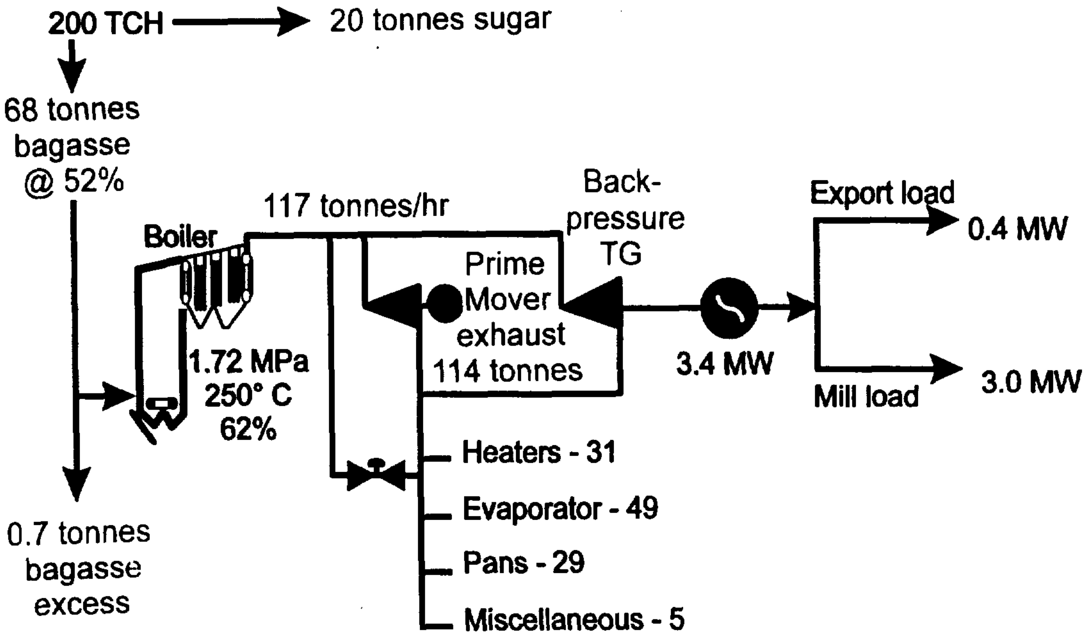
The production of sugar entails crushing the sugar cane to expel and extract the sucrose-containing juices. The fibre remaining, called bagasse, is typically used as a fuel for the sugar production process, which requires extensive water evaporation.

Typically, cane is harvested slightly green, and when it arrives at the sugar mill it may have about 30 per cent total solids and about 70 per cent water. To a first approximation, the weight of sucrose and the weight of the bagasse are in the ratio of 1:1.5. FAO and the United Nations use rule of thumb is that 1 tonne of cane sugar creates about 3.26 tonnes of bagasse at 50 per cent moisture content. This number depends greatly on the fibre content of the bagasse and the methods of preparing cane. In China, where cane is well prepared before shipping to the mill and has little extraneous trash, the ratio used is 1:1 sucrose to bagasse. Because of the vast quantities of bagasse, it is nearly all burnt, to generate the power and heat for mill operation on the one hand and to dispose of the bagasse on the other [13]. Bagasse is used very inefficiently in most developing countries because of the need to dispose of it and because the mill owners have minimized their capital investment. Any bagasse surplus would normally be considered for paper production, not for conversion to electricity for export from the mill [14]. Furthermore, in many developing countries, the generation of excess electricity is not profitable because subsidized grid electricity is sold at less than its production cost.

2. Bagasse-fuelled combined heat and power today

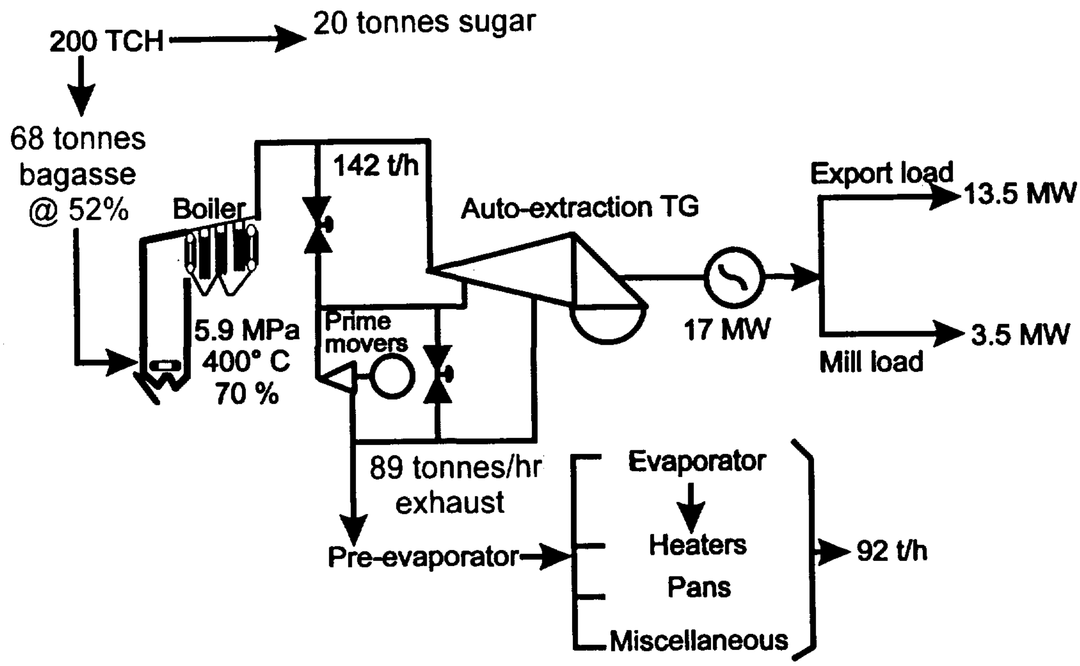
Typically, a sugar mill in a developing country generates about 20 kWh of electrical energy per tonne of sugar produced [15] (figure VIII.4). In the 1930s, the majority of sugar mills in Hawaii were similar to the mills that presently exist in developing countries, having only a small export of electricity to local communities serving the sugar mill. However, sugar mill generating capacity grew markedly in the 1970s as the sugar industry consolidated its low-pressure boilers into higher-pressure units and was able to produce more electricity for export [16]. In the United States, the 1978 Federal Public Utilities Regulatory Policies Act stimulated the use of bagasse to the point where, in 1991, the Hawaiian sugar industry supplied about 5.5 per cent of the grid electricity through the burning of bagasse in conjunction with fossil fuels [17]. The generation in that year was 495 TWh, down from a high of 681 TWh in 1988.

Figure VIII.4. Sugar cane energy production in a developing country



The improvements made to the mills entailed significant investments in both the boiler and power turbines and for process improvements [15]. Typically, the boilers were improved by increasing the 1operating pressure and temperature from 1.75 MPa and 250° C to 5.9 MPa and 400° C through the use of air preheaters and superheaters. The power turbines in general used in developing countries are typically back-pressure units [15] operating at the boiler pressure and an exhaust pressure of 0.1-0.15 MPa. The exhaust steam is used to provide the process heat (figure VIII.4). Several turbogenerator combinations may be used to modernize such mills: a topping turbogenerator that converts the high-pressure steam to the pressure of the remaining prime movers; a condensing turbogenerator that has a higher efficiency (because the low-pressure side of the turbine is at 10 Pa); or, as in current Hawaiian practice, an autoextraction/condensing turbogenerator that extracts 1.725 MPa steam for the direct drives and 0.15 MPa steam for the process. A typical efficient Hawaiian mill is shown in figure VIII.5.

Figure VIII.5. Sugar cane energy production in Hawaii

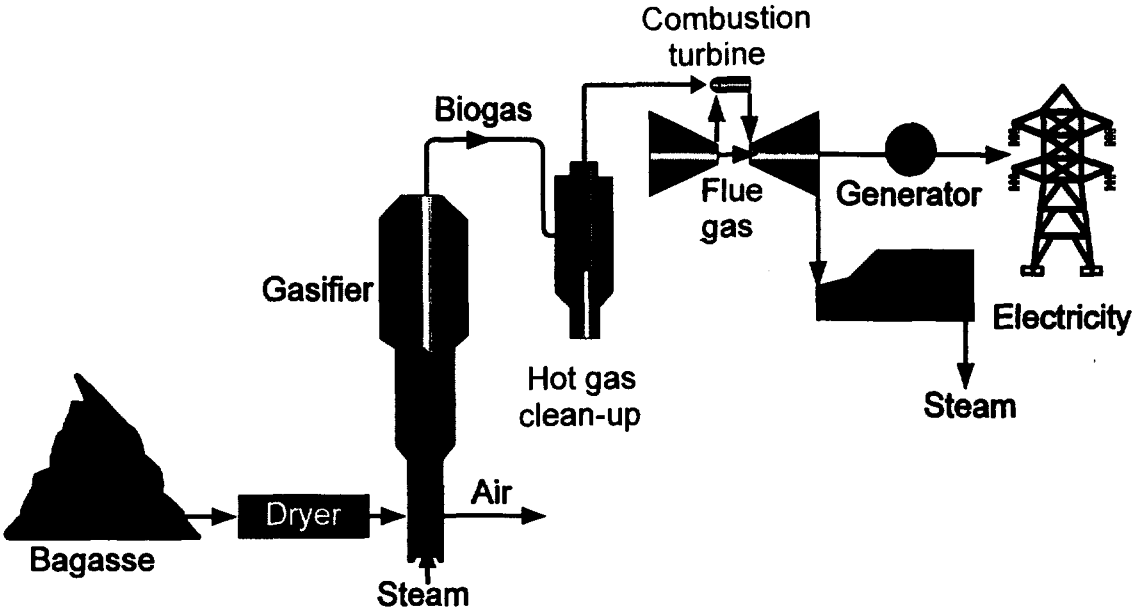


This level of sophistication is now being adopted in India. A World Bank ESMAP study [18] identified the state of Maharashtra as having the best potential for achieving higher electricity output from its sugar mills. These mills could usefully produce electricity from November through April, when hydroelectric input to the Maharashtra grid is low. A key factor, however, is allowing private power producers to sell their electricity to the Maharashtra grid at prices, negotiated with the State electricity board, that will give them adequate returns. This study was followed by a more detailed assessment of three mills by the Winrock Foundation [19]. A combination of steam pressure increases, from 1.4 to 6.3 MPa, and steam conservation measures that reduce the steam consumption from 55 per cent steam-on-cane to 40 per cent has been identified. These changes would cost-effectively increase the in-season output of the Aruna mill to 34 MW and the off-season output to 51 MW (using lignite fuel), for a total export of 295 GWh per year. At present, the mill generates only enough electricity for its own needs (6.5 MW).

3. *Advanced bagasse combined heat and power facilities*

The deployment of more advanced technology, such as the use of integrated gasifier combined-cycle (IGCC) systems, could result in a further significant gain in exportable electricity during the sugar cane processing season [20]. Figure VIII.6 illustrates a modification of the base-case mill to incorporate a gasifier and gas turbine combination. To maintain the high temperature and pressure steam conditions, the turbine exhaust is ducted to a modern and highly efficient heat recovery steam generator (HRSG). The bagasse would be dried with flue gas from the HRSG. The increased output also reflects the use of more advanced energy conservation techniques to reduce the steam-on-cane usage to 35 per cent. The system shown is an add-on that would allow the use of the boiler steam in the traditional way. An even more radical solution, and one that would significantly reduce investment costs, would be to use a steam-injected gas turbine (STIG) [21]. Such a turbine would provide steam for the process, produce electric power for internal use and export and be able to utilize additional steam when the mill load is to produce even more power. Preliminary calculations suggest that this option would be efficient enough to give a surplus of bagasse that could be used for pulp and paper production.

Figure VIII.6. Sugar cane energy production by IGCC technology



During the sugar cane season, therefore, the mill could become a major contributor of electricity to the grid and the local community. Excess bagasse could either be used to make pulp or medium-density fibreboard or be stored for use in the power plant after the mill operating period. Other fuels, such as fuelwood, could be stockpiled in the dry season and used in the wet season. The bagasse gasifier necessary to implement this type of scheme is being developed in Hawaii under the auspices of PICHTR with the pressurized RENUGAS system of the Institute of Gas Technology. Table VIII.1 compares the performance of the sugar cane systems to illustrate the benefits of a move to advanced gasification technology.

Table VIII.1. Summary of electricity export options for 200 tonnes/hr of cane processed

Factors	Base case	Hawaiian system	IGCC - based
Available bagasse (tonnes/hr)	68	61	40.5
Moisture content (%)	52	47.5	20
Excess bagasse 50% moisture (tonnes/hr)	0.7	0.0	0.0
Power generation (MW)	3.4	17	35
Electrical output (kWh/tonne)	16.8	84.6	175
Mill energy use (tonnes steam/tonnes cane (%))	58.5	45.9	35
Export in season, MW	0.4	13.5	30

C. Economic and environmental benefits

Managing biomass efficiently reduces overuse of the biomass resource, which may destroy the ecosystem and pollute the air and water. The results can be dramatic. In Jincunzhuang, the move from inefficient cooking to a system that used less than the annual straw and stalk residue production immediately eliminated the village's over-harvest of fuelwood. The use of improved stoves also immediately reduced household air pollution.

While the environmental gains described for Jincunzhuang are certainly subject to the law of diminishing returns with additional investments, the associated reduction in waste, in fossil fuel consumption and in air and water pollution associated with the extraction and conversion of those fossil fuels are also significant, especially in the context of the role of greenhouse gases in climate change.

The economic gains are also subject to the law of diminishing returns with additional investments. In the case of sugar cane energy systems, there is probably little incentive to make these investments unless a rational solution to the problem of externalities pricing is resolved, given the current cost of fossil fuels. In the United States, one externality has been monetized: sulphur oxides, for which there are tradeable emissions credits.

D. Potential and barriers

Much of the world's rural population depends on biomass energy for its daily needs. It is surprising, therefore, that so little attention has been paid to development of systems that would give rural populations living conditions and services similar to those experienced by urban dwellers. In the main, it is the developing countries that have been pursuing energy systems that fulfil basic needs while encouraging the sustainable use of biomass resources. The technology developments outlined above offer the promise of providing these quality energy services. However, to make the technologies economically attractive, the unit cost of the expensive prime movers that convert fuel gas to electricity will have to be reduced by mass-producing them. In this respect, village bioenergy systems are little different from other renewables such as solar or wind energy that must achieve low system costs at low power outputs.

The economics of larger scale CHP installations, such as the sugar cane processing industry outlined here, are very promising; however, there is a strong need for rational pricing for power exported from the mills. In many developing countries, the purchase price offered by the utility grids and state electricity boards would not support any investment in power systems at all.

E. Conclusions

As the scale of operation in developing countries moves away from the individual and the family, there is a need to consider the total fuel cycle with a view to optimizing its sustainability both economically and environmentally. In this respect, electrical systems seem to offer the best opportunity, at least in those developing countries that already have a significant degree of electrification and distribution grid coverage. The processing of urban and industrial residues could add many megawatts to the grid. These additions would come from CHP facilities providing process heat or district heating/cooling and electricity to their own facilities or to cities and towns. Advances in technology, ranging from higher performance combustion cycles to gasification combined cycles, both of which increase the electricity-to-heat ratio, will increasingly benefit society while protecting the environment. This is especially true for industries such as the processing mills and the pulp and paper sector, which produce significant biomass residues and demand concomitantly large amounts of thermal energy (steam).

At the village and township level, as more income is generated outside of agriculture and the need for clean, efficient and reliable energy sources increases, the use of biomass will move from the individual user towards the village or the large enterprise scale. However, logistical constraints make it likely that the assembly of large quantities of biomass will be very difficult in most developing countries. It will therefore be necessary to consider scales of conversion of 10 tonnes per day rather than the 1,100 tonnes per day that power stations in the United States utilize. Villages in China and India that have approximately 100-300 ha under their direct control probably have 3-10 tonnes per day of biomass available under a double cropping regime. Thus, the challenge is to find technologies that will achieve high conversion efficiencies at small scales and low cost.

Fortunately, advanced technologies such as fuel cells, Stirling engines and advanced turbines can, if mass-produced, break the dependence of economic power generation on large scale and can bring the benefits of high efficiency, low environmental impact and economic operation to villages and rural agricultural industries.

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IX. BIOMASS ENERGY RESOURCE ENHANCEMENT

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Abstract

The demand for energy in developing countries is expected to increase to at least three times its present level within the next 25 years. If this demand is to be met by fossil fuels, an additional 2 billion tonnes of crude oil or 3 billion tonnes of coal would be needed every year. This consumption pattern, if allowed to proceed, would add 10 billion tonnes of CO_2. to the global atmosphere each year, with its attendant risk of global warming. Therefore, just for our survival, it is imperative to progressively replace fossil fuels by biomass energy resources and to enhance the efficiency of use of the latter. Biomass is not only environmentally benign but is also abundant. It is being photosynthesized at the rate of 200 billion tonnes of carbon every year, which is equivalent to 10 times the world's present demand for energy.

Presently, biomass energy resources are highly underutilised in developing countries; when they are used it is through combustion, which is inefficient and causes widespread environmental pollution with its associated health hazards.

Owing to the low bulk density and high moisture content of biomass, which make it difficult to collect, transport and store, as well as its ash-related thermochemical properties, its biodegradability and seasonal availability, the industrial use of biomass is limited to small and (some) medium-scale industries, most of which are unable to afford efficient but often costly energy conversion systems.

Considering these constraints and the need to enhance the use base, biomass energy technologies appropriate to developing countries have been identified. Technologies such as briquetting and densification to upgrade biomass fuels are being adopted as conventional measures in some developing countries.

The biomass energy base can be enhanced only once these technologies have been shown to be viable under local conditions and with local raw materials, after which they will multiply on their own, as has been the case with briquetting technology in India. To set up the first units, private industries from both developed and developing countries will have to play a dominant role, with assistance from international funding organizations and their respective Governments.

Manufacturing activities should gradually be transferred to developing countries, under licensing agreements, because plants installed by developed countries tend to be more expensive and economically unviable. This approach has been successfully practiced for other technologies and will be addressed in this paper. Used sustainably, biomass resource can help to meet the growing demand for energy.

Introduction

The demand for energy is increasing worldwide, while fossil fuel resources are decreasing. Energy is crucial for the economic growth of developing nations, and a country's development heavily depends on the availability of indigenous energy resources, that is to say on whether it is a net importer or exporter of energy. In fact, countries with net exportable oil are developing more rapidly than those that depend on imported oil. In all, 80 of 112 developing countries do not produce oil, and many of these, including India, spend over 50 per cent of their total export earnings on imported energy. Energy use in developed countries is 208 x 10^9 GJ, compared with 92 x 10^9 GJ in developing countries [1].

In addition to its demand for development, energy is required to meet the needs of a growing population. The world's population is expected to increase from 5 billion in 1990 to 6.6 billion in 2005, with some 90 per cent of the increase taking place in developing countries.

Another factor is progressive urbanization in developing countries, with a higher quality of energy (electricity and gas) being called for in cities. By 2005, about 50 per cent of the population of developing countries is expected to be living in cities, and the number of cities with more than 4 million people is likely to increase to 90 in 2005 compared to 35 in 1980.

Given this scenario, the energy needs of developing countries could increase up to three times by the year 2015, which is equivalent to 2 billion tonnes of crude oil per year, or 3 billion tonnes of coal.

In energy equivalent terms, the energy stored in biomass through photosynthesis is approximately 3 x 10^{21} J, 90 per cent of it in trees, which nearly exceeds the world's annual energy use by a factor of 10 [2]. Despite this, its exploitation remains limited because of the present low cost of fossil fuels, the heterogenous nature of biomass and the huge area over which the feedstock must be collected for large-scale applications.

Biomass is not only a potential source of energy but also a potential feedstock. Technologically, it can provide all the forms of energy and products normally derived from fossil fuels, but it cannot at present compete with fossil fuels in scale and capacity. Meanwhile, biomass can be an attractive source of energy for direct use or, through conversion routes, to meet growing demand and to replace (i.e. to conserve) fossil fuels. For most developing countries, which have no oil resources, the use of biomass is a necessity, and because wood shortages are common, the poor population in rural areas is resorting more and more to agro-residues and cow dung for energy purposes.

Another concern is the potential danger of global warming due to the increasing concentration of $_{\mathrm{CO.}}$ in the atmosphere. Since the net contribution of biomass to the greenhouse effect is nil, its use as an energy source is also attractive from the global environmental point of view (3 billion tonnes of coal, for instance, would add 10 billion tonnes of CO_2 to the atmosphere every year.

A. Biomass characteristics

Before considering techniques and technologies for the enhancement of biomass energy resources, it is pertinent to know the characteristics of biomass. The physical shape and size of different biomass resources play a dominant role in the selection and design of energy conversion systems. Biomass resources can be classified into compact (woody) and loose (non-woody) resources, such as rice husks, straws and stalks. Other properties having a strong bearing on energy conversion technologies are the apparent and bulk densities as well as the moisture content and ash content and composition. Extensive data are available on the properties of biomass [3]. Energy content varies from 13 to 20 MJ/kg; nevertheless, on a moisture- and ash-free basis, the variation is much smaller. Because of these variations, conversion systems become biomass-specific, an important factor often ignored by the manufacturers of the systems in an effort to boost their sales.

In developing countries, biomass is being used in the domestic sector (cooking) and in small- and medium-scale industries. The traditional use of biomass for cooking, i.e. the burning of wood, agricultural residues and dung, is facing problems, including the scarcity of hand-gathered wood, soil nutrient depletion and deforestation and land degradation. In addition, such traditional methods are highly inefficient (5-15 per cent) and cause harmful indoor pollutants.

Because of increased industrial activities in some developing countries (India, for example), the lack of wood fuel and the prohibitive costs of fossil fuels, agro-residues (especially rice husk and bagasse) are being used in industrial furnaces in a highly inefficient manner, resulting in extensive land and air pollution. A typical example is that of Ludhiana, an industrial town in northern India, where 8,000 tonnes per day of rice husk are burnt in more than 500 inclined grate furnaces. This activity produces particulate emissions into the air of 2,000 mg/Nm^3 (the statutory limit is 250 mg/Nm^3) and 3,200 tonnes/day of disposable carbonaceous ash. The resulting pollution is so great that the Government has banned the loose burning of rice husk. Similar situations are arising in other cities in India and are likely to arise in many other developing countries.

In many developing countries, biomass is either not being used or is used inefficiently. Since wood is in short supply in most of these countries, the efficient use of agro-residues should be given equal emphasis. In India, for example, there is an acute shortage of wood fuel (shortfall of 138.4 million tonnes/yr vs. a production of 28.4 million tonnes/yr, but at the same time 156 million tonnes/yr of crop residues are available, an estimated 50 million tonnes/yr of which are being consumed [4].

In developing countries, the increasing use of coal and other fossil fuels will have serious effects on the global atmosphere. Even at the local level, pollution is severe, and there are as well health hazards associated with the burning of loose residues. Further, in many developing countries (for example, Myanmar and countries in East Africa) the bulk of the urban population depends on wood charcoal for domestic cooking, increasing per capita wood use and contributing to deforestation. This is the real energy challenge for the future: how to encourage development while protecting the environment and reducing dependency on fossil fuels without affecting standards of living [5]. Modern and environmentally sustainable biomass energy systems are the best response to the challenge in developing regions. In order to satisfy traditional energy needs and provide modern energy services it is imperative to enhance biomass energy resources and improve technologies [6].

B. Technologies for resource enhancement

Biomass energy resources must be enhanced both for traditional energy needs and the needs of modern industry. The most important aspect is to identify technologies suitable for developing countries. The technologies should be needs-based and capable of upgrading inconvenient biomass into convenient energy suitable for thermal, mechanical and electrical applications. They should be clean, cost-effective and convenient to handle.

1. Domestic sector technologies

Of immediate concern to developing countries is the conservation of wood resources. This could be achieved both by reforestation programmes and the widespread dissemination of improved wood stoves. It has been estimated that it is about 22 times cheaper to save wood by using improved cook stoves than by planting and growing trees [7], although plantation has many other ecological benefits and needs to be continued. As far as cook stoves are concerned, there is no necessity to develop new stoves. Worldwide, numerous models have been developed and field-tested that can be adopted and modified to meet local needs.

Since the direct burning of agro-residues in loose form is highly inconvenient and polluting, the residues could be converted into carbonized biomass briquettes. The briquettes should be in the shape of a beehive and have 12-19 vertical holes, each one acting as a pseudogasifier. Although briquettes made from coal are extremely popular in China and its neighbouring countries, those made from agro-residues are more easily ignitable, convenient to use and give sustained, clean combustion similar to domestic cooking gas.

Technologies to make these briquettes are available at any level, from manual units for family use to small-scale mechanized systems, and for any type of locally available wastes or bioresidues. At prevailing prices of charcoal, these systems are highly economical and can be deployed as an income-generating activity. They would also replace charcoal made from wood, and the labour force presently deployed in charcoaling could easily switch to making these briquettes from sustainable agro- and forest wastes. The author believes that this well-developed technology, if disseminated widely in developing countries, could have a considerable impact on biomass utilization. The agro-processing sector (sugar mills and oil-seed shelling industries, for example) could contribute in an effective manner.

The indirect biomass systems developed by the Indian Institute of Technology at New Delhi [8] are basically meant for cooking at the community level (restaurants, canteens etc.). They provide clean and odourless combustion for low-grade, loose biomass (sawdust, coffee husks etc.), either alone or in combination with other combustible wastes such as rejected vegetable and lubricating oils, old tires and household organic wastes. Based on the principle of staged combustion, biomass, encapsulated in an annular chamber, is indirectly heated by gases/volatiles that are directed to the combustion chamber. The biomass gets thermally cracked, followed by clean combustion. A system for the combustion of kitchen wastes is illustrated in figure IX.1.

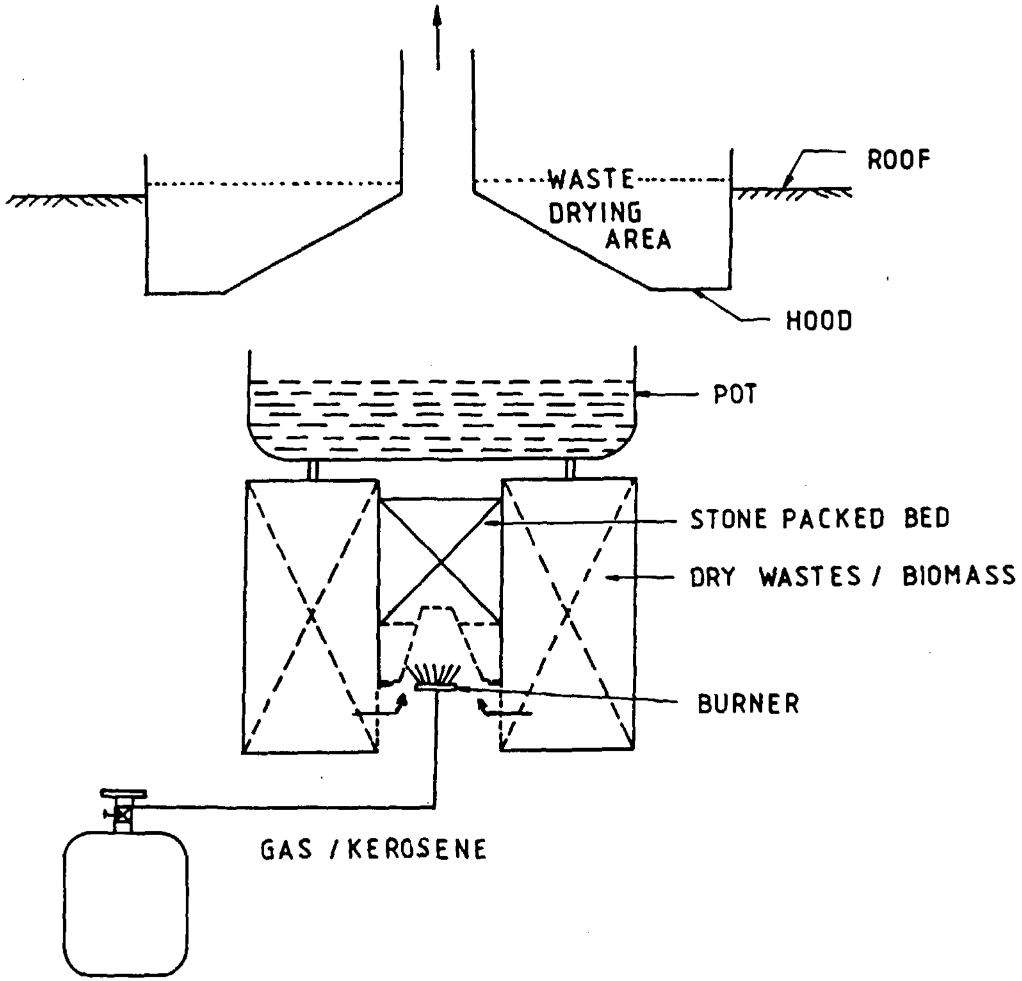
2. *Industrial thermochemical technologies*

Other technologies for the efficient utilization of biomass include gasification and staged fluidized-bed combustion, with waste heat recovery that can be deployed for drying biomass residues. The main impediment to the use of these technologies in preference to conventional burning is their economic performance: although they are energy-efficient and environmentally acceptable, they are too costly and need trained manpower for their operation and maintenance.

As long as biomass is available at low cost (i.e. at the cost of collection) and environmental protection measures are not strictly enforced, these technologies meant for only energy recovery will not be accepted by many developing countries. However, if they are modified to also recover marketable products, their economics become attractive and they will be exploited.

Integrated technologies for energy and marketable products cannot be identified without taking into consideration a developing country's infrastructure and the markets for products and energy. Of all the biomass-based thermochemical conversion processes, pyrolysis is the most flexible and has the best potential. It allows obtaining gases for power generation or for clean burning in boilers, liquid products that can be used as industrial raw materials and solids like char that can be used as metallurgical fuels or as clean domestic fuels, replacing firewood and petroleum products. Furthermore, depending on the raw material used as well as the demand for products, the proportions of these products can be varied. The basic idea behind these technologies is that instead of producing useless ash through combustion with its associated disposal problems, the ash is recovered with varying amounts of carbon. The product can be used as such or it can be briquetted and sold as industrial/domestic fuel. Depending on the characteristics of the biomass resources (such as size, ash and moisture content), different processes are used. These processes fall into four categories.

Figure IX.1. Scheme for conserving gas or oil by supplementing them with kitchen wastes



3. Category I processes

Category I processes are used for agro-residues having low ash content (<4 per cent) and a diameter of 20 mm or more. Some of the important species falling in this category are pigeon pea stalks, twigs, lantana, corn-cobs and similar woody types of biomass. These materials can be gasified in moving-bed gasifiers with down- or updraught configurations. The hot gas produced can be cleanly combusted in boilers with an overall efficiency of 60-70 per cent. The main advantage of down-draught units is that the gas can be used for power production. The gases are cleaned, cooled and then injected into internal combustion engines. Between 70 and 80 per cent of the fuel input to diesel engines can be saved. About 1.3 kg/kWh of woody or 2.0 kg/kWh of non-woody biomass is consumed. A simple version of these gasifiers that has been accepted for rural electrification partially carbonizes the biomass and then feeds the char to the gasifier.

4. Category II processes

Category IIa processes are used for category I agro-residues as well as other agro-residues with low ash content that are available in smaller sizes (sawdust, groundnut and walnut shells, jute waste, pine needles, mustard stalks and the like) and industrial organic wastes. These residues should be fed into gasification-cum-carbonization systems that simultaneously produce gaseous, liquid and solid products.

Many reactor configurations can be used. One of the most promising has already been commercialized: the inclined grate unit. This system consists of an inclined grate gasifier-cum-carbonization chamber of refractory in which part of the gases from the char is combusted with controlled air to maintain the requisite temperature for conversion. The quantities of char, gases and liquid can be varied. A typical product distribution is 20 per cent char, 25 per cent liquid and 55 per cent gases. Char production can be increased to 40 per cent, but the amount of gases available is reduced correspondingly.

Char is sold as such or briquetted to any desired size by well-established technologies. It is used for ferro alloys, calcium carbide, silicon carbide and carbon disulphide or, at the household level, for cooking. Tar is separated from the liquid product and processed into household germicide (popularly known as phenyl) and black paint. Gases from which the tar has not been removed can be used as fuel for boilers; after removal of the tar, they can be used for generation of power. Alternatively, the tar-laden gases can be cracked in a separate cracker-cum-gasifier (figure IX.2). The char can also be converted into activated carbon.

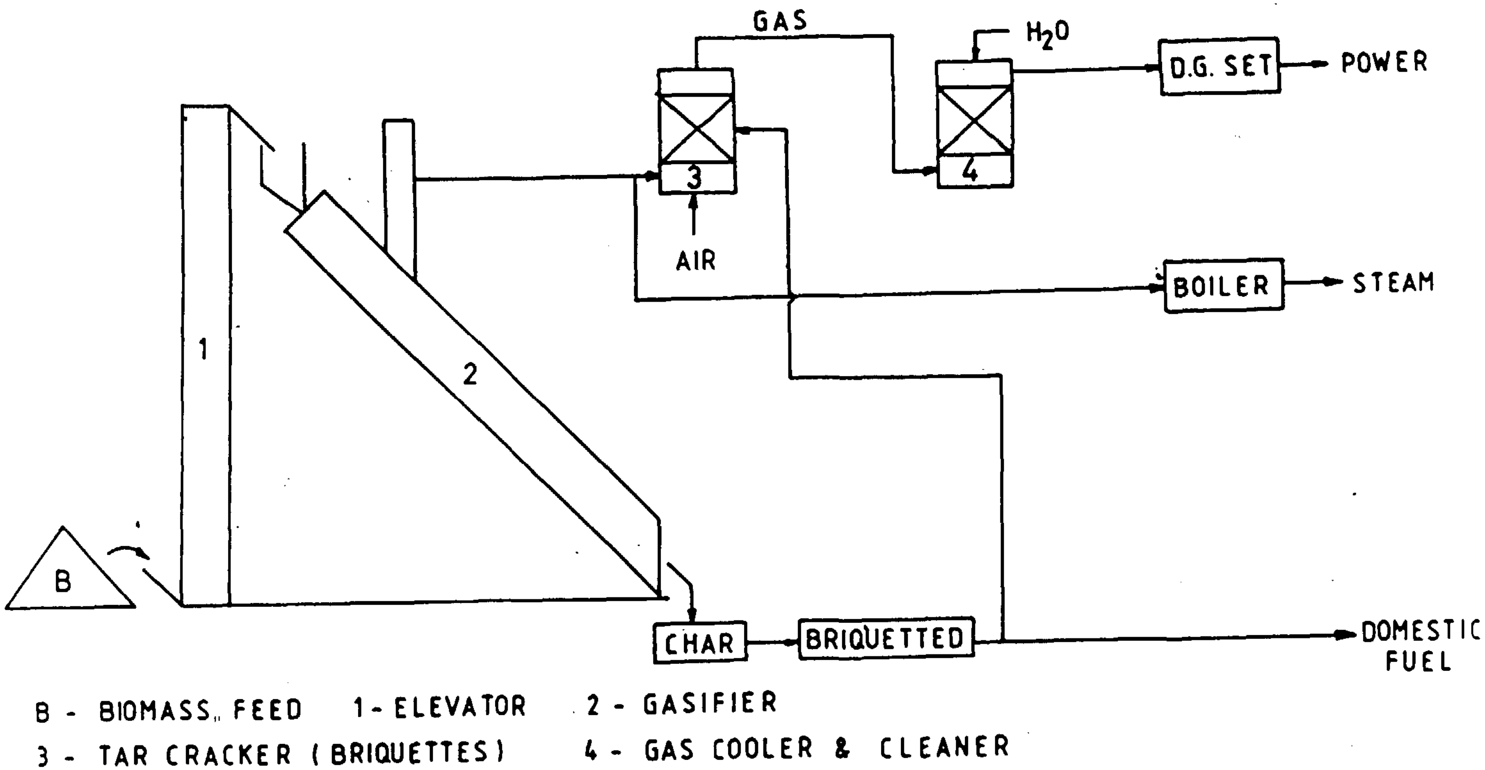
Category IIb processes are used for the same biomass species as category IIa processes, except that they are available in wet form, that is, they have a moisture content of 50 per cent or above. Such residues include bagasse and coir pith. The processes are the same as in category IIa except that pyrolizers should have integrated driers. The yield of products is also accordingly different.

5. Category III processes

Category III processes are used for biomass species having ash contents of greater than 4 per cent. These species include rice straw, soybean husks and sorghum bagasse. They may also have low ash melting points owing to the presence of potash and other alkali metals in ash. These are normally difficult materials to burn, even in boilers and furnaces, and they tend to produce more tar.

These high-ash materials can best be utilized by low-temperature (about 600° C) pyrolysis. With or without recovery of tar, the gases can be combusted in boilers, and the char, because of its high ash

Figure IX.2. Cracker-cum-gasifier



content, can be used only as domestic fuel. The latter is normally light and requires comparatively more compaction. Pyrolizer configurations similar to those for category II technologies can be employed.

6. Category IV technologies

Category IV processes are those based on rice husk, which has unique properties and is considered to be extremely promising for the recovery of energy and value-added industrial products.

Rice husk contains 65 per cent volatiles, 15 per cent fixed carbon and 20 per cent ash. The ash contains more than 97 per cent finely divided amorphous or reactive/biogenic silica, an extremely useful industrial product. However, when the rice husk is subjected to high temperatures in boilers (>750° C), its silica content tends to become crystalline and to partly combine with carbon, resulting in an inert black ash. This ash has no uses and is even worse than river sand. The disposal of this rice husk ash as well as the combustion of the rice husks themselves, which causes particulate emissions, are the two main causes of extensive pollution. Gasification systems based on the direct injection of air also generate useless black ash. Although the gas obtained can be used for clean combustion, the problems associated with the rice husk ash disposal are not solved. It is, therefore, important that only those technologies should be adopted that do not generate pollution and that also create value added. The products obtainable from rice husk are shown in figure IX.3 [9].

7. Direct briquetting of biomass

The manufacture of biomass briquettes enlarges the scope for loose biomass utilization and is one of the technologies that has great potential in developing countries. High-pressure, binderless briquetting technologies provide a product with a density of 1.2-1.4 g/ml, which is twice that of wood and about 10 times that of loose biomass. These briquettes are manufactured using either a high-pressure screw or a ram press. As a screw-pressed briquette has a central hole, which gives it better combustibility than a ram-pressed solid briquette, it can be used conveniently in most types of furnaces, including cook stoves.

Briquetting technology upgrades the fuel, giving a material that is convenient to handle, to transport, to store and to use for energy purposes. Since briquetting machines need constant maintenance, they should be introduced with caution. The logistics are important, and the proposed site should have facilities for maintenance and repair.

8. Other technologies

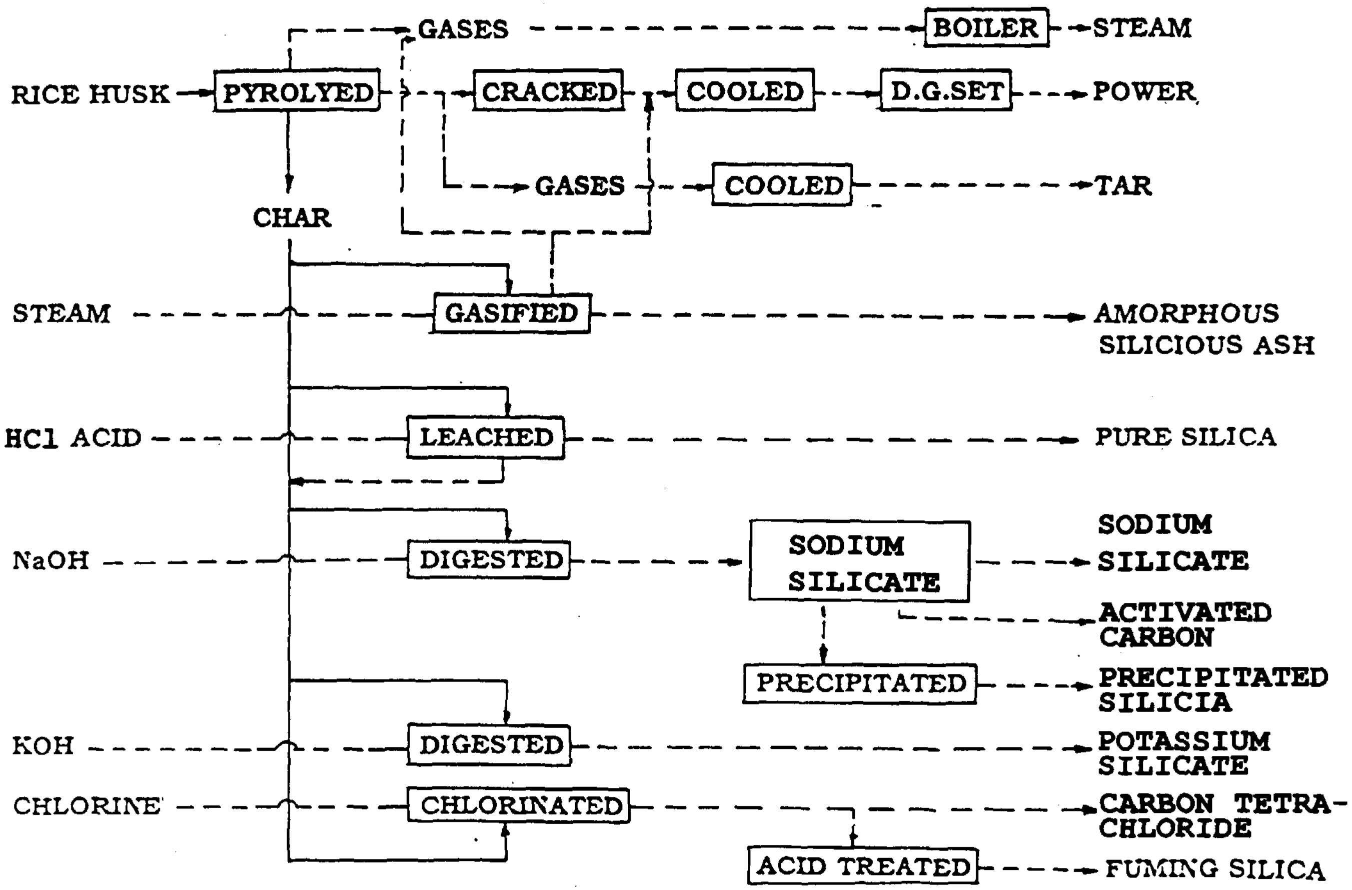
Biomethanation of cow dung with or without other biomass is a technology that has already been recognized as an ideal one for developing countries, and it is being propagated. The production of alcohol through fermentation is another popular technology, with the alcohol being used to supplement fossil fuels in the automotive sector.

Advanced technologies such as production of liquid fuels by flash pyrolysis or biochemical means should, however, only be considered as long-term projects. They should not be introduced in developing countries before having been fully developed in industrialized countries.

C. Typical examples of biomass energy enhancement

To enhance the use of biomass energy, developing countries should involve small- and medium-scale agro-processing industries such as those for rice dehusking, sugar refining, vegetable oil extracting (groundnut), coffee curing, coconut processing and woodworking, all of which generate a substantial amount of biomass residues, difficult to store and to transport to the users. Most of them inefficiently

Figure IX.3. Products obtainable from rice husk



burn these residues to get thermal energy for their processing and still have surplus residues. By improving their practices, additional surpluses of biomass can be obtained and then processed to produce both the power requirement and smokeless briquetted fuels, which can be sold to the neighbouring villages that supply these industries with agricultural products. If they did so, these mills would not have waste or ash disposal problems and the transport system could also be optimized (for example, the system for bringing sugar cane to the sugar mills could also be used to transport fuel briquettes to the surrounding areas). A typical system using bagasse and other sugar mill wastes co-produces energy and marketable products (figure IX.4).

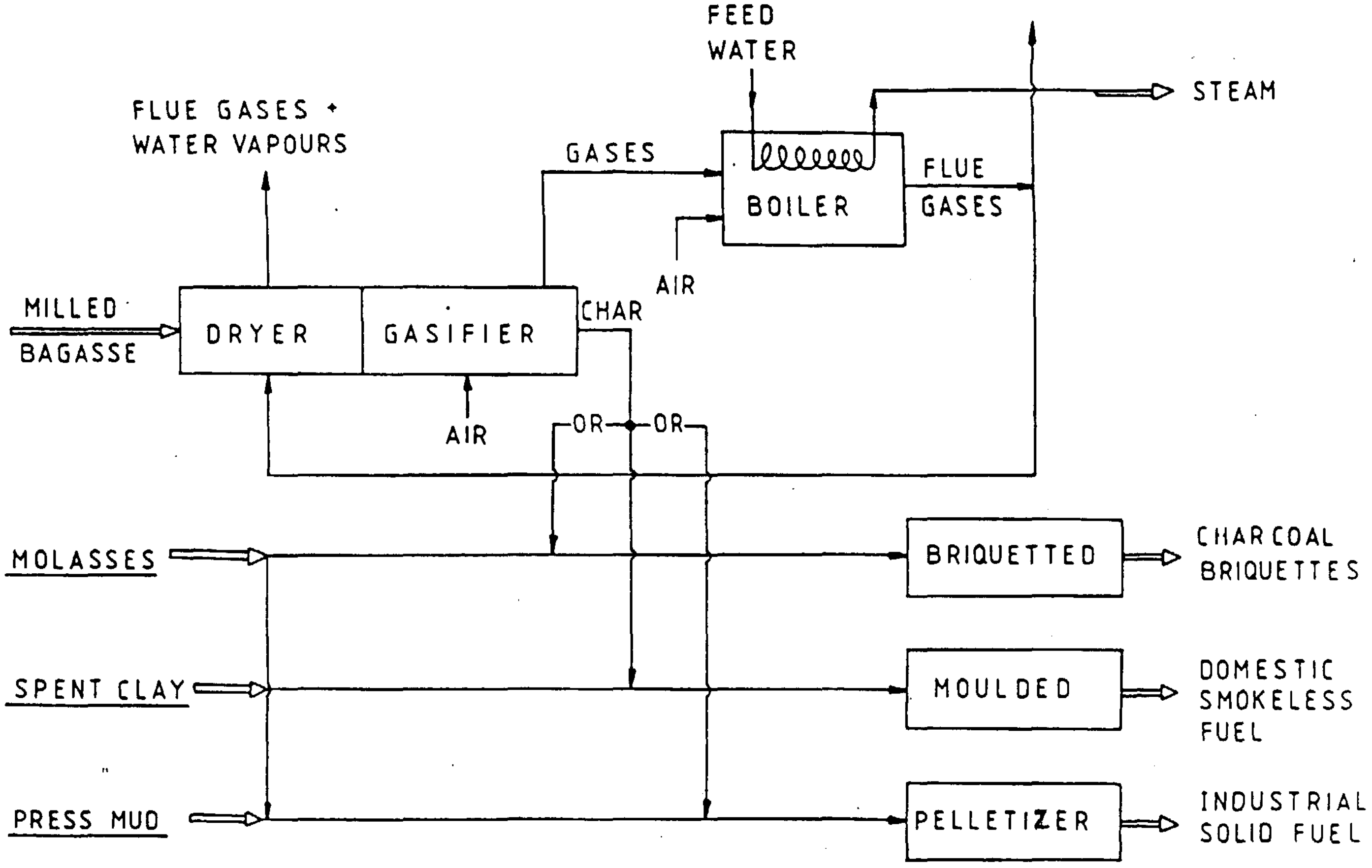
The largest problem faced by industry with regard to the adoption of these technologies is probably market penetration. Most of the other problems can be solved by careful planning, management and local commitment. A balanced system of taxes and subsidies needs to be adopted to enable the biomass to compete in the market. The availability of upgraded and convenient fuels at affordable prices would discourage the use of fossil fuels or loose biomass residues, which have their respective environmental and social costs.

D. Penetration of advanced technologies

To facilitate the adoption of these technologies in developing countries, it is crucial that public, industry and government perceptions of biomass energy should be improved, overcoming constraints and creating entrepreneurial opportunities. The most pragmatic approach is to put up a well-conceived and well-engineered demonstration plant in a modern local industrial sector in the public or private sector and use it to educate those who might set up plants in the future. The site, the local partners and the technology should be selected solely on economic considerations. The success of the venture will depend on local involvement, manifold benefits, flexibility and sustainability even after initial incentives have been withdrawn. This demonstration project should be assisted, monitored and evaluated by an international agency like UNIDO. There should also be an active involvement on the part of the local government, of industrial partners from developed countries willing to transfer know-how on a commercial basis and of local research organizations that can provide testing facilities. The chosen technology should be well proven and should not have any developmental component. At the most, it may have an adaptation component limited to making adjustments for local conditions. A successful plant operating in a country and based on local raw materials can propagate similar plants. For example, if a technology producing power and/or carbonized briquettes and processing associated tar to products such as black paint and household germicides is demonstrated, the system will be more widely adopted, because the associated products have already been marketed. Unfortunately, in the past there were more failures than successes for these technologies. There can be many reasons for failure, one of which is the eagerness of the manufacturers to sell plants without providing backup. Another is that they do not have any long-term interest in success and so supply technologies that are unsuited for the local conditions.

Once the success of a technology has been established, future plants should be progressively manufactured in the developing countries, as plants made in developed countries tend to be more expensive than those made locally and become unprofitable. However, to ensure that a plant is properly engineered, collaborative commercial agreements or joint ventures between the machinery supplier and local industry should be drawn up, with provisions to safeguard the rights of the manufacturer. If a plant or a piece of machinery is copied without backup technical assistance, performance is often poor, mainly because unsuitable materials of construction are used and because the duplicator tends to reduce the manufacturing costs to enhance profits.

Figure IX.4. Clean technology for bagasse utilization (with complete recycling of press mud and clay)



1. The case of biomass briquetting in Asia

Typically, manufacturing companies in Asia have attempted to duplicate standard biomass briquetting machines manufactured in Japan and Europe. Improper engineering led to failures so widespread that the potential technology got discredited and its usefulness was lost to many countries for well over a decade.

Particularly in India, a number of machine manufacturers and numerous briquette manufacturers who had bought these machines suffered heavy financial losses and went out of business. To the credit of this technology, more than 100 plants using ram-type briquetting machines have been installed in the last five years even though inferior machinery is being supplied. Entrepreneurs are still buying these machines because they cost not much more than half the price of the perfect machines available from industrialized countries.

One recent development in South and South-East Asia has restored the confidence of entrepreneurs in briquetting technology: as described earlier, screw-pressed briquettes with a central hole are superior in structure and combustibility to ram-pressed solid briquettes.

A large number of screw press machines are working worldwide on soft wood sawdust. However, when these machines were used for other agro-residues in India and elsewhere, they did not perform well. The mechanical wear on the contact parts, especially the screw, was enormous (only 15-20 minutes of operation were possible on rice husk) and the specific power consumption of the machine was higher than that of the ram press.

The University of Twente in the Netherlands and the Indian Institute of Technology collaborated on a development project that was generously funded by the Government of the Netherlands. When the screw was given a hard facing and was preheated, performance improved, making the technology economically viable for local residues. The results of this project were disseminated at an international workshop held in April 1995 at New Delhi [10].

Follow-up steps have been initiated to progressively manufacture these machines in India under joint ventures, which will bring down the cost of the machines. A capacity to manufacture 1 million tonnes of screw-pressed briquettes from rice husk and other residues is envisaged to be installed within the next five years. This case history is instructive as it presents a positive option of outcome for an advanced biomass technology introduced to developing countries; in this particular case, a once-discredited technology returned to the mainstream on its merits.

E. Conclusions

Biomass energy conversion systems must be modernized to provide modern and environmentally sound fuels that can meet the growing demand for domestic and industrial applications. Based on agro-residues and sustainable energy plantations on degraded land, such systems can alleviate deforestation and reduce dependency on fossil fuels, at the same time reducing atmospheric CO_2 levels.

Biomass should be considered not only as a renewable source of energy but also as a feedstock. If energy technologies are integrated with the co-production of marketable products, they can become more economically viable and sustainable, even when the costs of the raw material go up as a result of increased demand.

A balanced system of taxes and subsidies is needed to enable modernized biomass fuels and power to compete in energy markets. Hidden subsidies to the power sector and to fossil fuels should be reduced or similar subsidies should be provided for biomass energy, in consideration of its social and environmental benefits.

The technologies discussed can be introduced in developing countries by setting up demonstration-cum-commercial units with the local participation of industry, government and research institutions in partnership with technology suppliers from industrialized countries. More and more, plants and machinery should be manufactured in the developing countries themselves, under cooperative or joint venture agreements that would ensure the quality, reliability and economic sustainability of the technologies. International organizations such as UNIDO can promote such arrangements and bring partners closer by disseminating information and organizing business meetings in this important area.

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X. BIOMASS ENERGY CONVERSION: CONVENTIONAL AND ADVANCED TECHNOLOGIES

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Abstract

Increasing interest in biomass energy conversion in recent years has focused attention on enhancing the efficiency of technologies converting biomass fuels into heat and power, their capital and operating costs and their environmental emissions. Conventional combustion systems, such as fixed-bed or grate units and entrainment units, deliver lower efficiencies (<25 per cent) than modern coal-fired combustors (30-35 per cent). The gasification of biomass will improve energy conversion efficiency and yield products useful for heat and power generation and chemical synthesis. Advanced biomass gasification technologies using pressurized fluidized-bed systems, including those incorporating hot-gas clean-up for feeding gas turbines or fuel cells, are being demonstrated. However, many biomass gasification processes are derivatives of coal gasification technologies and do not exploit the unique properties of biomass.

This paper examines some existing and upcoming technologies for converting biomass into electric power or heat. Small-scale 1-30 MWe units are emphasized, but brief reference is made to larger and smaller systems, including those that burn coal–biomass mixtures and gasifiers that feed pilot-fuelled diesel engines. Promising advanced systems, such as a biomass integrated gasifier/gas turbine (BIG/GT) with combined-cycle operation and a biomass gasifier coupled to a fuel cell, giving cycle efficiencies approaching 50 per cent are also described. These advanced gasifiers, typically fluid-bed designs, may be pressurized and can use a wide variety of biomass materials to generate electricity, process steam and chemical products such as methanol. Low-cost, disposable catalysts are becoming available for hot-gas clean-up (enhanced gas composition) for turbine and fuel cell systems.

The advantages, limitations and relative costs of various biomass gasifier systems are briefly discussed. The paper identifies the best known biomass power projects and includes some information on proposed and planned projects worldwide.

The main incentives, such as greenhouse gas reduction, the expanded use of various biomass sources and improved efficiency, are often insufficient to overcome barriers to the development and commercialization of advanced conversion systems and even to the introduction of conventional biomass-fired combustors for heat and power. Site characteristics, handling and transport costs and the availability and reliability of fuel feedstocks are major considerations in selecting system designs. In transferring biomass conversion technology to developing countries, these factors and others, such as sufficient data on the composition of the indigenous biomass, economics and training, are important. Successful transfer, however, will depend on a facilitator from the developing country and a technology champion from the developed country.

Introduction

The last two decades have witnessed substantial interest in and development of technologies for converting various forms of biomass (paper, wood, specially grown crops, trees and grasses, agricultural wastes, to name a few) into energy. Not only is the conversion of biomass into power CO_2-neutral if the cultivation of plants is disregarded, it has other advantages as well, namely, it mitigates an increasing agricultural waste disposal problem, encourages the cultivation of specialty crops for energy production on out-of-use land, slows the depletion of diminishing fossil fuel resources and provides countries and regions with domestic alternative-energy feedstocks. Ten years ago biomass represented some 15 per cent of primary energy use worldwide, slightly less than that of natural gas (17 per cent) and about three times that of nuclear or hydroelectric energy [1]. In developing countries, biomass as an energy source accounts for 35 per cent of primary energy usage, although its share of national energy balances in some countries is declining [2]. However, as noted by Ghislain [1], the positive impact of biomass is by no means automatic. Specific criteria have to be taken into account, since even biomass production can inadvertently harm the environment, e.g. the operations in the process from feedstock production to energy conversion, which are many in number and type, can cause ecosystem disorder and climate change.

This paper addresses the nature of the energy conversion process, a very important factor in determining the overall efficiency of biomass usage for heat and/or electrical power production, as well as in controlling pollutant emissions. Combustion and gasification technologies will be discussed, but the focus will be on gasification, both conventional and advanced systems for generating electrical power, which offers greater value added than other energy modes [3]. However, the labour-intensiveness of biomass cultivation, the wide dispersion of the production areas, harvesting and transport have a considerable impact on costs. Moreover, although biomass residues are a useful lower (or even negative) cost substitute, they incur added transport and processing costs. For these reasons, Bridgwater [3] has concluded that there is an upper limit to the capacity of a biomass-fired electric power facility, namely, between 10 and 100 MWe, depending on location. Mainly small-scale units (1-30 MWe) will be discussed here. This overview is selective; for more detailed information, reports on biomass combustion and gasification system reviews at a national and worldwide level have recently been published by Hein and Spliethoff [4], Nielsen [5], Malinen and Helynen [6], Van Swaaij and others [7] and Bridgwater and Evans [8].

A. Biomass energy conversion in selected developing countries

Biomass is an indigenous energy source for many developing countries. It sustains rural development and is labour-intensive, providing these countries substantial incentive to invest in, support and expand biomass opportunities. Establishing a biomass energy conversion industry also reduces the heavy financial and social cost of expanding urban and city populations and the attendant infrastructure and services they demand. However, the early rush to biomass-to-electricity conversion in some developing countries has not been without its pitfalls. Combustion and/or gasifier units have been purchased from developed countries without regard for the necessary training in operations and maintenance and with no guarantee of availability or supply of spare parts. Today there is greater awareness of the requirements for successful and sustainable energy systems dependent on biomass. To illustrate the current situation, examples of biomass-to-electricity systems in India, Jamaica and Brazil will be discussed.

1. Status of conventional versus advanced technology

Before proceeding with the specific country examples, it will be useful to review the conventional technology based on burning biomass in a boiler to produce steam for a turbine and the increasingly attractive, but not yet commercial, alternative technology based on gasifying the biomass for fuelling a gas turbine or engine. The boiler-steam turbine combination, which is some 100 years old, is particularly attractive since it can use a diversity of feedstocks and consistently exhibits good performance. Notwithstanding these attractions, a major drawback is the high capital cost for systems of 50-60 MW or less. Another is the relatively low operating efficiency (<25 per cent), which contrasts with the operating efficiency of 30-35 per cent achieved with modern coal-fired combustion systems. The successful economic performance of boiler-steam turbine technology, using grate or entrained operation, has depended on low-cost or almost no-cost biomass [9]. On the other hand, the gasification of biomass to mainly carbon monoxide, hydrogen and a small amount of methane has a higher base efficiency, which can be increased by means of pressurization and various system design options. Gas turbine system efficiencies of between 32 per cent and 41 per cent can be obtained. Moreover, emerging gas turbine designs are cheaper and more efficient than steam turbines for modest-scale electric generating systems. Substantial progress in efficiency and cost reduction for gas turbines has been evident in recent years as a result of R and D and commercial pressures on the aircraft industry [9]. Development of biomass gasifier-turbine systems has also gained from the large amount of money and effort applied to coal gasifier-turbine systems over the last decade.

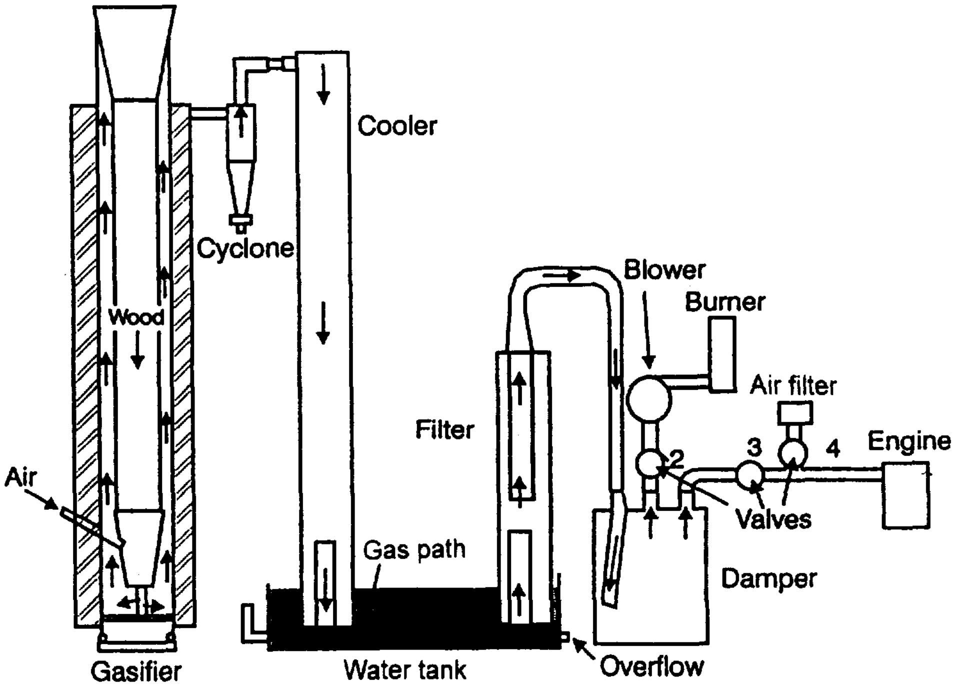
2. Biomass-to-electricity: India

India has a particular interest in establishing decentralized power-generating systems to meet the power needs of villages, small and isolated industries and irrigation pumping. Over 24 per cent of the electricity generated is used in over half a million villages for lighting and stationary-shaft power devices, which are mainly used for agriculture. Currently, almost 70 per cent of electricity in India comes from coal-fired power plants [10]. For decentralized power generation, several wood-based gasifier systems of capacities between 5 and 100 kW are now available in India [11]. Since 1988, a wood gasification technology has been field-demonstrated in a southern Indian village (Hosahalli in the Tumkur district in the state of Karnataka) to assess the technical and economic feasibility of forest-wood-based gasifier systems for meeting the power needs of villages. The gasifier is connected to a diesel engine generator. The initial design of the wood gasifier system is shown in figure X.1. Over the course of four years, the wood gasifier power generator unit was used to provide electricity (2.68-kW load from a single-phase 3.7-kWe alternator) for 42 households, to pump drinking water and to operate a flour mill. The reliability of the system has been 95 per cent over the period, reducing diesel fuel consumption by 67 per cent. Over an operational period of 32 months, the gasifier consumed 10.2 metric tonnes of wood. Diesel engines need only slightly more maintenance than gasoline engines. The wood gasifier-engine system was managed by two local people, and the project was seen as a motivator for self-reliance and sustainable development of villages in India [11].

3. Biomass-to-electricity: Jamaica

The second largest cane sugar factory at Monymusk in Jamaica was the model in a detailed economic case study of co-generation using a biomass integrated gasifier/steam-injected gas turbine (BIG/STIG) [12]. The BIG/STIG units would allow sugar producers to sell large quantities of excess electricity to power utilities; alternatively, utilities could use them as a low-cost generating option. Steam injection increases the power and efficiency of a simple gas turbine, which is not very efficient at producing electricity and is especially inefficient at the partial loads inherent in the seasonal sugar industry. Steam, produced in an exhaust heat recovery system, is injected into the combustor of a STIG co-generation system to boost power output and power efficiency. In the Jamaican study, a fixed-bed gasifier coupled to each of three General Electric STIGs of different sizes (5-50 MW) or aeroderivative turbines was envisaged. The BIG/STIG was compared economically to commercially available condensing-extraction steam turbines (CESTs) or Rankine systems for biomass applications. Assuming the sugar factory processes 175 tonne/hr, it was determined that sufficient bagasse would be available to support a 27-MW CEST or a 53-MW BIG/STIG. Briquetting of the bagasse for the gasifier was assumed to be necessary, thus raising the fuel costs of the BIG/STIG. Based on an electricity price range of US$ 0.05-0.058/kWh, it was estimated that the rate of return on investment for the BIG/STIG with steam-conserving retrofits would be 18-23 per cent, in comparison to 13-16 per cent for the CEST. Conservatively, it was estimated that the sugar industry worldwide could support 50,000 MW of BIG/STIG capacity. More than 90 per cent of the units would be in developing countries in Asia and Latin America.

Figure X.1. Indian village application of a wood gasifier-engine system with cooling and cleaning units



Source: Adapted from S. N. Srinivae and others, *Pacific and Asian Journal of Energy* [new series], No. 2, 2, 81 (1992).

4. Biomass-to-electricity: Brazil

The southern part of Brazil is currently producing biomass-derived electricity, for example, in sugar-alcohol plants, from bagasse. In some facilities, more than sufficient electricity is being produced and the surplus is sold to the power grid system. This development is relieving pressure on the Brazilian electric power sector to build new generating plants and at the same time reducing the environmental impacts of such plants, be they hydroelectric or fossil-fuel-fired [13]. Hydroelectric generation accounts for over 95 per cent of the electricity produced in Brazil [9]. The situation in the northern region of Amazonia is dramatically different, however: some 60 per cent of the local population depends on local utilities, which operate aging diesel electric generators using over 7 million litres of diesel oil and 71,000 litres of lubricating oil per month [13]. In a recent study, Zylbersztajn and others [13] evaluated four options for future electricity generation based on crop residues from oil palm (yield, 7 tonnes/ha) and *buriti*, a common Amazonian palm (yield, 29 tonnes/ha): biomass integrated gasifier/single-cycle gas turbine (BIG/GT), biomass integrated gasifier/gas turbine combined cycle (BIG/CC), conventional boiler/condensing steam turbine (CST-Rankine cycle) and BIG/STIG. The preliminary evaluation, based on bagasse data as there were no data on oil palm residue, showed that oil palm crop residues could more than cope with the demand for electricity (>12,000 GWh/yr) by the year 2000. *Buriti* is much more efficient than oil palm (2.5-5 kW/ha vs. 1.0 kW/ha) but still less efficient than other biomass-derived electricity (5-7 kW/ha). Although biomass gasification is currently available, it needs refinement, and Zylbersztajn and others suggest exploring conventional technology using boilers with condensing steam turbines (CST). Generation costs with CST are projected to be lower than costs with current diesel oil generators.

Electricity from tree plantations in north-eastern Brazil was the focus of another study [9]. Currently, virtually all electricity is from hydro plants. About half of the region's hydroelectric potential remains untapped because it is in environmentally sensitive areas, but this potential will have been realized not long after 2000. Beyond that time, consideration is being given to importing hydroelectricity at an increased cost. Eucalyptus tree plantations, a potentially viable alternative, are being used as a fuel source for a conventional boiler/CST technology (735 TWh/yr) and an advanced gas turbine–steam turbine combined cycle (GTCC). The electricity cost is comparable to that for sugar cane facilities, namely, US$ 0.073/kWh for CST technology and US$ 0.043/kWh for GTCC systems, the latter cost comparing favourably with the projected marginal cost of hydroelectricity in Amazonia. To utilize the eucalyptus trees, a consortium of companies has had designed a 25-MWe demonstration plant based on a GTCC system. Construction of the plant was scheduled to begin after June 1994 and to be completed by the end of 1997, following a grant from the Global Environment Facility (GEF). To be operated as a commercial unit, the project will offer not only environmental benefits but also social benefits, such as job creation.

B. Selected conventional and advanced technologies for biomass conversion in developed countries

1. Biomass potential

The potential availability of biomass for burning or gasification is currently much greater than the availability of reliable, cost-effective and environmentally sound commercial systems to take advantage of this fuel. Given the time required and the high cost of establishing new combustion systems, which would probably be small-scale units, countries in Europe have been modifying existing coal-fired power plants for the co-combustion of coal and biomass. In Germany, the cost of conversion for each installed kilowatt of thermal power is one third to one fifth the cost in new biomass-fired district heating plants [14]. Co-combustion offers several other advantages: apart from minimizing CO_2 levels and reducing costs, it reduces pollutant emissions. It also utilizes existing surplus biomass such as straw and wood waste, eliminating the need to dispose of them by other means, and it provides new cultivation activities for farmers, allowing them to grow crops for energy when surpluses exist for some food crops. Co-combustion allows for the levelling out of seasonal or yearly variations in biomass supply. Finally, it reduces the demand for fossil fuels, thus extending their lifetime, at the same time as it stimulates the use of biomass [15]. In Germany alone, the co-combustion of biomass to the maximum extent possible, i. e. 3 per cent of the total primary energy budget, would save 10 per cent of the coal being used [14].

2. Research and development

Investigations of biomass/coal co-combustion at different scales, from pilot plant to semi-industrial scale, are being undertaken in several countries, including Germany, the Netherlands, Sweden and the United States. The effects of biomass size, grinding energy, burner design, pollutant emissions, burnout level, ash composition and corrosion on plant operations are being assessed. The preliminary results have been very promising. For example, Siegle and others [14] have reported that when a pulverized fuel-fired combustor of 500 kW is used with straw, wood or miscanthus and coal, burnout is unaffected for biomass additions up to 20 per cent of total fuel. For wood, the particle size should be less than 4 mm. NO_x emissions of less than 300 mg/m^3 at 6 per cent O_2 can be achieved, and more sulphur is retained in the ash with increasing biomass/coal ratios.

In The Netherlands, Andries and others [15] used a pilot-scale, pressurized-bubbling-bed, fluidized combustor with a maximum pressure of 10 bar and a thermal capacity of 1.6 MW. They concluded that with co-combustion of straw pellets and coal, more sulphur was retained, NO and N_2O emissions were unaffected, and combustion efficiency was only very slightly affected. However, the preparation and feeding of the biomass need special consideration.

The need to burn biomass alone has generally been driven by environmental regulations and legal agreements, as well as availability. In the United States, regulations and legal agreements have been the prime motivators. However, burning biomass alone often has resulted in unexpected difficulties such as poor burnout, fouling and corrosion. Since the late 1980s, Denmark has burnt straw in small combined power and district heating plants. What was and still is largely lacking is the ability to predict the properties of the boiler deposits. Recent investigations by the Risø National Laboratory [16] in Denmark on power plants of 18 and 30 MW have demonstrated that (a) no correlation exists between the softening and melting temperatures of laboratory-generated ash and those of the deposits in the boilers, (b) the formation of hard deposits is related to the chlorine content of the straw and (c) the higher chlorine/potassium ratio probably leads to condensation at a lower temperature. On the other hand, an investigation at Sandia [17] in the United States that tested several biomass fuels, including straw, using a multifuel combustor (30 kW), stressed the distinguishing characteristics of the large amount of silica and vaporizable alkali, which have the propensity to combine chemically on heat-transfer surfaces. Because the melting temperatures of alkali silicates are below the prevailing gas temperatures, sintering and molten phases will form in the deposits. The problems with alkali and chloride species in coal combustion systems are not new, and valuable insight can be gained from a review of relevant monographs and papers, for example Raask [18], Williamson and Wigley [19] and Scandrett and Clift [20].

3. Combustion applications in the United States

The commitment to biomass for power generation is exemplified in the United States by the state of California. For at least 10 years, more than 900 MW of biomass-fired capacity has contributed to the utility grid of Pacific Gas and Electric, subsequent to the passing of the Public Utility Regulatory Policies Act [21]. This act allowed independent producers to participate in power production and fostered the use of renewable fuels and/or co-generation technologies. Currently 46 operating plants, mainly in central and northern California, provide in excess of 750 MW; they are fuelled by sawdust or pulp process wastes, hogged fuel, in-forest thinnings, clean landfilled wood, orchard or vineyard wastes, or other agricultural residues. The combustion technologies for these fuels range from pile burning in a simple Dutch oven furnace to basic fixed- or travelling-grate burners for spreader-stoker units and, more recently, state-of-the-art atmospheric bubbling or circulating fluidized-bed combustors. In general, the combustors are refractory-lined.

Fluidized-bed combustors, which are the most tolerant of variation in particle size and composition, provide enhanced control over emissions and attain better burnout of the biomass, resulting in less waste ash. The smallest plant provides less than 3 MW of power to the grid and the largest almost 50 MW. The plants consume over 7 million dry tonnes of fuel each year, and one dry tonne of fuel generates 1 MWh of electricity at about 20 per cent overall efficiency. Further details on the California experience with biomass conversion are reported by Turnbull [21].

As with coal combustion, advanced designs for biomass are being demonstrated or commercialized to realize higher operating efficiencies, lower emissions and lower operating costs. These include the already mentioned pressurized fluidized-bed combustor and a variety of other pressurized and atmospheric fluidized-bed systems, direct-fired combustion turbines and pulsed combustors. A noted example is the innovative direct-fired 391 kW combustion turbine now in the demonstration phase in the United States and reported by McCarroll and Partanen [22]. It operates on pulverized wood and is predicted to have an efficiency of up to 70 per cent in the co-generation mode. The direct-fired unit involves an external combustor fed with pressurized air from the compressor associated with the gas turbine. After passing through a cyclonic separator to remove damaging entrained particulate matter, the combustion gases enter the turbine that drives the generator.

4. Worldwide gasification applications

Substantial progress is being made at demonstrating and commercializing biomass gasification for electric power as well as other uses. Table X.1 summarizes recent and ongoing projects for power generation, with capacities from 2 to 60 MW, in various countries. Table X.2 lists the status and capacity of proposed or planned demonstration systems. This information is derived from a recent paper by Bridgwater [3]. Each of the systems referred to in the tables involves the combustion of biomass to produce a hot, combustible gas that is used in a closely coupled steam boiler or gas turbine. These systems use the gasifier's output quite efficiently, since the potential and sensible heat of the gas are equally useful. Another comprehensive survey on biomass gasifiers has been released by the Tennessee Valley Authority [23]. Hauserman [24] has just completed a detailed report of available and emerging technologies for electric power generation, including biomass gasification systems at small or remote sites where units delivering less than 10 MW are required [24]. This report addresses the basic design of gasifiers, the available commercial gasifiers, gas engines, and gas turbines and their capital costs and compares the cost of electricity from biomass-based systems and alternative systems.

Table X.1. Summary of biomass power projects in the developed countries using conventional or advanced gasification processes

Organization	Country	Process type
Aerimpianti (TPS process)	Italy	Circulating fluid bed
Ahlström[a]	Finland	Atmospheric circulating fluid bed
Arizona State University	United States	Twin fluid bed
Battelle Columbus[a]	United States	Fast fluid bed
Battelle PNL	United States	Wet gasification
Bioflow (Ahlström/Sydkraft)[a]	Finland	Pressure circulating fluid bed
Bioneer[a]	Finland	Up-draught
Ebara[a]	Japan	Twin fluid bed
EFEU	Germany	Fixed bed with cracking
General Electric	United States	Up-draught
Gotaverken	Sweden	Circulating fluid bed

Organization	Country	Process type
Hitachi[a]	Japan	Up-draught
HTW[a]	Finland	Pressure oxygen fluid bed
IGT[a]	United States	Pressure oxygen fluid bed
JWP Energy Products (EPI)[a]	United States	Fluid bed
LNETI	Portugal	Fluid bed
Lurgi GmbH[a]	Germany	Circulating fluid bed
Lanzano Linz	Italy	Up-draught
MTCI[a]	United States	Fluid bed
NEI Fluidyne	New Zealand	Down-draught
Sofresid/Caliqua[a]	France	Up-draught
Southern California Edison	United States	Down-draught
Southern Electric Int.[a]	United States	Fluid bed air
Steine Industrie (ASCAB)	France	Pressure oxygen fluid bed
Tampella Power[a]	Finland	Pressurized fluid bed
Thermoselect[a]	Switzerland	Two-stage pyrolysis–gasification
TNEE	France	Twin fluid bed
TPS (Studsvik)[a]	Sweden	Circulating fluid bed
Tsukishima[a]	Japan	Twin fluid bed
University of Sherbrooke	Canada	Fluid bed
Veba	Germany	Entrained flow
Ventec	United Kingdom	Down-draught
Voest Alpine	Austria	Up-draught
Valiant	Denmark	Up-draught
VAB	Belgium	Fluid bed
Wellman[a]	United Kingdom	Up-draught

Source: A. V. Bridgwater, *Fuel*, No. 5, 74 (1995).

[a] Process that has been or is being seriously considered for large-scale commercial application.

Table X.2. Proposed or planned demonstration systems and capacity

Organization	Gasifier	Technology	Generator[a]	Status	MWe
Aerimpianti	TPS	CFB	Steam turbine	Operational	6.7
Bioflow	Ahlström	Pressure CFB	Gas turbine CC	Commissioning	6
Elsam	Tampella	Pressure fluid bed	Gas turbine CC	Design	7
ENEL	Lurgi	CFB	Two gas turbines CC	Design	12
General Electric	GE	Updraught	Not specified	Design	–
GEF	Not decided	Not decided	Gas turbine CC	Evaluation	27
PICHTR	IGT	Pressure O_2 FB	Not specified	Commissioning	2-3
North Powder	JWP (EPI)	Fluid bed	Steam turbine	Not known	9
MTCI	MTCI	Fluid bed	Gas turbine	Design	4
Vattenfall	Tampella	Pressure fluid bed	Gas turbine	Deferred	60
VUB	VUB	Fluid bed	Gas turbine (Brayton)	Design	0.6
Yorkshire Water	TPS	CFB + cracker	Gas turbine CC	Design	8

Source: A. V. Bridgwater, *Fuel*, No. 5, 74 (1995).

[a] CC = combined-cycle operation.

5. *Gasifier designs and implementation*

Having already mentioned a few gasifier types, it would now be appropriate to illustrate the gasifiers available. Figure X.2 depicts four directly heated and two indirectly heated gasifiers. The more common biomass gasifiers employ a simple fluidized-bed design, with or without pressure, or a circulating fluidized bed. A few commercial or near-commercial gasifier systems and their application in different countries will now be briefly described. In some instances, conventional gasifiers for biomass conversion can be coupled with advanced generation systems such as fuel cells.

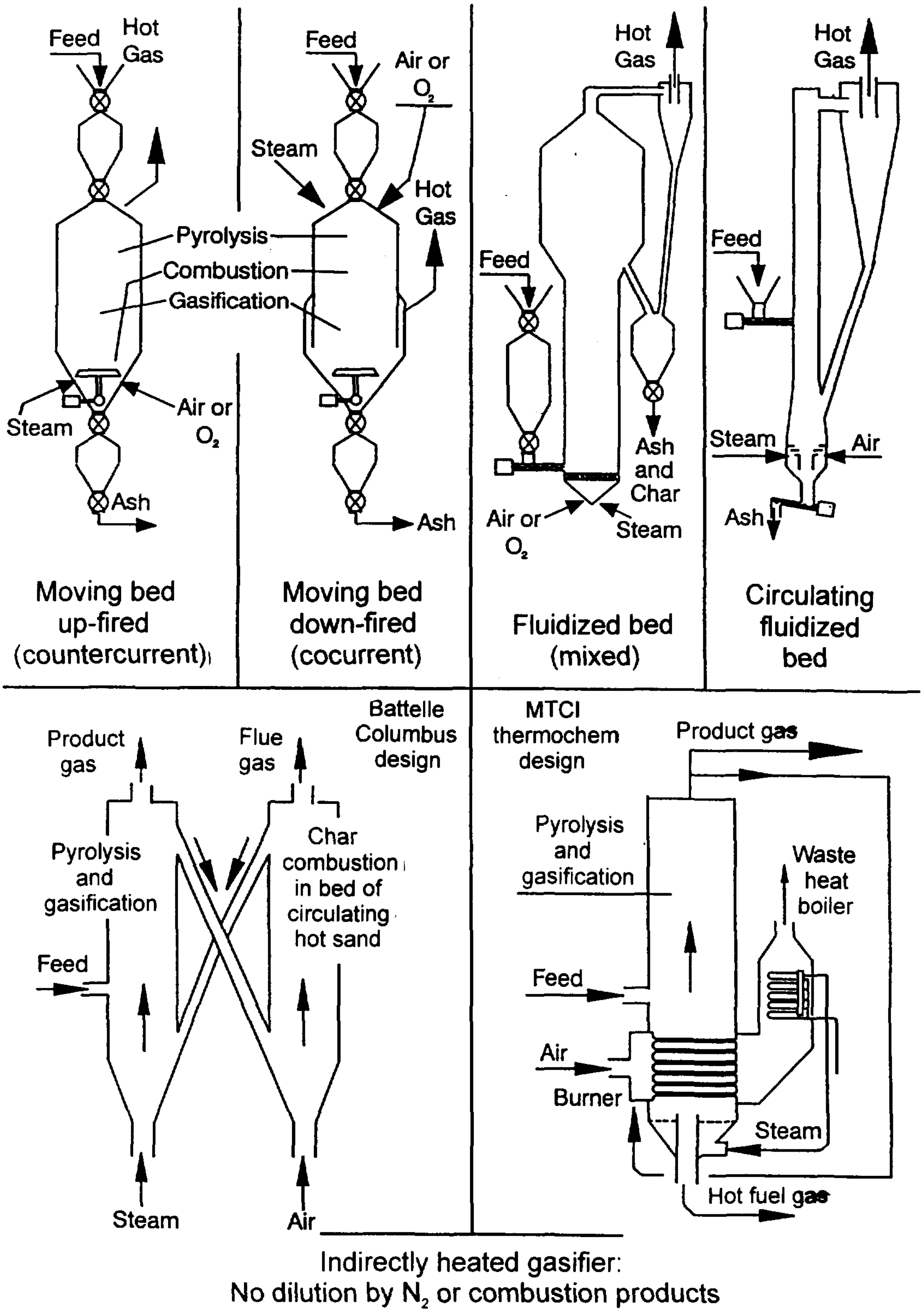
Conventional down-draught packed-bed gasifiers offer simplicity of design and low tar yield, making them very attractive for use with gas engines. However, of the basic systems being considered, they typically yield the lowest heating value . Using this design, Fluidyne Gasification Ltd. of Auckland, New Zealand, offers minimal-scale gasifiers rated at 41 kW to supply gas to small diesel engine generators, assuming average conversion efficiencies somewhere in the 30-40 per cent range. This unit, with gas clean-up equipment, is offered at a cost of US$ 558/kWe. It has been estimated that combinations of one or two Fluidyne down-draught gasifiers supplying single Caterpillar (United States) engine-generators may have capital costs as low as US$ 1,100/kW and US$ 760/kW, respectively. Fluidyne is also currently installing a 500 kW test unit in Germany. The company is expecting to eventually couple its gasifiers to fuel cells, which would represent an advanced system for electricity generation [24].

Developing a niche market for rice hulls, PRM Energy Systems of Arkansas provides a stirred-bed gasifier with a relatively deep, upward-tapered design for minimal turbulence and very little carry-over [25]. No fluidizing media are used, but with mechanical stirring the unit should have the process characteristics of a simple fluidized bed. Apart from rice hulls, the PRM gasifier has been tested with wood chips, peat, bagasse and other biomass wastes. Units have been sold in the United States, Malaysia and Australia. Currently, PRM Energy Systems is building a 330-tonne/day gasifier that will produce 33.7 MW (115 MMBtu/hr), which will in turn produce boiler steam. Under a new licensing agreement, PRIMEnergy of Tulsa, Oklahoma, will market, manufacture and install biomass gasification systems in the United States.

Energy Products of Idaho offers pilot units from 73 MW to 290 kW (250 down to 1 MMBtu/hr) for gasifier diameters from 6.71 to 0.61 m (22 to 2 ft). The units use a simple fluidized bed of proven design that has the potential for modification for use with engines or fuel cells in addition to kiln and boiler operations. A 14.7 MW (50 MMBtu/hr) rated unit was successfully demonstrated in Sacramento, California, for burning dry, chipped bark and wood waste from a lumbermill. Over 40 units of various capacities have been sold [26].

The Renugas technology, specially developed for biomass by the Institute of Gas Technology in Chicago, represents an advanced process incorporating a single-stage, pressurized fluidized-bed reactor with a deep bed of inert solids that provides stable fluidization, high carbon conversion and low oil and tar production [27]. Starting from a 12-tonne/day process development unit, commercialization is being advanced by a demonstration plant, financed by the National Renewable Energy Laboratory of Golden, Colorado, that is being built in Hawaii for gasifying 70 tonnes/day of bagasse. The Renugas gasifier provides various operating conditions, depending on the selected pressure and an whether air or oxygen is the oxidant. The unit can be used for steam generation or IGCC operation and also provides synthesis gas for chemicals such as methanol. This technology, which incorporates high-pressure vessel and feed systems, is designed for large-scale installations (>110 MW), according to the licensee, Tampella Power of Finland and Williamsport, Pennsylvania [24]. However, a 75 MWe IGCC facility based on alfalfa stems is being technically evaluated for Minnesota.

Figure X.2. Classification of gasifier designs



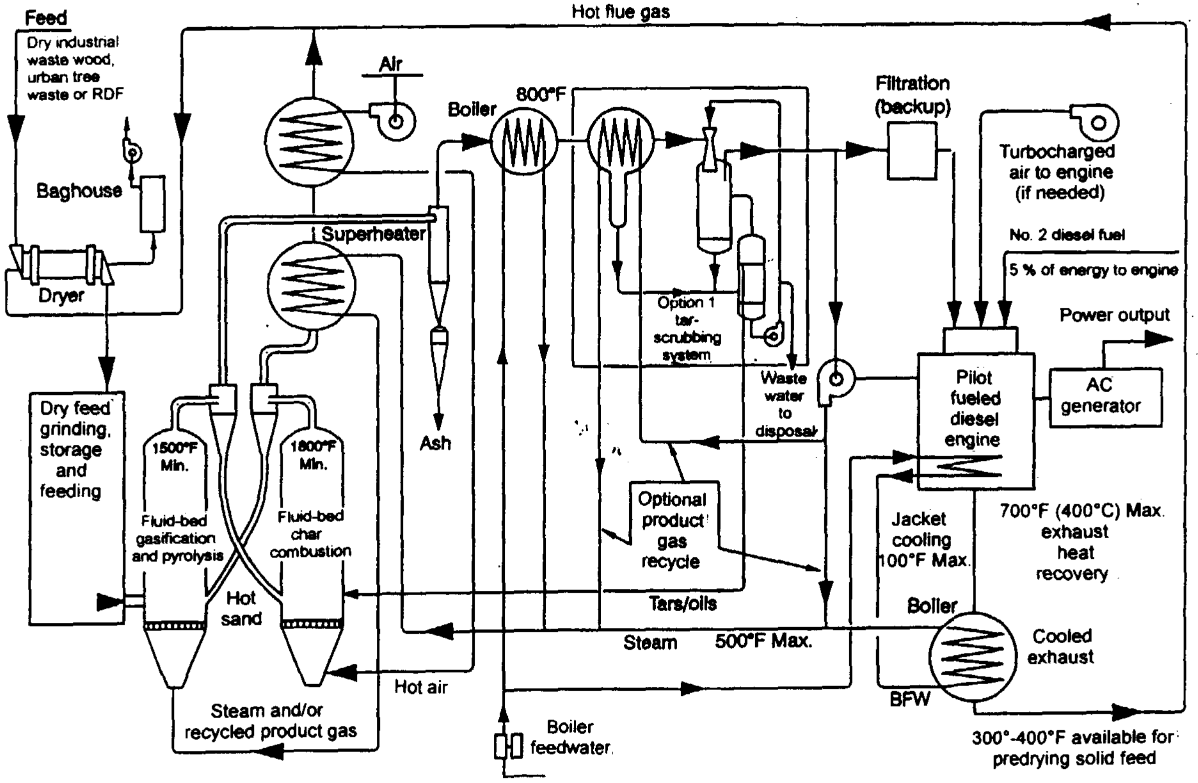
Circulating fluidized-bed (CFB) gasifiers involve injecting feed into a fast-rising stream of very hot combustion gases, promoting rapid pyrolysis. The gaseous and char products are then separated in one or more cyclones. The hot char is burned to supply heat. The design concept offers durable, low-cost gasifiers that are free of problems due to fluidization, bridging or channelling. Although the development of such gasifiers is proceeding slowly in the United States, they are offered commercially in Europe by, for example, Ahlström Corporation of Finland and TPS Termiska Processor of Sweden. The latter firm has a fluidized-bed gasifier operating in the United Kingdom [24]. Similar units have been built and operated in China [24].

Battelle Laboratories of Columbus, Ohio, one of the leading-edge developers of gasification technology, has designed an indirectly heated process that exploits the unique properties of biomass [28]. It has licensed its process to Future Energy Resources Corporation (FERCO) in Atlanta, Georgia. The process uses a separate circulating fluidized-bed steam gasification reactor for converting the biomass into medium-Btu gas and residual char and a combustion reactor that burns this char to supply heat for the gasification. Circulating sand between the gasifier and the combustor transfers heat between the two reactors. This novel process offers exceptionally high yields of high-quality gas for integration with a turbine system. The gas must be scrubbed to remove condensabletars and compressed. Alternatively, the scrubbed gas can be used in a fuel cell or gas engine application, where the rejected heat would superheat steam for gasification or preheat air for combustion. The circulating sand may include dolomite, limestone or taconite as sulphur-capturing agents. The Battelle process has the advantage of burning only the char and not the product gas. FERCO is presently designing an IGCC demonstration facility, to be constructed in Burlington, Vermont, that will consume 200 tonnes/day of wood chips and supply gas to a turbine. Assuming a gasifier efficiency of 75 per cent, it is expected that the integrated system will deliver an overall efficiency of 40-45 per cent and produce about 15 MW of power at a projected cost of US$ 500/kW for the gasifier alone. FERCO has a business plan for the mass production of modified gasifiers in 1 MW and 5 MW sizes for use with engine generator sets. A conceptual sketch of the gasifier, without specific mechanical details of the FERCO design, is shown in figure X.3. The cost of these units, excluding the generator sets, is projected to be US$ 750/kW (thermal) for the 1 MW model and US$ 500/kW (thermal) for the 5 kW model. Based on a heating value of 0.93-1.16 MJ/kg (400-500 Btu/lb), it is expected that the fuel gas cost would be US$ 0.06/kWh. These units are tentatively scheduled to be manufactured in the United States and Italy [24].

Arguably the most novel of advanced gasifier designs is that developed by ThermoChem Inc. of Santa Fe Springs, California, which is the commercial development branch of Manufacturing and Technology Conversion International (MTCI) of Columbia and Baltimore, both in Maryland [29]. The essence of the MTCI/ThermoChem design is the proprietary pulse-assisted heater, consisting of tube bundles immersed in a fluidized-bed reactor. A resonant frequency, determined by the combustor and tube dimensions, is applied to the tubes, creating turbulent mixing, a reduced boundary layer and substantially improved heat transfer to the combustor. The energy source for the heater is derived from burning a small portion of the product gas in the tubes. As the heater exhaust gas does not enter the reformer, no dilution of the product gas occurs. The temperature of the steam entering the fluidized bed and the energy input from the tube bundles can be adjusted independently, and recycled, heated gas can be substituted for some or all of the steam. These key factors, along with its flexibility to use dry or slurry feeds, make the gasifier versatile enough to meet different process objectives. For use with fuel cells, the anode exhaust gas can be substituted for the recycled product gas to the heating tube bundles. ThermoChem is developing a unique family of indirectly heated modular gasifiers, available in 2 MWt increments, and it has several demonstration plants for various applications worldwide, including installations in India.

Although not quite commercial, mention should be made of the Cratech pressurized integrated gasifier/gas turbine (BIG/GT) utilizing a fluidized bed and designed for small-scale electricity generation

Figure X.3. The FERCO indirectly heated gasifier using recovered heat from an engine-generator



plants (1-20 MWe) [30]. The system is designed to gasify a wide range of biomass, including sugar cane leaves, rice hulls, animal manure, cotton stalks, cotton gin trash, cornstalks and straws and grasses. The pressurized fluidized bed is air-blown and uses no steam. The gas exiting the gasifier, which has several novel design features, passes through a single-stage cyclone and a hot-gas filter vessel to remove particles that would damage the turbine of a simple heat engine capable of burning the low-heating-value gas. Cratech, of Tahoka, Texas, has operated a test unit 0.61 m (24 in.) in diameter at two atmospheres, and plans are under way to operate at 1 MPa (10 atmospheres) and evaluate the hot-gas clean-up system. Financial analyses for 1 MWe and 10 MWe generically sited BIG/GT power plants have been reported, using different assumptions, to give an internal rate of return on investment of as much as 25-30 per cent over 10 years at US$ 0.05 kWh and US$ 6.00/kg-lb of steam.

All of these gasifier designers claim encouraging track records in their pilot and demonstration projects. However, few processes have been formally handed over to owner-operators for extended operation and eventual in-country replication. Although European-provided gasifiers have been installed in Costa Rica, Guyana and other developing nations, they were shut down because of inadequately trained operators. These experiences are not documented in the technical literature by the developers. In publicized projects, the operators have years of experience designing and building the units. The time, cost and importance of transferring this level of skill to developing nations is not generally appreciated.

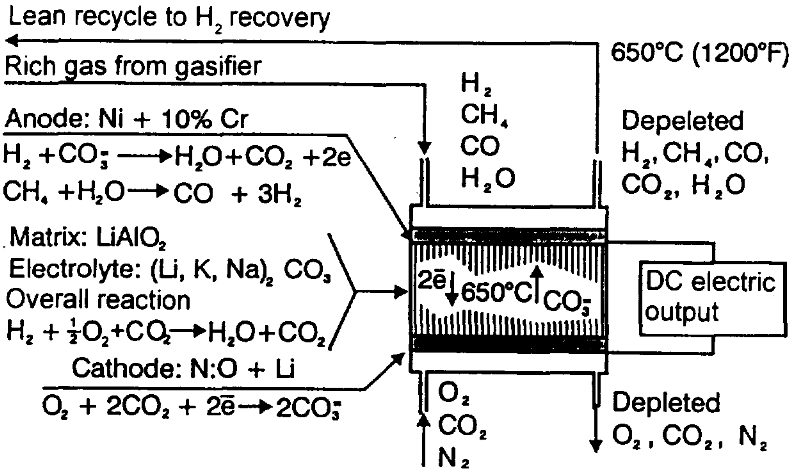
Cost estimates for not-yet-commercial gasifiers generally fall into three categories:

- Liberal estimates based on the cost of replicating existing pilot systems; these tend to be excessively high.
- Projections based on the repeat production of standardized units not yet completely designed, which may be unrealistically low.
- Estimating methods assuming the most nearly similar components for which standard cost data are available, which may fall anywhere between the above two extremes. Consequently, site-specific estimates must be based on quotes from equipment providers, who are motivated to take seriously the possibility of a sale, which has proven a very difficult barrier to overcome in generic studies [24].

6. *Fuel cells*

A fuel cell can be simply described as a battery in which the key reaction is indirect combustion. In molten carbonate fuel cells (MCFCs) and solid oxide fuel cells, which are suitable for integration with gasifiers, H_2 and CO react with O_2 through porous electrodes separated by an electrolytic medium. Electrons from reacting gases are exchanged and passed between electrodes by an external circuit, providing useful electric power. The external direct current is then converted to alternating current. MCFCs are the closest to commercial availability and the most reliable for power generation from biomass- or coal-derived gas [31]. The essential reaction chemistry of an MCFC is shown in figure X.4. The carbonate ion is the charge carrier through the electrolyte (Li_2CO_3) at 650° C (1200° F), requiring a supply of CO_2 at the cathode. Typically, an individual cell like the one in figure X.4 produces 0.7 volts at a current density that varies widely with temperature and with the partial pressure of the reacting gas components at each of the two electrodes. Commercial-scale modules using natural gas consist of stacks of thin sandwich-like layers of anode electrolyte, cathode and insulation in series or parallel connections to give the desired voltage and current. Research activities by VTT Energy, Finland, on a solid oxide fuel cell for electricity production from biomass gasification has been reported [32]. More details and the development status of fuel cells can be obtained elsewhere [33, 34].

Figure X.4. Essential chemistry of an MCFC



A unique advantage of MCFCs in integrated systems with gasifiers is that their exhaust heat is available at about 600° C (1100° F) and is adequate to supply all of the reaction heat and losses for a gasifier. This feature can mean overall system efficiencies of more than 55 per cent [24], which is an important reason to propose their use with biomass. In contrast, steam boiler systems in the 10 MW range seldom achieve efficiencies much over 30 per cent, and the gasifier-engine systems discussed here can probably exceed 40 per cent, but only with careful optimization of exhaust heat recovery schemes. For this reason, even in developing countries, second-generation MCFC systems may well prove competitive some time after 2000, especially where biomass fuel resources may be strained by limited production acreage and exploding populations.

As to the developmental status in the United States, an MCFC with a capacity of 250 kW has demonstrated extended operation on cleaned gas from a coal gasifier, although no MCFC has been operated on gas from biomass gasification. Two manufacturers in the United States expect to offer commercial units, rated at 1.0 and 2.8 kW for natural gas, in 1998, at a cost of around US$ 1,500/installed kW [24]. For lower-energy gas from biomass, the capacity will be derated, resulting in increased costs, to perhaps US$ 2,000/kW.

7. Gasifier gas clean-up

The performance of fuel cells is reduced, as with gas turbines and gas engines, by gaseous, tarry and particulate pollutants. Hydrogen sulphide (H_2S), condensableorganics above butane (C_4H_{10})and alkali/ash/soot particles need to be removed. Zinc oxide sorbent will reduce the level of H_2S to less than 1 ppm, the critical level. Tars may be removed by catalytic cracking using inexpensive catalysts such as dolomite or by a chill-scrub system. Particulate removal, after scrubbing, can be effected by a relatively cheap filter, but under the hot conditions of the gasifier outlet (600°-900° C), porous ceramic filters will probably be required. Designs under active development include ceramic candles, monolithic structures and honeycomb ceramic membranes. These have the disadvantages of thermal shock fracture and high cost and are irreversibly plugged by tar or alkali mists. For a more detailed discussion of removing gaseous/tar/particulate from biomass gasifier exit gas streams, the reader is referred to recent publications by Bridgwater [3], Hauserman [24] and Corella and others [35].

The area of gas clean-up has tended to be relegated to the future by developers of gasifiers, fuel cells and turbines. Costs of gas clean-up for the more complex systems are not generally predictable, having been lumped together as contingency factors in the few specific feasibility studies [24]. The current development efforts described above envision large advanced power systems in the less-than-immediate future. For practical gasifier-engine combinations, the problem is fortunately less daunting, as indicated by recent developments in India [10, 11] and New Zealand [24]. For this reason, such systems are more suited to immediate application in developing countries than systems involving fuel cells or turbines.

C. Criteria for the effective application of conventional and advanced technologies in developing countries

Many criteria can be listed for the effective application of biomass–gasification power technologies in developing countries. The set of criteria for conventional technologies will be slightly different from that for advanced technologies. Furthermore, the criteria may depend on the stage of development. Bridgwater [3] recently published an informative article on the technical and economic feasibility of biomass gasification for power generation, and additional insight can be found in a paper by Boldt [36].

Establishing biomass energy supplies in developing countries will depend on finding technologies that are affordable, quickly installed and locally made, if possible, and that use locally available biomass materials, keeping transport and handling costs to a minimum. Some key technical and economic criteria are as follows:

- Knowledge of available indigenous biomass, including residues. The biomass inventory should be quantified, ranking the different potential feeds by sustainability of supply, ease of access and real cost. Composition and variability with locality, soil, climate and other factors must be fully known.

- Knowledge of commercially available biomass gasifiers and associated gas clean-up and electrical generating systems. As discussed above, there is a diverse range of gasifiers; most are still under development, but a few are available commercially. Unless well demonstrated, gasifiers that have not been operated for extended periods across a broad range of conditions present a significant risk. The purchaser needs some guarantee and backup services to deal with breakdowns, even for proven technology. To achieve reliability, the level of expertise developed by the providers must be transferred to operating personnel by means of a period of tutelage involving, ideally, actual building and testing of units in the country of use.

- Testing of the selected biomass in the selected gasifier. The purchaser needs the results of some trial runs to establish the performance and gas quality under different conditions. Testing must involve the future operators.

- Size and location of the biomass gasification/electricity generation system. These need to be realistically assessed, taking into account the effect of the availability and quality of feed on variability in electrical demand. Location of the system is also important with respect to availability of labour, transport requirements and power distribution. Owner-operators should be thoroughly familiar with the local market for feedstocks and understand how to adjust their units to variation.

- Budget strategy for the gasifier and the associated gas clean-up and electrical generating system. Different options and budget scenarios are needed to provide a guaranteed supply of electric power. Knowledge of tax incentives for the use of renewable fuels, including their restrictions and their duration, is required. Firm cost data are needed for gas turbines and engines, although it may be difficult to elicit quotations from some suppliers.

- Expertise and training in gasification technology. Not only the decision makers but also the technicians who will operate the plants require sufficient knowledge to determine the causes of breakdowns and to maintain operability. Technicians must receive training by the company marketing the technology. As mentioned above, this could best be achieved by involving future operators directly in construction and on-site testing, as the final stage of a development programme.

- Political considerations. Transferring the later stages of the development effort to developing countries could face objections from the transferor nations. For the minority of components that are already being manufactured profitably (two or three simple gasifiers, engine generators and small steam power plants), financing is a relatively simple matter of the owners raising the money from any willing source. However, most of the components considered here (novel gasifiers and fuel cells) and combined systems are still in the development stages and depend on government funding. Both the United States Department of Energy and its European Union counterparts have policies, quite understandably, against funding these efforts in foreign or non-member countries. Funding then, is left to the United Nations, to the developing countries themselves or to various, limited foreign sources of aid. This factor is, of course, a convincing argument in favour of the more commercial technologies, such as steam boilers as small as 2-5 MW and gasifier-engine-generator systems of 40 kW to 1 MW and more.

- Fouling, corrosion, erosion and environmental emissions. Sufficient understanding of the contaminants that might build up in the overall system and the potential pollutant emissions from the process is required so as to control excessive breakdown and wear and reduce safety hazards. This knowledge requires experience in the extended operation of specific units and familiarity with local environmental regulations.

- Need for a facilitator. The successful transfer of technologies to developing countries has suffered numerous set-backs over the last 40 or more years. Motivation on the part of both transferor and transferee is not enough to guarantee success. Nor is the amount or source of funding. The successful process involves many actors and strategic pathways. The essential actors include a broad array of technical and administrative personnel in both countries. But even a team with all essential people will not guarantee success. The key is the liaison agent, a representative of the developing country who must understand its vision for adopting the technology and have appropriate connections in the relevant government departments.

- Role of the facilitator. The facilitator's most important task is to make the relevant contacts at the appropriate department level. Other tasks would be to determine the power structure in the different government agencies of the developing country and at the same time to learn about the operations of the technology company and how it handles its overseas business and to develop the local connections needed to facilitate customs clearance, site location, personnel visas and work permits and other official documents and correspondence. The technology company operating in a developed country also needs its own counterpart to the liaison agent, someone who will champion the technology and its potential usefulness to the targeted developing country.

- The lead time for the various tasks. Each country has its own expectations and agenda with respect to when certain actions or procedures should take place. Scheduled deadlines may not always be adhered to. The costing of tasks will need to reflect inevitable delays.

The above discussion, though not exhaustive, considers some of the important issues. Adaptability and flexibility are critical in responding to a wide variety of sometimes unfamiliar or abstruse matters or in interpreting actions or correspondence.

D. Concluding remarks

The overriding constraint on the development of biomass energy in developed countries is the high cost of the collected feedstocks relative to the cost of the conventional fuels to be displaced. A close second in importance is the high development cost of the technologies discussed in this review. Developed nations with the financial and technological assets to sustain the current biomass research community tend to concentrate on large-scale, high-tech solutions rather than on future problems. In the United States, biomass power research is still coasting on the dedication engendered by the energy crisis of the 1970s, with fresh impetus from the current emphasis on global warming. Bringing the various process concepts to the point of commercial demonstration is sharply restricted by the fact that the delivered cost of almost any biomass-derived power is substantially higher than that of power generated by fossil fuels. In Europe, the outlook for biomass power is considerably brighter, mainly because of the higher costs of fossil fuels but also because of more intensive land use policies, which stimulate the more efficient use of forest and agricultural residues. For these reasons, it can be recommended that the United States developers of the biomass energy concepts reviewed here should look to European technology markets.

Transferring state-of-the-art biomass energy technologies from the United States and Europe to developing countries will depend generally on lower labour costs for feedstock collection and on the urgent necessity to reduce oil imports. The success of specific scenarios will depend primarily on the abilities of the key personnel in the developing countries. While the developed countries will provide initial tutelage, the final efforts must be guided by local personnel, who must be thoroughly familiar with what technologies, engineering practices and development strategies are appropriate to the local infrastructure. A good example is the success reported for simple, cheap gasifier-engine systems in India [10, 11] a decade after the collapse of similar drought gasifier research in the United States [24]. Similarly, a recent review of minimum-scale fluid-bed boiler technology for potential use in remote locations in Alaska revealed that the cheapest 5 MW capacity system was offered by an Indian manufacturer [24]. These relatively simple technologies must be the first to be transferred, with lower priorities assigned to next-generation technologies, such as fuel cells, which should first find their windows of economic opportunity in Europe.

Various technologies for the combustion and gasification of biomass along with new ways to integrate the products into electric power systems have been designed, developed, demonstrated and, in a few cases, commercialized. Pressurized fluidized-bed combustors and gasifiers and integrated combined-cycle and fuel cell systems all offer some promise, but many challenges remain. Simple gasifiers linked with engine generating sets are being introduced into developing and developed countries. Many criteria are important to achieving the goals of technology transfer, including sufficient knowledge of indigenous biomass and gasifier-electric conversion systems, site location specifics, the budget strategy and technology training. To achieve successful technology transfer requires not only well-organized teams from the technology company and the developing country, but also a liaison agent, who is the primary facilitator, and a technology champion, both of whom must embrace the vision.

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XI. CIRCULATING FLUIDIZED-BED TECHNOLOGIES FOR THE CONVERSION OF BIOMASS INTO ENERGY

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Abstract

The paper introduces circulating fluidized-bed (CFB) combustion and CFB gasification. CFB combustion units are state-of-the-art and have proven their ability to convert biomass into power and/or steam. The existing units and projects in developing countries are discussed as examples of conventional technology. To illustrate advanced technologies, CFB gasification is discussed. Important process parameters of plants already in operation or under construction in developed countries are shown. Criteria for the selection of CFB combustion or gasification based on available feedstocks and products required are discussed. Finally, a procedure for implementing Lurgi's CFB technology in developing countries is proposed.

Introduction

The paper presents an introductory description of CFB combustion and CFB gasification. CFB combustion units are state-of-the-art and have proven their ability to convert biomass into power and/or steam. The existing units and projects in developing countries are discussed as examples of conventional technology. To illustrate advanced technologies, CFB gasification is discussed. Important process parameters of plants already in operation or under construction in developed countries will be shown. Criteria for the selection of either CFB combustion or gasification based on available feedstocks and products required are discussed. Finally, a potential procedure for the implementation of Lurgi's CFB technology in developing countries will be proposed.

Lurgi is a group of technologically leading engineering contractors operating worldwide that focuses on plants for the oil, gas, chemical, metallurgical, energy and environmental sectors as well as the polymer and synthetic fibres industries. It offers 400 processes, including 200 proprietary processes, for the engineering and construction of turnkey plants and plant units. As it is not bound to any company-owned manufacture of plant and equipment, it is free to select the most suitable suppliers in terms of quality, reliability and financing, including those in the client's own country or in third countries.

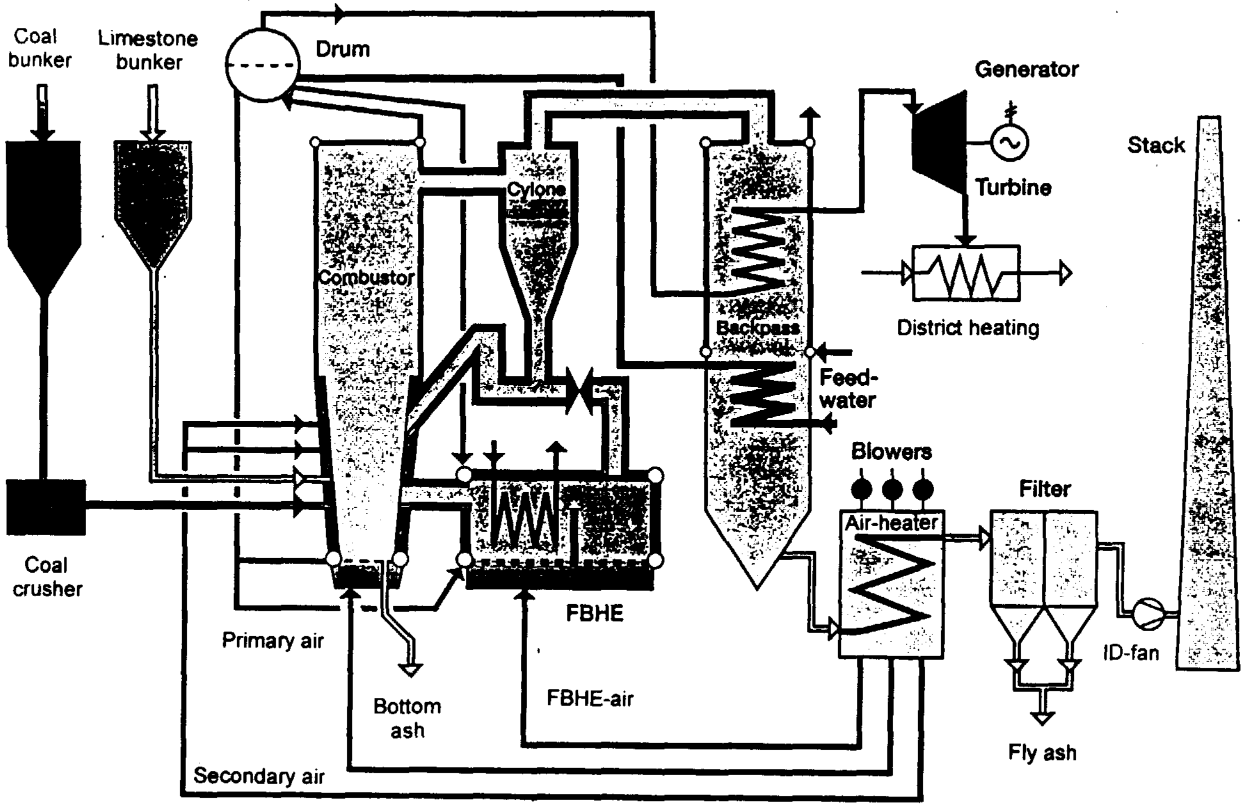
A. Circulating fluidized-bed combustion and gasification technologies

In this section basic information on CFB combustion and gasification is provided (figure XI.1).

1. Circulating fluidized-bed combustion

The CFB combustion process utilizes a fluidized-bed combustor in which crushed coal and limestone are suspended in a stream of upward-flowing air. Owing to the fine particle size of the coal feed and the high gas velocities, the bulk of the solids is carried out of the combustor with the flue

Figure XI.1. Basic flow sheet of a CFB boiler



gases,collected in a recycling cyclone and returned to the combustor. This gives the process its name: circulating fluidized-bed [1].

(a) Combustion

The fuel is burnt at a temperature of about 850° C. It is fed directly to the combustor and does not require costly fuel preparation and distribution systems. The combustion air is fed in two stages: primary air through the nozzle grate at the bottom of the combustor and secondary air part way up the combustor above the fuel feed point. The limestone required for desulphurization is added near the bottom of the combustor.

(b) Steam generation

Depending on the mode of operation of the CFB power plant (base load or intermediate load), as well as on the plant size and the type of fuel used, the plant may be designed either with or without a fluid-bed heat exchanger (FBHE). In FBHE-equipped plants, the heat transfer surfaces for steam generation are located both in the combustor and in the FBHE. On leaving the recycling cyclone, a portion of the hot solids is diverted to the fluid-bed heat exchanger, where it is cooled before being returned to the combustor. The heating surface for economizer and superheat duty is typically installed in the convective pass.

(c) Flue gas clean-up

The flue gases are cleaned of particulates in a downstream electrostatic precipitator or baghouse filter. Add-on flue gas desulphurization and/or NO_x removal systems are not required in CFB power plants. The fine-grained limestone required for desulphurization to control the pollutant SO_2 is fed to the process near the bottom of the combustor.

Desulphurization takes place directly in the combustion zone. The reaction steps are as follows:

Oxidation of the fuel-bound sulphur: $S + O_2 \rightarrow SO_2$

Calcining of the limestone to form calcium oxide: $CaCO_3 \rightarrow CaO + CO_2$

Gypsum formation: $CaO + SO_2 + 1/2\ O_2 \rightarrow CaSO_4$

The combustion temperature of 850° C is generally too low to allow for any significant oxidation of atmospheric nitrogen. Formation of NO_x from fuel-bound nitrogen compounds is suppressed by staged combustion air addition. This allows for low (<200 mg/Nm^3) NO_x emission levels. Chlorine and fluorine compounds are largely retained in the ash

(d) Ash

The only CFB by-product is a dry ash consisting of the original ash from the fuel, the gypsum, a small amount of free lime and residual amounts of carbon. This ash is well-suited for blending into cements and other construction materials. Owing to its basicity and its hydraulic characteristics, CFB ash can be landfilled without any problems.

(e) Design features

The CFB unit is well-suited for power plants with capacities of 60-1,000 MWt per unit. Its excellent part-load behaviour and load-following capabilities as well as its ability to start up quickly after temporary shutdowns (overnight, weekends) make it an ideal system for co-generation plants and industrial applications. The excellent heat storage capacity of the hot ash prevents the plant from cooling down excessively, ensuring rapid restarting. In addition to burning high-grade coals, CFB firing systems can also burn low-quality fuel with high ash and sulphur contents. In particular, fuels that are difficult to burn or that cannot be burnt at all in conventional steam generators (shale oil and carbon containing refuse, for example) may lend themselves well to CFB combustion. Carbon burnout of 98-99 per cent can be achieved owing to intimate gas/solids mixing and the long retention time of the fuel in the CFB. Desulphurization is accomplished in the combustion zone itself by the addition of small quantities of limestone. At a Ca/S molar ratio of approximately 2, over 90 per cent of the sulphur contained in the fuel is converted to gypsum. Low combustion temperatures in combination with staged combustion, a typical feature of the CFB process, permit NO_x emissions to be reduced to less than 200 mg/Nm^3. Chlorine and fluorine are largely retained in the ash. Flue gas dedusting to the statutory emission limits (less than 50 mg dust/Nm^3) is accomplished in electrostatic precipitators or baghouse filters. The CFB ash lends itself for use as an aggregate for cement or other construction materials or can be landfilled without any problems. Part loads down to 25 per cent are well within reach at load-change rates up to 7 per cent per minute. Normally, crushers are sufficient for preparing the CFB fuel. Only with firing fuels that have both high ash and moisture contents are crushing and drying required. Owing to their compact design, CFB power plants can be located in densely populated areas. CFB plants require less floor space than conventional steam generators, which have downstream flue gas cleaning equipment.

2. *Circulating fluidized-bed gasification*

A process related to CFB combustion is atmospheric CFB gasificastion [2], which is suitable for feedstocks like coal, biomass or wastes. The Lurgi CFB gasifier operates at near-atmospheric pressure and is therefore well suited for smaller capacities (i.e. up to around 20 tonnes/hr of coal). The CFB gasification unit (figure XI.2) consists of a vertical cylindrical refractory-lined vessel with recycle cyclone, bottom ash cooling and, if required, dry fly ash removal and wet gas scrubbing systems. The CFB gasifier operates in a mode intermediate to the classical bubbling bed and the pneumatic transport reactor. Under those conditions the slip velocity between solids and gas (or the velocity differential) is highest, leading to maximum heat and mass transfer between gas and solids, requiring the smallest reactor diameter of all fluidized-bed concepts. Coal, biomass, wastes or other solid fuels are introduced into the reactor near its bottom. Gasification agents, which depending on product gas specification would be air, O_2 and steam or O_2 and CO_2, are introduced through a nozzle grate in the lower part of the reactor. Ash is partly withdrawn through the reactor's grate (bottom ash) and partly recovered from the product gas (fly ash). Gasification reactions start close to the bottom of the reactor at the fuel feeding point. The reaction temperature typically ranges from 800° C to 1050° C, depending on the type of feedstock. The dust-laden product gas leaves the reactor at its top and passes through a cyclone. Most of the dust is removed from the gas and recycled to the gasifier bottom through a standpipe with seal pot, leading to high carbon conversion. The product gas is then cooled, dedusted and purified depending on the requirements of its further use. Commercial gasification plants with capacities of up to 100 MWt are in operation or under construction. The high-temperature Winkler (HTW) gasifier (figure XI.3), developed by Rheinbraun (Germany), operates as a bubbling fluidized bed at pressures between 1 and around 2.5 MPa [3]. Thus it lends itself to larger capacities, up to around 700 MWt per reactor. It is being engineered and marketed by Lurgi in cooperation with Uhde (Germany). The HTW gasification system consists of a vertical refractory-lined cylindrical vessel with recycle cyclone, a system for feeding

Figure XI. 2. CFB gasification unit

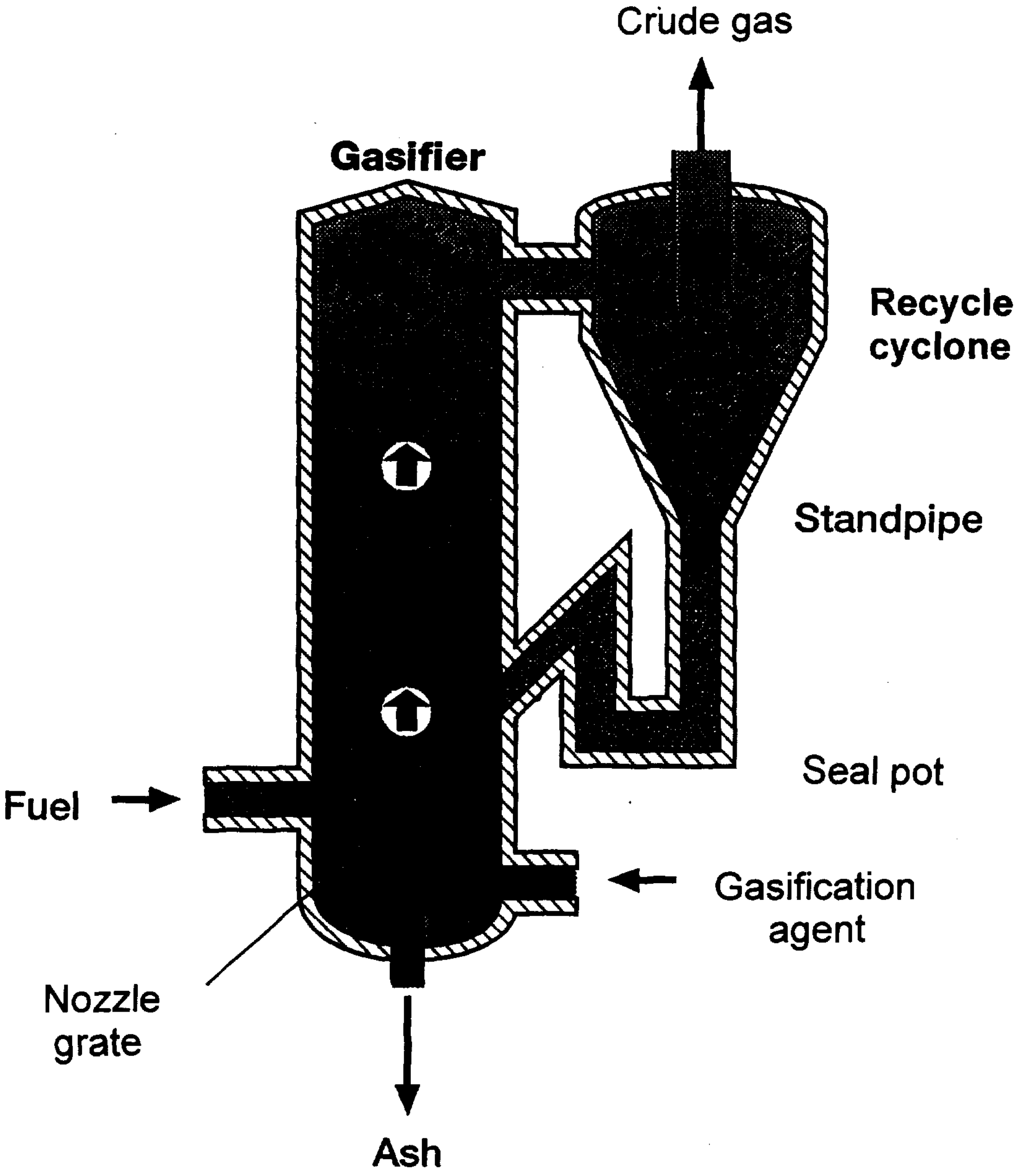
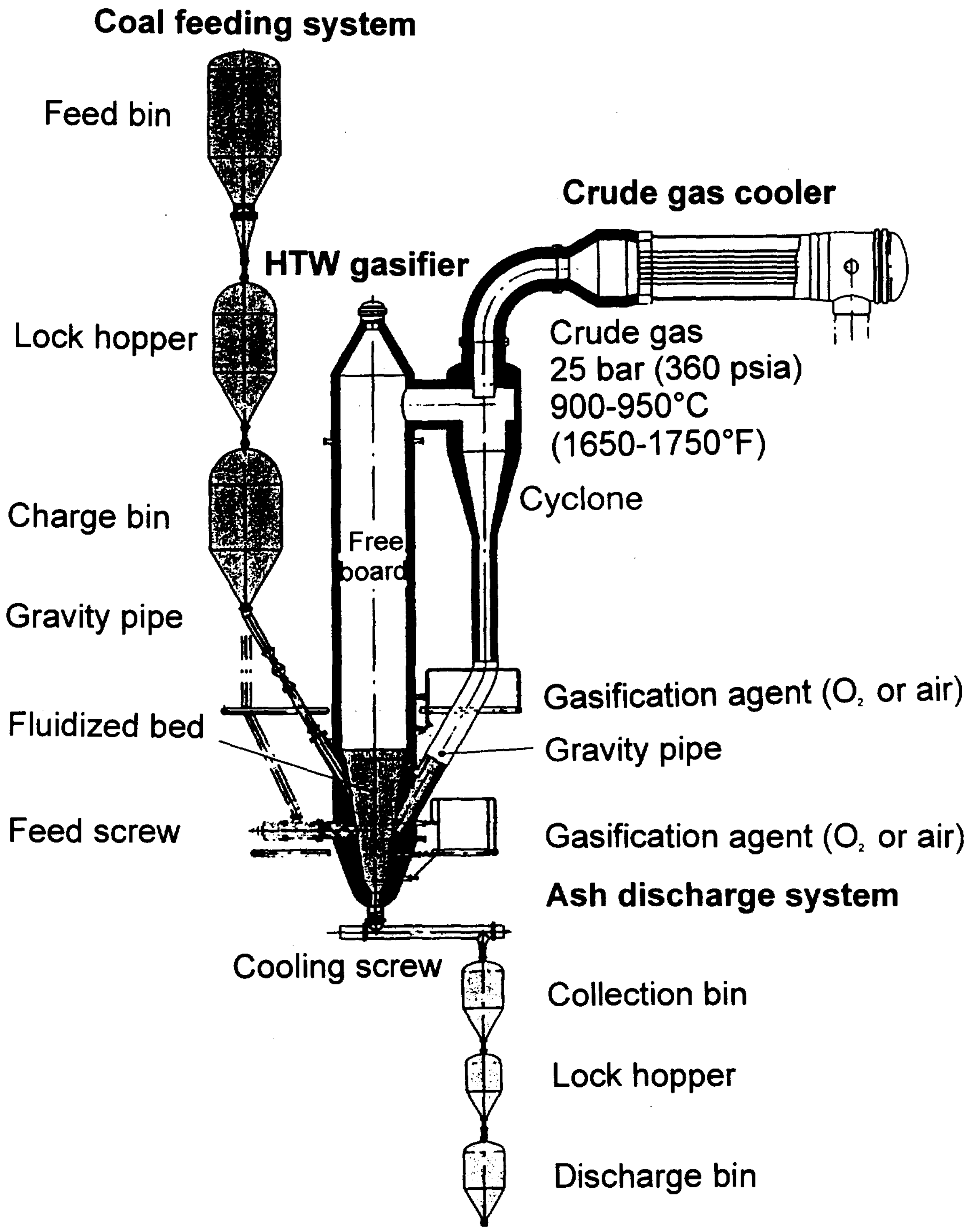


Figure XI. 3. High-temperature Winkler (HTW) gasification system



coal into the pressurized gasifier (screw or gravity depending on feedstock) and an ash cooling and removal system. The gasification agent (a mixture of air or oxygen and steam, depending on the use of the product gas) is introduced at different levels into the fluidized bed and into the freeboard for further gasification and decomposition of the hydrocarbons in the gas. The main portion of the entrained dust is removed from the hot crude gas (typically around 850-1 000° C) by a cyclone and recycled to the fluidized bed via a downpipe. The hot crude gas is then cooled and treated to the conditions required for further use. The operation of the gasifier at elevated pressure leads to a gasifier capacity of about 100 MWt/m^2 of gasifier cross-sectional area when using oxygen and 50 MWt/m^2 when operated in the air-blown mode (at 2.5 MPa pressure). Commercial-scale plants in operation include Rheinbraun's demonstration plant in Germany, where methanol synthesis gas is produced from lignite (capacity approximately 730 tonnes/day of dried lignite). Decisive for the application of either atmospheric or pressurized gasification is the required thermal capacity of the plant and the availability of biomass as feedstock. The typical plant capacity for atmospheric circulating fluidized-bed (ACFB) gasification is in the range 10-100 MWt. For larger plant capacities, the pressurized HTW gasifier will be more economical.

A wide variety of biomass feedstocks is suitable for CFB gasification, including the following:

- Woodchips, tree bark and forest wastes.
- Miscanthus, straw and other farmed biomass.
- Biomass wastes (bagasse etc.).

As an alternative to combustion plants, which produce steam for power production or CHP only, the gasification plants convert the fuel into a product gas that has a variety of uses:

- Fuel gas for the supplemental firing of existing power plants, kilns etc.
- Synthesis gas for chemical processes (methanol, for example).
- Fuel gas for combined cycle power generation.

B. Circulating fluidized-bed combustion: a "conventional" technology

Since 1985, when the first CFB power station started commercial operation, more than 80 CFB power stations have been ordered. Their capacities range from 20 to 250 MWe [4]. Various feedstocks are utilized depending on the plant's location: hard coal, lignite, anthracite culm, paper sludge, petroleum coke, oil shale, residue-derived fuel and wood.

Most of the plants are located in the United States, Germany, Italy, France, Japan, Republic of Korea, China, India and Slovakia. A few of these plants utilize wood only. Their successful operation (table XI.1) proved the ability of CFB combustion technology to utilize unconventional feedstocks [5].

Table XI.1. Lurgi commercial wood-fired CFB combustion units

Location	Capacity (MWt)	Steam	Start-up	Fuel
Fresno, California	89	100 tonnes/hr 87 bar 515° C	1988	Wood
Rocklin, California	89	100 tonnes/hr 87 bar 515° C	1989	Wood
Mecca I + II, California	2 x 79	103 tonnes/hr 89 bar 496° C	1992	Waste wood

C. Circulating fluidized-bed gasification: an "advanced" technology

This section of the paper describes an IGCC project, including fuel preparation, gas production and power production. The power plant envisaged in this project is based on the integration of an atmospheric gasifier with a combined gas-steam power cycle and can be adapted to co-generate heat and power. The plant will be fed by wood chips from short rotation forestry at an hourly rate of 7.1 tonnes. The net generated power is estimated at 12 MWe and the number of operating hours per year is expected to be 7,000. This implies a yearly consumption of dry wood chips of 49,700 tonnes [6, 7].

A schematic diagram of the system is shown in figure XI.4. The overall system can be divided into three main areas:

- Gasification process and related equipment.
- Gas turbine electricity generating sets.
- Heat recovery system and steam cycle.

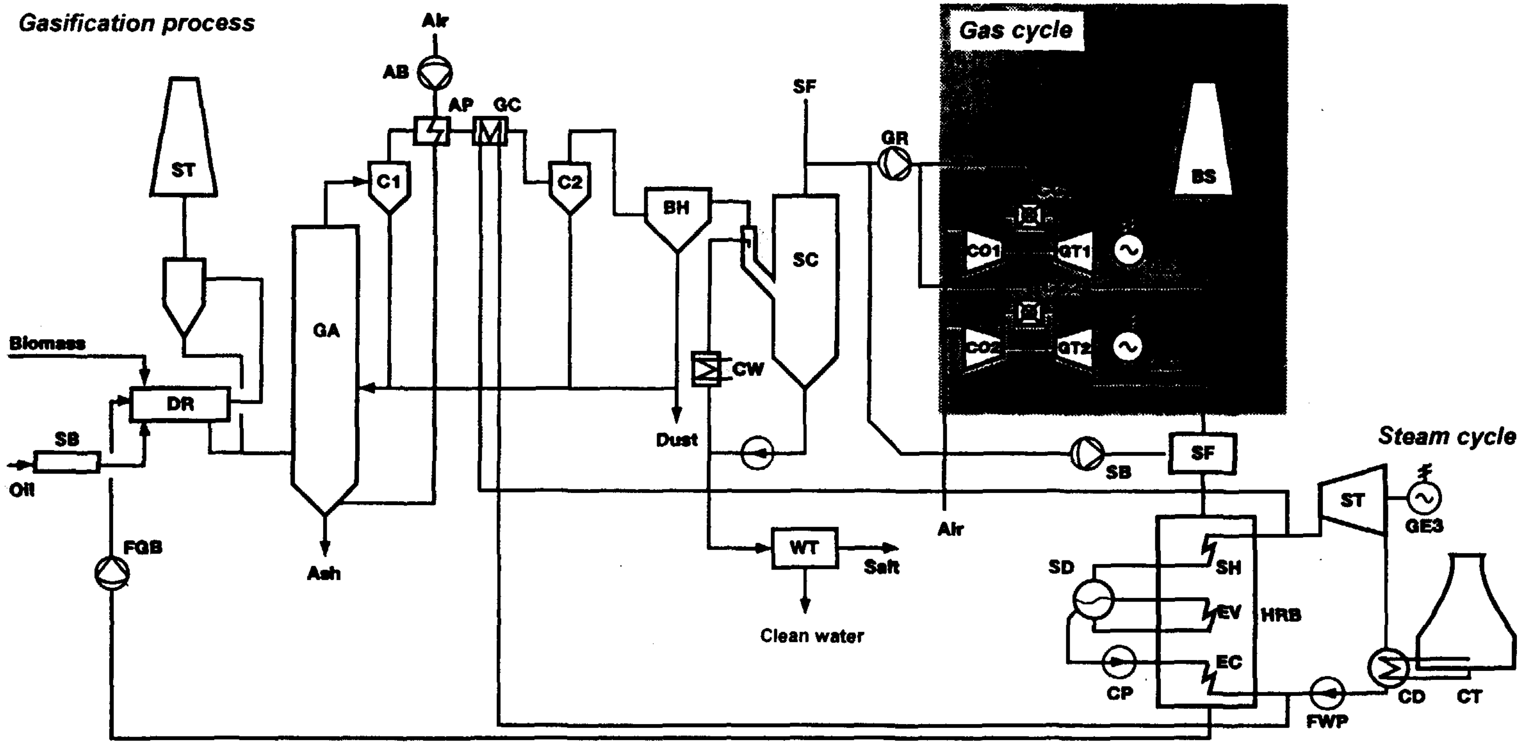
The gasifier and its associated gas clean-up train will consist of the following processes or subsystems: fuel preparation, syngas production, clean-up subsystem, gas compression and delivery and liquid waste treatment.

1. Plant description

(*a*) *Biomass drying*

After metal and stones have been removed, the wet biomass is shredded to a maximum particle size of less than 30 mm x 30 mm x 6 mm and delivered to a wet biomass bunker. From there, it is fed to a rotary drier, where it is dried to a final moisture content of 8-10 per cent by direct contact with flue gas recycled from downstream of the economizer of the steam cycle. Dust collected in the drier filter is combined with dust from the drier off-gas cyclone, and the coarse biomass material leaving the rotary drier is fed to the dry biomass bunker. From there, it is metered and introduced into the CFB gasifier via screw conveyors fitted with a special rotary valve to seal off the gasifier pressure. The drier off-gas is filtered and scrubbed before it is released into the atmosphere.

Figure XI.4. Power from biomass atmospheric gasification combined cycle (overall process scheme)



Gasification process - Lurgi

GA	Gasifier	SF	Start-up Flare
C1, C2	Cyclone 1, 2	GR	Syngas Recompressor
AB	Air Blower	FGB	Flue Gas Blower
AP	Air Preheater	SB	Start-up Burner
WT	Water Treatment	DR	Dryer
BH	Bag House Filter	ST	Stack
SC	Scrubber	CW	Cooling Water
GC	Gas Cooler		

Steam cycle

ST	Steam Turbine	FWP	Feed Water Pump
GE3	Generator 3	SF	Supplementary Firing
CD	Condenser	EC	Economizer
CT	Cooling Tower	SH	Superheater
HRB	Heat Recovery Boiler	EV	Evaporator
SD	Steam Drum	CP	Circulating Pump
SB	Syngas Blower		

(b) *Circulating fluidized-bed gasification*

Ash from the biomass with a carbon content of about 2 per cent is returned to the gasifier via a cyclone. The dry biomass introduced into the system mixes with this recirculating material in the lower part of the gasifier and is gasified during vertical transport in the expanded fluidized bed to form gas with a calorific value of approximately 5,860 kJ/Nm^3 of wet gas. Preheated air for fluidizing the recirculating material is injected into the gasifier through the grate. The steam generated from the residual biomass moisture and the air react with the biomass to generate the product gas. The gasification reaction is controlled at approximately 800° C and 1.4 bar. The gas produced, together with the water vapour, carries the reactor bed material to the recycle cyclone. Material separated from the gas by the cyclone is returned to the lower part of the gasifier through a standpipe and a seal pot.

(c) *Gas cooling*

The gas is cooled in two stages. During the first stage of gas cooling the product gas is cooled from about 800° C to 600° C in the air preheater, while the gasification air is heated to about 500° C. During the second stage, the gas leaving the air preheater at a temperature of about 600° C passes through a waste heat boiler (WHB) where it is cooled to about 240° C. The steam production (20 bar, saturated) of the WHB is about 3.4 tonnes/hr.

(d) *Dust removal/recycle*

Downstream of the WHB there is a final cyclone where as much dust as possible is separated from the gas before it is finally dedusted in a bag filter. The dust from the final cyclone and the filter is routed to a combustor for complete carbon conversion. The combustion gas is returned to the gasifier.

(e) *Gas scrubbing*

The dedusted product gas leaving the filter is water-scrubbed in a multistage scrubbing system. The system includes the following:

- Scrubbing under acidic conditions.
- Scrubbing under alkaline conditions.
- Final scrubbing with clean water.

While it is scrubbed, the product gas is also cooled to about 45° C.

(f) *Gas compression*

The product gas is compressed to about 20 bar in a multistage compressor with intermediate cooling and water injection. After compression, the gas is ready for combustion in the gas turbines. Its composition and other characteristics are as follows:

Component	*Proportion (vol %)*	*Characteristics*
CO	20.25	
H_2	11.22	Gas flow: 16,200 Nm^3/hr
CH_4	5.83	Gas temperature: 105° C
H_2S	0.00	Gas pressure: 20 bar
CO_2	11.86	Lower heating value: 8,860 kJ/Nm^3
N_2	44.61	
H_2O	6.22	
	100	

The compressed gas meets the required specification for use in gas turbines.

(g) *Waste water treatment*

The water blow-down from the scrubbing system is treated in a wastewater treatment plant, where the following process steps are carried out:

- Removal of condensable hydrocarbons by adsorption and recycling of the hydrocarbons to the gasifier for destruction.
- Stripping off of gases dissolved in the water and recycling of the gases to the combustor for destruction.
- Evaporation of water: recycling of resulting condensate as scrubber make-up and disposal of the salt recovered to a suitable authorized facility.

(h) *Ash removal*

The ash from the gasification of the biomass is withdrawn from the lower part of the gasifier, cooled to approximately 70° C and discharged for disposal. Ash from biomass may be used as a (weak) fertilizer. The carbon content of the ash is less than 2 per cent.

(i) *Gas turbine generator sets*

Downstream of the gasifier and its associated gas clean-up train, the plant will include two identical gas turbine generator sets operating independently. The prime mover for each set will be a mature rated industrial gas turbine (simple-cycle, single-shaft and capable of delivering up to 4.7 MWe of electrical power at over 31 per cent efficiency). Its advanced cooling, blade design and corrosion-resistant materials and coatings not only maximize performance but also achieve low capital and maintenance costs. The advanced 10-stage transonic compressor incorporates low aspect ratio blading, which results in a robust design and efficient operation. The compressor features variable inlet guide vanes and stators to modulate air flow, assuring fast, easy start-up. The six reverse-flow combustion chambers are symmetrically positioned in the high-pressure casing and are capable of burning a wide range of gaseous and liquid fuels. The turbines will be fitted with a dual-fuel system to allow them to be started on diesel fuel prior to operation on the syngas fuel from the gasifier. An advanced two-stage, overhung transonic turbine, connected to the compressor rotor, provides all of the power to drive the compressor and output power for the driven unit. An integrally mounted epicyclic gearbox provides reduction to an output shaft speed of 1,500 rpm.

2. Status of technology

The Lurgi CFB gasification pilot plant has been operated since 1983 for more than 5,000 hr. The gasifier has a thermal capacity of 1.7 MWt. During the test periods various feedstocks such as hard coal, lignite, biomass, petroleum coke and all kinds of waste material were tested successfully. The CFB gasification technology has been commercially available since 1985 (see table XI.2).

Table XI.2. Commercial Lurgi CFB gasification units

Location	Capacity	Product	Start-up	Fuel
Pöls, Austria	27 MWt	Fuel gas	1987	Tree bark
Rüdersdorf, Germany	100 MWt	Fuel gas	1995	Wood, waste wood, residue-derived fuel, lignite waste, rubber waste
Project 1	12 MWe	Electricity	1998	Short-rotation forestry products
Project 2	20 MWt	Fuel gas	1999	Municipal waste

D. Guidelines for technology selection

Usually a project starts with a screening phase. During this early stage, quite often only the available feedstock and the required product are known and alternatives are being discussed. Technology vendors that can provide the applicable conversion processes have to be selected. Prior to establishing a ranked vendor list, evaluation criteria have to be determined. Naturally, at this stage of a project the capabilities of the potential vendors are of greater interest than the technical processes themselves:

- Technical and financial capabilities.
- Service spectrum.
- Flexibility relating to cooperation with local companies.
- Experience in financial analysis.
- Experience in project execution.
- Portfolio of processes owned or licensed (a large portfolio means the freedom to choose from many alternatives).
- R and D activities.
- Status of the technology.

For the technology selection step, the evaluation criteria should be based on parameters such as the following:

- Fuel properties/availability of feedstock quantities.

- Product required.
- Plant capacity.
- Environmental requirements.
- Plant availability required.
- Specific site conditions.
- Status of technologies.

To further reduce the number of processes considered, table XI.3 summarizes the technologies discussed in this paper: CFB combustion and gasification.

Table XI.3. Criteria for technology selection

Technology	Criteria			
	Feedstock	Product	Capacity (MWe)	Status
ACFB Combustion	Biomass	Electricity, heat	>20	Conventional
ACFB Gasification	Biomass	Electricity, heat, fuel gas, syngas	>10 <40	Advanced Conventional
HTW	Biomass	Electricity, heat, fuel gas, syngas	>40	Advanced

Since there will always be two or three (or even more) technical solutions, the final decision will have to be based on an economic evaluation. However, there are no general decision criteria that can be applied in all cases. Thus, it will be necessary to define project-specific selection criteria and to investigate the political, economic and technical factors case by case.

E. Project materialization: technology transfer

The organization and working methods of a technology vendor have to allow each project to be realized on a flexible and individual basis. The technology vendor should not be bound to any particular manufacturer of plant and equipment so it can be free to select the most suitable suppliers in terms of quality, reliability and financing, including those in the client's own country or in third countries. Furthermore it should have experience in a number of services:

- Engineering and construction of plants for all industries.
- Feasibility studies, proposals, procurement.
- Quality assurance, progress and cost control, erection and commissioning.
- Testing raw materials for their suitability and most effective use.

- Financial engineering on both a national and an international level.
- Developing overall concepts from the engineering and supply of a plant through the marketing of the product.

The classical route for the execution of a project from the first idea to the final product comprises the following steps:

- Market analysis
  - Products required
  - Consumer demographics
  - Available feedstocks
  - Location.
- Feasibility study
  - Selection of possible technical solutions
  - Cost estimate (investment, operating)
  - Investigation of different solutions/options
  - Recommendation of a viable solution
  - Decision to continue.
- Selection of bidders
  - Request for a proposal.
- Clarification of
  - Financial approach
  - Political support/loan guarantees.
- Decision on contractor
  - Identification of local manufacturers and/or engineering companies
  - Agreements.

If more is required than just the delivery of a plant (i.e. if technology is to be transferred), additional agreements have to be incorporated into the procedure. By way of example, one possible way is outlined next. The initiator of a project (for example, a regional government or a utility or a manufacturer) wishes to build a power plant using a new technology which is for the time being not available from local power plant manufacturers or engineering companies. Typically, the initiator will approach companies who are able to provide the required technology and are willing to cooperate. Assuming that mutual interest will lead to an agreement, a contract is prepared that should cover the following items:

- Definition of the technology.
- Geographical area where the contract is applicable.
- Targets of the contract.

- Execution of the cooperation agreement, tasks of the partners.
- Secrecy agreement.
- Duration of contract.

In the fourth item the specific responsibilities and tasks of each partner are to be determined in relation to:

- Marketing.
- Information transfer.
- Split of work (e.g. supply of hardware, engineering services).
- Training programmes.
- Exchange of personnel.
- Joint venture.

F. Conclusions

Lurgi CFB combustion and gasification technologies are commercially available for a wide variety of feedstocks. Both technologies have proven their reliability. Results from continued operation concluded that use of CFB technology to burn or gasify biomass achieves high conversion efficiencies and the required low emission levels. The process of choice has to be selected case by case and depends on the client's specific requirements.

With regard to the combustion, gasification, gas clean-up and synthesis processes Lurgi can offer, it is prepared to maximize local project content (e.g. detail engineering and manufacturing of much of the equipment), significantly reducing outlays of foreign exchange. In addition, Lurgi's willingness to cooperate as much as possible with local organizations (design institutes, manufacturers and so forth) will ensure that biomass or other solid feedstocks can be converted to high-value products in an economical and environment-friendly manner.

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XII. THE TRANSFER OF TECHNOLOGIES FOR BIOMASS ENERGY UTILIZATION

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Abstract

The first part of the paper presents the common perception of technology transfer as a trade relationship rather than a systematic approach to establish a complex technological capacity in a given field. It aims to correct this misperception by introducing some other ideas: (a) the need to support the people, adjust the relevant organizations and establish the capacities to provide the products and services; (b) the typical life cycles of technologies from the initial concept to the final stages of transfer and sustainable dissemination; (c) the needs and expectations of the groups targeted by the technologies for biomass energy utilization.

The second part of the paper discusses one example of successful technology transfer: the use of large biomass-burning stoves for food preparation in public institutions and private restaurants in East Africa.

The third part of the paper highlights two non-technological barriers to the transfer of biomass energy technologies: (a) weak market forces and business interests and a large number of State activities and projects and (b) conflicting interests of end-users, craftsmen, private and public project partners, which can threaten the success of the attempted technology transfer, even after local adaptation.

Finally, suggestions are made for overcoming some of these problems.

A. Technology transfer: beyond trade and business relations

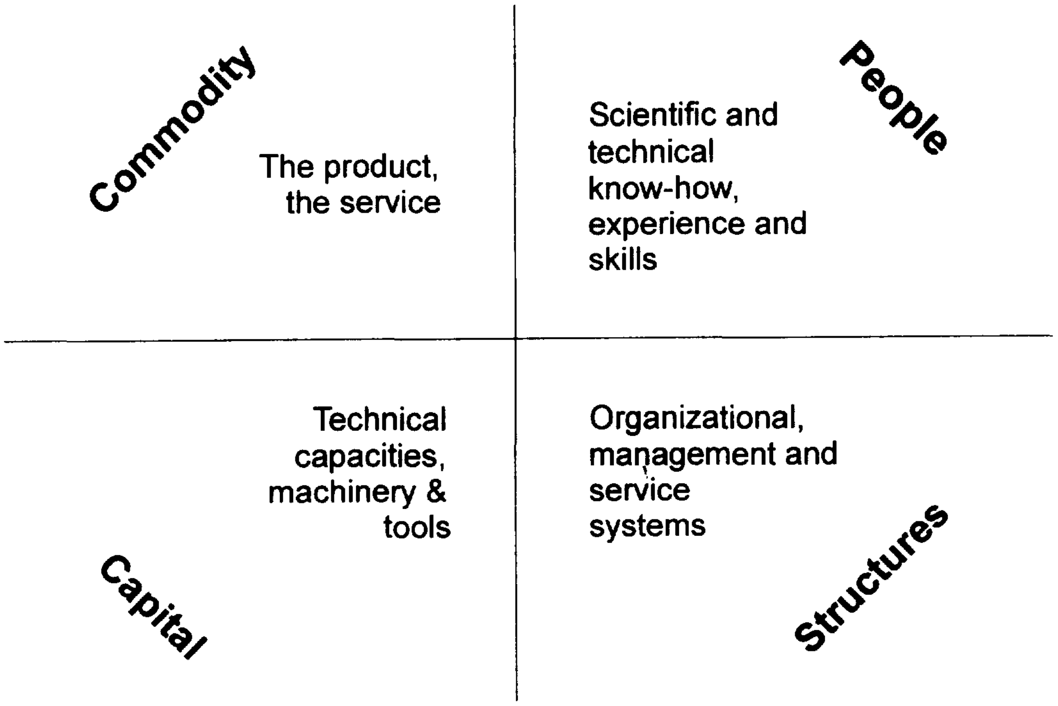
Talking about technology transfer on the basis of experience in project planning and implementation commonly leads people to imagine the process as being restricted to the transfer of goods or commodities between developed and developing countries. Part of this perception is that technology transfer is a one-way street and that development can be expected as the traffic increases.

Trade of products and technology transfer have a number of things in common. For instance, four-wheel-drive vehicles operate in all of the least developed countries (LDCs). Although the manufacturing technology has not been transferred, small workshops have been developed without external support and have gained the experience and skills needed to maintain these vehicles.

Technology transfer requires a more systematic support of the technological system. The recipient country itself must have in place the necessary products and services and avoid depending permanently on external support by building up its own personnel, managerial and technical capacities.

Technology transfer can only be achieved if the people of a developing country are enabled to adjust their organizational structures and establish the technical capacities to provide products and services. A sustainable technology transfer requires intervention in a complex system of interrelated sectors to increase technological competency (see figure XII.1).

Figure XII.1. The main capacity sectors for intervention in the process of technology transfer: the view of education planners



The transfer process has become more complex, and it is no longer enough to provide just a product. It has become necessary to intervene in a system and to guide the upgrading process in all areas needed to achieve the desired output of a product and/or service.

Another relevant aspect is the target group or, in business terms, the market potential, which determines whether the technology transfer is desirable and whether it will have a positive effect on development.

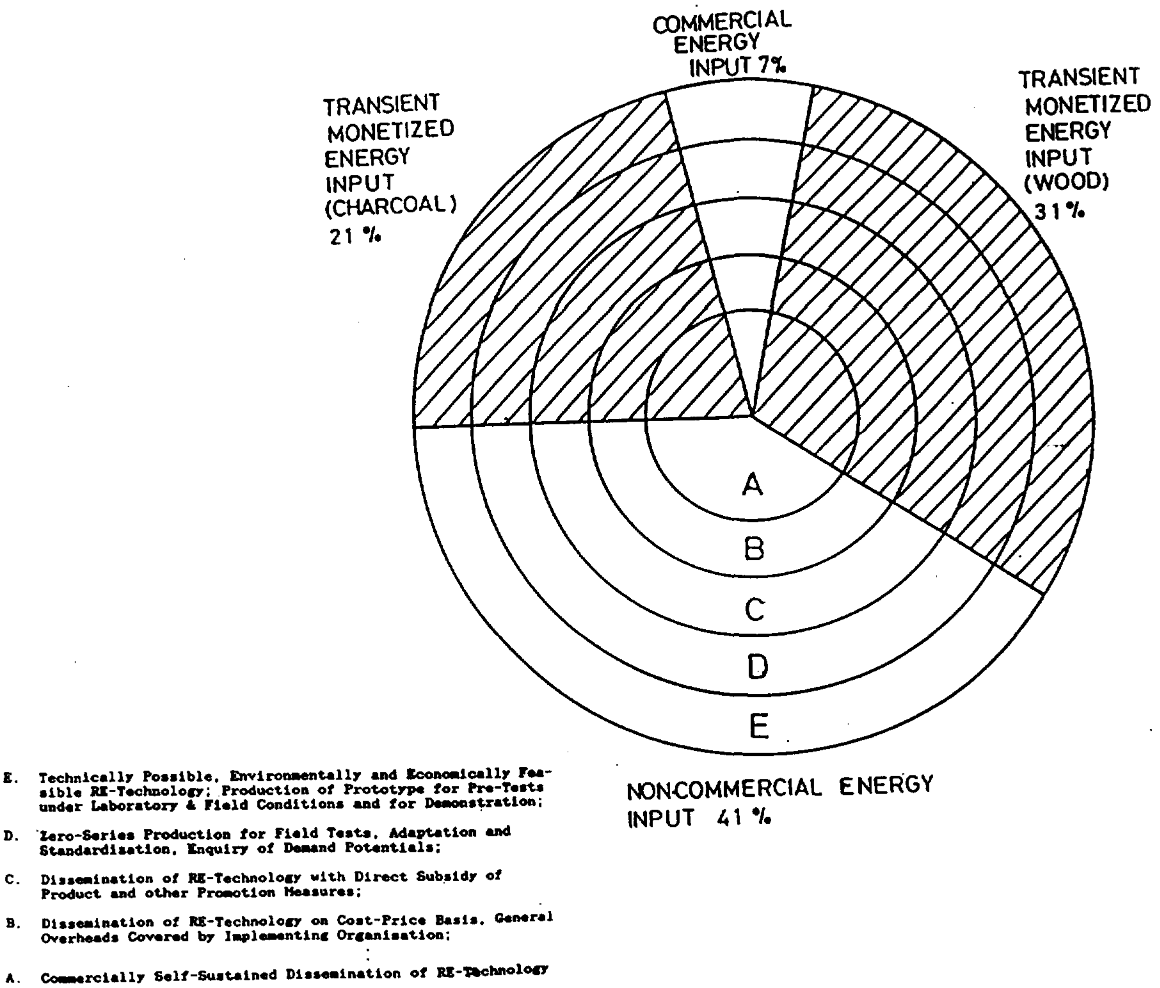
Looking at the transfer and local dissemination of one technology for the utilization of biomass energy resources, large stoves for cooking in institutions, several stages can be distinguished, from the initial idea to sustainable commercial dissemination. The technology has to pass through at least five distinct stages (see figure XII.2) of what may be called the product cycle.

- Prototype production for pre-tests under laboratory and field conditions and for first demonstrations to potential end-users.

- Zero-series production for field tests, design adaptation and standardization, subcontracting of private companies and estimation of immediate and future market potential.

- Introduction of stoves using schemes like direct product subsidy, demonstrations and other promotion measures and, possibly, national dissemination programmes.
- Dissemination of the stoves on a cost-price basis, with general overheads, staff training, establishment of technical capacities and marketing measures supported by international or national funding agencies.
- Commercially sustainable dissemination of biomass stoves to institutions.

Figure XII.2. The main adaptation and dissemination stages during the transfer of technologies for biomass utilization



Progress from one stage to the next should be attempted only if the product has successfully passed the previous stage. Depending on stove performance or feedback from target groups, a certain stove type might have to go back to a previous stage for re-design, change of materials, improvement of shape or a repetition of field tests.

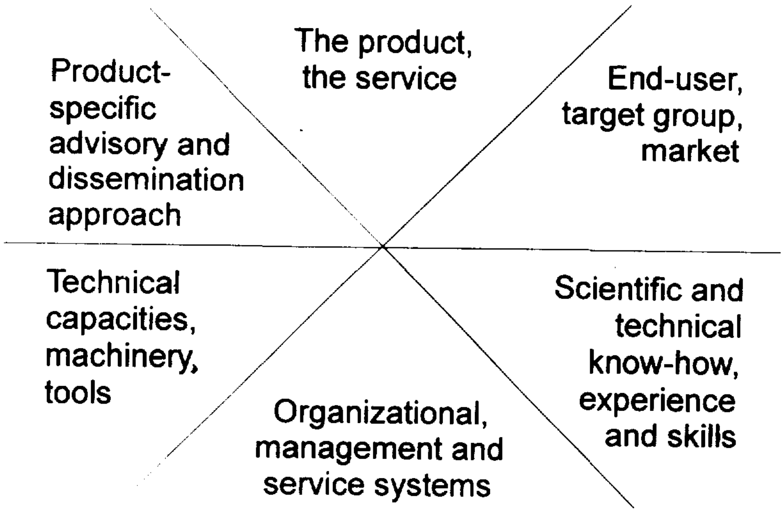
It is not, however, always necessary to start all technologies at stage one or to repeat all the stages in each location. If a conventional technology is well understood and similar to the technology prevailing in a nearby country, parts of phases (or entire phases) can be skipped and experience in the other country can be the teacher.

However, the local adaptation of a technology being transferred is a decisive and delicate matter, and setbacks should neither discourage nor be regarded as failure or lack of competency. Statistics on product innovations, which are compiled annually in industrialized countries, show that over 80 per cent of projects involving product innovation in industrialized countries are given up before they reach the fourth stage. These attempts are not easily perceived, because the companies withdraw them quietly and are not keen to report afterwards. In a successful technology transfer, the know-how, organizational structures and technical capacities take place during the different stages.

An important distinction should be made between site-specific technologies, which are not portable and standardized but tailored to fit the specific needs and conditions of each end-user (e.g. an industrial charcoal kiln), and mass technologies (e.g. the technology for a household rice husk stove). The mass-produced products can be standardized in the early stages and manufactured in central workshops. They require sales and marketing services instead of the engineering and advisory services required by site-specific technologies. This difference is less important at the technology transfer stage but more important at the dissemination stage.

Figure XII.3 presents an integrated picture of technology transfer. It combines the capacity sectors in the lower half and, in the upper half, the needs and priorities of the target groups, with the product-specific approach for technology transfer and dissemination. In practice, the process of technology transfer occurs by moving around this circle several times and linking the relevant aspects of each sector with each other to reach sustainability of the transfer. The process can best be visualized as a spiral.

Figure XII.3. Technology transfer: the integrated view



In the next section a practical example of a technology transfer is examined and the capacity sectors and the stages of adaptation and dissemination are described. The project is institutional biomass stoves in the United Republic of Tanzania, sponsored by the GTZ Special Energy Programme.

B. The transfer and adaptation of large biomass stoves for cooking institutions

Institutional stoves have been chosen as an example because they represent:

- A rather new technology for biomass conservation in developing countries.
- A relatively simple technology appropriate for transfer and local adaptation in other developing countries.
- A conservation technology with very high biomass savings.
- A combination of a standardized mass production technology and a tailor-made, site-specific technology.
- An economical short-term investment owing to the short amortization periods.
- A technology with significant benefits besides biomass conservation, such as improvement of safety, hygienic and health conditions in kitchens.

This example is particularly suited to a discussion of technology transfer because it involves both equipment (stoves, pots, chimneys) and services (energy system analysis, management advisory services).

1. From conventional to improved institutional biomass stoves

The design work began on 50-litre pot size charcoal stoves for restaurants that required a minor improvement, namely, better insulation for the combustion chamber. The stoves did not require enlargement since 50 litres is the largest suitable size, nor did they require a chimney attachment.

The positive reports on greater reliability, faster cooking, higher temperatures and reduced charcoal consumption of the first prototypes encouraged further design improvements. A survey conducted among private restaurants and public institutions in the United Republic of Tanzania also revealed the following:

- Charcoal was the prime energy source for cooking in private restaurants, wood was practically the only energy source in institutional cooking.
- In private restaurants, charcoal stoves should have the flexibility to boil or fry.
- Restaurant owners most often rented premises and were reluctant to invest in fixed, built-in stoves because of their immobility.
- Because a wide variety of dishes were offered in restaurants, a capacity of 50 litres was sufficient.
- A significant potential for biomass saving in institutional and commercial cooking existed, but there was no practical short-term potential for energy substitution.

Designs for the charcoal stoves for restaurants were standardized in 30- and 50-litre sizes for frying or boiling or as combined stoves, as shown in the annex. As for institutional wood stoves, it was clear from the beginning that technical improvements were called for: there was a need for a chimney attachment with a draught control and good insulation around the combustion chamber and pot, as well as the need to fully insert the stove/pot unit into the chamber. Experiments with a 50-litre aluminium pot suspended from a flat bar at the upper part of the stove showed that aluminium was too weak to withstand for longer than six months the weight of the food and the physical forces applied during food preparation.

2. *The need for larger pots and for energy advisory services*

While comparing conditions and menus in institutions that use wood and in commercial restaurants that use charcoal, one further potential for biomass savings became apparent. Restaurant customers choose the food at the time of order, so the kitchen has to keep a more or less equal number of different dishes ready. Therefore, in a restaurant that serves main dishes to about 400 people for lunch and dinner, the pots need not have a capacity of more than 50 litres.

In institutions, by contrast, only one type of food is prepared at each meal (if special diets for smaller groups are disregarded). A boarding school student, a police trainee or a prisoner does not have a choice of food but is served with the same kind of staple food, vegetable and/or meat as the others, allowing what is called "size adjustment". Before advising the management of an institution on the most energy-efficient stove arrangement, data have to be collected and processed.

The need for even larger stoves in institutions that prepare more than 100 dishes at each meal gave reason to investigate appropriate, hygienic and economical pot materials other than aluminium. The decision to import stainless steel was taken, paving the way for stove/pot units of up to 300 litres capacity, as shown in the annex.

The stove body consists of an outer galvanized sheet metal wall with a burnt brick lining. The stainless steel cooking pot is suspended within this body to allow maximum heat transfer from below and around the sides and to improve pot stability and make it safer for personnel. Attaching the stove to a pre-fabricated galvanized sheet metal chimney pipe or to an existing brickwork chimney reduces indoor air pollution by removing smoke, considerably improving the health environment for kitchen staff, who spend long hours tending the stoves.

One aim of the data collection is to advise on the least number of stoves of the largest suitable size to cater for a large number of people. An institution catering for 200 persons would do best to have two stove/pot units of 100 litres each; an institution catering for 800 people would be advised to acquire two stove/pot units of 300 litres and one unit of 200 litres.

Further efforts were made to come up with institutional wood stoves that can be adjusted for different end uses and different energy sources, in particular for using coal, coal briquettes or liquid gas. Finally, baking chambers for the 100-, 200- and 300-litre stoves were designed and tailored to suit the customers' needs. In general, stoves adjustable for different purposes and energies mean a lower investment since they make unnecessary the procurement of additional stoves or end-use equipment (e.g. baking ovens, boilers).

3. Expectations and preferences of target groups

In contrast to the relatively homogeneous target group for household stoves (individuals), the institutions and small-scale industries that use biomass stoves have different expectations and preferences with respect to new stove technology. Experience in the United Republic of Tanzania revealed that the reliability of stoves and energy supply is by far the most important priority. Accordingly, institutions, restaurants and small-scale industries are not appropriate places to work on stove adaptation or to test models with high risks of failure.

Delayed food service seriously affects the smooth running of any institution. Similarly, although in another end-use, interrupted heat treatment of agricultural or industrial products increases operational costs, may damage the company's image or even impair the quality of the final product enough to render it useless. In all cases it reduces sales, turnover and income and may negatively affect the demand for the stove technology.

An indicator for the unreliability of stoves or energy supplies is the presence of an emergency stove for cooking or a drying oven for industrial application. Such emergency stoves and ovens are installed and kept ready for use whenever the regular technology or the energy supply fails.

From the viewpoint of the institution, the procurement of new stove equipment should be regarded as an investment for the future. Thus it is important to assess likely developments in the energy sector to be able to advise clients on the feasibility of fuel switching, with the understanding that reliability–of stoves and of energy supplies–is one of the highest priorities of management. Also, the lifespan of the stove/pot unit and of the parts most exposed to heat and physical forces must be long enough to avoid frequent repairs, although in any case reliable after-sales service is needed in case repairs have to be carried out.

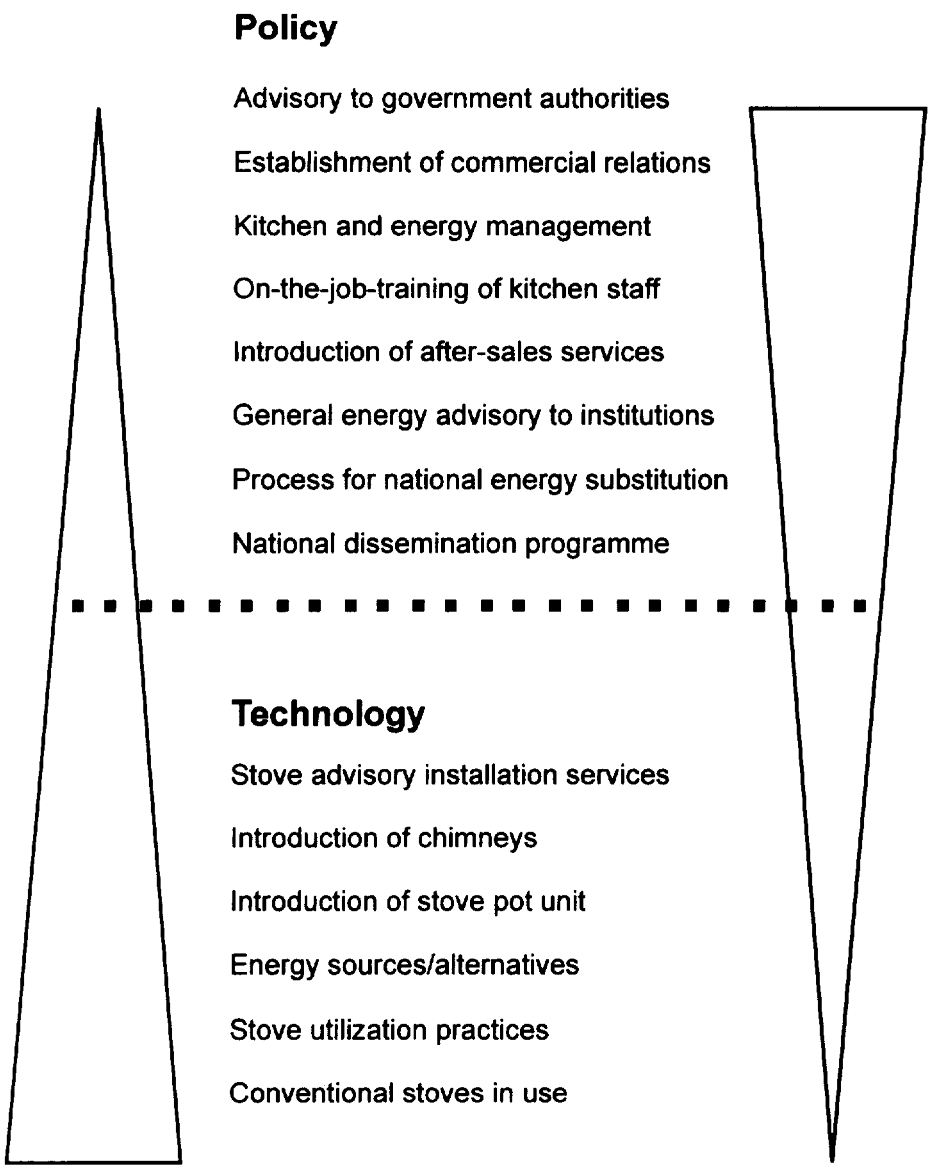
4. The savings in energy and financial terms

Four consumption surveys carried out independently showed that improved stove design and selection of the optimal stove arrangement for a given institution leads to energy savings of between 60 and 70 per cent. The exact percentage depends mainly on the size of institution, the wood type and preparation and the correct instruction of kitchen staff.

It was established that the average payback period for the investment in the unit (the pot price is equivalent to the price of the stove plus the chimney) is between one and two years; in large institutions procuring firewood all year round, the amortization period can be as short as 6-9 months. Savings may also be accrued by virtue of less energy consumption and the need for fewer kitchen personnel owing to shorter cooking periods, fewer cleaning duties (no ashes, no smoke) and no need to hold the pots while stirring the food.

By the end of 1990, the dissemination of the institutional wood stoves throughout the United Republic of Tanzania by the CAMARTEC stove project had been standardized in respect to technical specifications (stove types, dimensions, materials and quality standards), advisory services (data collection and processing, customer correspondence), administration (both internal and client-related) and after-sales service (maintenance and repairs). The main topics of this technology transfer and adaptation process are summarized in figure XII.4.

Figure XII.4. The main stages and topics during the transfer of institutional cooking stoves for biomass utilization to developing countries (from bottom to top)



Institutional perspective	National perspective
Necessary course to follow	Cooperation with government
Relevance of technical issues	Policy/socio-economic issues
Engineering aspects	Educational/marketing aspects
Access to information	Resource/time/support required
Control over activities	Complexity, system management
Predictability	Sustainability
Effects on micro level	Effects on macro level

C. Dilemmas in the transfer of biomass energy technologies

In section A, the transfer of commodities was described as a simple change in the location of goods and was distinguished from technology transfer, a systematic endeavour to increase the technological competence of recipient countries.

The transfer of technology aims to improve the living conditions of the population and helps to develop human resources, organizational structures and technical capacities. As a socio-economic and developmental process, technology transfer cannot be expected to progress steadily, quietly and smoothly; rather it should be understood as the dynamic adjustment of a complex social system.

In this chapter, the socio-economic aspects of technology transfer are emphasized; they entail problems that are not technical or product-related but that could still delay or hinder the transfer process.

Subsection C.1 examines some economic and policy issues that could deter the transfer of biomass energy technologies to developing countries. Subsection C.2 highlights issues of technology commercialization. Subsection C.3 makes five recommendations for the transfer of commercially oriented technology.

1. Basic issues in the transfer of biomass energy technologies

Some of the problems in the transfer of biomass energy technologies (both those that have been experienced and those that are only potential) summarized here are relevant to most biomass technologies, since they are based in the biomass energy economy. Others relate more generally to project policy and could apply to the transfer of technologies in general:

- Biomass energy sources are available at relatively low costs. In many places, people feel free to cut trees in public forests or private woodlands. One reason for this is the dispersed availability of biomass material, which cannot be easily protected or monopolized by governments or large companies. Even if biomass energy is purchased (which is the case for large consumers of charcoal and wood in many parts of Africa), costs for tree planting and protection, taxation, commercial transport charges and overheads are usually not contained in the wood and charcoal prices. This indirect public subsidy of biomass energy reduces the financial incentives for the new stoves and may extend the payback period to the point where the investment is not so attractive.

- It is only recently that commercial approaches to technology transfer have been applied in the field of biomass technologies. The private sector can best provide the products, it is closer to target groups, it reacts fast to demand and it promises better sustainability than the public sector. On top of that, it is expected that the commercial approach will allow shorter implementation periods because the market mechanism generally reacts faster. Offering the products commercially implies higher prices for improved products and competition for (but also dependence on) the customers' purchasing power.

- For developmental reasons, the target groups selected by social, environmental and technical aid programmes are among the poorer, less educated, less integrated, less favoured strata of the society (e.g. rural or urban poor, women, youth, children, jobless). In economic terms, these target groups for new biomass energy technologies can be characterized as possessing little purchasing power, restricted innovation potential and less ability and readiness to experiment with new products.

In short, it seems that low-income target groups are being offered, in short transfer periods, relatively expensive and luxurious technologies that conserve subsidized biomass energy sources. It should not be a surprise that businessmen are not seen here.

Looking at the national economy, a similar dilemma is observed. When biomass energy technologies are first transferred, there is a no man's land where no businesses have settled because the prospect for gains is bleak. Because the energy sector is controlled and supported by national policy and development aid projects, private business resists investing in biomass energy technology.

Increasingly, technical assistance requires the support of the private sector. Implementing agencies try their best to find private partners and joint ventures to make such assistance possible. However, the terms of the bilateral government agreements, as well as changing or dubious ownership of private companies and the interests of government institutions, can hamper technical assistance. Meanwhile, it often happens that although the private sector was envisaged as a local partner when the project was conceived, in the end a ministry or parastatal organization "caught the fish". This is clearly a dilemma for donor organizations, which find themselves forced to support the very State apparatus on which multilateral organizations such as the International Monetary Fund (IMF) are trying to impose conditions.

2. *Relevant problems in biomass energy commercialization*

With reference to the technology transfer stages in figure XII.3, some dynamics of the dissemination process that may be relevant to different kinds of technology transfer projects, particularly those that opt for a commercial approach, are discussed next. The transformation of the partly subsidized initial phase of technology introduction into a full-fledged commercial venture is a complex and delicate process. It can easily be delayed or jeopardized by factors beyond the control of the funding agency or implementing organizations.

The following contradictions and dilemmas were experienced during the commercialization of institutional stoves in the United Republic of Tanzania:

- To provide the required project budgets, funding and implementing organizations work according to quarterly or annual plans. When a commercially self-sustaining stove is first being disseminated, sales and sales growth depend on customer demand for the improved designs. Investment decisions are based on market demand, which cannot, however, be predicted accurately enough to satisfy the implementing organizations.

- Client expectations that the stoves would be partly or fully subsidized needed to change before investors would commit themselves to the rather high investments for the new, large biomass stoves. They had confused the idea of technology transfer with the idea of a hand-out.

- When stoves are manufactured in private workshops, minimum quality standards (material strength, labour input, finishing) are often neglected in order to increase income. This is a particularly tempting and dangerous attitude in the early stages of stove introduction, when the craftsmen, technicians and clients do not yet have a clear perception of the minimum quality standards since the product is still new to them. Moreover, competition among manufacturers is still limited, and poor stove performance, a need for early repairs or a short lifespan can seriously harm the image of the technology.

- The service that provides advice on selecting stove sizes aims to achieve maximum biomass savings in institutions and industry. From the perspective of commercial stove manufacturers and marketers, this approach increases costs because it necessitates data collection and processing and advisory services. At the same time, it reduces potential turnover and income compared to the approach that offers portable stoves in smaller sizes, i.e. if a customer needs a cooking capacity of 400 litres, it would be more profitable to sell him eight 50-litre units rather than two 200-litre units. In commercializing a technology, there is a built-in risk that turnover and income will be regarded as more important than biomass savings and hygienic, clean and safe cooking.

- The economic survival of commercial companies also depends on the scope of the products and services it provides. The broader the area of competence and the greater the differentiation of products and services, the better the chances for survival. Therefore, it would not be advisable to establish a highly specialized company for biomass stoves for institutions or industries. The risks involved in specialization would be significant since demand may not develop according to expectations. Changes in the energy sector, unreliable raw material supplies or activities of other development agencies could also endanger turnover and income.

- When establishing a self-sustainable commercial dissemination system, two issues can be expected to arise. First, there is a need for access to information, for project control over the technical standards and quality of the stoves and the services offered and for remunerative prices. Parallel to this development, the initial justification for the project–to support the introduction of biomass stoves that are more efficient, that consume less biomass and that provide better hygienic and health conditions–becomes less important and is replaced by the primary motivation for commercial activities: turnover, income, capacity utilization and/or economic survival.

- In the face of the economic decline that has led to rather low salaries for public servants in some countries, the procurement practices of State organizations or public institutions have deteriorated to the extent that price and product competition ceases to exist. At that point, features of competitive systems such as information, demonstration and advertising become futile, and none of them will work.

3. Recommendations for a commercial technology transfer

The above-mentioned experience and dilemmas inherent to the commercial approach should not lead to the conclusion that the approach is too problematic to succeed. The private sector is well–if not best–suited to manufacture and disseminate new biomass energy technologies for institutional and industrial application. Five considerations are important for a commercial approach to technology transfer:

- The cooperating private partners and manufacturers should be selected as soon as possible to involve them in design development and adaptation. The final selection should be based, among other things, on the quality of their other products and, possibly, their prior involvement in manufacturing biomass conservation products. More than one company should be asked to bid.

- Training and quality control should be carried out continuously, partly as on-the-job training when orders for stoves are subcontracted to private workshops, partly as formalized training, even outside the area or the country if technical know-how, materials and technical or vocational skills cannot be provided locally. The scope of commercial involvement can be widened by gradually extending the subcontracting work (e.g. first the inner stove structure, then, step by step, the complete stove, the chimney, the pots, installation and, eventually, advisory services).

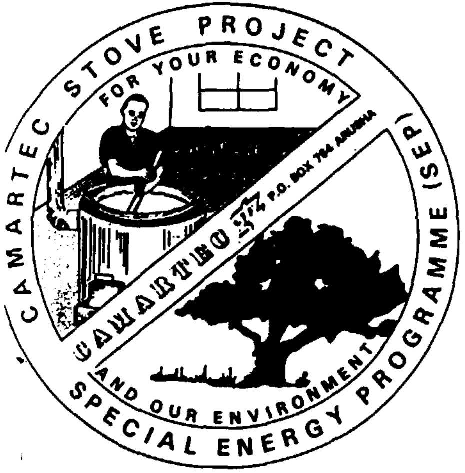
- Formalized and transparent administrative procedures with private workshops or customers as well as contracts between the implementing agency and the commercial companies elaborating the various duties and rights of the parties will help to avoid misunderstandings or unjustified expectations.

- Whenever useful and required, licenses, training documents or trade marks should be applied to identify the high-quality products from the implementing agent. For example, fixing a plate with the trade mark and model number on a stove will protect it from private entities that may want to copy it or sell the designs without proper training and authorization.

- Inputs of materials, machinery or financing to commercial companies should be avoided or at least kept to a minimum. Once it becomes clear that there will be no inputs, companies will be obliged to independently assess the market prospects for the new stove technology. The enterprise then makes a realistic costing and product pricing calculation that includes the procurement of equipment and materials as well as labour, capital and overhead costs.

THE DUMA COMMUNITY WOOD STOVES

The DUMA* Community Wood Stoves



DUMA community wood stove is a new duct which aims at low wood consumption, ironmental protection and cost effective king in institutions.

stove is specially designed for:

Reliable and Fast Cooking

Lowest Wood Consumption

Smokeless Indoor Operation

Improved Hygienic Standards

Reduced Heat Radiation, and,

Longest Lifespans

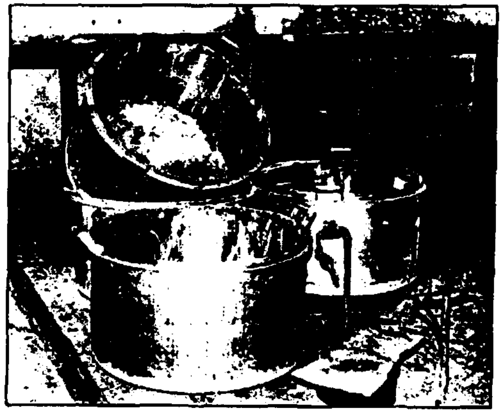
JMA — SUSTAIN THE ECONOMY AND NATURAL RESOURCES
JMA — DUMISHA UCHUMI NA MALIASILI

The main features of the DUMA community wood stoves are:

- —an outer body of galvanized sheet metal giving it a rustproof and always clean appearance,
- —a brick lining which directs the heat to the pot and assures a cool and comfortable stove environment,
- —a chimney attachment removing the smoke from the kitchen and avoids health hazards to kitchen staff,
- —a durable heavy metal combustion chamber with an exchangeable cast iron grate,
- —an ash drawer to keep the kitchen clean while removing the ashes,
- —a specifically selected stove arrangement of different sizes (25, 50, 100, 200 and 300 Liters) to suit the cooking needs of each single institution.

The Stainless Steel Cooking Pots

The DUMA community wood stoves of 100 and 200 Lit. size are offered as units with strong and durable stainless steel pots with lids. The material strength of the wall is 2 mm, the bottom sheets are made of 3 mm strength to withstand the heat and forces of preparing "Ugali". Stainless steel is more durable and more hygenic for food preparation as compared to mild steel or galvanized pots which pose health risks to food cunsumers.

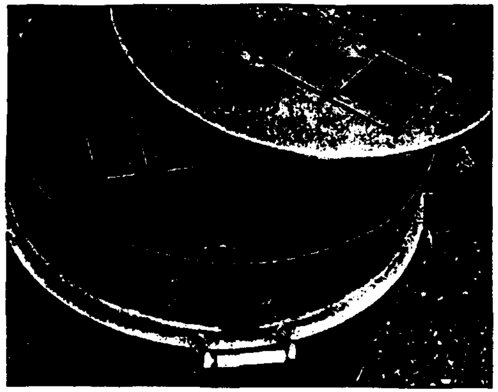


The Multipurpose DUMA Stove

An adaptation of the technology has resulted in the design of baking and drying chambers. For example, the baking chamber has three levels for placing the loaves. The chamber capacities are according to stove sizes as shown below:

200 Liter Stove — 33 Loaves
100 Liter Stove — 25 Loaves
50 Liter Stove — 18 Loaves
The appr. baking time is 15 minutes.

The Baking Chamber



Wood Chopping

Most efficient performance of the **DUMA** community stoves can be achieved, when the air control door is adjusted according to required fire output and when the firewood is chopped into pieces of up to 50 cm length and 10 cm in diameter. The wood should also be air dried. Dry wood reduces lighting and cooking time, wood consumption and avoids too early blockage of chimneys.

Easy to Get, Easy to Install

The CAMARTEC Stove Project offers advisory services on the wood stove technology. The advisory service is carried out to identify and plan the most efficient and economical improvement scheme for each single institution.

Before and after installation.

Highest fuel savings and economic benefits can only be achieved if a minimum number of stoves is installed for a maximum catering capacity. Therefore, institutions catering for more than 300 people require stoves of 200 L or 300 L capacity.

The order can be placed by advance payment. The average period for completion of an order is 3 months only. Generally, the prices include stove and pot manufacturing and countrywide stove installation services. With an area of 50 km around Arusha, the delivery of stoves and all materials is also included.

DUMA Stoves — A Rational Choice

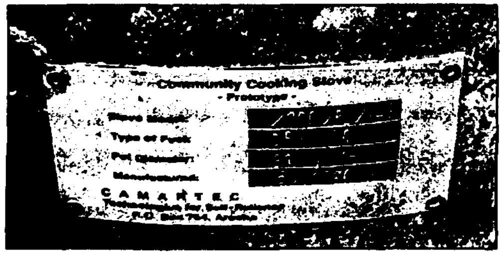
The **DUMA** community wood stove is the only choice for institutional cooking equipment which offers some vital improvements/benefits such as:

Health Improvements
- reduction of indoor air pollution
- avoidance of health risks to food consumers

Environmental Benefits:
- reduction of firewood consumption
- decreased pressure on forests

Economic Benefits:
- reduction in fuel and labour costs
- cost effective investment which is recovered by savings within 1 year.

DUMA community stoves and stainless steel pots have been designed and introduced in Tanzania by the SEP/CAMARTEC Stove Project which is jointly implemented by the Centre for Agricultural Mechanization and Rural Technology (CAMARTEC), Box 764, Arusha, and the German Agency for Technical Cooperation (GTZ).



NB: All **Genuine DUMA Stoves** bear the manufacturers model plate. High quality products can only be guaranteed for equipment carrying this quality control model plate : **DUMA** Stoves — Made in Tanzania.

Printed by Executive Printing Works Ltd. Nairobi

Part three

Funding sources and mechanisms

XIII. INTRODUCTION TO BIOMASS ENERGY PROJECT FINANCING, FUNDING SOURCES AND GOVERNMENT STRATEGIES

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Abstract

Biomass projects can help developing countries to protect their environment as well as to build a modern infrastructure. However, such projects present, in addition to the more typical risks associated with fossil-fuel projects, certain risks relating to the unique technologies and fuels used in such projects. Further, their location in developing countries regularly creates enhanced political and credit risk as well.

Biomass power projects, like any other power project, must be financed. To be financeable, a power project should allocate risk in the most efficient way, so as to maximize return on investment. This paper examines the way in which various project documents can be structured to allocate most efficiently the technology and fuel risks unique to biomass projects, as well as the more typical risks, such as construction risk, permitting risk, expropriation risk, currency risk, country risk, sovereign risks, operating risks and credit risk.

In addition, this paper summarizes the public financing sources and support that are available to assist in meeting the unique risk profiles of biomass projects. Specifically, it examines some of the principal multilateral and export credit agencies having involvement in this area.

Finally, it examines potential strategies available to the developer of a biomass project for soliciting the involvement of, and negotiating with, local governments and public financing agencies.

Introduction

Developing nations realize that as the global economy becomes more and more competitive, they must develop a modern infrastructure in order to compete with other nations for industry and, consequently, prosperity. One of the key elements of a modern infrastructure is power. In fact many firms around the world are racing to enter the international independent power industry, and many developing countries are wisely opening their doors to these developers.

Developing nations, like developed nations, must also keep in mind the environmental impact of modernizing their power industries. One of the key issues for any nation and any power developer that impacts the environment is the type of fuel used to generate power. Traditionally, power developers have preferred fossil fuels such as coal, oil and gas. However, many developing nations, as well as multilateral and other financing sources, increasingly realize the environmental benefits of using renewable fuels, such as water, sun and wind, to generate power. Biomass fuels are another renewable source of electric power and are environmentally friendly as well. Biomass projects can often be developed on a smaller scale than traditional power projects. Nevertheless, biomass projects, as energy projects, are susceptible to the same array of risks facing fossil fuel projects. In addition, the unique nature of biomass projects renders them susceptible to additional risks, which must be resolved to achieve a successful project.

This paper begins by analysing the risks faced by power projects in general and by biomass projects in particular and continues by discussing the role of various project and financing documents in allocating such risk. There follows a discussion of the principal specialized financial sources and support available to mitigate and cover the risks a developer will encounter in completing a biomass project in developing countries, together with a discussion of optimal developer strategies for managing the role of financing institutions and advisors during the development process. The paper concludes by discussing the ways in which developing country governments can facilitate the development and financing of biomass projects.

A. Risk factors governing the financeability of biomass energy projects

1. Risk factors in general

Developers of and lenders to all power projects face numerous risks that must be assessed when determining the financeability of a project. Some of these risks are commercial, including market, fuel supply, construction, operating and plant performance risks. Others are legal, such as government permitting, environmental and contract enforceability risks. Still others are perceived as political, such as expropriation, change of law and currency convertibility risks. Where any of these risks are deemed material with respect to a project, they must be mitigated, usually through interparty contractual allocations of risk, insurance or government guaranties.

2. Risks in biomass projects

Biomass power projects have all of the risks associated with other energy projects to one degree or another. However, owing to the nature of biomass power projects, certain risks, including technology risk and fuel price and supply risk, are enhanced.

(a) Technology risk

Technology risk involves the risk that the project will not operate as designed because the technology is new or unproven. Since biomass technology is generally new technology, it is particularly sensitive to these performance risks. Moreover, biomass fuels tend to be bulky, that is, they have high volume for a given heat content. These factors make biomass projects particularly sensitive to the performance of the technology and the design of the overall plant.

Technology problems caused the cancellation of biomass power projects in the United States in the mid-1980s, when several power plants were constructed to burn cow manure. The fuel was certainly plentiful and high in energy content. Moreover, an efficient method of disposal could have relieved environmental stress on streams and other water resources in areas of concentrated agricultural activity. Unfortunately, the projects did not perform well. The fuel proved to be too acidic and too wet, causing poor performance of the fuel handling equipment and requiring excessive maintenance and costly shutdowns. The end result was that many of the projects failed for technological reasons.

Similar problems have afflicted projects using other agricultural wastes, especially where moisture content or other fuel characteristics created difficulties with fuel handling. Many early MSW facilities, which burned garbage to produce steam and electricity, employed technology that was unable to assure the even and complete burning of the waste. The result was an inefficient heat rate, excessive air emissions that proved costly to redress and excessive costs of handling and disposing of the incompletely burned bottom ash.

Because of the sensitivity of biomass projects to problems with fuel handling and other technology and design risks, lenders and equity investors tend to be particularly sensitive to the experience of the design and engineering firm, the construction contractor and the operator. More importantly, they will look to the track record of the technology. Well-known technology that has proven successful under operating conditions similar to those likely to be experienced by the proposed project will be received favourably. Newfangled technology, or technology developed to burn fuels other than those proposed, will not be well received.

However, with the development of gasification systems and improved boilers and fuel handling systems, biomass power projects are becoming less sensitive to technology risks. Gasification systems take biomass fuels such as wood, alfalfa, rice hulls and waste and convert them to gas. The gas can then be readily used as fuel for more traditional and reliable turbines that produce electricity. Improvements also are being made in methods of handling varied types of fuels, and the industry gradually has developed more efficient boiler designs for the mass burning of bulk fuels.

(b) Fuel price and supply risks

Fuel price and supply risks are the risks that the price of the fuel will increase or the supply of fuel will decrease. Fuel risks may be passed through directly to the power purchaser, either by provisions in the power contract requiring the purchaser to reimburse the project for the actual costs of fuel or by tying energy payments to some market index expected to reflect the price of fuel. Fuel risks for biomass projects tend to be very high. Biomass fuels tend to be low energy, bulk fuels with high transportation costs, so that such projects depend heavily on the ability to produce the fuels locally. Drawing on smaller regions and dependent on specialized products, markets for biomass fuels tend to be more volatile than mass markets for other fuels, which are volatile enough as it is.

Another important biomass fuel risk factor is that such fuels generally are by-products. Other than fuel crops grown specifically to be burned (certain fast-growing breeds of trees often are mentioned as examples), biomass fuels tend to be wastes or by-products of some other activity. Rice hulls are unlikely to be produced solely to supply fuel to a power plant: they are produced because people eat rice. The same is true of other agricultural by-products. MSW and industrial wastes obviously are not produced for fuel but are the result of other economic activity. This means that predicting supply and demand for biomass requires predicting the future of the primary activity that produces the biomass fuel as a by-product. These primary activities generally are unrelated to, and often unaffected by, trends that affect the power industry. For a lender or developer assessing the risks of a power project, this adds yet another dimension of uncertainty and creates risks that lenders, certainly, and developers, most likely, will be unwilling to bear.

For example, wood waste is the most common type of biomass fuel in use for power production. Wood chips generally are produced as a by-product of lumbering, papermaking or other forest product industries. If the market for lumber products changes on either the demand side or the supply side the availability (and hence the price) of the project's fuel will change too. An example would be the great number of wood-waste-fired power projects built 10 years ago in northern California and southern Oregon, in the Pacific North-west of the United States. At the time, forestry was the region's principal industry, employing tens of thousands of people directly and in related industries. When the spotted owl (an endangered species whose habitat is protected under United States law) was discovered living in these forests, lumbering there was scaled back drastically by federal authorities. Because of this decline in the primary industry, wood waste became scarce and local prices for it jumped dramatically. The owners of the projects-many of them small, independently owned power projects in the 20-30 MW range-were forced to make substantial investments in wood chippers or other fuel handling equipment, seek alternative sources of fuel such as packing crates and other industrial wood wastes or even to renegotiate their power contracts with the purchasing utility.

This dependence of biomass projects for fuel on another industry also may increase political risk. The primary industry (like the power industry) often is one that local governments may consider to be affected by the public interest: agriculture, for example, often is a highly regulated industry with powerful political interests. This dependence on government policy may create some stability in the underlying market, but it may also create risk. Thus, if the government changes the law or adopts regulations that serve to increase the price of biomass fuels or decrease their availability, biomass power projects in the region may be affected adversely. The changes that affected the timber industry in California and Oregon were changes in government policy, although the subsequent decrease in logging in the Pacific North-west led to increased logging in the South-east of the United States, affecting wood-fired projects there.

B. Allocation of project risk

No matter how a biomass project is developed or financed, the risks described above, both those unique to biomass projects and those of a more general nature, must be borne by someone. If the government of a developing country sponsors, finances and operates the project as a sovereign undertaking, all of the risks associated with a project ultimately are borne by the taxpayers and citizens of that country. If a utility develops, finances and operates the project, all of the risks would be borne by the utility's shareholders (including governments, if the utility is publicly owned) or by the utility's customers. However, a government or utility (including a government-owned utility) may not have access to the necessary capital, owing to its poor credit rating or other demands on public resources, to develop and finance a project.

Private lenders and entrepreneurs are generally not in a position to bear all of the risks related to a power project. However, the advantage that private lenders and private entrepreneurs bring to the table is their ability, under favourable investment conditions, to quickly supply financial capital and technical expertise and to support development efforts. While there is no way, ultimately, to avoid any particular risk associated with a power project, if each risk is allocated to the party best able to bear it, then the party bearing the risk will have a strong incentive to reduce the risk and thereby reduce the risk premium demanded by the lenders and project sponsors. If the risk premium is reduced, then the overall cost of the project will be reduced, and private lenders and developers (and multilateral agencies) will be more likely to find the project financeable.

Properly structured project financing allocates each risk of a power project to the party most able to bear the particular risk. This is accomplished through a suite of bilateral or multilateral contracts which, taken together, embody the entire project and, hopefully, efficiently allocate all of the financial and operating risks the project is likely to face.

1. Implementation agreement

Typically, the initial phase of the development of a power project begins when the local government grants the project developer an exclusive right to develop the project, either independently or with the public utility or government, as the case may be, by signing either a letter of intent or a memorandum of understanding, or by a definitive implementation agreement. It is at this stage of development that the principal allocation of risks between the developer and the host government occurs.

A project is typically structured such that the power developer constructs, finances, owns and operates the project for a period of years, typically 10-20 years. Upon termination of the power purchase contract, the project facilities are typically transferred to the utility or government free and clear of any liens or claims, for a minimal cost. In return, the utility or government agrees to assume some commercial risks of the project by paying a fixed or formulated price for access to the fixed capacity of the project, as well as for the electrical energy actually delivered by the project to the utility or government. If the utility or government is in a better position to mitigate the risks associated with the fuel, it will often take on additional operational risk by assuming responsibility for obtaining fuel and delivering it to the project.

The implementation also allocates to the host government certain political risks such as currency risks, exchange risks and risks of political *force majeure*. Developers and lenders may seek additional protection against these risks through currency swaps, offshore holding accounts and political risk insurance such as that offered by Overseas Private Investment Corporation (OPIC), various export financing agencies, other multilateral agencies and even private insurers. However, by assigning these risks in the first instance to its own government, a developing country can help to reassure financiers that the political powers with the most influence on the success of a project themselves have a stake in the outcome.

2. *Power purchase contract*

The power purchase contract is the single most important contract for any power project. In addition to being generally the only source of revenue for a biomass project, the power purchase contract is the principal vehicle for the formal allocation of risks, which is not usually addressed until the implementation stage. The power purchase contract may allocate exchange risks by requiring that payments be made in or linked to either United States dollars or pounds sterling. If payments can be made in local currency, the project may require that the customer or some creditworthy entity be responsible for converting project revenues paid in local currency into United States dollars or pounds sterling. Finally, to mitigate and allocate political risks, the project may require that rate adjustments be made to account for the negative impact on the project of a change in law or political *force majeure*. The power contract may even require that a change in law that adversely affects the project must trigger a right to transfer the project to the customer at a price sufficient to pay debt, accrued interest and a return on equity, and that a sovereign or creditworthy party back the customer's obligation to buy back the project.

The power contract also allocates purely commercial risks. The project company typically requires fixed or formulated energy prices in order to allocate the risk of price fluctuations in the electricity market to the customer. The pricing formula also allocates certain fuel risks and technology and operating risks, which are particularly acute in biomass projects. For instance, if all fuel costs are paid by the customer, the customer takes the fuel price risk and the risk that the project might perform less efficiently than expected. On the other hand, energy pricing that is based on the product of some fuel price index (or on market prices for fuel) and an agreed heat rate leaves operating risks with the power project; if the equipment degrades, is not maintained properly or is poorly designed, the seller of electricity, not the buyer, will suffer first.

3. *Fuel supply and transportation contract*

Project developers also try to allocate fuel risk through the project's fuel supply and transportation contracts. Since the single biggest cost to any power project, and particularly to biomass power projects, is fuel supply and transportation, the risks to the project that the price of fuel for the project will increase or that the supply of fuel will decrease are particularly critical. To mitigate these risks, the project will either attempt to shift full responsibility for obtaining fuel onto the electricity customer, as discussed, or will attempt to obtain fuel supply and transportation commitments from creditworthy parties at prices tied to electricity revenues over the life of the power purchase contract.

In a typical project, the developer will attempt to suspend fuel payments when the project is not operating by matching purchase obligations with the dispatch profile of the project. Further, in order to avoid damages that may be incurred by the project in the event the fuel supplier is not able to deliver fuel, the project typically establishes fuel reserves as well as access to stand-by fuel commitments or alternate fuel supply sources.

Unfortunately, such techniques seldom work with biomass projects. The volatility of supply markets for biomass fuel, and the dependence of those markets on a primary industry driven by its own supply and demand, make long-term, fixed-price contracts extremely difficult to obtain. In addition, because of the nature of the primary industries that throw off the biomass by-products (agriculture, forestry and the like), the players in the primary industries tend to be smaller, undercapitalized, marginal operators. Even if a supplier is available, the likelihood is slim that the supplier would be creditworthy enough to withstand the market fluctuations typical of biomass (in what, after all, is likely to be only a sideline business for the fuel supplier). For instance, a farmer, even a large farmer, is unlikely to worry about supplying agricultural wastes under a long-term contract if his crops have failed.

Nevertheless, these risks must be faced. Biomass projects typically rely on a combination of solid, medium-term supply contracts for a small portion of their fuel, two- or three-year contracts for a larger portion and spot market purchases for the balance. Projects even may seek a captive supply by entering the biomass fuel business directly, although this may mean burdening the project with the additional risks of the primary industry. Since these measures will at best only partially mitigate the fuel risk and will themselves demand considerable, costly management time to balance a portfolio of fuel supply options, biomass projects, perhaps more than any other type of power projects, are candidates for a direct pass-through of fuel price and supply risk to the electricity customer. Especially in developing countries, where the government is likely to own the purchasing utility, fuel price and supply risk are likely to be controllable, if at all, by the government, which also determines agricultural policy, environmental policy or other factors that affect the underlying agricultural or waste disposal markets that determine fuel prices. Private parties may be convinced to shoulder these risks, but if they are wise, they will demand a high risk premium in the price of power itself, and the customer will ultimately pay in any case. If the government assumes these risks, that premium need not be charged. The government, being in the best position to determine fuel prices, is the party best able to bear the risk of fuel prices.

4. Construction contract

The construction contract is also a very important contract and is highly scrutinized by the lenders. It determines the bulk of the capital costs of the power plant. The project also can reduce technology risk and costs of operating the plant by providing the contractor an incentive to construct a plant that is properly designed, maintainable at a low cost and efficient. The construction contract sets forth the time by which the plant must be constructed (lost time means lost revenues) and the standards by which the completed project is to perform.

Contractors often attempt to reduce the risks associated with constructing a project by bringing in local partners, especially for the civil construction aspects of the project, because these in-country contractors are familiar with the market and labour conditions, with local law and with government policies and procedures.

5. *Operation and maintenance agreement*

The operation and maintenance agreement allocates operating risk. An experienced operator familiar with the technology can reduce the costs of operation and maintenance. To help assure that the project operates in accordance with the financial projections, the operating contract attempts to align the operator's interests and payment schedule, such as bonuses or liquidated damages, with revenue, bonuses and penalties to the project under the power purchase contract.

6. *Government guaranties*

In addition to the traditional project documents discussed above, another critical aspect of project finance risk allocation relates to the credit support obtained by the project developers from the host-country government. For example, the government could provide a guarantee of the debt, a guarantee of the power purchaser's obligations under the power purchase contract or a guarantee of the obligations of other publicly owned project participants, such as fuel suppliers and transporters. Although governments often are reluctant to dedicate their borrowing capability to grant guaranties, some sort of sovereign guarantee often is crucial to the successful establishment of an independent power industry. This is especially true for the first several projects attempted in a developing country. After a track record of success is demonstrated, the requirement for governmental guaranties, either of repayment of debt or performance by the power purchaser, may be reduced or eliminated.

In any event, governments of developing countries almost invariably will be required to provide some level of support or comfort to project investors. For example, where a multilateral agency has provided financing or political risk insurance to a project, the government or governments backing that agency may enter into a government-to-government agreement that would require the host government to reimburse the government providing credit support or political risk insurance. Alternatively, the multilateral agency itself may require certain concessions from the host government if it is to do business in the host country. The role of multilateral and other public funding agencies is discussed in more detail below.

C. Financing strategies in developing countries

1. *Difficulty of risk allocation in developing countries*

In an industrialized country with a predictable, well-developed legal system and substantial domestic sources of credit, the independent power industry may rely on debt financing sources such as banks, institutional lenders (pension funds and insurance companies) and the capital markets (public or private placements of debt bonds or indentures). On occasion, the project sponsors may even be willing to finance small projects on their own balance sheet, although this is still quite unusual. In developing countries, however, these sources of debt financing are often completely or partially unavailable. This is because the political, legal, regulatory and credit risks are often perceived by private, commercial and industrial lenders to be greater than allowed under their credit guidelines. After all, these private entities have a substantial duty to their own depositors, pensioners, regulatory authorities and shareholders to maintain stringent and prudent lending guidelines.

2. *The role of export credit agencies in developing countries*

Project sponsors often must turn to the multilateral development agencies and export credit agencies (ECAs) of more industrialized nations to satisfy their financing requirements. Then, once multilateral agencies and/or ECAs are participating, commercial banks or institutional debt providers may be brought in on a *pari passu* basis for a portion of the project's financing needs. The multilateral agencies or ECAs and the private debt sources together take comfort from one another as to the political, economic and structural viability of the project. On the one hand, the presence of multilateral agencies or ECAs provides some reassurance against arbitrary political action that might harm the project and adversely affect the host country's diplomatic relationships. On the other hand, the presence of private lenders gives some reassurance on the commercial structuring and viability of the transaction. For this reason, credit agreements applicable to all secured lenders, both public and private, to these projects often require that a constant ratio of private to public funding be maintained throughout the term of the loans.

3. Available public financing sources

(a) Overseas Private Investment Corporation

OPIC is a United States government agency whose mission is to mobilize and facilitate United States private capital investment in developing countries and countries in transition from non-market to market economies. OPIC assistance is available in some 140 countries through three principal programmes: investment finance, investment insurance and investor services.

The OPIC investment finance programme provides medium- to long-term direct loans and loan guaranties on a "project finance" basis to overseas ventures involving significant equity and/or management participation by United States businesses. Direct loans are available for projects sponsored by United States small businesses or cooperatives. These loans are generally in amounts from US$ 2 million to US$ 10 million.

Loan guaranties, which typically are used for larger projects such as independent power projects, range in size from US$ 10 million to US$ 75 million but can be as high as US$ 200 million. OPIC loan guaranties normally take one of two basic forms:

- One or more investors lend money to the borrower in exchange for promissory notes issued directly to the investors. OPIC guaranties repayment in full of the loan by affixing a guaranty endorsement to each promissory note, making it an OPIC-guaranteed note. OPIC usually also executes a separate guaranty agreement.

- OPIC loans money to the borrower in exchange for a promissory note issued by the borrower to OPIC. In prearranged transactions, OPIC sells to one or more investors ("participants") fractional interest totalling 100 per cent of OPIC's interest in the loan. These interests are evidenced by certificates of participation. Pursuant to these certificates of participation, OPIC guaranties repayment in full of the investor's loan participation investment, subject to the terms and conditions of a separate guaranty agreement.

In both structures, OPIC guaranties repayment to the investor of the full principal and interest of the loan against all risk-commercial, political or otherwise. OPIC thus assumes all the credit risk associated with the loan, and the investor receives the full-faith-and-credit guaranty of the United States Government.

OPIC also provides political risk insurance to United States investors, contractors, exporters and financial institutions involved in international independent power projects. Insurance can cover equity investments, parent company and third-party loans and loan guaranties and other forms of investment exposure. Coverage is also available for contractors' and exporters' exposures.

OPIC insurance, which includes insurance of project loans made or arranged by United States banks, can play a critical role in financing independent power projects in developing countries. OPIC insurance can cover the following three political risks:

- Inability to convert profits, debt service and other remittances from local currency into United States dollars.
- Loss of an investment due to expropriation, nationalization or confiscation by a foreign government, including creeping expropriation.
- Loss of assets or income due to war, revolution, insurrection or politically motivated civil strife, terrorism and sabotage.

Insured loans must have an average life of three years and borrowers must be private-sector enterprises in the foreign country.

OPIC does not participate in projects subject to certain performance requirements (such as host government local content and maximum import requirements) that would substantially reduce the potential United States trade benefits of the project. In addition, it is required by statute to conduct an environmental assessment of every project proposed for financing or insurance and to decline support for projects that would have an unreasonable or major adverse impact on the environment of the host country.

The proceeds of OPIC financing may be spent for capital goods and services in the United States, the host country or other less developed countries. If a project involves substantial procurement from industrialized countries other than the United States, financing for such procurement generally must be obtained from other sources.

(b) Eximbank

The Export-Import Bank of the United States (Eximbank) is a United States Government agency whose mission is to aid in financing and to facilitate the export of United States goods and services. Eximbank's programmes fit into five categories: working capital, direct loans, intermediary loans, guaranties and insurance. In response to the substantial growth in the demand for financial support for project financing, Eximbank formed a Project Finance Division in May 1994 to help United States exporters tap the enormous market for infrastructure projects, including independent power projects, in developing countries.

Eximbank offers fixed-rate loans directly to foreign buyers of United States goods and services to help United States exporters compete against foreign suppliers offering officially supported subsidized financing and to fill in gaps in the availability of private export financing. Eximbank direct loans generally involve loan amounts over US$ 10 million or a repayment term of more than seven years. Capital equipment, large-scale projects and related services are eligible for direct loan financing.

Eximbank's Intermediary Loan Program provides funding for intermediaries that extend Organisation for Economic Co-operation and Development (OECD) fixed-rate loans to foreign buyers of the United States exports. Only transactions with an Eximbank authorization value of US$ 5 million or less and a repayment term of five years or less are eligible. An Eximbank intermediary loan may be combined with an Eximbank guaranty.

Eximbank's guaranties provide repayment protection for private sector loans to creditworthy buyers of United States exports. Its comprehensive guaranties cover all risks of non-payment of principal and interest. Guaranties covering only political risks are also available. Lenders may receive Eximbank guaranties on (a) loans extended directly to foreign buyers (buyer credits) or (b) foreign buyers' debt obligations (in the form of a promissory note) purchased from the exporter and without recourse to the exporter (supplier credits). Eximbank also offers credit guarantee facilities that can be used to extend medium-term credit to buyers of United States capital goods and services through banks in certain foreign markets.

Eximbank offers a variety of export credit insurance policies to exporters and financial institutions to reduce repayment risks on foreign receivables owing to political or commercial risks. Policies may be obtained for single or repetitive export sales and for leases. They generally cover 100 per cent of the principal for political risks and 90-95 per cent for commercial risks, as well as a specified amount of interest. As determined by the product, policies are available for short-term sales (up to 180 days, exceptionally 360 days) and medium-term sales (181 days to five years). Policies are principally used to cover short-term sales.

Currently, Eximbank insurance does not cover construction risk and offers only limited political coverage during the construction period. Eximbank's programmes have neither a minimum nor a maximum project size requirement. Generally, Eximbank requires that the equity investors, which do not need to be United States entities, have at least a 25 per cent equity stake for the duration of Eximbank's exposure. Eximbank's direct loan, intermediary loan and guaranty programmes assist the export of United States capital equipment, projects and services, including power generation and transmission installations and project-related services.

Generally, Eximbank programmes may support only sales of United States goods and services. If the United States export contains foreign-made components, Eximbank will provide support for the United States content. Under medium- and long-term programmes, Eximbank will finance, guarantee or insure up to 100 per cent of the United States content, provided that the total United States content is at least 50 per cent of the export price. For medium- and long-term programmes, the total amount financed, guaranteed or insured by Eximbank must not exceed 85 per cent of the contract price. The buyer must make a cash payment to the United States exporter of at least 15 per cent of the United States export value. However, for short-term insurance, the entire gross invoice value is covered if the product is at least 50 per cent United States content.

Eximbank is also committed to increasing the level of support it provides to exporters of environmentally beneficial goods and services as well as to exporters participating in foreign environmental projects. To achieve this objective, Eximbank has an Environmental Exports Program that will provide enhanced levels of support for a broad range of environmental exports. Exports of products and services specifically used in the abatement, control or prevention of air, water and ground contamination or pollution or that provide protection in the handling of toxic substances will be considered eligible for support under that programme, subject to a final determination by Eximbank.

(c) International Finance Corporation

The International Finance Corporation (IFC) is a member of the World Bank Group and is the largest source of direct project financing for private sector projects in developing countries. In August 1992, IFC, which has 161 member countries, established an infrastructure department that includes a power division staffed by a specialized team of project officers.

IFC offers a range of financing and advisory services, primarily through three types of activities: project finance, resource mobilization and advisory services and technical assistance. In its fiscal year that ended 30 June 1993, IFC approved US$ 438 million in financing for power projects, the total cost of which was US$ 1.8 billion. IFC services include long-term loans in major currencies, at fixed or variable rates; equity investments; quasi-equity instruments (subordinated loans, preferred stock, income notes); guaranties and stand-by financing; and risk management (intermediation of currency and interest rate swaps, provision of hedging facilities).

IFC mobilizes financing by syndicating loans with international commercial banks. In addition, IFC underwrites investment funds and corporate securities issues. To be eligible for IFC financing, projects must be profitable for investors, benefit the economy of the host country and comply with environmental guidelines.

Although it is primarily a financier of private sector projects, IFC may provide finance for a company with some government ownership, provided there is private sector participation and the venture is run on a commercial basis. It can finance companies that are wholly locally owned as well as joint ventures between foreign and local shareholders. IFC funds may be used for permanent working capital or to acquire fixed assets.

(d) Multilateral Investment Guarantee Agency

The Multilateral Investment Guarantee Agency (MIGA), founded in 1988, is a member of the World Bank Group. Its purpose is to encourage foreign investment in developing countries by providing investment guaranties against the risks of currency transfer, expropriation, war and civil disturbance, and breach of contract by the host government; it also provides advisory services to developing member countries on improving their attractiveness to foreign investors.

MIGA offers long-term political risk insurance to eligible investors for qualified investments in developing member countries. Coverage is available for exchange risk (other than currency devaluation), expropriation risk (including creeping expropriation), risks arising from politically motivated hostilities (including limited business interruption insurance) and risk of contract repudiation by the host government.

The maximum amount of coverage MIGA will issue for a single project is US$ 50 million. The standard term of coverage is 15 years but may be increased to 20 years if justified.

For each risk category, MIGA can insure equity investment for up to (a) 90 per cent of the investment contribution and (b) an additional 180 per cent to cover earnings attributable to the investment. For loans and guaranties, MIGA can insure up to 90 per cent of (a) the principal and (b) the amount of interest that will accrue over the term of the loan. Regardless of the nature of the project, the investor is required to remain at risk for at least 10 per cent of any loss.

An eligible investor is any national of a member country other than the country in which the investment is to be made. A corporation is eligible for coverage if it is either incorporated in or has its principal place of business in a member country or if it is majority-owned by nationals of member countries. Host government approval must be obtained before MIGA can issue a guarantee.

(e) Asian Development Bank

The Asian Development Bank (ADB-Asia), one of several regional multilateral development banks, is currently active in private power finance. ADB-Asia's mission is to promote investment and foster economic growth in Asia and the south Pacific by lending funds and providing technical assistance to its developing member States. ADB-Asia has 53 shareholding and member countries. In 1986, ADB-Asia established a direct lending facility that does not require a government guaranty. ADB-Asia will make direct loans to governments and national development financial institutions and direct loans to equity investments in private enterprises.

ADB-Asia maintains a US$ 50 million per project limit and usually invests US$ 10-20 million total in loans and equity. ADB-Asia also limits its participation to 25 per cent of total project costs on private sector loans.

Proceeds of ADB-Asia loans and equity investments must be used for the procurement of goods produced in or services supplied from member countries of ADB-Asia, and such procurement must be in accordance with procedures acceptable to ADB-Asia. ADB-Asia normally incorporates this procurement requirement in its investment agreements and requires the developer to provide evidence of compliance.

(f) Export Credit Guarantee Department

The Export Credit Guarantee Department (ECGD), a department of the Secretary of State for Trade and Industry of the United Kingdom of Great Britain and Northern Ireland, was established to help British exporters overcome many of the political risks associated with exporting British goods. The ECGD Overseas Investment Insurance Scheme (OIIS) covers investments (i.e. equity, loans or loan guaranties) against political risks such as expropriation, war and restrictions on remittance.

Only entities that carry on business in the United Kingdom or subsidiaries of such entities may apply for coverage under OIIS. OIIS insurance covers initial equity investments plus retained earnings up to two times the amount of the initial investment. With respect to loans and loan guaranties, OIIS insurance covers the principal and interest on the loan. Once insurance coverage is issued, ECGD is committed to maintain coverage for the initial period of the insurance (15 years) irrespective of any deterioration in the political climate in the host country.

(g) African Development Bank

The African Development Bank (ADB-Africa) was created in 1964 to provide financial and technical resources for the economic development and social progress of African member countries, with particular emphasis on projects that are regional in scope, in order to foster intra-African trade and development.

The principal activity of ADB-Africa is development-oriented lending in support of the industrial and social (notably, health and educational) sectors of the regional member countries. The Bank provides financial assistance in the form of project loans and lines of credit.

ADB-Africa endeavours to make loans at close to market rates. Some loans, however, are made available to member countries from special funds under ADB-Africa administration. The largest of these special funds are the African Development Fund and the Nigerian Trust Fund. Financing from these funds is restricted to projects located in poorer countries or projects with exceptional developmental benefits that would not be feasible at regular ADB-Africa rates.

ADB-Africa has reduced its level of support in recent years for industrial and agro-industrial projects in order to dedicate more resources to housing, utilities and problems of structural adjustment. A significant percentage of ADB-Africa industrial and agro-industrial lending is undertaken through loans to subregional financial institutions on their own guaranties. These guaranties are in turn underwritten by the member States that own the institutions. Although at the present time ADB-Africa does not make any direct loans to private sector enterprises, it contributes indirectly to various private sector promotion programmes.

ADB-Africa is particularly interested in lending to projects that form part of a national or regional development programme required for the economic or social advancement of its members. It attaches special importance to projects that foster intra-African trade and development. High priority is also given to projects that mobilize local resources, help member States to attract additional capital from non-African sources or demonstrate clear self-help efforts.

(h) Inter-American Investment Corporation

The Inter-American Investment Corporation (IIC) was created in 1986 to supplement the private-sector lending activities of the Inter-American Development Bank (IDB). IIC seeks to promote the development of its member countries through the establishment, expansion and modernization of private businesses in the region. It is constituted as an independent merchant banking entity affiliated with IDB. Its board of governors is identical to that of IDB, and the board chairman is president of IDB.

IIC lends to, and takes equity positions in, productive business ventures of private enterprises located in developing member countries, with preference given to the projects of small- and medium-scale companies. All economic sectors are eligible for IIC support. Projects are expected to offer good prospects for success, satisfactory collateral security and tangible benefits for the economy of the host country. IIC investment in a project may take the form of long-term commercial loans, the purchase of stock or the extension of financial guaranties to other institutional lenders.

The share capital of firms supported by IIC may be held in part by foreign investors, but the majority of voting power must be in the hands of Latin American or Caribbean investors.

In addition to direct financing, IIC is authorized to make indirect investments through other financial institutions and to promote participation of other lenders through vehicles such as syndications, co-financing and joint ventures. Small-scale projects are financed through investment funds and lines of credit established in conjunction with financial intermediaries in the private sector. Loan syndications have been used for larger-sized projects.

As lender, IIC will finance up to 33 per cent of the cost of a new venture and 50 per cent of the cost of expanding an existing business. It will hold no more than one third of the share capital of a company in which it invests as equity holder. Its direct commitments as lender or equity holder will not, generally, exceed US$ 6 million per transaction, given IIC's present level of capitalization and lending capacity.

(i) Bureau for Asia and Private Enterprise

The Bureau for Asia and Private Enterprise (APRE) was created within the United States Agency for International Development in 1981 to encourage increased reliance on private investment capital in promoting economic growth in the developing world. Through its loan and loan guaranty programme, APRE seeks to promote the private sector in developing countries through support for small-scale private enterprises. In recent years, it has placed particular emphasis on its loan guaranty activities.

Loans are intended to support small private business ventures and may not exceed US$ 3 million. In general, loans mature within seven years, including a grace period on the principal of the loan. The interest rate charged is usually slightly higher than the prevailing United States Treasury rate for similar maturities. APRE assumes the credit risk of a project but not the foreign exchange risk, since all loans must be repaid in United States dollars.

Loans may take the form of direct credits to eligible small businesses for projects meeting APRE developmental objectives or loans to intermediate credit institutions that are committed to relending the funds to eligible private businesses. In 1990, APRE stressed projects of benefit to the environment, supporting rainforest preservation, development of renewable energy resources and the preservation of fragile ecosystems.

In 1988, Congress authorized APRE for the first time to issue loan guaranties to open new credit avenues for private businesses in developing countries. Two loan guaranty programmes are currently in effect involving guaranties of bank loan portfolios to foreign small businesses and guaranties of trade finance paper supporting the export of capital goods.

4. Drawbacks of using public financing sources

The mere availability of these sources of financing does not, however, guarantee success. Developers are often frustrated by bureaucratic bottlenecks at some large agencies that can delay closing and funding for months. These delays can impose large carrying costs on the developers, driving down expected returns. Additionally, many international funding sources require a backstop agreement with the host government as a condition of project support, an agreement which may or may not be available. Further, many agencies, particularly the World Bank, require projects to be placed out for public tender. This requirement often discourages developers who have spent substantial resources to develop a project opportunity only to find that opportunity made available to competitors.

Moreover, some agencies, particularly ECAs, are reluctant to accept commercial credit risk, although they do protect against political and currency convertibility risks. Those ECAs will insist on prudent lending structures and, at times, credit support, to give reasonable assurance of loan repayment. This may be a substantial concern in developing countries where the sovereign itself is not rated as investment grade. In those situations, the lending agency may insist on structures that reduce dependence on non-creditworthy electric utility purchasers, such as the use of escrow or offshore accounts that give the project's lenders access to revenues generated from the ultimate electric consumers. The escrow account structure, for example, is currently being proposed for power projects in India that will not benefit from payment and performance guaranties from the central Government.

5. Optimizing financing strategies during development

Project developers consider financeability from the inception of any project. Indeed, access to and creativity with respect to financing often mark the difference between successful and unsuccessful developers. Accordingly, when negotiating power purchase, implementation, fuel supply and other key project agreements, developers will seek to obtain terms that would likely be required by the financial markets. Developers often employ financial advisors at the outset, particularly in untested markets, to assist in contract negotiations. Sophisticated legal advisors are usually also employed for this purpose. Thus, in any negotiation of a key project document, the potential project lenders, in effect, sit in on the negotiations as the parties seek to accommodate financeability in the documents.

Often, in typical project financing in an industrialized country, developers prefer not to approach the financial market until the key project agreements are executed or, at least, near execution. Developers seek to maintain a relatively strong bargaining position with lenders. If the project is still unformulated in material respects, the lenders may well demand changes to the contracts during negotiations.

Developers prefer to avoid this level of interference by lenders. They prefer to anticipate lender concerns without having to respond to dictates from the lenders themselves.

After the key agreements are executed, developers typically approach the financial market through a bidding process in which the developer presents proposed financing terms. Banks eager to provide the financing often are reluctant to require material changes to the term sheet, aware that they are competing with other lenders. In this way the developer is best positioned to obtain financing on the most favourable terms.

In untested or difficult markets, however, developers may well prefer to involve public financing agencies at the outset of a project. They may, for example, retain the IFC or the European Bank for Reconstruction and Development as financial advisor to assist in structuring as a strategy to facilitate ultimate financing. Alternatively (or concurrently), agencies such as the IFC or the Commonwealth Development Corporation might be invited as equity participants early in project development. Particularly where the availability of credit to a country is perceived as restricted, the developer might be willing to cede some measure of management influence to a multilateral agency in return for greater financing certainty.

Even in markets with greater credit availability, developers may seek to involve lenders during the negotiation of the key construction agreements. Often contractors or equipment suppliers are required to make financing part of their bid packages. Construction contractors, accordingly, are quite familiar with the ECAs of the countries where they have manufacturing facilities. Multinational suppliers such as Asea Brown Boveri can use their flexibility to service equipment from various countries to shop among ECAs. In any major project, developers will invite bids from the United States, Japan, Germany and other countries to ensure healthy competition not only from the contractors but also from their ECAs and banks. While this strategy involves lenders earlier in the process than the typical project finance model, the developer may still maintain its bargaining leverage through careful use of competitive tendering procedures.

D. The role of developing country governments in providing incentive for biomass projects

Although biomass projects tend to be costlier per kilowatt-hour to operate than fossil-fuel-fired projects, developed countries and developing countries alike realize that there are significant benefits to the host country from biomass power projects. Biomass power projects not only provide power, but they provide it at little cost to the environment as compared to fossil-fuel-fired power plants. Also, biomass power projects tend to be smaller and modular and to use indigenous fuels, so they are less prone to cause political embarrassment than are large, high-visibility fossil-fuel projects using imported fuels. As technology continues to improve, the cost of biomass power will continue to decrease.

Governments in some cases may need to give their local utilities incentives to purchase power from biomass projects by requiring utilities to set aside a block of power to be purchased from renewable-sourced power projects, to require utilities to factor in the environmental impact of projects when considering competitive power bids or even to subsidize biomass projects through research grants, below-market financing, tax abatements or equity participation.

Finally, to facilitate the financing of biomass energy projects, governments should be willing to assume the risks associated with obtaining the appropriate approvals, converting and remitting currency, political *force majeure*, changes in law and increases in taxes, since they are best able to mitigate those risks. Fuel risks, as discussed, also are likely candidates for being retained by the government. In return, the cost of financing the project will be less and the likelihood of success for the lenders, the project sponsors, the government and its citizens alike will increase.

E. Conclusions

Developing nations, in seeking to become more competitive in today's global economy, are striving to develop and upgrade their infrastructure, and many international firms are seeking to participate in such development, especially in the area of power projects. Despite the urgent need for power in many developing nations, power requirements must be balanced against the need to maintain proper environmental controls over development. As a result, many developing nations are investigating the feasibility of small projects using fuels having a low impact on the environment. Biomass fuels are often considered in this context.

While offering certain advantages relating to size and environmental impact, biomass projects are susceptible to the same commercial and political risks inherent in the financing of all power projects. However, in addition to traditional risk factors, biomass projects can also contain additional risks relating to the unproven nature of the technology and to the instability in price and supply of the fuel. Unless such risks can be transferred to other parties, such as the power purchaser, the contractor or the host government, financing biomass projects on a strictly private basis may be difficult.

In such instances, public financing entities can help to alleviate risks inherent to projects in developing countries, including biomass projects. Such assistance can include loan guaranties, export financing and direct debt or equity participation. While the presence of a public financing entity can delay the closing of the financing and lead to restrictions on the structure of the project, project developers, by drawing on all resources available, including public financing, can ultimately obtain more flexibility in the number and variety of financing options available.

XIV. PRIVATE CAPITAL REQUIREMENTS FOR INTERNATIONAL BIOMASS ENERGY PROJECTS

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Abstract

In developing countries, the use of biomass for energy production faces two contradictory pressures. On the one hand, biomass costs very little and it is used inefficiently for fuel or charcoal production, leading to widespread destruction of forested areas and environmental degradation; this problem is being attenuated by the promotion, through aid programmes, of more efficient cook stoves for poor people. On the other hand, the conversion of biomass into high-grade fuel such as ethanol from sugar cane or burning urban refuse or gasifying it to produce electricity is not economically competitive at this time and requires subsidies of approximately 30 per cent to make it as attractive as conventional fuels. Only electricity production using residues from sawmills, crops and other biomass by-products is competitive, and a number of plants are in operation in some countries, particularly the United States. For such plants, the usual rates of return and long-term contract purchases that characterize investments of this kind are applied. Although technologies are available for the widespread efficient use of biomass, the financial hurdle of high initial costs has impeded their market penetration, which in turn precludes any decline in costs that might otherwise have come from production increases. Intervention by governments or by GEF, justified on grounds of environmental protection, is needed to accelerate the introduction of the new technologies. The only private flows that are taking place at the moment are those from enlightened investors wishing to guarantee themselves a strong position in the area for the future or to preempt command and control regulations, such as carbon taxes, imposed by governments. The joint implementation of biomass technologies between industrialized and developing countries might be one method of accelerating this flow.

Introduction

To estimate the private capital requirements for international biomass energy projects in developing countries, the use of biomass on a small scale for cooking and biogas production will be discussed first. Then the large-scale use of biomass for electricity and ethanol production will be discussed. In the last section the capital requirements will be presented: the amounts being invested are small and will have to increase substantially in the next 30 years.

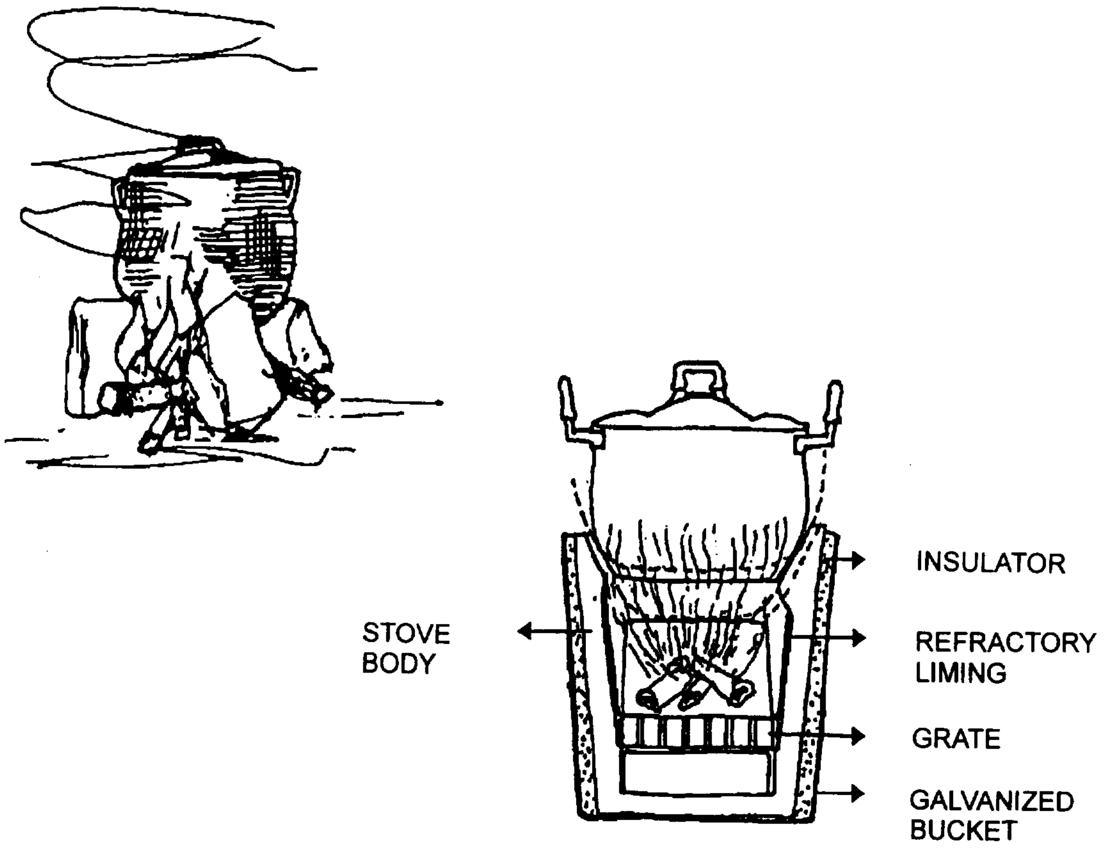
A. The small-scale use of biomass in developing countries

Biomass in the form of dung, agricultural residues or fuelwood makes an important contribution to the energy supply of developing countries, mainly in rural areas, where it is used primarily as fuel for cooking purposes. The conversion of fuelwood into charcoal is also important in some countries since charcoal is less bulky than fuelwood to transport to urban areas, where it is used for small industries and also for cooking. It is estimated that such uses of fuelwood are responsible for 30 per cent of the deforestation taking place in many areas in Africa and Asia. Most of these activities take place on the border between the formal and informal economy and are difficult to control; deforestation usually takes place on public lands since the fuelwood itself costs nothing and the main monetary cost is for transportation. Enterprises involved in such activities are generally very small and scattered over rural areas.

Heightened concerns over the environmental consequences of deforestation and desertification, mainly in Africa, led to a number of programmes to improve the efficiency of fuelwood cooking as a means of attenuating the problem. Indeed, as is well known, the efficiency of primitive cook stoves is dismally low (approximately 10 per cent), so they require large amounts of fuel: typically a family will consume one cubic metre of fuelwood for cooking every month. The approach has been to disseminate more efficient cook stoves either through subsidized government programmes or through commercial enterprises [1].

After a number of unsuccessful efforts, the Jiko stove was developed and introduced in Kenya, where it was widely adopted (see figure XIV.1).

Figure XIV.1. Primitive cooking stove and the improved Jiko stove



Improved bucket stove for wood

Currently more than half of all urban households in Kenya own ceramic Jiko stoves, and purchasers range from the poor to the affluent. Early stove programmes, which commonly targeted users in the countryside, where more than 70 per cent of the Kenyan population lives, seemed justified because they met the needs of the poorest segment of society. But the stove price of US$ 2 to US$ 5 proved too high for many households that had the option of collecting their own firewood at no cost and cooking over open fires. For city dwellers, who sought ways to cut their fuel costs, the more efficient stoves had a greater allure. Establishing an infrastructure for stove production was essential; the unit cost dropped from US$ 12 to US$ 2 once mass production of the stoves started. Over 13,000 Jiko stoves are produced by several hundred commercial enterprises and sold each month in stores and markets throughout urban areas in Kenya. The capital requirements in this case were not for the biomass raw material but for the equipment (cook stoves) that used it. There are many opportunities for such investments in household stoves in other countries in Africa and South-East Asia.

The use of briquettes made of agricultural residues is also technically possible and could significantly expand the resource base of biomass from fuelwood to other abundant resources, but little has been done in this area.

The large-scale, inefficient production of charcoal for the production of pig iron takes place only in Brazil, where it has led to widespread deforestation. It seems clear that the continued use of charcoal would require improved efficiency and recovery of some of the emitted gases.

Biogas digesters are used widely in China and India, using as raw materials animal and human wastes and agricultural residues [2]. China seems to have the largest programme in this area: 5.25 million farm households had biogas digesters in 1993 with an annual production of 1.18 billion m^3, which corresponds roughly to 14,000 barrels of petroleum equivalent per day. Biogas has a heat value of 5,500 kcal/m^3, higher than that of coal gas, and is used mainly in urban areas for cooking and space heating. In addition, China has built more than 600 large and medium-sized utilities that use organic waste from animal and poultry farms, wineries and food factories. Their combined capacity is 220,000 m^3. The biogas produced services 84,000 households, replacing traditional coal and fuel. In India, family-size biodigesters have been in use for many years. There is no information on the cost of such devices. Community-size biogas digesters were also built in India, with the gas being used for electricity generation in plants producing a few kilowatts of power.

B. The large-scale use of biomass

To explore the flow of private capital in the area of biomass, large-scale projects of several kinds must be looked at:

- Electricity production from biomass (municipal waste, energy crops, agricultural and forest wastes and landfill gas).
- Gasification for electricity generation.
- Ethanol production from sugar cane.

1. Electricity from biomass

Electricity is being produced from agricultural waste, energy crops, sawdust, urban refuse and landfill gas in several industrialized countries, mainly the United States, where more than 8,000 MW of electricity is produced from forest residues and sawdust [3]. Most of the plants are privately owned and do not require subsidies (an exception is plants burning urban refuse and landfill gas, where frequently the municipalities pay a fee for the removal of the waste).

A reasonable idea of the subsidies involved in this case, in 1994, can be gained from an analysis of the projects submitted to British electricity companies for the production of electricity from renewables. The British Government [4] applies a levy of approximately 1 per cent to all electricity bills, which is used to promote the use of renewables. Known as the non-fossil fuel obligation (NFFO), this levy yields approximately US$ 30 million every year. In the last round of NFFO activities, 520 projects were presented corresponding to an aggregate capacity of 2,464 MW [5]. Table XIV.1 gives the characteristics of such projects.

Table XIV.1. NFFO projects in Great Britain, 1994

Technology	Number of projects	Capacity (MW)	Average bid price (pfennings/kWh)	
			1991	1994
Wind	198	663	8.65	5.5
Hydro	72	39	5.10	5.2
Landfill gas	96	165	5.46	4.1
Municipal waste	75	991	4.78	4.5
Energy crops, agricultural and forestry wastes	79	606	-	0.0
Total	**520**	**2 464**		

Note: The cost of electricity in 1994 in Great Britain was 3.0 pfennings per kWh approximately (1 pfenning is approximately US$ 0.015).

The landfill gas projects are almost all under 5 MW. Energy crop projects (including agricultural and forestry wastes) vary in size from under 1 MW to 50 MW. The municipal waste projects are generally the largest, averaging about 13 MW.

Biomass-based project bids indicate costs approximately 50 per cent higher than the present costs of electricity but with a declining trend. These costs are estimated on guaranteed purchases over 20 years, which are an integral part of the NFFO scheme.

2. *Gasification for electricity generation*

Present systems for burning fuelwood and agricultural residues to produce electricity use low-pressure boilers, and their efficiency is usually lower than 10-20 per cent. Simple improvements such as using condensing-extraction steam turbines and higher temperatures could increase efficiencies to 20-30 per cent.

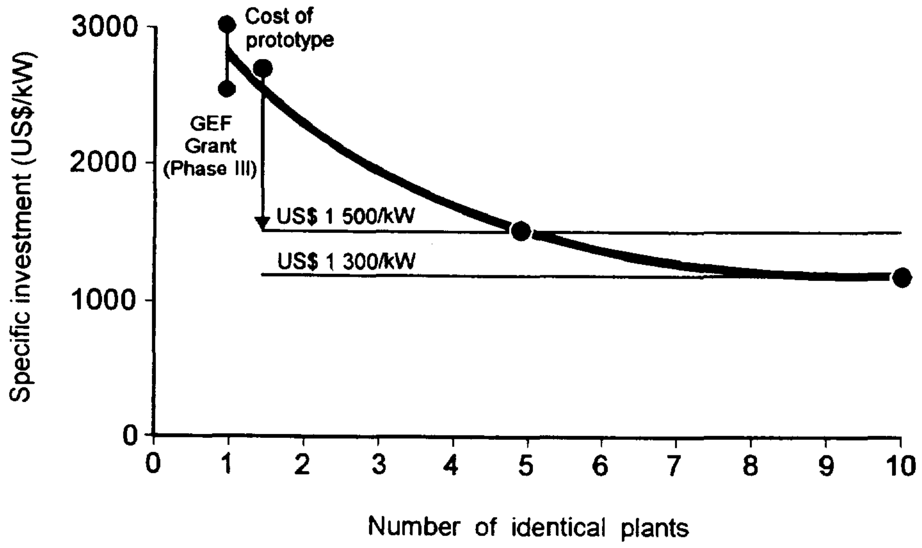
The Indian Institute of Science at Bangalore [6] has developed gasifier systems in the 5 kW range for converting solid agricultural residues to a gaseous fuel using a thermochemical process; the fuel can be wood chips, corn-cobs, cotton stalks, coconut shells etc. The gas can power a diesel engine, replacing up to 90 per cent of the diesel fuel. The technology has been transferred to local manufacturers in India, and over 200 diesel pump sets are in operation in that country. The initial cost of approximately US$ 1,000/kW seems to be competitive with other methods, and the commercial opportunities are great, mainly in isolated rural areas not only in India but in China, Brazil and other countries as well. A demonstration unit for 100 kW is undergoing field tests.

Advanced technologies have been proposed to convert solid biomass into a low-Btu gas through gasification and to use the gas to power aeroderivative gas turbines [7]. Efficiencies higher than 40 per cent can be expected from a BIG/GT system. This efficiency is not surprising since large combined-cycle plants, running with natural gas, operate with efficiencies equal to, or even above, this value. The merit of BIG/GT systems would be the ability to provide such high efficiencies in small units, in a range suitable for the economical use of biomass (20-100 MW).

The BIG/GT technology is still under development; it is not yet clear whether higher pressure gasification will dominate BIG/GT power generation in all circumstances or whether atmospheric pressure systems could retain an economic edge. A project in Brazil for a 25 MW, full-scale demonstration plant, with the financial support of GEF, is being implemented with General Electric's aeroderivative gas turbines.

Although the cost per kilowatt of this first plant will surpass US$ 2,000, the learning curve for this technology is expected to rapidly reduce investment costs (figure XIV.2).

Figure XIV.2. Expected cost decline with BIG/GT system

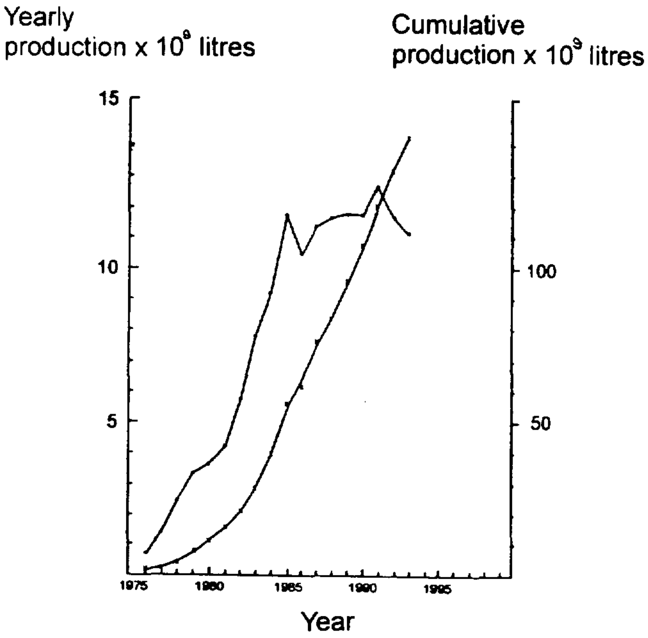


3. Ethanol production

In the 1970s, hard-pressed by rising costs of oil imports that seriously threatened its balance of payments, the Government of Brazil encouraged the production of ethanol from sugar cane and the adaptation of Otto cycle engines to work either on neat ethanol (96 per cent ethanol, 4 per cent water) or gasohol (78 per cent gasoline, 22 per cent ethanol). The programme started in 1976 and rapidly reached a yearly production of 12 million m^3 (about 200,000 bbl/day) of ethanol [8], replacing one half of the gasoline that would have otherwise been used in automobiles in Brazil (figure XIV.3). At one time, one half of all automobiles in the country were running on gasohol and the remainder on neat ethanol. Recently, that percentage has declined.

Other reasons for the establishment of the programme were to reduce the country's dependence on imported oil and to help stabilize sugar production in the face of cyclical variations in international prices. An important consideration has always been the contribution to the increase of direct job opportunities for both skilled and unskilled workers. The programme was almost entirely based on locally manufactured equipment, helping to establish a strong agro-industrial system and generating 700,000 jobs, 75 per cent of them direct.

Figure XIV.3. Evolution of ethanol production in Brazil



The cost of alcohol is not yet competitive with the international selling price of gasoline of about US$ 25 a barrel. Most countries, however, have established heavy taxes (100 per cent or more) on gasoline to discourage unnecessary driving and/or to produce revenue. The difference between the price paid by drivers and the real cost is redistributed to lower the cost of other petroleum derivatives such as diesel or liquified petroleum gas (LPG) or to support social programmes. In the case of ethanol in Brazil, the extra cost is not available for redistribution and goes to the producers. The justifications for such a policy are the positive environmental and social consequences of the programme.

The local benefits of using ethanol as a fuel are evident in the city of São Paulo, where the quality of the air has improved despite an increasing number of automobiles, since alcohol fuel, unlike gasoline, does not contain sulphur and other impurities. In addition, there are the global benefits of a reduction in net CO_2 emissions, since ethanol is a renewable resource when produced from sugar cane, except for the small amount of fossil fuel used in its production.

Table XIV.2 shows that the emission of 9.45 million tonnes/yr of carbon (approximately 15 per cent of the total emissions in Brazil attributable to the use of fossil fuels) is avoided by substituting ethanol for gasoline [9].

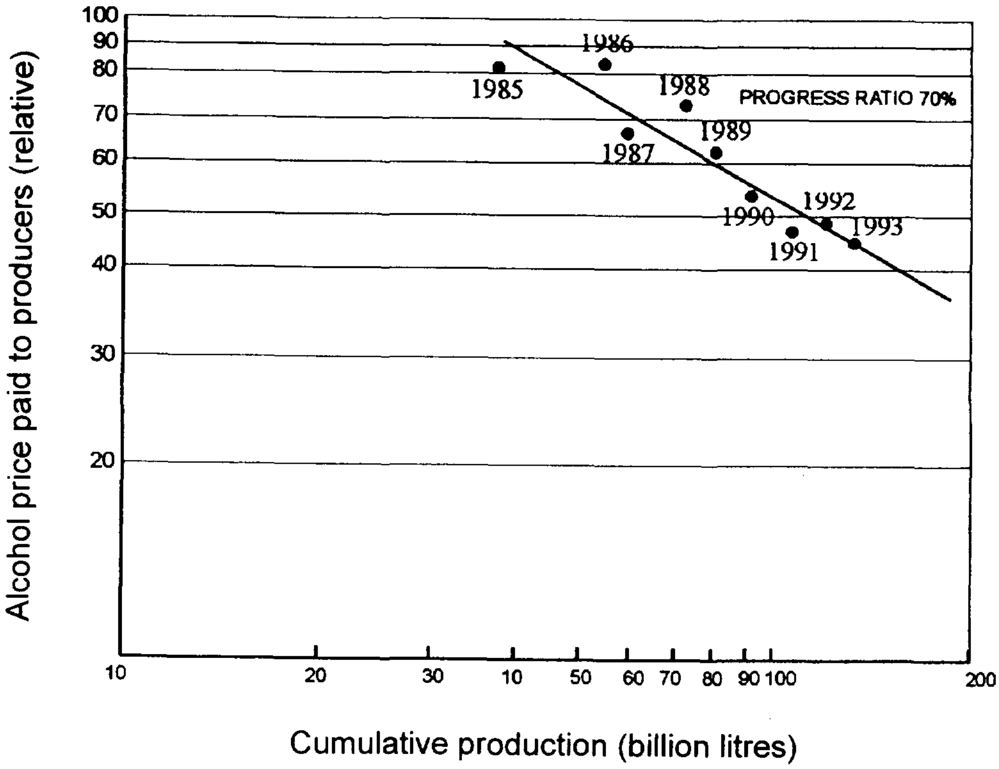
The programme has led to technological developments in both agriculture production and sugar cane processing, leading to lower ethanol costs and the possibility of a large surplus in biomass-based (bagasse and trash) electricity production. This would further enhance biomass as a CO_2-neutral energy source.

Table XIV.2. Net CO_2 emissions due to sugar cane production and use in Brazil

Source of decrease/increase	Net CO_2 emissions (million tonnes C/year)
Ethanol substitution for gasoline	-7.41
Bagasse substitution for fuel oil (chemical and food industry)	-3.24
Fossil fuel utilization in agro-industry	+1.20
Net contribution (uptake)	-9.45

The cost of ethanol has been going down as production increases, declining by 30 per cent for each doubling of production (see figure XIV.4). The present cost is US$ 0.208-0.229/litre, or US$ 33-37/bbl. The technical equivalence of ethanol per litre of gasoline (in a neat ethanol engine) is 1.20, so the cost of replacing gasoline by alcohol is US$ 40-44/bbl.

Figure XIV.4. Market penetration of ethanol in Brazil



C. Private capital requirements for biomass projects

At present the flow of capital to biomass energy projects is rather small because the high initial capital makes them non-competitive compared with conventional sources (coal, oil, gas, hydro and, to some extent, nuclear). In almost all cases, overcoming the initial financial hurdles requires subventions of one type or another.

Demonstration projects for renewable energy sources in general and biomass in particular have been implemented in many areas through official development aid from a number of countries and NGOs. Even if successful, such demonstration projects in general do not reach the commercialization stage except in some cases such as Jiko stoves in Kenya or alcohol production in Brazil. GEF is supporting, through grants, new demonstration projects but not commercialization. The level of GEF resources spent in the energy area is not larger than US$ 200 million per year.

Recently the World Bank established the Solar Initiative to lend money to governments that ask for renewable energy technologies; since most of the technolgies are not competitive at this time, the idea is that GEF would add to the loans the fraction of the resources needed to make them competitive. Typically GEF would contribute 30 per cent of the total loan. It is expected, of course, that after a learning period the renewable sources would require less initial capital and eventually would become competitive.

Joint implementation schemes could benefit from GEF funds, and a few investors are trying to identify suitable partners in developing countries where projects involving renewables could affect CO_2 emissions in industrialized countries. Some investors are willing to invest their own resources to establish themselves as pioneers in the area and as a public relations strategy.

Other companies are proposing innovative financial schemes to make viable their proposals in the area of renewables, although not in the particular area of biomass. Recently Solarex proposed building a 100 MW power plant using photovoltaics in Nevada, in the United States, that would generate electric power at a cost of US$ 0.05/kWh. Built into the financial scheme is a 30-year guarantee for the purchase of the power.

The key prerequisites for investments in renewables are the following:

- Power purchase agreements.
- Long-term loans,
- Low interest rates guaranteed by real assets or Government.
- Political stability.

They are always insisted on before making financial commitments to biomass projects in developing countries.

Table XIV.3 gives the results of a study commissioned by E&Co, an energy investment service established by the Rockefeller Foundation to determine the willingness of corporations and utilities in the United States to invest in renewables.

The only estimates possible for the total amount of capital needed are order of magnitude estimates. To make such an estimate, it is assumed that renewables will account for 10 per cent of the total world energy consumption in the year 2025 of 10 Gtoe (billion tonnes of oil equivalent) and that half of that 1 Gtoe will be consumed as liquid fuel and half as electricity. Since one tonne of oil equivalent of conventional liquid fuel (7 bbl) costs typically US$ 200, 0.5 Gtoe would cost US$ 100 billion, and since electricity production typically costs twice as much because of the loss in efficiency in converting heat into electricity, 0.5 Gtoe of electricity would cost US$ 200 billion. Therefore, 1 Gtoe from conventional sources would cost US$ 300 billion.

If this energy were produced from renewables today it would probably cost 30 per cent more, i.e. approximately US$ 100 billion additional. Over 30 years this represents an average total cost of US$ 1.5 trillion (since renewables contribute very little today and will probably grow linearly to 1 Gtoe in this span of time).

Table XIV.3. Willingness to invest

Entity	Resources (equity)	Principal area of action
Corporations		
Bechtel's new energy company	Yes	Wind, biomass, village grid systems
Kenetech	Yes	Wind
Rolls Royce	Yes	Gas turbines for biomass
Solarex	No	PV (large-scale amorphous silicon)
Zurn Nepco	Yes, up to 49 per cent	Biomass combustion
Utilities		
AES	Up to US$ 200 million in 1995	Conventional
Canadian	Up to 25 per cent of project	Minihydro
International Energy Partners	Up to US$ per million	Biomass
Trans Alta	US$ 50 million until 2000	Co-generation

In all likelihood, however, in the 30 years between 1995 and 2025, the additional cost would drop substantially, decreasing the additional capital needed: if one assumes that in 15 years the cost of fuels or electricity from renewables would be competitive with the cost of fuels or electricity from other sources, having dropped linearly between 1995 and 2010, the total additional cost of adopting the biomass option would be reduced to US$ 120 billion, or approximately US$ 10 billion/yr. This is the flux of capital needed in the next years. Such an investment would reduce carbon emissions by approximately 15 billon tonnes in the next 30 years, at a cost of US$ 8/tonne carbon.

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Part four

Environmental economics of biomass energy utilization

XV. ENVIRONMENTAL IMPACTS OF BIOMASS ENERGY RESOURCE PRODUCTION AND UTILIZATION

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Abstract

The purpose of this paper is to provide a broad overview of the environmental impacts associated with the production, conversion and utilization of biomass energy resources and compare them with the impacts of conventional fuels. The use of sustainable biomass resources can play an important role in helping developing nations meet their rapidly growing energy needs, while providing significant environmental advantages over the use of fossil fuels. Two of the most important environmental benefits biomass energy offers are reduced net emissions of greenhouse gases, particularly CO_2, and reduced emissions of SO_2, the primary contributor to acid rain. The paper also addresses the environmental impacts of supplying a range of specific biomass resources, including forest-based resources, numerous types of biomass residues and energy crops. Some of the benefits offered by the various biomass supplies include support for improved forest management, improved waste management, reduced air emissions (by eliminating the need for open-field burning of residues) and reduced soil erosion (for example, where perennial energy crops are planted on degraded or deforested land). The environmental impacts of a range of biomass conversion technologies are also addressed, including those from the thermochemical processing of biomass (including direct combustion in residential wood stoves and industrial-scale boilers, gasification and pyrolysis); biochemical processing (anaerobic digestion and fermentation); and chemical processing (extraction of organic oils). In addition to reducing CO_2 and SO_2, other environmental benefits of biomass conversion technologies include the distinctly lower toxicity of the ash compared to coal ash, reduced odours and pathogens from manure, reduced vehicle emissions of CO_2 with the use of ethanol fuel blends, and reduced particulate and hydrocarbon emissions where biodiesel is used as a substitute for diesel fuel. In general, the key elements for achieving the full benefits of biomass energy are the establishment of sustainable practices for obtaining biomass supplies and the use of efficient biomass conversion technologies.

Introduction

Developing countries are expected to substantially increase their demands for new energy supplies over the next few decades as their economies continue to grow. For example, a worldwide market for more than 600,000 MW of electric power capacity is expected within the next 10 years. If fossil fuels are used to meet the vast majority of these new energy requirements, this could contribute to significant environmental problems at the local, regional and global levels. In many parts of eastern Europe, Asia, Africa and Latin America, biomass energy offers a competitive option that could provide an important alternative to overdependence on fossil fuels. Use of sustainable biomass resources can help developing nations to meet their rapidly growing energy needs while providing significant environmental benefits. Efforts have only begun to address the international opportunities that exist for sustainable biomass energy development.

In recognition of the potential for biomass energy in developing countries, UNIDO is facilitating a dialogue among technologists, scientists, decision makers and potential donors to identify and promote biomass energy assistance projects. This paper has been prepared as input to the UNIDO initiative. It aims to compare the impacts on environmental assets (air, land and water) of the production, conversion and utilization of biomass energy resources with the impact of conventional fuels.

In addressing the impacts of biomass energy on the environment, it will be helpful to begin by briefly clarifying what the term biomass encompasses. Biomass is produced from growing, living plants through photosynthesis. It is any organic (non-fossil) material that can be converted to energy, including wood from forest thinnings and residues, tree harvesting, lumber-mill or paper-mill residues, crop residues, food processing residues, energy crops, animal wastes, sewage sludge and urban solid waste (including urban wood waste from tree trimming, land clearing or building demolition, as well as other forms of combustible MSW).

This paper incorporates a total fuel-cycle perspective. It addresses fuel supply impacts (i.e. obtaining residues or growing and harvesting biomass), processing, transportation, storage and, finally, conversion to meet end-use energy requirements. Impacts on air, land and water were the focus of the paper's comparative analysis, including discussions on greenhouse gases, urban air pollution, soil erosion and degradation, deforestation and acid rain. The types of fuel used will clearly have a significant bearing on the environmental impacts; other important factors include the scale at which the energy is harvested/obtained and converted, as well as the relative level of affluence or poverty in a given setting. The paper addresses environmental impacts associated with supplying a range of specific biomass resources, including forest-based resources, numerous types of biomass residues and energy crops. In addition, the environmental impacts associated with a range of biomass conversion technologies are addressed, among them those from the thermochemical processing of biomass (including residential wood stoves and industrial-scale direct combustion, gasification and pyrolysis); biochemical processing (anaerobic digestion or fermentation) and chemical processing (extraction of organic oils).

One of the most important environmental advantages of biomass fuels compared to fossil fuels is minimal net emissions of CO_2, the primary greenhouse gas. Given their importance, a detailed accounting of CO_2 emissions is provided for a number of biomass and conventional fossil fuel options. Then, general guidelines are provided for the quantification of the environmental impacts of biomass and fossil fuels.

While it is clearly possible to obtain and use biomass in environmentally unacceptable ways, when acceptable and sustainable practices for its use are followed, biomass offers important environmental advantages over fossil fuel alternatives.

A. Worldwide opportunities for biomass energy

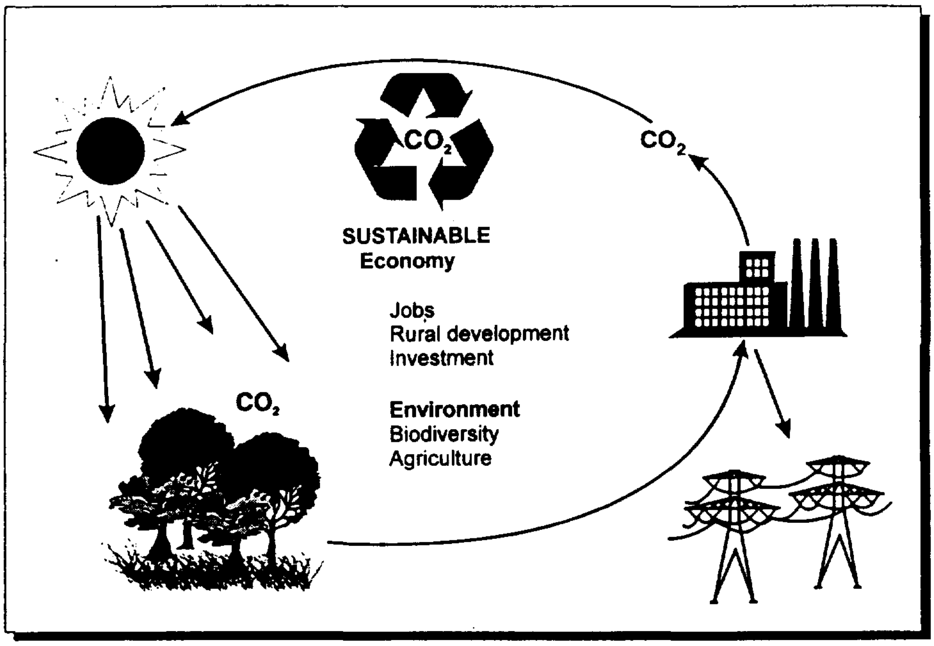
Many developing countries have large quantities of biomass residues from forest products industries and food processing industries, including residues such as rice hulls, sugar cane waste, bark and sawdust. The management and disposal of these residues can have significant environmental and economic costs. Sometimes the residues are burned in open piles, causing air pollution. Another approach is to burn them in inefficient boilers, where the primary function is to reduce the volume of waste and energy recovery is only secondary. Efficient boilers, or other energy-efficient conversion technologies, can make these residues valuable energy resources, while helping to reduce gaseous, liquid and solid waste emissions.

In addition to having biomass residues, many developing countries have large areas of degraded agricultural land or deforested land where perennial energy crops could offer significant economic and environmental benefits. The key elements for achieving the full benefits of biomass energy is the establishment of sustainable practices for growing and harvesting biomass and the use of efficient conversion technologies. When these key elements are in place, biomass energy offers significant environmental benefits, both locally and globally.

The use of sustainable biomass instead of fossil fuels significantly reduces greenhouse gas emissions (CO_2 and methane). The combustion of sustainable biomass fuels represents the recycling of CO_2, since the CO_2 emitted during biomass combustion is derived from atmospheric CO_2 taken up during the biomass growth process. Also, because biomass has a low sulphur content it can offset fossil fuel emissions of SO_2, a key contributor to acid rain. Combusting waste biomass before it decomposes in landfills or refuse piles avoids methane emissions. (Significant releases of methane are associated with coal mining or with oil or natural gas wells.) The use of biomass residues also makes unnecessary their storage or disposal. Finally, the roots of perennial energy crops planted on previously degraded or deforested land remain in place and help to reduce erosion.

In addition to the environmental benefits noted above, sustainable biomass energy also offers social and economic benefits. It contributes to rural revitalization by increasing local and regional economic activity, infrastructure development and tax revenues for governments. It can enhance national energy self-sufficiency by reducing the need for costly imported energy. Adding biomass to the resource mix contributes to fuel diversity and energy price stability by drawing on indigenous fuel supplies. Finally, as a renewable fuel, biomass contributes to sustainable development goals established at the local, national and international levels. Figure XV.1 illustrates some of the broad environmental and social benefits of biomass energy use.

Figure XV.1. Biomass energy supports sustainable development



B. Traditional biomass energy use

In developing countries, over 2 billion people still rely heavily on biomass fuel for cooking and heating. Biomass fuels used in these applications include wood, charcoal, crop residues and dung. The most common method of cooking and heating with biofuels is over an open fire. Man-made clay, wooden or scrap metal cook stoves are also common in developing countries. Most traditional methods of cooking and heating with biomass fuels are inefficient. These inefficient, small-scale methods generate a number of air pollutants, including particulates, CO and a variety of volatile hydrocarbons, all of which can adversely affect health, primarily because they concentrate in indoor air.

Poor and rural communities are typically limited by inadequate or non-existent infrastructure such as pipelines, roads, usage meters and billing systems. In addition, they often have no financial or physical access to improved cook stoves or to alternative fuels like kerosine and LPG.

Although more efficient cook stoves and heating units exist, the incentive to purchase one is reduced by its cost (which, even if small, can be a financial hardship for a poor rural family) and by cultural barriers associated with cook stove design. Cook stoves that are sensitive to culture, fuel source and price are likely to have the greatest success in reducing inefficient use of biomass, specifically fuelwood. However, if individuals use improved cook stoves improperly, efficiency savings can be lost, and even if cook stoves are improved, biomass use on the small residential scale is likely to remain relatively inefficient.

The widespread perception of residential biomass use as smoky and inefficient creates barriers for other biomass energy technologies and applications. For larger industrial or utility-scale installations, biomass technologies can provide much higher efficiencies and significantly lower emissions. This negative public perception of biomass energy as a polluting, outdated energy source is a barrier that needs to be addressed. There is a need for information dissemination and technology transfer to close the gap between the actual performance and benefits offered by state-of-the-art biomass energy technologies and public perceptions that are tied to outmoded biomass technologies of the past.

C. A fuel cycle perspective on the environmental impacts of biomass

In comparing the environmental impacts of biomass and conventional fuels, it is important to consider the impact of obtaining the fuel supply as well as the impact of converting it to useful energy. The biomass fuel cycle encompasses growing and harvesting of the feedstock, processing, transportation, storage and, finally, conversion to meet energy requirements. These operations are analogous to the fuel cycle of fossil fuels, which begins with mining and drilling rather than growth and harvest.

This section describes the environmental considerations for each of the various stages of the biomass fuel cycle: biomass growth, harvesting and residue production; processing, transportation and storage; and conversion. For comparison, it highlights some of the environmental effects associated with the supply and conversion of fossil fuels.

1. Biomass growth, harvesting and residue production

Depending on the specific biomass feedstock, there are often distinctly different environmental impacts associated with the fuel supply portion of the biomass fuel cycle. These impacts are described below for three general categories of biomass fuel: forest-based feedstocks, biomass residues and energy crops. In general, the largest source of biomass in the near term is expected to be from residues, since they can often be obtained at very low cost or no cost by the industries that produce them. In the long term, as their costs drop and the cost of fossil fuels rises, energy crops could also provide significant supplies of energy. Forest-based wood fuels, in the form of forestry residues or wood harvested specifically for use as a fuel, will be economically and environmentally viable in select cases where sustainability factors allow the removal of wood from forests. The issues associated with each of the three categories of biomass fuel supply are discussed below.

(a) *Forest-based feedstocks*

Forest-based biomass feedstocks are generally harvested in conjunction with other ongoing timber harvesting operations. An important environmental impact of supplying forest-based biomass is the potentially negative effect on the forest of harvesting practices, although there are varying opinions on this. The potential negative effects of forest-based biomass fuel production could include:

- Soil compaction, disturbance and erosion.
- Loss of organic matter to soil through biomass removal.
- Ecological change in forest character and loss or change of biological diversity.
- Air emissions from logging equipment.
- Impacts on forest stream water quality.
- Nutrient losses and long-term productivity issues.
- Altered appearance of the natural forest setting after logging.

Several issues determine the direction of the net effect on the forest from harvesting biomass for fuel. One environmental concern is that biomass harvesting for fuel will increase demand for wood resources that would result in overharvesting and damage to the forest ecosystem (logging residues return nutrients to the soil when allowed to decompose *in situ* and can serve as a habitat as well as a food source for wildlife. On the other hand, it can be argued that harvesting forest residue for energy as fuel markets develop for low-grade forestry waste material (tree tops and limbs, low quality remnants of desired species, and low quality species) will provide opportunities to improve forest stands [1]. By setting an economic value on forest residues, markets for biomass energy could encourage desirable forestry practices such as thinning and early stand releases, which improve forest growth and quality. In general, there are strong incentives to pursue sustainable practices in forest management, since a healthy, productive forest is a prerequisite for higher value forest products.

(b) *Biomass residues*

Biomass residues include lumber-mill or paper-mill residues, crop residues, food processing residues, animal wastes, sewage sludge and urban solid waste (including urban wood waste from tree trimming, land clearing or building demolition, as well as other forms of combustible municipal solid waste). Not all residues are suitable for combustion or efficient conversion. In many cases, the recovery, transport and conversion of specific residues are not economically viable or there are benefits to leaving the residues in place. For example, if the biomass residues have a low bulk density and are not close to a conversion facility, the costs associated with transportation may be prohibitively high. Depending on the crop and on site and climate conditions, it may be important to leave some or all of the residues in the field to restore nutrients or reduce erosion. In other cases, there may be competing uses for residues, such as building materials, paper or animal fodder [2].

The use of biomass residues for energy applications can make this material a valuable resource rather than a costly waste management problem. Fuel uses represent one of the largest potential markets for biomass residues, especially clean, untreated wood waste, debris from land clearing, mill residues, pallets, some agricultural residues and other untreated lumber, some of which are abundant.

Recovering biomass residues for energy offers a variety of benefits including the following:

- Decreased quantities of solid waste for disposal.
- Reduced solid waste hauling costs and tipping fees paid by generators of wood waste.
- Avoidance of open burning of biomass residues and of fugitive dust from residue stockpiles.
- Extended life for existing landfills and a decreased need to site new landfills.
- Creation of a new supply of fuel for existing or proposed wood-fired power plants, industries, businesses and institutions.
- Avoidance of potential CH_4 emissions from biomass decomposition in landfills [3].

Since treated wood materials such as plywood, particle board, pressure-treated wood, creosote-treated wood or other residues containing non-wood materials can pose a greater risk to the environment and public health when combusted for energy [3], their use requires especially close attention to emissions. However, when matched with appropriate conversion systems, they can in many cases be acceptable energy resources.

(c) Energy crops

In the long term, a significant proportion of biomass feedstock could come from energy crops, either short-rotation woody crops or herbaceous crops. Hardwood trees offer important advantages as a woody crop. Many of them will produce vigorous shoots from the stumps that remain after harvesting, a form of regrowth known as coppicing. The resulting abundant growth can then be harvested again in 5-10 years. Because the root systems of energy crops remain in the ground between harvests, energy crops can help to reduce soil erosion problems [4].

The most promising sites for energy crop plantations are deforested and otherwise degraded lands in developing countries and excess croplands in industrialized countries. Revenues from the sale of biomass crops grown on plantations on degraded lands can help to finance the restoration of these lands. Establishing plantations on degraded or underutilized croplands can be a new livelihood for farmers who might otherwise abandon their land owing to poor yields or poor returns for traditional crops on such land [2].

Inputs to energy crop production and harvest include production chemicals, land, labour, machinery and the fuels required for that machinery. Energy crop management operations include some control of soil erosion and compaction, of releases to the air of particulates and gases such as CO_2, CO and NO_x that arise from the use of fuel and chemicals and of run-off or leachate containing nitrogen, phosphorus and potassium. Additional impacts include the loss of biodiversity [5] and habitat. Like any crop, energy crops require water-roughly 1,000 tonnes of water per tonne of biomass harvested. This is groundwater taken up by the tree or plant roots (not necessarily through irrigation). Where precipitation and evapotranspiration are generally in balance, water use associated with energy crop production would not be a problem. However, in areas prone to drought or shortages of groundwater, it would be of concern.

Although short-rotation woody crop production does not eliminate the need for chemicals, initial soil disturbance or erosion potential, it requires much less intensive management than most traditional agricultural crops, especially in terms of lower inputs of fertilizer and pesticides.

The wide range of potential local environmental benefits offered by energy crops is as follows:

- Protection of water quality by planting energy crops between waterways and land planted with annual agricultural crops, allowing the roots of the energy crops to serve as filters for chemical run-off from the agricultural cropland.
- Reduction of floods during wet seasons and maintenance of water supplies during dry seasons.
- Improvement of the microclimate through evaporative cooling and humidification.
- Reduction of erosion and conservation of water by planting wind-breaks and shelters, particularly in dry regions.
- Reduction in the use of fertilizer and agricultural chemicals compared to traditional crops.
- Improvement of soil properties.
- Protection of wildlife and other components of biodiversity.
- Benefits to habitats when energy crops are used as buffers around (or corridors between) fragments of natural habitat.

Another potential local benefit of biomass energy crops is their ability to remediate contaminated soils through the gradual uptake and removal of heavy metals and other contaminants from otherwise productive soils that have been made unsuitable for human food crops. For example, the species *Salix* takes up cadmium more readily than most plants and in 25 years of growth can remove all the cadmium supplied to arable land through atmospheric deposition and fertilizers. Cadmium concentrated through combustion can then be removed from the ashes [6].

2. Processing, transportation and storage

Depending on the form and characteristics of the particular biomass material, the processing stage may involve washing, sizing, classifying, drying, combining and/or densifying to produce a useful feedstock. Biomass is reduced in size for many reasons, including greater ease of handling and storage, increased bulk density and easier combustion by virtue of the greater surface-area-to-volume ratio.

Biomass is most commonly air-dried in storage or used as received. However, some facilities use thermal drying or mechanical presses. There are various means for thermal drying, such as the use of a single-pass rotary dryer, where stack gases from the boiler provide heat for drying. Some of the volatile gases can be driven off the biomass feedstock and discharged to the air as a result of the heating process. The use of a mechanical press requires special disposal of removed water that contains dirt, fines and extractives. The float tanks sometimes used to separate rock and metal from waste wood also result in waste water discharges. Machinery in processing facilities may generate fugitive dust and air emissions. However, compared with fossil fuel processing, the environmental impacts of biomass processing are relatively minor. Some of the significant total fuel cycle impacts associated with fossil fuel use may be summarized as follows:

- *Coal.* The coal fuel cycle consists of coal mining, coal preparation, transportation, storage and combustion or conversion into other fuels. Surface mining operations remove the topsoil and overburden to expose the coal seam and have both long- and short-term effects on land. The most obvious effect while the mine is open is the unavailability of the land for former uses. Once the mine is closed, it is usually impossible to replace the original ecology. Underground mining can have land area effects as serious as those caused by surface mining. Acid mine drainage is a potentially severe consequence of underground mining. The operation of a coal preparation plant can cause problems, including noise, vibration and dust. The solid wastes left behind after coal treatment can pose a disposal problem. Transportation of coal by rail can cause pollutant emissions, noise, fire risk, leaching of chemicals and detrimental aesthetic effects. Stockpiling at the mine and/or point of combustion is an integral part of coal production, causing fugitive dust emissions and leachate run-off. Major emissions from coal-fired facilities include SO_2, NO_x, CO, CO_2 particulates, trace elements (cadmium, nickel, lead and arsenic) and very small amounts of radioactive elements (uranium, radium, thorium and decay products naturally found in coal deposits).

- *Natural gas.* The natural gas fuel cycle consists of gas exploration and production, processing, transportation and combustion in power plants. Some environmental issues associated with natural gas exploration and production include the disposal of drilling muds and produced water. Drilling muds are the primary wastes from exploratory well drilling. Their major chemical constituents include benzene, arsenic, lead, barium, fluoride and antimony. The major waste generation during the production phase of natural gas is "produced water", those fluids brought up from the subsurface along with the gas. They are composed primarily of water but may also contain cadmium, lead, benzene, naphthalene, zinc, emulsified oil, grease and normally occurring radioactive materials. Natural gas processing facilities have a variety of negative impacts on the local environment, including the production of liquid effluent, flaring of sour gas (H_2S releases), emissions of SO_x as well as methane leaks, physical impacts from construction activities and excessive demands on fresh water supplies. The latter is a concern, as gas processing facilities require an estimated 30-220 million litres of water annually. Transportation of raw gas (unprocessed), sales gas (processed) and gas by-products poses public safety risks and generates a broad range of environmental impacts. Methane leakage from the production and distribution of natural gas also contributes to increasing atmospheric concentrations of methane, a potent greenhouse gas. Air emissions from gas combustion facilities include SO_x, NO_x, particulates and CO_2.

- *Oil.* The petroleum fuel cycle is composed of crude oil exploration and production, transportation, refining and burning of residual fuel oil in power plants. The exploration, development and production of petroleum create much of the same environmental problems as natural gas (see above). Oil is usually transported over long distances via tankers or pipelines. Tankers pose a serious risk of oil spills and are responsible for about 35 per cent of the petroleum hydrocarbons that enter the marine environment each year. Oil pipelines that are not buried in the ground can cause disturbances to wildlife. Petroleum refineries are complex systems of many processes and operations designed to convert crude oil into various products. Their environmental impacts include land use as well as the emission of large quantities of airborne and liquid effluents. The main air emissions from oil-fired combustion facilities include SO_2, NO_x, particulates and the most important greenhouse gas, CO_2.

Although some biomass feedstocks are used on site for industrial energy production, most will need to be transported at some stage of the fuel cycle. For example, biomass power plant operators typically purchase wood from within an 80-120 km radius of a wood-burning facility, since transportation costs for delivering biomass over longer distances tend to make the wood uncompetitive. There are examples, nevertheless, of fuelwood suppliers transporting the wood up to 300 km one way to find a market for the wood.

Fuel storage systems range from open, uncovered fuel piles to partially covered piles (such as pole barns with open sides) to enclosed storage bins or hoppers, usually at the power plant. Some environmental and safety issues associated with biomass storage systems include the risk of spontaneous combustion, odour and the proliferation of mold spores. In addition, storage piles may need to be watered for dust control. Little information is available on the quality of run-off from biomass storage piles, but these aqueous wastes are believed to contain fewer pollutants than coal leachate.

3. Conversion

There are three general processes for converting biomass into fuel or energy:

- Thermochemical processes include direct combustion, gasification and pyrolysis; they require extreme heat.
- Biochemical processes include the use of anaerobic bacteria to digest organic substances into a methane-rich biogas fuel; another approach is to ferment biomass into liquid ethanol fuel.
- Chemical processes are used to convert biomass into fuel; for example, organic oils are converted into a diesel fuel substitute known as biodiesel.

(a) Thermochemical conversion processes

The scale of biomass conversion systems typically has important implications for emissions. As noted earlier, the small-scale residential combustion of biomass for cooking and heating often produces higher levels of emissions such as particulates. With larger scale applications, biomass supply and conversion systems benefit from economies of scale, achieving much more efficient conversion, lower emissions and lower costs per unit of energy delivered. Efforts are under way in many countries to develop mid-size and smaller biomass conversion technologies that have high efficiencies and low emissions.

Emissions to the air from biomass combustion include particulates, CO_2, NO_x, CO, VOCs and SO_2 in negligible amounts. Biomass combustion emissions vary considerably depending on the technology used. Direct combustion is more likely to limit higher levels of CO than coal direct combustion; however, advanced biomass combustion technologies using gasifiers have very low CO emissions. Experts disagree about whether biomass combustion results in greater or lesser NO_x emissions than coal per unit of energy, and more information is needed. The primary comparative advantages of biomass combustion over fossil fuel consumption are the low to negligible net CO_2 emissions and the very low SO_2 emissions.

Given the minimal sulphur content of biomass, one option for reducing SO_2 emissions from existing coal plants is to co-fire biomass with the coal, in which case SO_2 reductions would be proportional to the fuel blend percentages. In most cases wood is the most suitable biomass fuel for co-firing in existing coal plants. Pulverized coal boilers can accept up to 5 per cent wood by heat input (10 per cent wood by mass) in the fuel mix with no modifications to the boiler. An existing pulverized coal boiler can accept 10-15 per cent wood by heat input with modifications to the fuel handling and burners. Coal cyclone boilers can burn up to 15 per cent wood by heat input without modifications [7]. In addition to reducing SO_2 emissions, co-firing will reduce net CO_2 emissions at coal plants.

Biomass bottom ash and fly ash is generally easier to dispose of than coal ash because it contains smaller amounts of trace toxic substances. It can contain some heavy metals that came from the soils where the biomass was grown. Spreading the ash back on the land where it came from is generally considered to be a form of recycling. However, if the original soil is highly contaminated with heavy metals, their uptake by plants and subsequent concentration in the ash can serve to remediate the soil. In this case, the ash can be disposed of at special containment sites.

Wood has a lower ash content than coal, measured as a per cent of the fuel, and wood ash generally has a lower pH than coal ash. Waste solids from wood-fired combustion are generally composed of silica and alumina oxides with minor fractions of sodium, magnesium and potassium and very minor quantities of lead [8]. Coal ash generally has a higher arsenic content [9].

Ash from the combustion of untreated wood has been used as a liming agent and as a source of potash and other nutrients on agricultural land for many years. The application of wood ash to crop lands can improve agricultural productivity and can improve soil conditions for growing turf, shrubs, trees, flowers and other ornamentals; it may also reduce the adverse effects of acid rain. Other uses, such as sludge compost amendment, sludge odour control and landfill cover, are expanding as landfill capacity becomes scarce and more expensive [9].

The water requirements of steam-generating electric plants fuelled by biomass are roughly comparable per unit of energy produced to the requirements of fossil-fuelled plants. Run-off water from the site may pose a water pollution threat, and aqueous wastes from combustion may contain trace amounts of metals and metal compounds.

In general, one of the best ways to reduce emissions from biomass energy conversion systems is to seek technologies that offer the highest possible conversion efficiencies. One approach for achieving high efficiencies is to use system configurations that are inherently efficient, such as combined heat and power applications (co-generation) or to seek opportunities for the co-production of other energy or non-energy co-products that will facilitate naturally high conversion efficiencies. Another approach is to seek advanced conversion technologies that are individually more efficient and that facilitate system configurations allowing higher efficiencies. For example, one of the most promising advanced biomass conversion technologies under development uses a biomass gasifier coupled to a combustion turbine: energy from the turbine's hot exhaust gases is recovered by a heat exchanger that produces steam, which is then used in a steam turbine to produce additional electricity. This is referred to as an IGCC system.

(b) Biochemical conversion processes

Anaerobic digestion

Anaerobic digestion is the controlled decomposition of organic waste in an oxygen-free environment. It relies on specific types of bacteria that break down the organic matter into more basic components until all that remains is biogas, comprised of methane, CO_2 and trace gases. Depending on the waste feedstock and the system design (e.g. batch reactor, plug flow reactor with baffles, continuously stirred tank reactor, upflow sludge blanket reactor, two-tank reactor system), biogas is typically 55-75 per cent pure methane. In a typical reactor, cattle manure produces biogas at a rate of 0.1-0.3 m^3/kg volatile solids in waste water; human sewage produces 0.4-1.0 m^3 and distillery waste produces 0.7 m^3 or more.

Capturing methane for energy applications serves both economic and environmental goals and expands the use of renewable energy resources. Methane is second only to CO_2 in its contribution to global warming, and it is about 22 times more potent than CO_2 in trapping heat inside the atmosphere. In addition to reducing emissions that contribute to global warming by capturing and converting released gases, anaerobic digestion eliminates undesirable odours associated with the decay of manure or organic material. Anaerobic digestion also eliminates pathogens found in manure, thus providing important health benefits.

Fermentation

Biomass can be converted to a liquid for use in the transportation sector. Ethanol is one of the most common liquid biofuels currently in use. Proven technologies are available for fermenting starch or sugar-based biomass into ethanol, and advanced conversion technologies are under development for converting cellulosic biomass (such as wood or grasses) into ethanol. Starch or sugar-based biomass undergoes a fermentation reaction that is catalyzed by zymase, the enzyme supplied by yeast. Cellulosic biomass such as woody plants, grasses and many biomass waste materials contain sugars that cannot be extracted using traditional methods. Efforts are currently under way to develop a process known as enzymatic hydrolysis by which cellulosic biomass can be converted into ethanol.

Today ethanol or ETBE, which is made from ethanol, are often used in blends with gasoline to increase the oxygen content of gasoline. Oxygenated blends help improve the ambient air quality in large cities, primarily by reducing CO emissions from automobiles [10]. Other benefits of ethanol include significant reductions in net emissions of CO_2, the main contributor to global warming, and reductions (by displacing fossil fuels that contain sulphur) in emissions of SO_2, the main contributor to acid rain.

(c) *Chemical conversion processes*

Biodiesel

Some forms of biomass can be used to produce a substitute for diesel fuel known as biodiesel. Biodiesel is widely used in western Europe and is also used, to a limited extent, in the United States. Blends of biodiesel and diesel can be used without modifying existing diesel engines. Biodiesel is produced by a process called transesterification. Vegetable oil or waste animal fat from cooking is first filtered and then preprocessed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol) and a catalyst (usually NaOH or KOH). Its triglycerides react to form esters and glycerol, which are then separated from each other and purified. One potential disadvantage of biodiesel is that if the engine is not adjusted, greater amounts of NO_x, a precursor of ground-level ozone, are emitted than with fossil diesel. The benefits of biodiesel include significant reductions in engine particulate emissions as well as reductions in hydrocarbon and CO emissions, which are major contributors to urban air pollution. In addition, biodiesel is readily biodegradable, so that spills of biodiesel would be much less of an environmental problem than spills of petroleum-based fuels [11]. The key drawback to biodiesel is its cost. Some form of subsidy is now required to make biodiesel affordable.

Like the other biomass fuels, biodiesel also reduces the net amounts of CO_2 released into the atmosphere. While the production of the initial biomass crops typically requires inputs like fertilizers and harvesting operations, which add some CO_2, the net CO_2 emissions per gallon of fuel produced and used is significantly less than for petroleum fuels.

D. Analysis of net greenhouse gas emissions

When electric utilities or industrial facilities compare emissions from biomass fuels and fossil fuels, they tend to look only at the emissions from combusting the fuel. This overlooks important reductions in the net emissions of greenhouse gases. For example, as noted earlier, the carbon emitted from biomass combustion is essentially CO_2 recycled from the atmosphere by the growth of plants. When viewed from a total fuel cycle perspective, the substitution of biomass for fossil fuels also significantly reduces net methane emissions to the atmosphere (by contrast, significant amounts of methane can be released from coal mines or natural gas wells or pipelines). Since the ability of biomass energy use to reduce greenhouse gas emissions is one of its most significant environmental benefits, a detailed accounting of these benefits is provided in the following section for selected biomass and fossil fuel technologies.

E. Total fuel-cycle analysis of selected biomass and fossil fuel alternatives

The following analysis of net CO_2 and methane emissions was done with the aid of the computer model Total Emission Model for Integrated Systems (TEMIS) [12]. The model was developed by the OKO Institute to evaluate the environmental effects of various energy systems used to deliver electricity and fuel. It accounts for site emissions, global emissions and emissions associated with the total fuel cycle. The analysis here addresses all of the upstream and combustion impacts of biomass, including carbon sequestered in growing trees, carbon emissions from managing, harvesting and transporting biomass, and carbon emissions from manufacturing the equipment and materials needed for the harvesters, transport trucks and power plant facilities.

The quality and availability of data for documenting CO_2 emissions from conversion plant operation, material production and other upstream processes vary significantly depending on the technology. A large body of primary and secondary literature is available that inventories methane emissions for the processes addressed in the following analysis.

A comparison of the emissions of CO_2 and methane from coal- and natural-gas-fired systems shows that, in general, the CO_2 emissions come mainly at the plant, from combustion, and the methane emissions come mainly from other parts of the fuel cycle. This shows that electric utility sector resource choices have significant repercussions for CH_4 emissions in other sectors of the economy.

The bar graphs in figures XV.2 and XV.3 summarize CO_2 and methane emissions associated with each of the technologies. The analysis uses typical technologies, whereas specific power plants may vary significantly in their total fuel cycle emissions. The data represent average or levelized total fuel cycle emissions over the lifetime of a typical plant per gigawatt-hour of electricity output. For example, the contribution of emissions from the use of materials in the power plants, such as the emissions from manufacturing the steel used in power plants, is amortized over the life of the plant so as to not skew the results of those technologies that are fuel-intensive and those that are materials-intensive.

As shown in figure XV.2, the biomass-fuelled technologies emit far lower levels of net CO_2 than the fossil-fuelled technologies. The CO_2 emission rates for the biomass technologies range from 59 tonnes/GWh to 106 tonnes/GWh, while the rates for the fossil technologies all fall between 458 and 1,037 tonnes/GWh.

Figure XV.3 shows methane emissions from the same technologies. Methane emissions are nearly three orders of magnitude smaller than CO_2 emissions. Even accounting for methane in CO_2 global warming potential equivalents (methane is generally assumed to have at least 22 times more global warming potential per mole than CO_2), total methane emissions do not significantly change the overall greenhouse gas ranking of the technologies. As shown in figures XV.2 and XV.3, the relative ranking of technologies for methane emissions is different from that for CO_2 emissions. In general, methane emissions, like CO_2 emissions, are much higher for the fossil-fuelled technologies than for the biomass technologies.

Each of the technology combinations shown in figures XV.2 and XV.3 is discussed in more detail below.

Figure XV.2. Total fuel cycle CO_2 emissions per gigawatt-hour

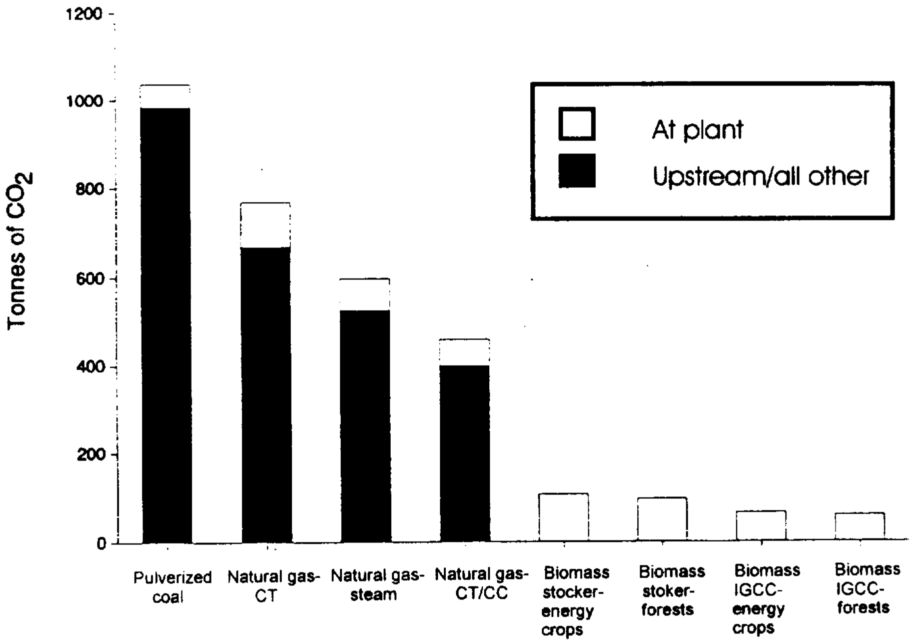
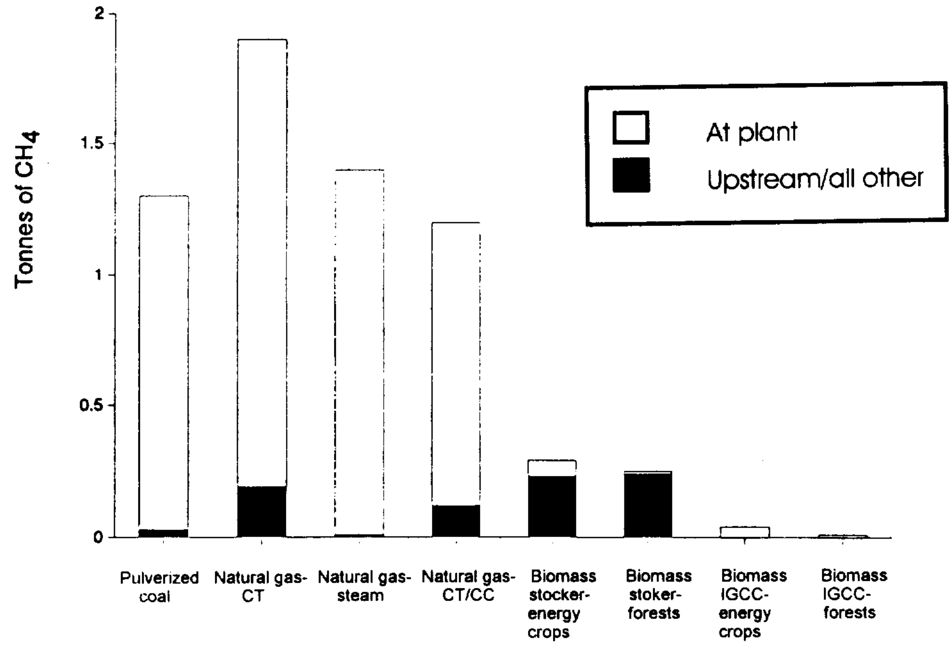


Figure XV.3. Total fuel cycle methane emissions per gigawatt-hour



1. Wood stoker using wood energy crops

When energy crops are used as the fuel for biomass stoker power plants (using conventional steam turbines), 106 tonnes of CO_2 and 0.29 tonnes of methane are emitted, on an average total fuel cycle basis, for every gigawatt-hour of production.* For biomass stoker technology, crediting regrowth as a carbon sink almost fully offsets the CO_2 emissions from the total fuel cycle. In this study, the regrowth credit was determined to offset 100 per cent of the total CO_2 emissions from fuel consumed at the power plant. The amount of fuel harvested exceeds the amount actually consumed at the power plant by about 15 per cent. This 15 per cent represents losses in fuel transport and processing. Because the fate of these losses is uncertain (they could result in a permanent store of carbon or they could eventually be combusted, decomposed or otherwise re-release carbon into the atmosphere), the following analysis makes the conservative assumption that these losses should not be treated as a carbon sink.** If these losses were included in the carbon offset, the total fuel cycle CO_2 emissions for stoker technology would be negative. That is, the total energy system would have a net negative impact on atmospheric CO_2. If the regrowth credit is not counted, carbon emissions for wood energy crop stoker technology would exceed 1,560 tonnes/GWh, exceeding all of the fossil generation technologies in total carbon emissions.

2. Wood stoker using forest wood

When woody forest materials are used as the fuel for a biomass wood stoker power plant, on an average total fuel cycle basis, 96 tonnes of CO_2 and 0.25 tonnes of methane are emitted for every gigawatt-hour of production. Emission levels for wood stoker technology vary somewhat according to the feedstock used, with fuel and fertilizer usage for forest materials being different from that for energy crops. Direct fuel use for harvesting forest trees is considered by several sources to be greater than fuel use for harvesting energy crops. Conventional woodland equipment typically operates intermittently (e.g. the shear on a feller buncher cuts the tree and then remains out of use until the tree has been lifted and bunched by the other parts of the machine). Energy crop harvesting equipment such as mobile chippers are similar in design to forage crop harvesters, which move continuously (that is, each component performs its function the whole time), offering distinct fuel economies [13]. On the other hand, energy crops are more fertilizer-intensive than forest operations.

On average, the energy required for tree management and harvesting was 25 per cent greater for energy crops than for forest trees. However, since energy crops significantly expand the supply of biomass, one cannot assume it would be better to use forest trees than energy crops. Energy crops also produce four or five times as much biomass per acre as forests, so they require less land per megawatt of fuel.

3. Biomass integrated gasification/combined cycle using wood energy crop

It was estimated that a biomass IGCC power plant fuel cycle would emit 65 tonnes of CO_2 and 0.04 tonnes of methane for every gigawatt-hour of production. IGCC technology has significantly lower emission levels than stoker technology because of the greater conversion efficiency of the power plant. As with the stoker technology, regrowth of feedstock was counted as a carbon sink and only the fuel actually consumed is counted as a regrowth credit. Since the upstream processes for IGCC and stoker

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*The information on wood stoker and biomass IGCC technology is based on energy crop data for Rochester, New York, from Oak Ridge National Laboratory.

**The carbon in the wood that is lost is not counted as a carbon offset against power plant emissions. The CO_2 and methane emissions associated with the production of the feedstock that is lost during fuel transport are included in the total emissions profile for biomass. That is, the emissions generated from the 15 per cent that is lost are applied to the remaining 85 per cent that is eventually consumed.

power plants are identical, the same potential for net negative CO_2 impact exists. If regrowth credit is not counted, carbon emissions for IGCC technology would exceed 960 tonnes/GWh, slightly less than pulverized coal but exceeding all of the natural gas generation technologies in total carbon emissions.

4. Biomass integrated gasification/combined cycle using forest wood

The forest-wood-fired IGCC fuel cycle emits 59 tonnes of CO_2 and less than 0.1 tonne of methane for every gigawatt-hour of production. If regrowth credit is not counted, carbon emissions for IGCC technology would exceed 950 tonnes/GWh, slightly less than pulverized coal but exceeding all of the natural gas generation technologies in total carbon emissions.

5. Natural gas technologies

The rates of CO_2 emissions vary for the natural gas technologies, from 458 tonnes/GWh for a combustion turbine/combined cycle (CT/CC) up to 768 tonnes/GWh for a combustion turbine (CT). These differences are a result of variations in conversion efficiencies of the three technologies and, to a lesser degree, the capacity factors of each technology. For example, a CT/CC operates at 45 per cent efficiency, while the steam plant operates at 35 per cent. The lower steam efficiency results in higher carbon emissions at the plant as well as larger methane emissions from upstream processes per unit of electricity output. The capacity factor of the CT plant also plays a role. Because CTs are peaking units and operate at about 10 per cent of capacity, producing a gigawatt-hour of energy requires more investment in plant capital (that is, more plants are required to provide the same energy in a given period of time) than it would in a unit with a higher capacity factor. The increased capital component slightly increases the total fuel cycle emissions generated in producing the material components of the power plant.

Over 85 per cent of the CO_2 emissions are generated during the combustion phase in natural gas technologies. The remainder of the CO_2 emissions can be attributed to fuel combustion for pipeline operation and wellhead flaring. Methane emissions for the natural gas technologies ranged from 1.2 tonnes/GWh for the CT/CC system to 1.9 tonnes/GWh for the CT. These methane emissions emanate largely from the extraction and transmission of natural gas, not from power plant operation. Methane is vented during natural gas extraction and is also lost during transmission.

6. Pulverized coal steam boiler

Coal has the highest CO_2 emissions rate of any of the fossil technologies. Ninety-five per cent of the 1,037 tonnes/GWh of carbon emissions are attributable to the coal's combustion. The remaining 5 per cent is divided among mining and coal transportation. Methane emissions for coal are predominately due to releases during the mining process. The level of methane emissions, about 1.3 tonnes/GWh, is approximately equal to the methane emissions of the total fuel cycle from the natural gas steam power plant.

F. Guidelines for comparing biomass energy impacts

The incorporation of total fuel cycle impacts can help to level the playing field for energy resources, making biomass more competitive. Total fuel cycle analysis accounts for the full range of long-term and indirect environmental and socio-economic costs and benefits of energy resources.

There are a number of approaches for comparing the environmental impacts of energy alternatives, spanning a range of evaluations from qualitative to quantitative. A key issue is whether or not enough data are available to allow for adequate comparisons:

- Qualitative evaluations are particularly useful where there is a shortage of data, time or funds.

- Ranking and weighting can be a cost-effective way of making comparisons where only limited data are available for comparing very different types of environmental impacts.

- Cost of control analyses generally address the relative cost of equipment for meeting specified emissions limits, a highly quantitative approach for comparing biomass energy impacts.

- Damage cost evaluations assess actual harm to the environment in terms of health risks, damage to buildings, damage to forests etc. While these types of costs are of fundamental concern, they are hard to measure accurately, and estimated values often arouse counter opinions and controversy. The cost and complexity of evaluating damage costs generally means this method is less attractive than the other methods.

In many cases decision makers know the impacts of the use of conventional fuels but do not have a comparable knowledge of the impacts of biomass fuel use. Where data are available on biomass energy impacts, it is important to distinguish whether they refer to older/obsolete technologies (which are more polluting), current state-of-the-art systems or advanced technologies that will soon be available. There is a need for better collection and dissemination of information and data on biomass energy impacts so that decision makers will be adequately equipped to evaluate these impacts and compare them with other energy alternatives.

G. Summary

As the earlier sections of this paper showed, biomass energy offers significant environmental benefits. However, it can also have harmful impacts if it is not developed and used properly. It is important that sustainable practices be followed when obtaining biomass supplies and that efficient, low-emission conversion technologies be selected. While this approach may add somewhat to the short-term, up-front costs of biomass energy, it will also add substantially to the long-term viability of a biomass project, reducing costs by ensuring that fuel supplies continue to be available and reducing the amount of fuel required and emissions produced per unit of energy delivered.

An important aspect of biomass use for energy applications is the degree to which biomass use for energy is interwoven with non-energy uses. For example, the effective management of biomass resources must address demands for food and fibre (e.g. paper or lumber), management of waste streams, habitat impacts, recreation impacts (forest retreats) and other broad land use requirements and issues. These competing demands can actually create natural checks and balances that support environmentally sustainable practices in biomass use. For example, food and fibre have a higher value than fuel, which means that demand for these uses will outbid demand for the energy use. This economic pressure helps avoid unwise environmental practices, such as overharvesting of biomass for energy.

As a renewable fuel, biomass contributes to sustainable development goals established at the local, national and international levels. Planning for sustainable biomass development requires approaches that balance short- and long-term considerations. In many instances, a look at short- and long-term costs and benefits demonstrates that two options apparently having nearly the same short-term costs can have significantly different long-term costs. This is particularly true when traditional fossil fuels and biomass power are compared. The immediate economic costs of using biomass may be marginally greater than the immediate costs of using traditional fossil fuels, but the biomass may have significant mid- and long-term benefits, including important environmental benefits, that add substantially to the total value of biomass investments.

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XVI. ECOSYSTEMS AND BIOMASS ENERGY

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Abstract

Biomass, particularly fuelwood and charcoal, is one of the main sources of fuel to meet the energy needs of traditional, commercial and industrial activities in developing countries. While it satisfies only about 14 per cent of the world's primary energy needs, in some countries it satisfies up to 80 per cent of those needs.

As a result of population growth, urbanization, economic reforms, restructuring and new development targets in most of these countries, new forms of energy and a more intensive use of energy are expected for the years ahead. This additional demand for energy will be met mainly by hydroelectricity, coal and fossil fuels. However, where biomass is available or can be planted, biofuels can be converted into new forms of energy (electricity and power) and energy carriers (liquid and gaseous fuels) to meet not only the energy needs of the modern sectors but also to maintain a sustainable supply to traditional users. In fact, FAO estimates that biomass could provide nearly three times more energy than it does without affecting the current supply of other commodities and goods such as food, fodder, fuel, timber and non-wood fuel products.

The benefits derived from the utilization of biomass as a source of energy are twofold: (a) the task of supplying biofuels can help to attract new investment, create new employment and income opportunities in rural areas, raise the value of natural resources and preserve the environment and (b) new forms of energy and energy carriers could foster increased production and productivity at the rural and community level, particularly in remote areas where conventional fuels are not easily available at affordable prices.

Bioenergy can be easily developed in modular and decentralized schemes and offers many advantages. It could be an inexpensive source of energy, even at present energy prices, and it requires less capital investment for its implementation than alternative solutions. However, there are many disadvantages, too. For instance, the potential bioenergy supply varies considerably from country to country and depends on ecological/climatological conditions. Moreover, although some of the technologies are mature, novel and more efficient conversion technologies still have to be proved, local environmental impacts need to be more carefully examined and conflicts between land for energy use and other uses such as food and fodder may arise. Last, but not least, several technical, economic and institutional barriers need to be removed.

This paper briefly describes the main problems, conflicts and barriers in order to stimulate an exchange of views among the participants of this Symposium. Finally, it describes the FAO Bioenergy and Environment Assistance Programme (BEAP), which aims at providing technical assistance to member countries for the development of bioenergy activities.

Introduction

Nowadays, with the agenda of developing countries focused on sustainable development and developed countries concerned about environmental issues, wood and biomass energy can play an important role in addressing these issues.

This paper provides an overview of the present use of biomass for energy and describes its future potential. It is divided into four sections. Section A describes the dynamics of wood energy systems for traditional uses. Section B focuses on the past and present consumption of wood and other biomass resources for energy to determine the future contribution and role of biomass. Section C discusses the main opportunities and limitations of the development of bioenergy as an environment-friendly source of energy. Section D briefly describes BEAP.

A. Wood energy systems

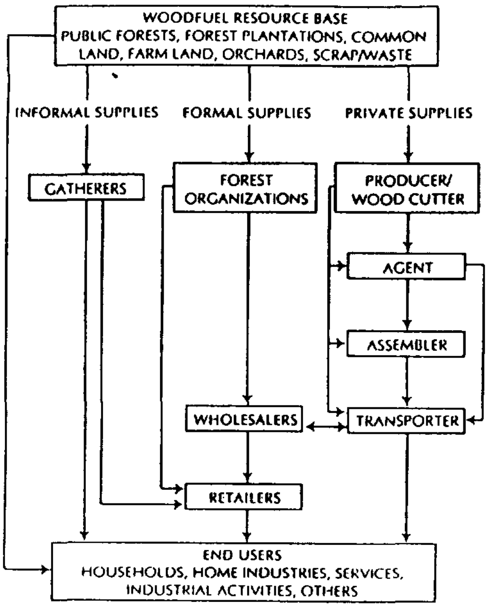
The flow of woodfuel in a country is made up of individual operations and processes interwoven between the different economic layers of rural and urban areas. These operations and processes (figure XVI.1) are influenced by multiple technical, socio-economic and cultural factors prevailing in the particular area, community or town. They are also interrelated with other general activities, particularly at the level of woodfuel supplies.

The distribution of woodfuel from production areas to final users requires the participation of actors in both rural areas (those involved in woodfuel supply) and urban areas (charcoal sellers, truck drivers, users) who are not clearly identified and about whom information is scarce.

The flows of woodfuel are regulated by policies, legislation and regulations emanating from the government entities concerned with the forestry, energy and agriculture sectors. Often these regulations are not tailored to reflect the special conditions prevailing for wood energy systems.

This ensemble of policies, legislation, actors, operations and processes constitutes a wood energy system. A knowledge of the system is vital for understanding its dynamic in a specific geographical area and also for distinguishing rural from urban users and household users from industrial users

Figure XVI.1. Woodfuel flows



1. Rural and urban woodfuel consumption

Practically all of the fuelwood is used in rural areas, where most of the people in developing countries still live. Rural users collect the fuelwood themselves from their own yard or from surrounding fields and forests. When they have fuelwood surpluses, and if they live near roads, small communities or urban centres, they sell the fuelwood in informal markets.

The distinction between rural and urban users is important for two reasons: (a) rural people use fuelwood (dead wood, branches, roots and a combination of residues) collected locally from their farmyards and neighbouring woodlands, while urban dwellers prefer to use charcoal and (b) the fuelwood consumed by rural people rarely exceeds the supply available in the forest and woodlands surrounding the place where they live.

Of course, there are other differences that depend on the ecology of the area. For instance, users of woodfuels in countries well endowed with tropical forests have more woodfuels available than users living in mountainous or arid and semi-arid areas. However, the wood energy situation of an area is also greatly affected by other factors such as population density, urban versus rural population and the prevailing economic, cultural and social conditions. In table XVI.1, urban woodfuel consumption is estimated for some developing countries, showing the differences that exist, from one country to the next, in the proportion of consumption accounted for by urban users. This difference between rural and urban consumption is very important, and wood energy planning is carried out to tackle woodfuel shortages and/or alleviate pressure on forest resources, particularly for arid, semi-arid and densely populated areas where already-cleared forest areas cannot sustainably provide all the woodfuel required by the different sectors.

In urban areas facing woodfuel shortages, other sources of energy such as kerosine, gas and electricity are also available and can complement fuelwood, charcoal and other residues. In rural areas of, for instance, Bangladesh and India, where residues such as rice husks, cotton stalks and dung are widely available, people can use more of these residues and sell fuelwood (or charcoal) to earn some cash.

Table XVI.1. Urban woodfuel consumption in selected developing countries

Country	Total population (millions)	Urban population (millions)	Average per capita consumption (kg/yr)	Woodfuel (million tonnes)		Share of urban in total (%)
				Urban	Total	
India	850	230	152	35	94.5	37
Nepal	19	2	248	0.5	11.3	4.4
Thailand	57	13	130	1.7	25.0	6.8
Philippines	62	27	220	6	25.3	24

The fact that net migration is to urban areas and that the economic conditions of certain segments of society seem to continue to deteriorate will probably influence woodfuel consumption patterns, and pressure will grow on forest resources near large urban centres, particularly for charcoal production.

2. Household and other users

Table XVI.2 shows that 70-90 per cent of fuelwood is consumed by the household sector for cooking and heating, while the rest is consumed by "other users". These other users are made up of a

Table XVI.2. Energy consumption by household and by other users for countries in the Regional Wood Energy Development Programme (RWEDP)

(Percentage of total)

Country	Commercial energy		Fuelwood and/or charcoal		Residues, dung etc.		Traditional energy sources			Year/source
	Household	Other	Household	Other	Household	Other	Household	Other	Total	
Bangladesh	3.8	9.8	11.7	3.4	57.6	13.7	69.3	17.1	86.4	1981/BEPP, 1987
Bhutan	1.5	11.3	75.1	11.8	0.6	-	75.7	11.8	87.2	1988/FAO, 1991[a]
India	..	..	..	..	..	..	..	..	39.1	1989/1990 Est.[a]
Indonesia	12.6	33.1	50.9	3.5	..	0.8	..	..	54.3	1979/World Bank 1989[b]
Myanmar	0.6	12.0	84.1	..	2.5	..	86.6	0.8	87.4	1990/World Bank 1990[a]
Nepal	1.2	4.4	92.8	1.5	-		92.8	1.5	94.4	1982/World Bank 1983[a]
Pakistan	7.1	40.1	41.2	11.6[c]	[c]	3.6	41.2	11.6	52.8	1991/Ouerghi
Philippines	10.1	44.8	32.6	5.3	3.5	2.3	36.1	8.9	45.1	1992
Sri Lanka	6.6	21.6	59.0	10.3[d]		7.6	59.0	12.6	71.8	1989/World Bank 1992[b]
Thailand	8.8	60.9	18.9	2.4	1.2	5.2	20.1	10.0	30.3	1990/CEB 1990
Viet Nam	2.0	24.0	29.6	4.4	34.7		64.3	9.6	73.9	1988/NEA[e] 1988/FAO 1992[a]

Note: Other = industry, transport, agriculture, commerce, government and other uses. Conversion losses have not been accounted for. For more information on this table, please contact the author.

[a] Estimate by author, based on World Resource Institute/United Nations data for commercial energy and unofficial World Bank data for traditional sources of energy.

[b] The domestic sector includes use by the Government as well as by commerce.

[c] Residues are included under fuelwood.

[d] Domestic fuelwood consumption apparently includes residues also.

[e] Domestic use includes use by commerce as well.

large number of small and medium-scale industrial, commercial and institutional users such as restaurants, street food vendors, brick-burning and tea-drying. Where there is a high concentration of these activities, particularly those that are energy-intensive (brick-making, lime-burning, tea-drying and fish-smoking, to mention a few), local forests and woodlands can come under great pressure.

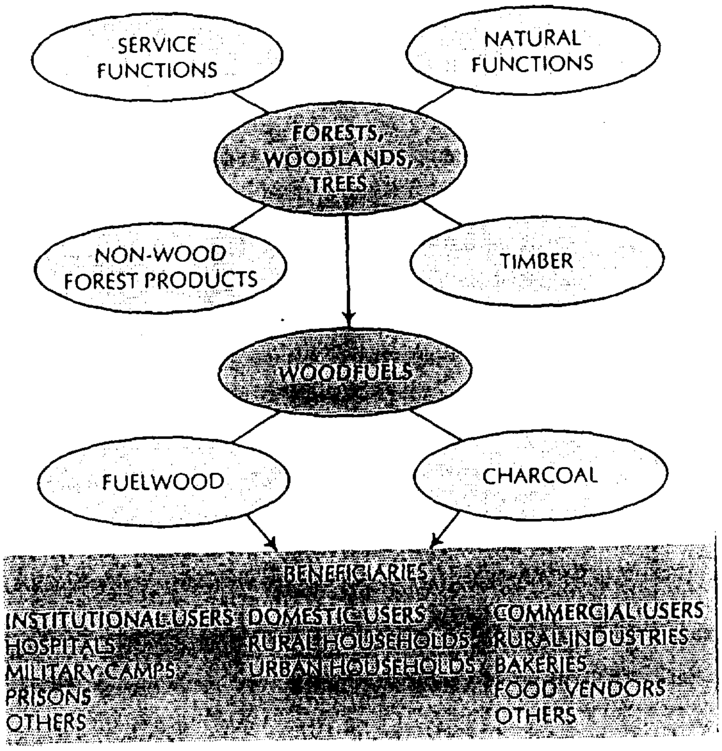
These are the vital economic activities that keep society running in the rural and peri-urban areas of developing countries, generating jobs and income for the poorest of the poor. For most of them, fuelwood and charcoal are probably the most affordable source of energy and, in remote areas, the only source of energy.

3. Woodfuel flows

The utilization of wood and biomass for energy is complex and site-specific and depends on many technical, economic and social factors, which in most cases have not been properly documented by the government organizations responsible for the forestry, energy and agricultural sectors.

Accurate woodfuel surveys in a particular geographical area would enable a diagram of woodfuel flows (figure XVI.1) to be drawn up, would facilitate the collection of desegregated data for individual unit operations and would clarify the relationships with other economic sectors. They would also allow an analysis of the relationship between wood energy systems and other forest products, such as timber, non-wood forest products and services provided by forests, woodlands and trees (figure XVI.2). Such surveys also distinguish between fuelwood derived from forest and non-forest lands, as will be explained later on. Clearly, detailed information of the wood flows in a particular geographical area is vital for a better understanding of wood energy systems and the implementation of systems that are environment-friendly.

Figure XVI.2. Wood energy in multiple-use forestry



Considering that wood energy is directly related to livelihoods for poor people and families in developing countries, as well as to economic growth in rural areas and protection of the environment, the implementation of improved and sustainable systems should become a priority for policy and decision makers involved with wood energy matters. The aim of a sound wood energy system is to improve each of the components and processes involved, from production to the use of wood as a fuel.

4. Woodfuel supply sources

In general, five main sources of woodfuel can be identified based on information from a number of parts of the world:

- Tree and forest cutting directly for fuel.
- Dedicated woodfuel plantations.
- By-product wood: forest and forest industry residues.
- Dead branches and twigs.
- Surpluses from land-clearing activities.

The last two appear to be by far the most important for most areas in developing countries. In urban areas, one more source could be added: wood from construction activities (demolition of buildings, shuttering from concrete work, fences etc.).

To clarify and quantify the amount of woodfuel from different sources, FAO has undertaken several studies. The results of these studies were described in the papers presented at the Expert Consultation on Data Assessment and Analysis for Wood Energy Planning, held at Bangkok in May 1993. The main results are shown in here in table XVI.3. (The total forest area used to calculate the amount of fuelwood from forest land does not include protected forests, because most of the wood there is not available for energy use.)

Table XVI.3. Overview of available data on the sources of fuelwood consumed

Country	Total amount of fuelwood consumed (million tonnes)	Share of forest wood (%)	Share of wood from other sources (%)
Bangladesh	5.5	13	87
India	94.5	26-53	47-74
Nepal	11.3	66	34
Pakistan[a]	33.0	27	73
Philippines	25.3	15	85
Sri Lanka	9.1	25	75
Thailand[b]	8.8	48-50	50-52
Thailand[c]	16.0	50	50
Viet Nam[a]	33.0	25	75

[a] The shares are based on estimates, assuming that only an amount equal to the mean annual increment is removed from the forests.

[b] Wood used as fuelwood.

[c] Wood used for the production of charcoal. Amount has been estimated by the author

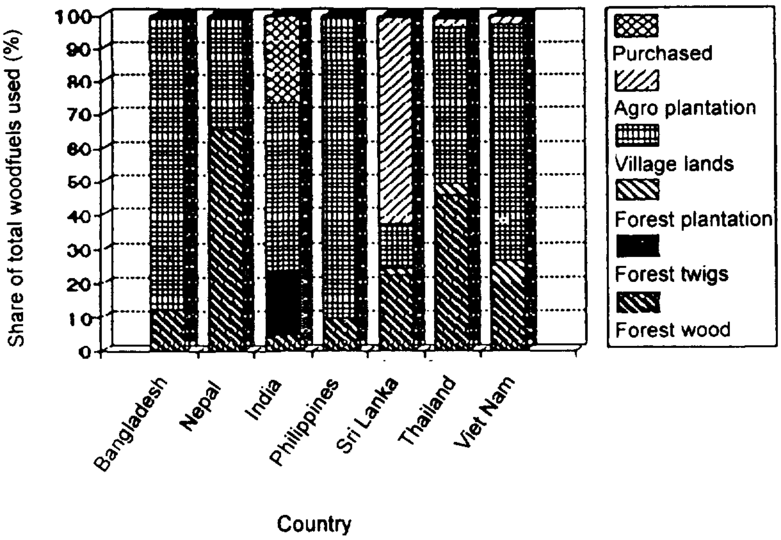
Looking at table XVI.3, it can be noted that forests are just one source of woodfuel, and in most Asian countries less than half, and often as little as 25-30 per cent of the total amount of fuelwood consumed is from forests.

Most of the fuelwood derived from non-forest lands comes from trees scattered around homesteads, trees along roads and canals, trees on agricultural land, wood from plantation crops, brushwood from waste land trees on grass and range lands etc. (figure XVI.3). These data have been confirmed by other studies carried out by FAO in Latin American countries [1].

The woodfuel described in figure XVI.3 as coming from village lands comes from trees located in rural communities in neighbours' land, roadsides, along the banks of canals and scattered planted trees. Forest plantations and, even more so, other tree-growing activities such as rubber wood and palm frond production also play a role:

- In Sri Lanka, about 0.2 million tonnes of the 9.1 million tonnes total came from forest plantations.
- In India, out of 131 million tonnes of fuelwood consumed, 4 million tonnes were apparently derived from social forestry schemes.
- In Viet Nam, 2.2 million tonnes were estimated to come from forest plantations, while trees planted by the population under various schemes on their homesteads, along roads, school grounds, village areas etc., probably supply a staggering 8 million tonnes, equal to over 75 per cent of the total amount consumed.
- In the Philippines, the 85 per cent of woodfuel derived from village lands includes woodfuel derived from agricultural plantations such as rubber and coconut.

Figure XVI.3. Woodfuel sources



There is a discrepancy between the amount of woodfuel available from non-forest lands and the amount actually being used. It is to be expected that other uses for local timber (furniture, fences, poles etc.) compete with the energy use, in which case only a part of the wood available is used as a fuel.

Furthermore, in hilly areas and watersheds, it may not be advisable to remove fuel crops, even on a sustainable basis, as they prevent further degradation due to erosion.

The other factor to be considered in this analysis is the accessibility of forests to the most important woodfuel markets. Even though a certain amount of fuelwood might be removable on a sustainable basis, it is not known if this would be feasible, as the lack of roads makes transport difficult. For instance, in Bhutan it was estimated that the natural forests could supply, on a sustainable basis, 10-11 million tonnes. However, this amount dropped to 1 million tonnes once accessibility and critical watershed areas and forest and wildlife reserves had been taken into account.

It may be concluded that non-forest land is an important, if not the most important, source of fuelwood; however, very little is known about this source. Both agroforestry and community forest schemes can considerably increase the availability of woodfuels if concerted efforts are made by both the private and public sectors.

On the other hand, although some data suggest that only a modest amount of wood is derived from forests, there are indications that in certain areas the actual amount of fuelwood being derived from them is much greater.

As a broad indication of the sustainability of the supply system in RWEDP countries, data on the amount of fuelwood derived from forest and non-forest land are shown in table XVI.4. Data on the amounts of residues (excluding dung) are also shown. Although these data provide only a rough idea of the sustainability of woodfuel supplies from forest lands, they can also be used to identify countries or areas where fuelwood shortages and/or pressure on forests can be expected to become serious.

It is clear that Nepal and Pakistan are facing problems with the supply of forest fuelwood. Looking at Pakistan, which derived about 2.5 tonnes/ha of fuelwood from its forests, it can be assumed that there is serious overcutting, as the mean annual increment of Pakistan forests is said to range from 0.4 to 1.0 tonnes/ha. In Nepal, where many forests are inaccessible, the average increment is much higher, 3 tonnes/ha.

It can be concluded that the wood energy situation in many developing countries is still full of uncertainties. Information is too general and inaccurate and there is a great need for more in-depth studies on sources of supply as well as other aspects of the wood energy system. The dearth of information also makes it difficult to calculate potential biomass production and use for energy in the different ecological regions.

Perhaps efforts such as those undertaken in Asia by FAO (RWEDP) and in Africa by the World Bank (the Review of Policies in the Traditional Energy Sector (RPTES)) need to be expanded to other regions. The Latin America Tech Cooperative Network on Dendroenergy could be an example to follow on that continent.

B. Biomass energy perspectives

There is enough information on wood energy to draw a relatively good picture of its relevance at the national, regional and international levels. The following sections summarize the present wood energy situation in developing countries and explore its potential to contribute to the national energy demand.

Table XVI.4 Indicators of the sustainability of traditional fuel supplies[a]

Country	Forest and woodland (thousand ha)	Agricultural land, pasture and other land[b] (thousand ha)	Fuel used (million tonnes)			Fuel derived (tonnes/ha)	
			Forest wood	Other wood	Residues	Forest land	Other land
Bangladesh	1,950	11,067	0.7	6.8	23.1	0.37	0.43 + 2.09
India	66,736	230,583	25-50	70-45	30.6	0.37-0.75	0.30-0.19 + 0.13
Nepal	2,480	11,200	7.5	3.8	1.4	3.01	0.34 + 0.13
Pakistan[c]	3,500	73,588	8.9	24.1	10.7	2.55	0.33 + 0.15
Philippines	10,550	19,267	3.9	4.5	2.6	0.37	1.15 + 0.13
Sri Lanka	1,747	4,716	2.3	6.8	0.6	1.31	1.45 + 0.12
Thailand	14,240	36,849	12.3	12.5	9.7	0.86	0.34 + 0.26
Viet Nam	9,800	22,749	8.3	24.8	0.84	0.84	1.09 + 0.60

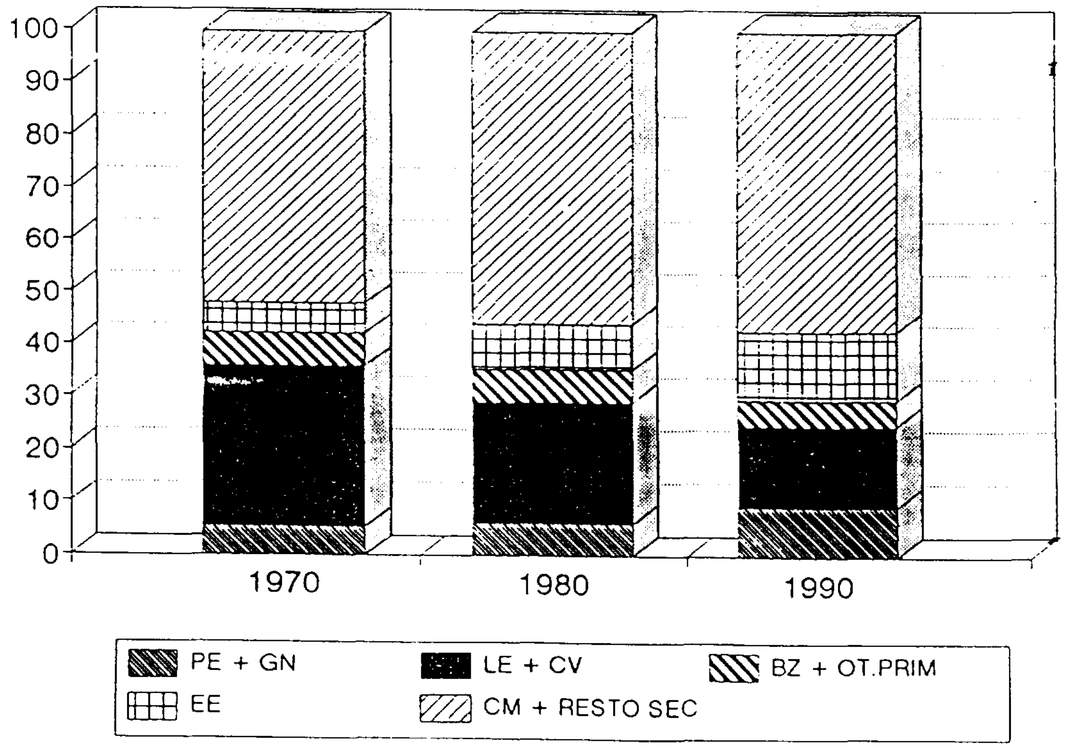
[a] Land area based on FAO statistics and valid for 1990. These figures may not represent the situation today.
[b] Agricultural land, permanent pastures and other land also include built-up areas, rivers etc.
[c] The amount of residues has been estimated.

1. Present situation

Biomass in general, and fuelwood and charcoal in particular, are important sources of energy for most developing countries and will remain so for the foreseeable future. In fact, biomass provides around 14 per cent (1.4 billion tonnes of biomass) of the global primary energy consumption (table XVI.5). This is a relatively small proportion compared with fossil fuels, but it is the second largest renewable source of energy in the world after hydroelectricity. Indeed, the information in table XVI. 6 shows that biomass is the main source of energy in many developing countries, and it can be deduced that wood energy is an important source of energy for most of them.

Figure XVI.4 shows the declining use of wood for energy in 19 Latin American countries and the growing use of fossil fuels. However, a more detailed analysis shows that in absolute terms woodfuel consumption remains stable at the regional level and is even growing in many countries (table XVI.7). Indeed, woodfuel consumption per capita has remained more or less stable despite the many external factors-population growth, emigration from rural to urban areas, socio-economic conditions and fossil fuel prices-that are affecting more or less directly this consumption.

Figure XVI. 4. Final energy consumption



Note: Please consult author for explanation of abbreviations.

It is not clearly understood how these factors can influence the woodfuel consumption pattern and the energy mix of a given country. However, rapid population growth starts to affect the other, related forces, which then puts pressure on fragile land and natural resources, leading to damaging agricultural practices that ultimately degrade the environment. Moreover, since woodfuel is the mainsource of energy

Table XVI.5. Global distribution of energy use, 1987[a]

	Developed countries			Developing countries			World total		
Fuel	**EJ**	**Mtoe**	**%**	**EJ**	**Mtoe**	**%**	**EJ**	**Mtoe**	**%**
Oil	97	2,211	37	32	730	23	129	2,941	32
Coal	66	1,502	25	39	884	28	105	2,386	26
Gas	59	1,333	23	10	222	7	69	1,555	17
Biomass[b]	7	169	3	48	1,088	35	55	1,257	14
Hydro	16	355	6	7	169	6	23	524	6
Nuclear	17	377	6	1	27	1	18	404	5
Total	**262**	**5,947**		**137**	**3,120**		**399**	**9,067**	
Share of world total (%)		66			34			100	100
Population (billion)		1.2			3.8			5.0	5.0
Share of world population (%)		24			76			100	100

Source: Scurlock and Hall, 1990.

[a] 1.0 EJ = 10^{18} J (approximately 1 quadrillion Btu); 1 Mtoe = 44 x 10^6 GJ (10^{15} J); 1 Mtoe (million tonnes coal equivalent) = 29 x 10^6 GJ (10^{15} J); 1 tonne oil = 44 GJ; 1 tonne air-dry biomass (20 per cent moisture) = 15 GJ; 1 tonne woodfuel = 1.4 m^3 wood; 1 tonne charcoal is derived from 6-12 tonnes wood.

[b] Biomass includes woodfuel, charcoal, agricultural wastes, dung, bioethanol and other forms of biomass energy.

for the poorest of the poor, the problem of wood energy is part and parcel of the underdevelopment problem in developing countries. Experience indicates that a more rational, more efficient and more decentralized wood energy system is possible if the necessary political and technical support is provided.

Table XVI.6. Contribution of biomass energy to energy mix in selected developing countries
(Percentage)

Africa	Asia	Latin America
Burundi (93) Burkina Faso (92) Chad (92) Ethiopia (92) Malawi (88) Sudan (82) United Republic of Tanzania (92)	Bhutan (92) Nepal (92) Cambodia (90) Lao People's Democratic Republic (90) Papua New Guinea (62) Philippines (40)	Haiti (84) Honduras (67) Guatemala (64) Paraguay (65) Nicaragua (50) Brazil (35)

Source: FAO, *Statistics Today for Tomorrow.*

2. A future role for bioenergy

With the agenda of developing countries focused on sustainable development, more energy inputs will be required to modernize their industrial and economic sectors. Biomass can play a significant role in meeting this additional energy requirement, not only via existing mature and well-proven technologies but also with new ones that allow it to be converted into secondary fuels (pellets and gaseous and liquid fuel) with special physico-chemical characteristics.

A number of mature technologies exist for biomass utilization as a competitive fuel, and several novel technologies are expected to be on the market for commercial use very soon as a result of intensive R and D activities. These R and D activities have two main aims: (a) to increase the productivity of the biofuel supply and (b) to reduce its use by achieving a higher utilization efficiency.

The preliminary results of the use of mature technologies are already being observed in many developing countries, especially in those well endowed with woody residues, where bioelectricity can be generated today at competitive market prices. In addition, changes in the energy legislation in these countries has helped to attract private investors to this business, which in the past was centralized and controlled by governments and public companies.

Many power plants have been installed at sugar mills in developing countries. Those in Nicaragua are perhaps worth mentioning. There, bagasse is the main fuel for half of the year (the sugar cane season); during the rest of the year the power plants are fuelled with wood chips from an energy plantation established in marginal lands around the sugar cane plantation. In this way the sugar mill can make use of its energy infrastructure and labour all year long. If the sugar mills also start to produce ethanol, as is the case in Brazil, the sugar industry will look quite different from what it is today.

The capacity of existing and planned biomass-fuelled power plants in developing countries is still relatively small when compared with that of power plants based on coal, gas and bunker fuel oil. The

Table XVI.7. Final energy consumption in 19 Latin American countries

	PE + GN		LE + CV		BZ + OT		EE		CM + RES.SEC		Total	
Year	**Consumption**	**Share of total (%)**	**Consumption**	**Share of total (%)**	**Consumption**	**Share of total (%)**	**Consumption**	**Share of total (%)**	**Consumption**	**Share of total (%)**	**Consumption**	**Share of total (%)**
1970	65,194	5.36	372,069	30.56	78,591	6.46	71,617	5.88	629,845	51.74	1,217,316	100
1980	123,527	6.07	470,431	23.11	129,533	6.36	181,507	8.92	1,130,322	55.54	2,035,320	100
1990	212,224	9.35	353,722	15.59	112,304	4.95	296,455	13.07	1,294,206	57.04	2,268,931	100

Note: For more information on this table (i.e. on consumption units and explanations of abbreviations), please consult the author.

power capacity varies considerably, from just a few hundred kilowatts to 20-25 MW, and energy policies and legislation are being rapidly adjusted to the new energy scenarios, which are opening new market opportunities for bioenergy initiatives.

The above-mentioned cases are not isolated. Many forest industries, pulp industries, board manufacturers and timber industries have for years been using their residues to generate energy, and their numbers are rapidly increasing. Such usage is also appearing in other agro-industrial activities, such as rice and edible oil mills, which want to make more efficient use of all their resources, to reduce costs and to become more competitive. The pig iron, lime and cement industries are examples of other industries where the use of biomass as a fuel is a well-appreciated solution.

In addition, the use of bioethanol for ETBE production to be used as an octane enhancer for unleaded gasoline, and the use of plant oil for biodiesel are new solutions that are being expanded in some developed countries and will also soon start in those developing countries with good potential for bioenergy initiatives.

As trade and markets become globalized, such technical solutions for energy generation will grow along with demand for biomass as fuel. Nevertheless, bioenergy in these countries will remain, for many years to come, a local solution that depends on specific conditions such as biomass availability, energy prices and residue values.

In developing countries with local comparative advantages in terms of soil fertility, favourable climate, land availability and low manpower costs and where trees are available or energy crops can be planted and novel technologies can be applied, bioenergy will make a significant contribution to the national energy mix, bringing associated economic, social and environmental benefits.

3. The bioenergy potential

Experience shows that the use of biomass for energy is a complex and very site-specific matter and that it is difficult to estimate the potential use of biomass for energy given the present international energy situation and an insufficient amount of information. Countries with great biomass potential, such as Brazil, Malaysia, Indonesia and Zaire, and even countries in semi-arid areas with low population density, have, in general, tremendous possibilities of using biomass to meet the energy needs of their modern sectors. However, the potential needs to be properly assessed for each country, to meet the particular demand of their markets.

A favourable climate, good soil fertility, water availability, insolation, low prices for land, and skilled, cheap manpower, along with other local factors such as energy policies, legislation and regulations, credit lines and taxes lend themselves to high biomass productivity and comparatively lower production costs for biofuels. In countries like Brazil, which has a sparse rural population, bioenergy can become an important source of energy. In fact, it has been estimated that 3 per cent of Brazil's land could supply the country's present energy needs.

Two recent studies examine the future role of biomass as a modern energy carrier [1], [2]. Table XVI.8, prepared with data from the Shell/WWF Study [3], shows that most of the energy needs of developing countries can be provided from biomass without provoking a conflict between food and energy needs. It can be noted that there is enough land to support present use of wood and biomass for energy without having to take over land required for food production and other services. The results of the FAO study [2] are also in line with this estimate: they show that biomass could supply about three times the present global energy demand, even taking into account the increased cropland required for food production by the year 2025.

Table XVI.8. Potential land for biomass production in 91 developing countries (regional summary) based on water and techno-economic criteria (FAO-LWT)

Region	Total land area (million ha)[a]	Total potential land (million ha)[b]	Present energy use (million GJ)[c]	Cropland requested by 2025 (million ha)[d]	Remaining land (million ha)[e]	Biomass on remaining land (million GJ)[f]	Share of present energy use (%)	Variable biomass production (million GJ)[g]	Share of present energy use (%)
Developing	6,084.8	2,054.9	53,197	1,059	995	149,313	281	26,807	50
Africa	2,571.9	752.7	8,615	268	484	72,673	844	9,919	115
Latin America	2,002.7	889.6	16,501	269	621	93,138	564	11,532	70
Central America	259.8	74.6	5,681	56	18	2,742	48	1,094	19
South America	1,742.9	815.0	10,820	212	603	90,395	835	10,438	96
Asia[h]	1,510.2	412.5	28,081	522	(110)	-	-	5,356	19

Note: For further information on this table, please consult the author.

[a] Data from FAO, *Production Yearbook*, Rome, 1989.

[b] Data from FAO, *Land and Water Use Inventory*, 1990, Bruinsma, Rome. "Total potential land" is defined by FAO as all land that is physically capable of economic crop production within soil and water constraints. It excludes land that is too "steep, dry or with unsuitable soils"; also excluded is "potential irrigable" land (127 million ha: our decision).

[c] Total present energy use: commercial + fuelwood only (FAO, *Forest Products Yearbook*, Rome, 1989).

[d] Cropland required by 2025; assumes a 50 per cent increase in demand for cropland in developing countries and no change for industrialized countries.

[e] Assuming that the increased demand for cultivated land will take priority, "remaining land" shows the land that would be available after future cropland requirements have been subtracted from total potential land.

[f] Estimate of the potential for biomass energy production on "remaining land", assuming 10 tonnes/ha/yr and 150 GJ/ha.

[g] Calculates the potential for biomass energy production using different subcategories of land: low rainfall and deserts: 2 tonnes/ha/yr; problem land: 5 tonnes/ha/yr; uncertain rainfall and naturally flooded land: 10 tonnes/ha/yr; good rainfall: 20 tonnes/ha/yr.

[h] Does not include China.

There is a great potential for bioenergy in most developing countries, and many benefits can be expected from its increasing use. However, the many uncertainties that still exist need to be properly assessed.

C. Main barriers

The complexity and site-specificity of biomass energy systems are at the root of the constraints to the large-scale development of these systems.

If biomass is to become a modern source of energy, all, or at least the most important, barriers must be removed. These barriers can be categorized as technical, economic, institutional, legislative, cultural and social.

1. Technical barriers

Wood energy systems comprise a large array of operations and processes that need to be efficiently organized to become profitable and competitive with alternative sources of energy at present and future market prices. The development of efficient wood energy systems is, therefore, the main aim of wood energy planners and experts, who are working to improve each of the components and processes involved, from production to the use of woodfuels and other biomass.

However, a great number of technological barriers make it difficult to implement a sound wood energy system. They cover a wide range of disciplines and areas of expertise, from different schemes for tree plantation (mechanized plantation, community forestry etc.) to harvesting and transportation issues, marketing and trade of different types of biofuels and all the aspects of preparing biomass and converting it into energy. The lack of information and the poor understanding of existing wood energy systems should also be addressed since they can cause new investment opportunities to be overlooked.

The traditional use of wood and other biomass to generate energy is hampered by the simple and relatively inefficient devices, giving a huge potential for improvement using new technologies.

At the same time, there are few experts on wood energy, and most of them specialize narrowly. There is a tremendous need for properly trained and educated experts in all aspects of wood energy systems, including trees and energy crops.

The quality of biomass as a fuel varies considerably in terms of its heating value, moisture content and composition. In many countries, the technology for the production, preparation, transportation, storage, distribution and conversion of biomass into energy is not easily available. Moreover, wood and other forms of biomass are also becoming a raw material for secondary fuels such as briquettes, pellets and other gaseous and liquid fuels that require relatively sophisticated technologies and equipment, which are almost unobtainable in developing countries.

Special consideration should also be given to climate and local conditions such as temperature, water resources, pest and diseases, and other factors that influence the yield, productivity and cost of biofuels.

The availability of land for bioenergy production at reasonable prices is also crucial for the development of competitive bioenergy systems. Sometimes, conflicting demands for land for food, fuel and other uses arise that need to be resolved to mitigate the negative impact of a project.

In populous areas where land is mainly used for agricultural purposes, the incorporation of modern agroforestry schemes into the farming system can provide multiple benefits in terms of agricultural production, diversification of farming activities and biodiversity.

The production of biomass for energy on marginal lands or degraded agricultural lands is cheaper than its production on normal agricultural lands, but it entails additional investment and production costs that need to be properly assessed.

2. Economic barriers

Bioenergy derived from residues is becoming an attractive business. However, when wood and other energy crops have to be planted, the production costs and market prices of the resulting biofuels do not always allow them to be competitive with alternative sources of energy. Very often, direct and indirect subsidies and incentives are required for the implementation of bioenergy projects.

The adoption of proven and efficient new technologies is expected to reduce biofuel consumption, through increased energy efficiencies, and to raise biofuel production, through higher productivity and lower production costs. However, this needs intensive investment, which is not readily available, particularly in developing countries.

Despite the large number of successful power plants fuelled by biomass all over the world, particularly in forestry industries, sugar mills and agro-industries, there is still insufficient financial support for the implementation of new bioenergy initiatives. Soft loans, together with ad hoc incentives and special taxes, could help to mobilize the huge amount of biomass resources (mostly wastes and residues) available for energy use.

3. Institutional barriers

Bioenergy in general and wood energy in particular are not sufficiently integrated into national energy policies, and a lack of information, political awareness and adequately educated human resources is impeding the development of new bioenergy initiatives. R and D for the development of new and more efficient bioenergy technologies has not yet received the priority that it deserves in developing countries. This situation is expected to change more rapidly when new investments start to arrive for the implementation of bioenergy initiatives, as has been happening in several Central American and Asian countries.

Some projects promoted by FAO (RWDEP), the World Bank (RPTES and the Energy Sector Management Assistance Programme (ESMAP)) and the European Union (COGEN), to mention just some, are assisting developing countries in building their national capabilities and in solving most of the above-mentioned problems. However, a large number of developing countries are still not covered by these projects.

4. Legislative barriers

Most of the legislation regulating the production, markets, trade and use of biofuels has been established by agencies other than those that have direct responsibilities in the energy, forestry and agriculture sectors. It does not, therefore, adequately consider the special characteristics of bioenergy systems. In most countries there are no standards for the types and qualities of biofuels to be produced and commercialized.

5. Social and cultural barriers

Many specialized energy operators and the general public still think that the use of wood and other biomass for energy is the main cause of deforestation and environmental deterioration. Well-planned campaigns are required to change this perception.

D. The bioenergy and environment assistance programme of the Food and Agriculture Organization of the United Nations

With the developed countries' agenda focused on environmental issues and the developing countries' priorities focused on sustainable development, only biomass seems to be able to meet (with careful management of the resource base) the growing demand for energy from both groups. The primary concern of BEAP, being organized by FAO, is to mobilize the dispersed sectors and units that need to be involved at the international and national level in sustainable and successful development of bioenergy projects. BEAP aims to promote bioenergy as an environmentally sound, technically mature, economically feasible and culturally and socially acceptable alternative, by providing an international framework for action and the required technical assistance to achieve a new energy order.

BEAP will assist public and private organizations, national and international, in a number of ways:

- Collecting, collating and distributing information and data on bioenergy issues.
- Enacting bioenergy policies and strategies for the energy, forestry and agriculture sectors.
- Carrying out studies to identify, evaluate and select bioenergy projects.
- Mobilizing resources for the implementation of bioenergy projects.

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XVII. ELECTRICITY AND FLUID FUELS FROM BIOMASS AND COAL USING ADVANCED TECHNOLOGIES: A COST COMPARISON FOR DEVELOPING COUNTRY APPLICATIONS

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Abstract

Recent analyses of alternative global energy supply strategies, such as the forthcoming report of the Intergovernmental Panel on Climate Change (IPCC), to be published in 1996, have drawn attention to the possibility that biomass modernized with advanced technologies could play an important role in meeting global energy needs in the next century. This paper discusses two promising classes of advanced technologies that offer the potential for providing modern energy carriers (electricity and fluid fuels) from biomass at competitive costs within one or two decades. These technologies offer significantly more efficient use of land than currently commercial technologies for producing electricity and fluid fuels from biomass, as well as substantially improved energy balances. Electricity is likely to be the first large market for modernized biomass, but the potential market for fluid fuel production is likely to be much larger. As coal is likely to present a more serious competitive challenge to biomass in the long run, we present an economic comparison with coal-based electricity and fluid fuels. A meaningful economic comparison between coal and biomass is possible because these feedstocks are sufficiently alike in their physical characteristics that similar conversion technologies may well be used for producing electricity and fluid fuels from them. When similar conversion technologies are used for both feedstocks, the relative costs of electricity or fluid fuels will be determined by the distinguishing technical characteristics of the feedstocks (sulphur content, moisture content and reactivity) and by the relative feedstock prices.

Electric power generation from biomass and coal are compared here using an advanced integrated gasifier/gas turbine cycle that offers the potential for achieving high efficiency, low unit capital cost and low local pollutant emissions: the steam-injected gas turbine coupled to an air-blown gasifier. For both feedstocks, generation costs are prospectively lower than with present-day coal-fuelled steam electric power generation using flue gas desulphurization, while sulphur emissions would be much lower. Assuming costs for plantation-grown biomass based on commercial plantation practice in Brazil, it is shown that the break-even coal price is lower that the cost of coal projected by the World Bank for many developing countries for the year 2005.

For fluid fuels, a comparison is made between biomass and coal as feedstocks for the production of methanol and H_2. These fuels are the energy carriers of choice for vehicles based on fuel cell technologies. Fuel cell technology for transport applications is rapidly advancing, and fuel cell buses have already been demonstrated and will be available commercially before 2000; fuel cells could be available for automotive applications in the period 2005-2010. The main attractions of fuel cell vehicles for developing countries are their favourable emissions characteristics (zero or near-zero pollutant emissions without the need for control technologies), their high fuel economy (energy requirements per kilometre are just one third to one half those for internal combustion engine vehicles) and their energy supply diversity advantages (natural gas, biomass and coal can be used at fuel costs per kilometre that are prospectively competitive with costs for petroleum). As in the case of power generation, it is shown that methanol and H_2 derived from plantation-grown biomass have good prospects for being competitive with coal-derived methanol and H_2 in many regions, assuming biomass prices based on Brazilian experience with commercial plantations and World Bank projections of coal prices for developing countries.

Introduction

In its recent study, the Intergovernmental Panel on Climate Change [1] explored alternative strategies for meeting anticipated global energy requirements over the next century while reducing greenhouse gas emissions. A key finding of that study was that biomass could play an important role in meeting global energy needs. In each of five alternative energy supply scenarios considered for the twenty-first century in the IPCC study, the fraction of global commercial primary energy provided by biomass exceeds 10 per cent by the year 2025 and 25 per cent by the end of the century, two thirds of it provided by developing countries. For biomass to make so substantial an economic contribution to the global energy supply, despite its marginal current contribution of less than 1 per cent of the commercial primary energy supply in 1990,* it will be necessary for today's conventional biomass technologies to be superseded by advanced biomass technologies. This paper discusses two promising classes of advanced technologies for producing modern energy carriers (electricity and fluid fuels) from biomass at costs that could be competitive within one or two decades. It presents a detailed cost analysis, including a comparison with the analogous electricity and fluid fuel production technologies that would use coal.

Historically, biomass was known as "the poor man's oil", and its contribution to the energy supply mix has declined as incomes have risen, reflecting the end-user's preference for higher quality energy carriers. In the case of cooking fuels, for example, consumer preferences are known to shift from dung to crop residues, fuelwood, coal, charcoal, kerosene, liquefied petroleum gas, natural gas and electricity, in increasing order, as incomes rise [2]. Biomass is currently relegated to the lower rungs of the energy ladder because there exist no commercial technologies for converting suitable biomass feedstocks to easy-to-use energy carriers such as electricity and high-quality fluid fuels that are competitive with conventional energy sources. However, modernization of the production of biomass, of conversion technologies and of end-use systems offers good prospects for enabling biomass to contribute significantly to the commercial energy economy, by making possible favourable economics, energy balances and environmental impacts.

In the production of biomass feedstocks, modernization entails the choice of biomass feedstocks that (a) offer the potential for high yields, low cost and minimal adverse environmental impacts, (b) can be cultivated without unacceptable disruption to patterns of land ownership and use and (c) are suitable for use in modern energy systems. This modernization of the biomass feedstock processing has not been applied to the production of synthetic fuels from grains, sugar cane, sugar beets or rapeseed; since these crops were originally developed to provide food, their use as energy crops tends to be suboptimal.

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*Today, most biomass energy is used non-commercially for domestic applications, particularly in rural areas of developing countries. This consumption amounts to an estimated 15 per cent of total global energy use.

In the conversion phase, modernization entails using technologies that offer, at the scales appropriate for biomass energy conversion facilities, low unit capital costs and high thermodynamic efficiencies for producing electricity and fuels. Without advanced technologies to replace today's low efficiency technologies, the use of biomass for energy will be economical only in those limited situations where the available biomass feedstocks are much less costly than conventional fossil fuels, as are, for example, various biomass residues of the agricultural and forest product industries. With today's conventional conversion technologies it will generally not be possible to compete with fossil fuels using the more costly biomass supplies that might be provided by growing biomass on dedicated energy farms or plantations.

As will be shown, conversion technologies characterized by both high efficiency and low unit capital cost offer good prospects for enabling biomass to compete with fossil fuels. Such technologies make it possible to obtain high yields of energy services per unit of land committed to growing biomass, and to do so with favourable energy balances (e.g. with small fossil fuel inputs compared to the biomass energy outputs, on a life-cycle basis).

As coal is likely to be the main competitor for biomass energy in the long run, sections A and B contain economic analyses comparing prospective production costs for electricity and fluid fuels derived from biomass and coal, emphasizing the use of advanced conversion technologies in both instances. A meaningful economic comparison between coal and biomass is possible because these feedstocks are sufficiently alike in their physical characteristics that similar conversion technologies might ultimately be selected for producing electricity and fluid fuels from them. When similar conversion technologies are used for different feedstocks, the relative costs of electricity or fluid fuels in the long term will be determined mainly by the distinguishing technical characteristics of the feedstocks (sulphur content, moisture content, and reactivity) and by the relative feedstock prices.

The electricity analysis (section A) compares prospective costs of electricity from biomass and coal based on the use of advanced IGCC power cycles, which offer the potential for higher thermodynamic efficiency, lower unit capital costs and much lower local pollutant emissions than conventional steam-electric conversion systems. The fluid fuels analysis (section B) focuses on the prospective costs of converting biomass and coal, via processes that begin with thermochemical gasification, into methanol or hydrogen. These are the energy carriers of choice for transport vehicles powered by fuel cells, an emerging vehicle technology promising much higher fuel economy and much lower pollutant emissions than today's internal combustion engine vehicles.

The production of electricity is likely to be the largest initial application of modernized biomass energy. Biomass electric generating technology with thermodynamic and cost characteristics similar to those for the technology described in section A could be commercially available by 2000-2005 if ongoing demonstration projects for similar technologies are successful and are followed up with commercialization programmes and technological improvements.

The production of fluid fuels is likely to be a larger market for biomass in the long run, however. Synthetic fuels (synfuels) will be needed as substitutes for oil throughout much of the twenty-first century, beginning at the end of the second decade, owing largely to the growing demand for transport fuels in the face of limited oil resources.* Since significant synfuel production will not be needed in the

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*According to the United States Geological Survey [3], identified reserves plus the mean value of the estimated undiscovered ultimately recoverable conventional oil resources is about 11,200 EJ worldwide. If these resources were wholly consumed in the next century, their average rate of exploitation, some 100 EJ/year, would be less than 75 per cent of the worldwide rate of oil consumption in 1990 (some 141 EJ/year). The potential (continued...)

very near term, it is appropriate to consider biofuel strategies that offer good prospects for serving the multiple needs of the transport sector over the longer term, including cost-effectiveness, energy security, decreased urban air pollution and limited CO_2 emissions. As will be discussed, the combination of fuel cell vehicles with methanol and hydrogen derived from biomass is especially promising in this regard. All the technologies needed for the biofuels strategy described here could become well-established in the market by the time synfuels are needed if they are given priority in R and D programmes in the near term.

A. Electric power generation

1. *Background*

Essentially all biomass power plants today operate on a steam-Rankine cycle, a steam turbine technology that was introduced into commercial use about 100 years ago. The biomass is burned in a boiler to produce pressurized steam, and the steam is expanded through a turbine to produce electricity. Biomass-fuelled steam turbine power plants tend to be much smaller than modern coal-fired steam-electric systems, because plant capacity is constrained by the local supply of biomass fuel. Owing largely to the strong scale-dependence of the unit capital cost (US$/kW) of steam turbine systems (the main reason why large size is favoured for coal and nuclear steam-electric power plants), biomass power plants are equipped with steam turbines that operate at relatively modest temperatures and pressures. This penalizes efficiency, and biomass power plants typically operate at efficiencies below 20 per cent compared with 35 per cent for a modern coal-powered plant. Such low efficiencies explain the reliance of the biomass power industry on low-, zero- or negative-cost biomass for fuel, primarily residues of agro- and forest product-industry operations and urban refuse. While there is a continuing role for biomass power generation based on the use of such residues, the expansion of biomass power to the scales envisioned in the IPCC scenarios will require the use of higher cost feedstocks, such as residues that are harder to recover and biomass that is purpose-grown for energy on dedicated energy plantations. To make higher cost biomass resources economically viable for power generation, it is necessary to have technologies that offer higher energy efficiency and lower unit capital cost at modest scales.

2. *Gas turbine-based power generation*

An alternative to the steam turbine cycle for biomass power generation is a set of technologies that marry advanced gas turbine power-generating systems to closely coupled biomass gasifiers that are similar to gasifiers already developed for using coal in gas turbine power cycles. These so-called integrated gasification/gas turbine (IG/GT) technologies are being pursued for coal for two reasons; they make possible coal-based power with much less air pollution than is possible using stack gas controls on steam-electric plants, and they achieve much higher thermodynamic efficiencies than steam turbine-based power cycles. In the case of biomass, another attraction of IG/GT technologies is that

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*(...continued)

importance of synfuels is indicated by examining their role in the reference scenario constructed by the Intergovernmental Panel on Climate Change [1] to describe the prospective global energy economy between 1990 and 2100, in which it was assumed that the world population increases from 5.3 to 11.3 billion, world economic output increases 12-fold, global primary commercial energy use increases fourfold and society takes no action to limit greenhouse gas emissions. Under these conditions, the IPPC projected that consumption of coal and biomass for synfuels production would increase from 14 EJ/year in 2020, to 64 EJ/year by 2025, 154 EJ/year by 2050 and 608 EJ/year by 2100. In 2100, the consumption of coal for synfuels production in this IPCC reference scenario is 417 EJ/year, which is 60 per cent of total coal use and accounts for half of total CO_2 emissions from fossil fuel burning at that time.

the unit costs for gas turbine power systems are less sensitive to scale than are those for steam turbine-based power systems, which makes it possible to achieve favourable economics at the scales of interest for biomass power generation.

A set of gas turbine technologies that is particularly promising for biomass is the aeroderivative gas turbines, so-called because they are directly derived from aircraft jet engines. Most gas turbine development for stationary power applications has focused on heavy-duty industrial gas turbines designed specifically for large-scale stationary power applications. These heavy-duty industrial turbines dominate the rapidly growing worldwide market for natural-gas-fired simple-cycle and combined-cycle power plants that account for most electric power expansion programmes today. Most of the advanced technology incorporated in heavy-duty industrial turbines has been transferred from advances in jet engine technology, which have been enormous in recent decades, largely as a result of military R and D investments. Aeroderivatives are also being sold in these burgeoning natural gas markets, but primarily for peaking service applications. The particular attraction of aeroderivatives for biomass applications is the prospect of high efficiency and low unit capital costs at the modest scales that are of interest to biomass.

3. *Comparing biomass and coal gas turbine systems*

When comparing biomass and coal in IG/GT cycles, many possible combinations of gasifiers and gas turbine-based power cycles are possible: oxygen-blown vs. air-blown gasifiers, entrained-flow vs. fluidized-bed vs. fixed-bed gasifiers, gas turbine/steam turbine combined cycles vs. steam-injected gas turbine cycles vs. humid air turbine (HAT) cycles vs. Kalina cycles etc. Some combinations are better suited for coal, others for biomass. If different combinations of gasifiers and gas turbine cycles are used in making a comparison between biomass and coal, the reasons for any power generation cost differences are obscured.

The approach taken here is to focus on a particular combination of gasifier and gas turbine cycle that (a) is appropriate for use with both coal and biomass feedstocks and (b) would lead, for both biomass and coal, to substantial reductions in power generation cost relative to first-generation IG/GT technologies.* The technology chosen for this comparison is a gas turbine cycle that combines the use of an air-blown, fixed-bed gasifier with an intercooled steam-injected gas turbine (ISTIG). This particular combination of gasifier and gas turbine cycle may not be the least costly option for either biomass or coal (and over the long run, IG/ISTIG technology might be commercialized for neither biomass nor coal), but it allows exploring in a fair way how the relative costs of biomass and coal power depend on the moisture and sulphur contents of the feedstocks and on feedstock prices-characteristics that are likely to be crucial to biomass and coal for power generation applications in the long run.

Since this preliminary approach assumes the same gasification technology for biomass and coal, it does not take into account the third distinguishing characteristic, differences in reactivity. The higher reactivity of biomass enables the use of lower temperatures to achieve the same degree of gasification. The lower temperature requirement allows gasification to occur by indirect heating instead of partial oxidation, leading to the production of a medium-heating-value gas (undiluted by nitrogen) without the use of oxygen. By comparison, the production of a medium-heating-value gas from coal relies on

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*First-generation IG/GT technologies are (a) in the case of coal, integrated gasification/combined cycles based on the use of oxygen-blown entrained-flow gasifiers (technology that is commercially available) and (b) in the case of biomass, integrated gasification/combined cycles based on the use of air-blown fluidized-bed gasifiers (technology that will probably be demonstrated commercially by the year 2000).

gasification via partial oxidation using oxygen, the production of which is costly and highly scale-sensitive. There may be cost and efficiency advantages associated with the lower temperatures and higher reactor throughput rates that can be achieved with biomass gasification compared to coal. However, the detailed analysis of alternative gasifiers (and best-suited gas turbine cycles) needed to determine the relative advantages is beyond the scope of this paper.

Scale is not likely to be a key factor once advanced gas turbine technologies become established in the market, even though existing biomass steam-electric plants tend to be small and coal electric plants tend to be large. Electric power plants fuelled with plantation-grown biomass can economically be much larger than today's biomass power plants, which are now typically sized around 25 MWe or less owing to fuel availability constraints. Electric generation costs are not very sensitive to transport distances for the feedstock [4, 5] notwithstanding the somewhat lower energy density of biomass compared to coal. Capacity is proportional to the planted area, while biomass transport distance is proportional to only the square root of the area planted. Site-specific analyses of biomass power systems in the United States and Brazil that take into account the distribution of biomass supplies and power plant scale economies have shown that electricity costs are minimized for capacities in the range 230-320 MWe [6]. In addition, coal plants based on air-blown gasification would make possible plants much smaller than current IGCC technologies that rely on oxygen-blown gasification [7], for which costs are very scale-sensitive.

4. Intercooled steam-injected gas turbine systems

The gas turbine cycle studied here, the ISTIG, has two unique features that make it possible to achieve low costs at modest scales as well as efficiencies comparable to those of larger combined cycles based on heavy-duty industrial turbines: intercooling and steam injection. Intercooling between compressor stages leads to higher efficiency and increased electrical output because less compressor work is required and because improved cooling of the turbine blades with air bled from the compressor permits operation at higher turbine-inlet temperatures. Steam injection is a capital-saving simplification in which steam is generated using gas turbine exhaust heat (as in a combined cycle) and then injected into the gas turbine combustor and downstream points in the turbine expander to increase power output.

The combination of steam injection and intercooling dramatically increases the efficiency and power of a simple-cycle gas turbine. For example, consider the General Electric LM-5000 gas turbine, which is derived from the jet engine used in the Boeing 747, the DC-10 Series 30 and the Airbus 300. Fuelled with natural gas, this gas turbine produces 34 MWe at 33.6 per cent efficiency in simple-cycle mode, while the commercial STIG version produces 51 MWe at 39.0 per cent efficiency, and the ISTIG version is calculated to have a capacity of 114 MWe at 47 per cent efficiency [8]. Despite the added equipment required for steam injection and intercooling, significant capital cost savings arise compared to a combined cycle because no steam turbine is needed. One recent study [9] estimated that the unit cost* of a natural gas-fired ISTIG system (152 MWe at 48.7 per cent efficiency) is US$ 727/kW, whereas that of a combined cycle** based on the same gas turbine (104 MWe at 50.6 per cent efficiency) is US$ 1,100/kW.

The coal version of the ISTIG technology (CIG/ISTIG) was advanced by General Electric [7] as a promising option for using coal in an IG/GT cycle that would give rise to a very low cost for electricity generation. The attractive economics of this design derive partly from the benefits of

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*All costs in this paper are expressed in constant 1994 United States dollars using the United States GNP deflator [9].

**The efficiency of the combined cycle considered in the Flour-Daniel study is especially high owing to a "reheat" stage in the gas turbine topping cycle.

intercooling and steam injection, as discussed above, and partly from the use of an air-blown gasifier that eliminates the need for the oxygen plant required by the oxygen-blown gasifiers used in demonstration of coal-gasification gas turbine systems to date. Likewise, the IG/ISTIG concept is an attractive option for biomass (BIG/ISTIG), offering high efficiency and low unit capital costs at modest scales [8]. While there has been no focused effort to develop fixed-bed gasifier technology for biomass feedstocks, limited pilot-scale testing carried out in 1991 by General Electric confirmed that a gas with adequate heating value can be generated. Tests indicated that development work is also needed on pressurized feeding and on gas clean-up [11]. A recent study modelling the performance of fixed-bed gasifiers coupled to steam-injected cycles indicates that such systems demonstrate good thermodynamic performance, making them prospectively competitive with systems based on fluidized-beds and combined cycles [12].

For this study, the performance and costs of the CIG/ISTIG system are taken from a General Electric study based on that company's LM-5000 gas turbine [7]. The BIG/ISTIG system performance and costs are based on modifying the coal system to account for the main differences arising from operation on biomass. These differences in design are due to the different sulphur content and moisture content of coal and biomass.

High system efficiency and a high level of sulphur removal would require the use of "hot-gas" sulphur clean-up with the CIG/ISTIG system instead of the standard wet scrubber technology that is used with oxygen-blown gasification today. A hot-gas clean-up system would recover sulphur as saleable sulphuric acid (H_2SO_4). The value of this sulphur by-product would diminish in the long run to zero, however, because the market for sulphur would eventually become saturated. Biomass contains sufficiently little sulphur that a sulphur clean-up system is not required,* so the low-pressure steam needed for the sulphur recovery unit in the coal system is not needed in the biomass system and can instead be injected into the turbine to increase power output and efficiency.

On the other hand, biomass incurs a cost penalty because of its high moisture content. Typically biomass feedstocks contain 50 per cent moisture, so further drying is necessary for effective gasification. Biomass drying today is done with flue gas driers that involve an energy efficiency as well as a capital cost penalty. Part of the flue gas, which might otherwise be used to raise steam for a bottoming cycle or steam injection, is used instead to dry the biomass and is then vented. An alternative design currently under development would dry the biomass in superheated steam raised using the flue gas. The water evaporated from the biomass can be recovered as extra steam for injection into the gas turbine. If steam recovered this way from the biomass were integrated into a BIG/ISTIG system, there would be little, if any, efficiency penalty [12]. If a biopower industry were successfully launched, it is very likely that this technology would be commercialized quickly.

Overall, the output and efficiency of the BIG/ISTIG system are estimated to be 111 MWe and 42.9 per cent respectively, as compared to those of the CIG/ISTIG system, which are estimated to be 109 MWe and 42.1 per cent [7].

5. *Cost of electricity from biomass and coal IG/ISTIG systems*

Costs for a CIG/ISTIG system were estimated [7] using accounting rules set forth in the Electric Power Research Institute (EPRI) Technical Assessment Guide [15], and the BIG/ISTIG costs were derived therefrom. Table XVII.1 details the capital costs for the coal and biomass systems.** The

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*Biomass has a potential commercial advantage in the near term because hot-gas clean-up systems that would be needed for CIG/ISTIG have not yet been demonstrated to be economically viable on a commercial scale.

**This table and the ones that follow in this paper are taken from references 7, 24, 25, 30, 35, 37 and 54-68.

added cost of the hot-gas clean-up system in the coal case (an equipment cost penalty of roughly US$ 200/kW) and the steam drier system in the biomass case (a penalty of about US$ 80/kW for a 111 MWe BIG/ISTIG system [15]) are the main differences between the CIG/ISTIG and BIG/ISTIG columns. The biomass system would enjoy a slight capital cost advantage due to its improved efficiency relative to the coal system. Table XVII.2 details the calculated costs in United States cents per kilowatt-hour for electric power from the coal and biomass systems. All costs are calculated assuming a capacity factor of 75 per cent. The total cost of electricity is shown for the biomass system and coal system as a function of feedstock price.*

Table XVII.1. Estimated installed capital cost for IG/ISTIG power plants fuelled with coal and biomass
(United States dollars per kilowatt electric)

Cost component	CIG/ISTIG[a]	BIG/ISTIG
Process capital cost		
Fuel handling	48.5	47.6
Fuel drier	0.0	77.9
Blast air system	12.7	12.5
Gasification plant	109.7	107.6
Raw gas physical clean-up	10.2	10.0
Raw gas chemical clean-up	199.3	0.00
Gas turbine/HRSG	338.6	332.2
Balance of plant		
Mechanical	43.6	42.8
Electrical	63.9	62.7
Civil	80.1	78.6
Subtotal	905.7	771.9
Total plant cost		
Process plant cost	905.70	771.9
Engineering home office (10.0%)	90.6	77.2
Process contingency (6.2%)	56.2	47.9
Project contingency (17.4%)	157.6	134.3
Subtotal	1,210.1	1,031.3
Total capital requirement		
Total plant cost	1,210.10	1,031.3
AFDC[b] two-year construction at 10.0 per cent discount rate	60.5	51.6
Preproduction cost (2.8%)	33.9	28.9
Total installed capital	**1,304.5**	**1,111.8**
Inventory capital (2.8%)	33.9	28.9
Initial chemicals and catalysts	3.0	0.00
Land	1.7	1.7
Working capital and land	**38.6**	**30.6**

[a] Figures adapted from J. Corman, *Systems Analysis of Simplified IGCC Plants*, report prepared for the United States Department of Energy by General Electric Corporate R and D, Schenectady, New York, 1986.

[b] AFDC = allowance for funds during construction (i.e. interest charges that accumulate during construction).

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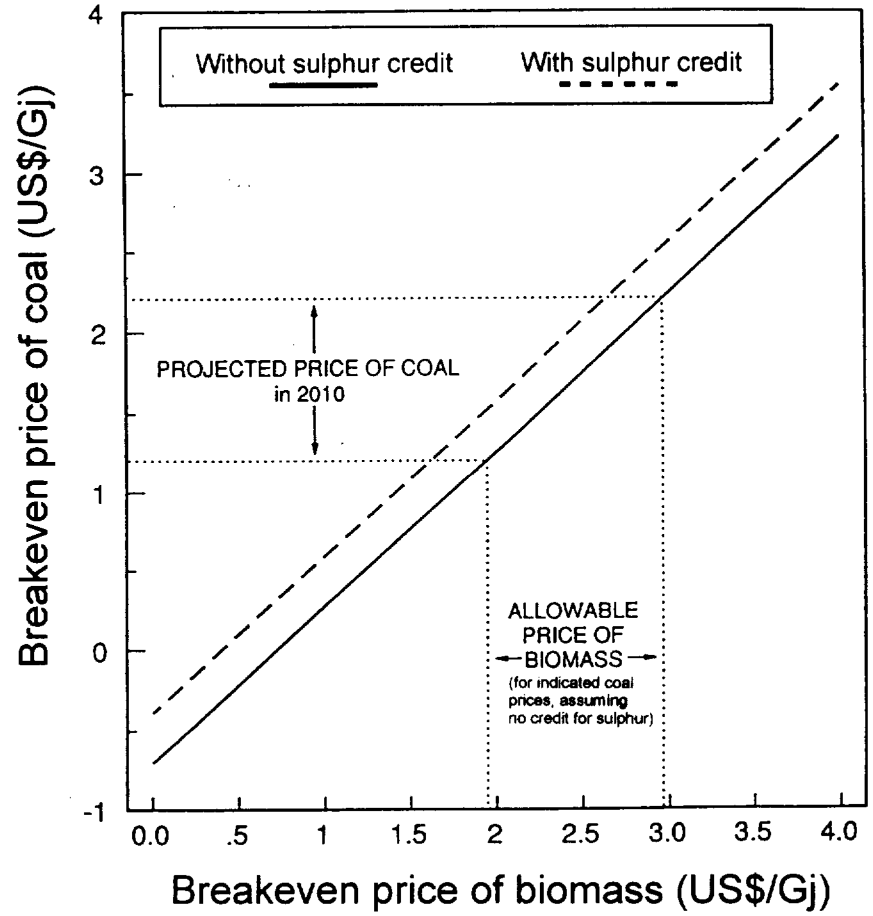
*Costs of electricity are shown for coal both with and without a credit for by-product sulphur. We assume H_2SO_4 is sold for a credit of US$ 90/tonne and that the coal feedstock is Illinois #6 coal containing 3.8 wt-% sulphur.

To compare the cost of electricity from the biomass and coal systems, figure XVII.1 shows the price of coal at which the cost of electricity from coal equals the cost of electricity from biomass. The projected coal prices are from recent exercise by the Energy Modelling Forum [16], in which estimates of average utility-electric coal prices for the year 2010 were developed using five different energy models. Their estimates ranged from US$ 1.2/GJ to US$ 2.2/GJ. Without a sulphur credit for coal, BIG/ISTIG would produce electricity that competes with CIG/ISTIG over this coal price range if biomass costs from US$ 1.9/GJ to US$ 3.0/GJ (see figure XVII.1). These biomass costs are likely to be achievable on energy plantations in many parts of the world (see section C, on biomass supply issues).

Figure XVII.1. Break-even coal price vs biomass price



Note: The price of coal at which the cost of electricity from coal equals the cost of electricity from biomass is shown. The indicated "project coal price in 2010" is taken from ref. [53] and reflects estimates of average utility-electric coal prices that range from US$ 1.2/GJ to US$ 2.2/GJ. Without a sulphur credit for coal BIG/ISTIG would produce electricity that competes with CIG/ISTIG over the coal price range if the cost of biomass ranges from US$ 1.9/GJ to US$ 3.0/GJ.

Table XVII.2. Busbar costs of electricity for IG/ISTIG plants fuelled with coal and biomass

(United States cents per kilowatt-hour)

Cost Component	Cost of electricity	
	CIG/ISTIG	BIG/ISTIG
Capital[a]	**2.26**	**1.93**
Fuel[b]	P_c x 0.86	P_b x 0.84
Labour[c]	0.32	0.22
Maintenance[d]	0.38	0.28
Administration[e]	0.14	0.10
Total fixed operating and maintenance	**0.84**	**0.60**
Water requirements[f]	0.03	0.03
Catalysts/binder[g]	0.02	-
Solids disposal[h]	0.07	0.07
H_2SO_4 by-product credit[i]	-0.27	-
Variable operating and maintenance		
With sulphur by-product credit	**-0.15**	**0.10**
With no sulphur by-product credit	**0.12**	-
Total cost		
With sulphur by-product credit	**2.95 + P_c 0.86**	-
With no sulphur by-product credit	**3.22 + P_c 0.86**	**2.62 + P_b x 0.84**

[a] Capital costs are calculated assuming a capital charge rate (11.11 per cent) on total installed capital cost (derived from the capital recovery factor for an assumed 30-year plant life at 10 per cent discount rate and an insurance charge rate of 0.5 per cent per year), plus a charge on working capital plus land determined by the 10 per cent discount rate. The capacity factor is assumed to be 75 per cent.

[b] P_c = coal price and P_b = biomass price, in US$/GJ (higher heating value (HHV) basis).

[c] The coal-based system requires three operators for the gasification system, four for the hot-gas clean-up and three for the power plant. At US$ 26.20 per hour, operating costs for the coal system are US$ 2.297 million per year. It is assumed that seven operators are needed for the biomass system, four fewer than for the coal system, because hot-gas desulphurization is not needed but one more because of increased fuel handling requirements. Thus, annual operating labour costs would be US$ 1.609 million per year.

[d] Annual maintenance costs (40 per cent labour and 60 per cent materials) are estimated to be US$ 2.72 million per year for the coal system (including US$ 0.697 million per year for chemical hot-gas clean-up). The corresponding cost for the biomass system, without chemical hot-gas clean-up, is US$ 2.04 million per year.

[e] Annual administration costs (30 per cent of operating and maintenance and labour) are US$ 0.1016/kWh for the coal system and US$ 0.0726/kWh for the biomass system.

[f] Raw water costs are US$ 0.220 million per year for both systems.

[g] Annual cost of catalysts and binder for the coal system is US$ 0.131 million.

[h] Annual costs for solids disposal for both systems are US$ 0.497 million.

[i] Annual H_2SO_4 by-product credits are US$1.928 million for the coal system and zero for the biomass system. This by-product credit applies initially but would diminish to zero in the long-run because the sulphuric acid market would become saturated and its value would fall.

B. Production of hydrogen and methanol from biomass

1. Background

In this section the production of H_2 and methanol (CA_3OH) derived from biomass, coal and natural gas is considered and comparisons to conventional hydrocarbon transportation fuels are made.

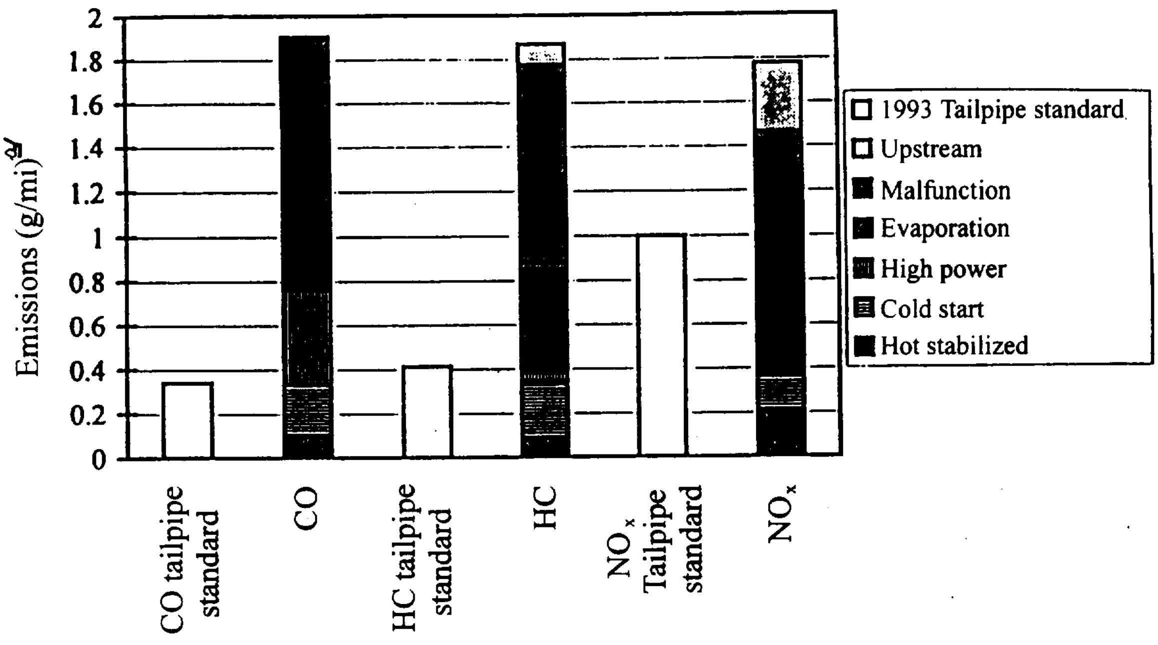
The production of synthetic fuels at a competitive cost is more challenging than the production of electricity, so the fuel market will probably develop after the power generation market. The main problem is that any synfuel, whether derived from biomass or coal, is inherently more costly than conventional hydrocarbon fuels, which require very little processing from the forms in which they are recovered from nature. It is therefore difficult for synfuels to compete with conventional hydrocarbon fuels on a cost-per-unit-energy basis. However, since the consumer is concerned not with energy per se but rather with energy services, synfuels that could be used more efficiently, conveniently and cleanly could still be economically preferable to conventional hydrocarbon fuels.

2. Fuel cell vehicles and biomass-derived fuels

A class of technologies that could make synfuels economically attractive is based on the fuel cell, which converts fuel directly into electricity without first burning it. The fuel cell offers the potential for making major contributions both in transportation [17, 18] and in the distributed co-generation of heat and power [19, 20]. A fuel cell using H_2 or methanol (MeOH) offers high efficiency, zero or near-zero local air pollution emissions, low maintenance and quiet operation. Fuelled by either compressed H_2 or MeOH (which would be re-formed on board the vehicle into a hydrogen-rich gas), a fuel cell vehicle (FCV) would require much less fuel and emit much less local pollution than even a hybrid internal combustion engine/battery-powered car, while offering range and life-cycle costs that are comparable or superior [21, 22]. Because of the good prospects for FCVs to be economically competitive even with conventional hydrocarbon-fuelled internal combustion engine vehicles [23, 24], the FCV is a leading candidate technology for accelerated development under an R and D initiative launched jointly by the United States Government and United States auto manufacturers in 1993. The aim of this initiative is to develop in a decade production-ready prototypes of advanced, low-polluting cars that could be run on secure energy sources, especially renewables, that would have up to three times the fuel economy of today's gasoline internal combustion engine vehicles of comparable performance and that would cost no more to own and operate. The Canadian fuel cell developer Ballard Power Systems introduced a prototype fuel cell bus in 1993 and has contracted to provide the city of Chicago with a fleet of three fuel cell buses starting in 1996. Ballard is scheduled to market fuel cell buses on a commercial basis starting in 1998. Germany's Daimler-Benz has also announced plans to develop fuel cell technologies for commercial automotive applications.

The interest in fuel cell vehicles stems largely from the recognition that, with conventional vehicle technology, the increasing demand for transportation services would contribute to declining air quality in urban areas of the world. The strengthening of tailpipe emissions regulation is the prevailing approach to controlling vehicle pollution, but as emissions standards tighten, tailpipe emission control devices get correspondingly more complicated, expensive and difficult to maintain, and regulatory strategies mandating tighter tailpipe controls have worked far less well in practice than in theory. Actual lifetime pollutant emissions from new cars in the United States are several times greater than the standards that ostensibly govern the emissions of these new cars (see figure XVII.2.) This discrepancy is likely to be amplified further in those developing countries that lack the inspection and maintenance infrastructure needed to help ensure that tailpipe pollution control technologies work properly. The introduction of an inherently clean technology such as the FCV is therefore likely to be especially important in developing countries needing to significantly reduce air pollution in metropolitan areas.

Figure XVII.2. Cars and emissions



Note: Over the lifetime of a motor vehicle the actual emissions of criteria pollutants are far higher than the tailpipe emission standards in the United States of America because (a) pollution control devices are designed to meet the performance levels specified in a test that does not faithfully reflect real-world operating conditions, (b) pollution control equipment sometimes malfunctions, and (c) some emissions come from sources other than the tailpipe (evaporative emissions from the fuel tank and emissions from the fuel production and delivery system upstream of the motor vehicle).

[a]Multiply by 10 for CO.

Because FCVs have a fuel efficiency that is 2.5-3 times that of internal combustion engine vehicles (ICEVs) of comparable performance, they can potentially start to provide an important market for MeOH and H_2 transportation fuels by about 2010 without requiring these synfuels to be competitive with oil-derived gasoline on a cost-per-unit-energy basis. Despite the very good prospects for H_2- or MeOH-consuming fuel cell vehicles, very little attention has been paid to the production of these fuels from biomass. Instead, the focus of biofuels development has been largely on the production of ethanol via fermentation from grain, sugar beets and sugar cane, or the production of rape methyl ester from rapeseed oil. Such biofuels have attracted attention largely because the crops involved are familiar to the agricultural sector, and producing them for energy provides an alternative market for agricultural products. However, the production of ethanol from grain or sugar beets and the production of rape methyl ester from rapeseed oil also represent inefficient uses of land, with low yields of transport services (vehicle-km/ha/yr) compared to what is achievable with the advanced technologies described here for producing MeOH or H_2 from woody biomass feedstocks. This is indicated in table XVII.3, which compares yields, in terms of transport fuel and transport services per hectare per year, for several different biomass feedstock-to-fuel alternatives. Moreover, producing ethanol from grain or sugar beets or rape methyl ester from rapeseed oil requires large fossil fuel energy inputs. For the Netherlands, energy output/fossil fuel input ratios are 0.9 and 1.2 for ethanol from winter wheat and sugar beets, respectively, and 1.8 for rape methyl ester derived from rapeseed [25]. This is in contrast to the production of MeOH and H_2 from biomass as described below, which yields energy balances of 9.3 and

10.3, respectively.* Whereas net fuel cycle CO_2 emissions are approximately the same for ethanol from maize as for gasoline [27, 28], MeOH and H_2 from biomass used in fuel cell vehicles would lead to a reduction in CO_2 of roughly 90 per cent relative to a gasoline-fuelled ICEV [29].

Table XVII.3. Energy yield for alternative feedstock/conversion technologies

Option	Feedstock yield (dry tonnes/ha/yr)	Transport fuel yield (GJ/ha/yr)	Transport services yield[a] (10^3 vehicle-km/ha/yr)
Rape methyl ester (Netherlands, 2000)[b]	3.7 (rapeseed)	47	21 (ICEV)
EtOH from maize (United States)[c]	7.2 (maize)	76	27 (ICEV)
EtOH from wheat (Netherlands, 2000)[d]	6.6 (wheat)	72	26 (ICEV)
EtOH from sugar beets (Netherlands, 2000)[e]	15.1 (sugar beets)	132	48 (ICEV)
EtOH, enzymatic hydrolysis of wood (present technology)[g]	15 (wood)	122	44 (ICEV)
EtOH, enzymatic hydrolysis of wood (improved technology)[g]	15 (wood)	179	64 (ICEV)
MeOH, thermochemical gasification of wood[h]	15 (wood)	177	64/133 (ICEV/FCV)
H_2, thermochemical gasification of wood[h]	15 (wood)	213	84/189 (ICEV/FCV)

[a] The fuel economy of the vehicles used (in litres of gasoline-equivalent per 100 km) are assumed to be 6.30 for rape methyl ester (assumed to be the same as for diesel), 7.97 for EtOH, 7.90 for MeOH and 7.31 for H_2 used in ICEVs; and 3.81 for MeOH and 3.24 for H_2 used in FCVs [55]. Note that 1 litre of gasoline equivalent = 0.0348 GJ, HHV.

[b] Per tonne seed: 370 litres rape methyl ester plus (not listed) 1.4 tonnes straw [25].

[c] For wet milling, assuming the United States average maize yield, 1989-1992; per tonne of grain: 440 litres EtOH plus (not listed) 0.35 tonne stover (out of 1 tonne of total stover, assuming the rest must be left at the site for soil maintenance), 275 kg corn gluten cattle feed and 330 kg CO_2 [56].

[d] Per tonne seed: 455 litres EtOH plus (not listed) 0.6 tonnes straw [25].

[e] Per tonne sugar beet: 364 litres EtOH [25].

[f] For the average sugar cane yield in Brazil in 1987 (63.3 tonnes harvested cane stems per hectare, wet weight); per tonne wet cane stems: 73 litres EtOH [57]. In addition, (not listed) the dry weight of the attached tops and leaves amounts to 0.092 tonnes and that for the detached leaves amounts to 0.188 tonnes per tonne of wet stems, altogether some 18 dry tonnes/ha/yr [58].

[g] Per tonne feedstock: 338 litres EtOH plus (not listed) 183 kWh (0.658 GJ) electricity, present technology; 497 litres EtOH plus (not listed) 101 kWh (0.365 GJ) electricity, improved technology [56].

[h] For the indirectly heated Battelle Columbus Laboratory biomass gasifier; per tonne feedstock: 11.8 GJ MeOH or 14.2 GJ H_2; per tonne feedstock, external electricity requirements are 107 kWh (0.38 GJ) for MeOH or 309 kWh (1.11 GJ) for H_2 (see table XVII.4).

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*Following Ho [27], we assume that 0.076 GJ of fossil fuel inputs are required for each gigajoule of harvested biomass. External electricity for fuels production is assumed to be provided by advanced gas turbine power plants fuelled with biomass (see note (j) of table XVII.4).

In this section, it is argued that the use of biomass-derived MeOH or H_2 in fuel cell vehicles offers a way to use a renewable energy resource as a transportation fuel, with high efficiency, low emissions of local pollutants and greenhouse gases, and prospectively competitive costs. Because this technology for fuels production involves first converting biomass into a synthesis gas via thermochemical gasification, there is much more flexibility in selecting a biomass feedstock than is the case for food agriculture or for biofuels based on feedstocks with high starch or oil content, such as those mentioned above. Biomass crops can instead be selected based on their environmental and economic suitability. The process for producing H_2 and MeOH from biomass (with comparisons to coal and natural gas) is described in the next subsection and their production costs are compared to those of conventional hydrocarbon fuels.

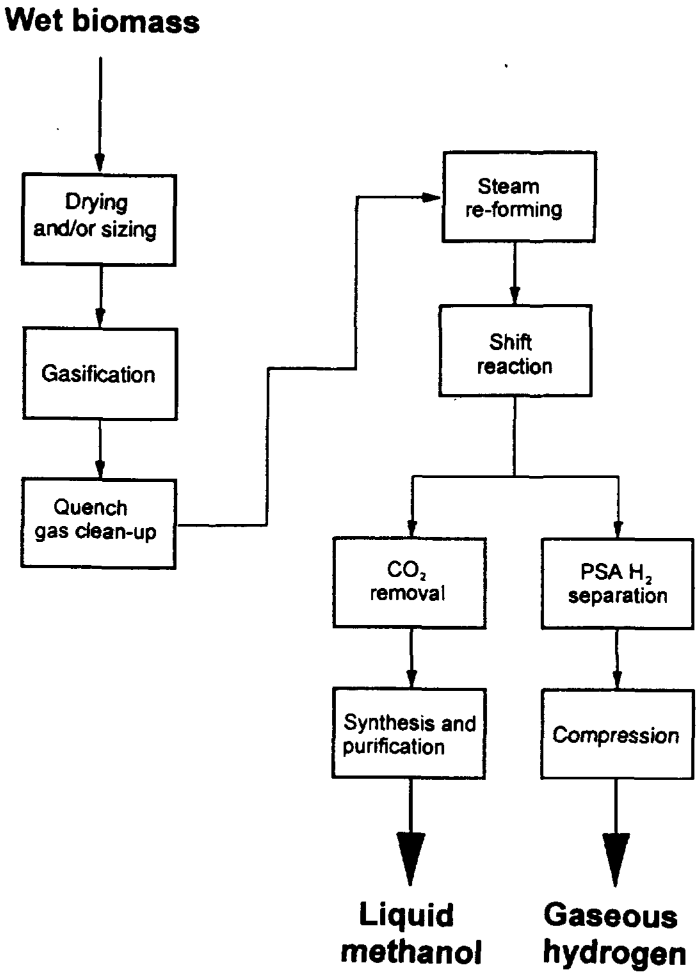
3. Process technology

The production of liquid MeOH or gaseous H_2 from biomass, coal or natural gas involves several similar basic processing steps (figure XVII.3) (see [29, 30] for further details). In the case of coal and biomass, the feedstock is gasified, as was discussed for power-generating technologies. Fuels production from biomass, unlike power generation, requires a gasifier product undiluted by nitrogen, so gasification must be either oxygen-blown or indirectly heated. The syngas exiting the gasifier is cooled and then quenched with a water spray to remove particulates and other contaminants. It then undergoes a series of chemical processes that convert it into the desired end product. Downstream of the gasifier, the equipment for conversion of syngas to MeOH or H_2 is the same as that used for conversion of natural gas to MeOH or H_2 and is commercially available. All equipment for fuels production from coal is commercially available today, while for biomass all equipment for fuels production will be commercially available once the anticipated development of biomass gasification technologies has occurred. Following gasification, additional clean-up of sulphur compounds (especially important with coal) is needed to prevent the poisoning of downstream catalysts. As in the case of electric power production, the low sulphur content of biomass implies that the costly sulphur removal systems required with coal are not required for biomass systems. A simpler guard bed is sufficient.

Detailed thermodynamic process models of MeOH and H_2 production from biomass, from natural gas and from coal were constructed using commercially available process simulation software (ASPEN-PLUS) (see [30] for details). For biomass, the Battelle-Columbus Laboratory indirectly heated twin-bed gasifier is assumed. A commercial-scale demonstration of this gasifier is under way in Vermont, in the United States. For coal, the Shell oxygen-blown entrained-flow gasifier is assumed. These process models allow quantitatively comparing the alternative fuels production processes with regard to efficiency as well as capital equipment needs, external energy demands and operating requirements.

Two measures are used to convey the energy efficiency of MeOH or H_2 production: (a) the energy ratio, defined as the energy content of the product fuel divided by the energy in the input feedstock, which takes no account of the energy required to provide electricity or heat from external sources and (b) the thermal efficiency, defined as the energy content of the product fuel divided by the energy content of all energy inputs to the process, including the feedstock and additional amounts of feedstock used to generate the electricity and heat requirements not provided from by-product process heat or purge gases (see table XVII.4). In effect, the thermal efficiency gives the energy performance of a facility whose only energy input is the feedstock under consideration. The production of MeOH and H_2 from biomass and coal, while less efficient than their production from natural gas owing in part to the losses associated with the gasification process, is an efficient process that will contribute to a favourable energy ratio for the entire fuel cycle.

Figure XVII.3. Process diagram for H_2 and MeOH



Note: Thermochemical processing steps in the production of methanol or hydrogen from biomass (PSA is pressure swing adsorption).

4. Costs of fuel production and use

Fuel costs are examined here at the points of production and of sale to final consumers, measured in US$/GJ of fuel and also in terms of the transportation service provided, US$/vehicle-km of driving, for automotive applications. Moreover, two measures are provided of the cost per unit of service: the fuel cost/vehicle-km, and the total cost/vehicle-km, including the capital, fuel and non-fuel operating costs for the vehicle.

Table XVII.4. Heat and mass balances for MeOH and H_2 from biomass, natural gas and coal

	MeOH			H_2[a]		
Balance	Biomass	Natural gas[b]	Coal	Biomass	Natural gas	Coal
Energy inputs						
Feedstock (GJ per GJ)	1.65	1.42	1.54	1.37	1.11	1.29
Electricity (kWh/GJ)						
Pumps	0.03	0.08	0.10	0.04	0.05	0.11
Compressors	29.72	13.05	9.37	22.84	7.69	8.28
Lock hopper	0.00	0.00	0.69	0.00	0.00	0.58
Oxygen[c]	0.00	0.00	18.92	0.00	0.00	15.87
PSA[d]	0.00	0.00	0.00	8.90	2.75	11.03
Total	29.74	13.13	29.08	31.79	10.49	35.87
Steam (kg/kg dry)	0.38	3.23	1.91	0.95	2.66	2.99
Energy ratio (ER)[e]	0.606	0.704	0.649	0.732	0.897	0.774
Fraction of electricity input from						
Waste heat[f]	0.696	0.446	0.416	0.317	0.219	0.086
Purge gases[g]	0.000	0.000	0.248	0.000	0.00	0.138
External sources	0.304	0.554	0.336	0.683	0.781	0.776
Thermal efficiency[h]	0.576	0.674	0.613	0.636	0.844	0.64

[a] In all cases the production facility is designed to produce gaseous H_2 at 75 bar.

[b] Natural gas is assumed to be available at the conversion site at 2.5 MPa and to have the following volumetric composition: 94.7 per cent CH_4, 2.8 per cent C_2H_6, O_2 per cent CO_2, and 2.3 per cent (N_2 + Ar).

[c] Production of 99.5 per cent pure O_2 is assumed to require 480 kWh/tonne, based on 442 kWh/tonne for 95 per cent purity [59], plus an additional 9 per cent for 99.5 per cent purity [60].

[d] Electricity consumption by the PSA unit is assumed to be 4.46 kWh/kmole CO_2 [61].

[e] The energy ratio is defined as [the energy content (HHV basis) of the product (CH_3 or H_2)]/(the energy content of the feedstock input to the process, excluding any additional feed used for electricity production).

[f] All waste heat that is available (after meeting as much of the process heating needs as possible) at sufficiently high temperature is assumed to be used to raise steam at 6.2 MPa and 400°C. The steam is expanded in a condensing steam turbine operating with an exhaust pressure of 0.005 MPa and an isentropic efficiency of 75 per cent. A 95 per cent generator efficiency is assumed. Pinch analysis techniques were used to determine how much of the process heating needs could be met with a highly integrated process-to-process heat exchange system. (All heating needs could be thus met in the Ch_3OH production cases.) The pinch analysis also provided the magnitude of waste heat remaining that was suitable for steam-electricity generation.

[g] Purge gases (from the MeOH synthesis loop or the PSA loop) are assumed to be used for electricity production with efficiencies achievable in a gas turbine/steam turbine combined cycle [30].

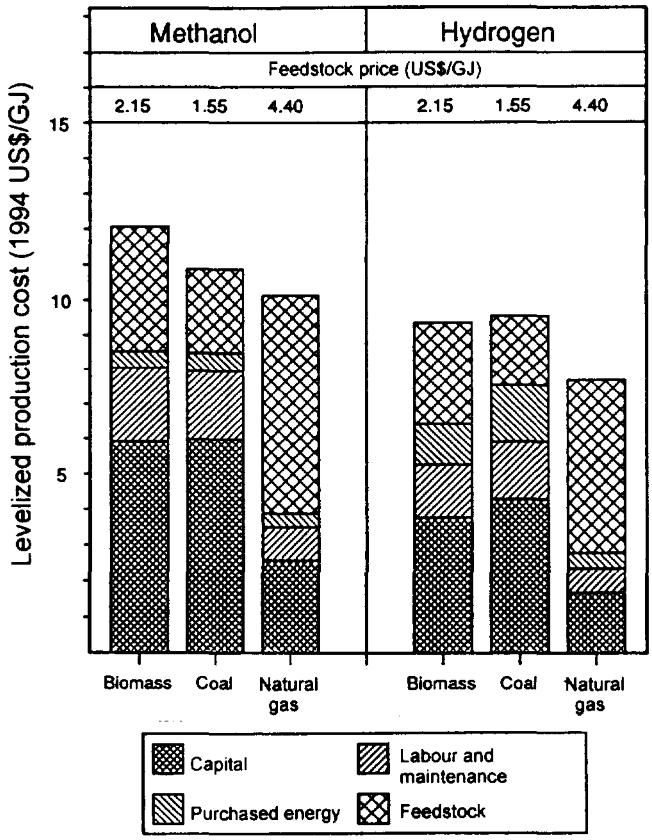
[h] The thermal efficiency is defined as [the energy content (HHV basis) of the product (MeOH or H_2)]/(the sum of energy content of all primary-energy inputs to the process). The inputs include the feedstock plus additional feed used to produce the electricity and heat that must be provided from external sources. No external heat addition is required for any of the MeOH cases, but is required for the coal-derived H_2 case at a rate of 0.031 GJ input/GJH_2 The cooling energy requirements per GJ of MeOH product are 0.0 GJ for biomass, 0.260 GJ for natural gas and 0.216 GJ for coal; per GJ of product H_2 they are 0.0 GJ for biomass, 0.040 GJ for natural gas and 0.189 GJ for coal [30]. It is assumed that "free" external cooling is available, such as river water, so cooling is not counted in the thermal efficiency. The efficiencies assumed for electricity production correspond to estimates for advanced gas-turbine-based power systems using the same feedstock [30]. For natural gas (or purge gas), the efficiency (in per cent) is given by 39.58 + 0.134 x MWe, where MWe is the required electrical capacity in megawatts. For biomass or coal, the efficiency is 37.00 + 0.047 x MWe.

(a) Costs of producing methanol

Estimates of the levelized costs of MeOH produced from biomass, coal and natural gas are presented in figure XVII.4.* (Table XVII.5 gives details of the cost estimate.) For biomass, the assumed plant capacity is 1,650 dry tonnes input/day, corresponding to 3,000 tonnes/day of green biomass (45 per cent moisture).** For natural gas, the assumed feed rate is 1.64 million Nm^3/day, typical for a large modern natural gas MeOH plant. For coal, the assumed feed rate is 5,000 tonnes/day, so that the output capacity is about five times as large as for the biomass cases.

The costs presented in figure XVII.4 are for "reference case" feedstock costs. The assumed cost of the biomass feedstock delivered to the conversion facility is US$ 2.15/GJ (for a discussion of this price, see section C). For natural gas and coal, prices are assumed to be US$ 4.40/GJ and US$ 1.55/GJ, respectively, which are taken as typical life-cycle prices for industrial customers in the United States for the period 2010-2035 (see note (s) of table XVII.5).***

Figure XVII.4. Levelized production costs



Note: Estimated total levelized costs (in 1994 US$/GJ) of producing MeOH and H_2 from biomass, natural gas and coal. See table XVII.5 for details.

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*The cost estimates in figure XVII.4 and tables XVII.5 and XVII.6 assume a real (inflation-corrected) discount rate of 9.9 per cent/yr and a real capital charge rate of 15.1 per cent/yr (based on average financial parameters for major United States corporations from 1984 to 1989).

**For comparison, this biomass input capacity is of the same order of magnitude as that of a modern pulp and paper making facility or a large cane sugar production facility.

***For comparison, the average industrial prices for natural gas and coal in the United States in 1990 were US$ 3.4/GJ and US$ 1.6/GJ, respectively.

Table XVII.5. Estimated production costs for methanol and H_2 from biomass, natural gas and coal MeOH

Item	MeOH			H_2		
	Biomass	Natural gas	Coal	Biomass	Natural gas	Coal
Feedstock input capacity						
Dry tonnes/day	1,650	1,224	5,000	1,650	1,224	5,000
GJ/hr	1,338	2,700	6,188	1,338	2,700	6,188
Output production capacity[a]						
Tonnes/day	858	2,012	4,252	1.87	4.62	9.13
GJ/hr	811	1,901	4,016	979	2,422	4,790
Annual feed and output						
Feed (PJ/yr)	10.55	21.29	48.79	10.55	21.29	48.79
Installed equipment costs (million US$)						
Feed preparation, including drying[b]	14.12	0.00	72.85	14.12	0.00	72.85
Gasifier[c]	13.64	0.00	128.70	13.64	0.00	128.70
High-temperature gas cooling[d]	0.00	0.00	121.43	0.00	0.00	121.43
Oxygen plant[e]	0.00	0.00	102.29	0.00	0.00	102.29
Sulphur removal[f]	0.00	0.00	38.86	0.00	0.00	38.86
Reformer feed compressor[g]	12.74	0.00	0.00	12.74	0.00	0.00
Reformer[h]	18.44	53.60	0.00	19.70	47.07	0.00
Shift reactor[i]	2.14	0.00	0.00	5.37	9.67	7.80
CO_2 removal[j]	15.37	0.00	63.78	-	-	-
Methanol synthesis and purification[k]	40.47	71.02	116.35	-	-	-
PSA recycle compressor[l]	-	-	-	2.61	7.62	17.61
PSA (with CO_2 removal)[m]	-	-	-	16.76	33.04	55.09
Hydrogen compressor	-	-	-	6.24	10.33	20.60
Steam turbine co-generation plant[n]	23.71	18.34	61.82	17.01	11.88	39.87
Utilities/auxiliaries[o]	35.16	35.74	176.53	27.05	29.91	151.28
Total installed equipment costs	**175.79**	**178.69**	**882.61**	**135.21**	**149.52**	**756.38**
Contingencies[p]	35.16	35.74	176.53	27.05	29.91	151.28
Owners' costs, fees, profits[n]	17.58	17.87	88.26	13.52	14.95	75.64
Start-up[q]	8.79	8.93	44.13	6.76	7.47	37.82
Total capital requirement (million US$)	**237.32**	**241.23**	**1,191.53**	**182.54**	**201.85**	**1,021.12**
Working capital[s] (million US$)	17.58	17.87	88.26	13.52	14.95	75.64
Land[r] (million US$)	2.23	4.57	7.93	2.23	4.57	7.93
Variable operating costs (million US$/yr)						
Feed[g]	22.62	93.56	75.83	22.62	93.56	75.83
Catalysts and chemicals[t]	2.40	2.77	11.65	2.40	2.77	11.65
Purchased energy[u]	3.10	5.84	16.58	8.98	8.38	56.33
Total variable operating costs	**28.12**	**102.16**	**104.06**	**33.99**	**104.71**	**148.79**
Fixed operating costs (million US$/yr)	0.00	0.00	0.00	0.00	0.00	0.00
Labour[v]	1.16	1.07	3.37	1.16	1.07	3.37
Maintenance[w]	5.27	5.36	26.48	4.05	4.48	22.69
General overhead	4.18	4.18	19.39	3.39	3.61	16.94
Direct overhead	0.53	0.48	1.51	0.53	0.48	1.51
Total fixed operating costs	**11.14**	**11.10**	**50.75**	**9.13**	**9.65**	**44.50**
Production costs (US$/GJ)						
Capital[x]	5.92	2.58	5.98	3.77	1.69	4.30
Labour and maintenance	2.12	0.92	1.97	1.49	0.65	1.62
Purchased energy	0.48	0.39	0.53	1.16	0.44	1.62
Feedstock	3.54	6.24	2.39	2.93	4.90	2.00
Total production cost	**12.05**	**10.14**	**10.87**	**9.36**	**7.69**	**9.55**
Break-even natural gas price (US$/GJ)[y]	5.75	-	4.91	5.90	-	6.07
Break-even coal price (US$/GJ)[z]	2.33	-	-	1.41	-	-

[a] Based on process energy ratios given in table XVII.4.

[b] Feed preparation costs include drying (and pulverizing for the coal gasifier cases). Costs are scaled from other estimates according to feed capacity (dry tonnes per day (dtpd)) raised to the 0.7 power. The other estimates are as follows: for biomass, US$ 8.05 million for 740 dtpd [62], for coal, US$ 104.3 million for 7,982 dtpd [63].

[c] Gasifier costs are scaled from other estimates according to feed capacity (dtpd) raised to the 0.7 power. The other estimates are as follows: for biomass, US$ 7.77 million for 740 dtpd [62]; for coal, US$ 178.6 million for 7,982 dtpd [63]

[d] For the coal-derived CH_3OH case, the cost of the high-temperature gas cooling system (plus the shift reactor) is scaled from an estimate of US$ 168.4 million for a plant with a coal feed rate of 7,982 dtpd [63]. A 0.7 power scaling factor is assumed. For the biomass-derived CH_3OH case, the cost is scaled (using 0.7 factor) from that for the coal case according to the heat removal rate in the gas cooler: 215.6 MW in the coal case and 48.2 MW in the biomass case. For the Shell gasifier cases, this item includes the high-temperature gas cooling and the shift reactors. For the hydrogen cases, the gas cooling costs are equal to the corresponding CH_3OH production cases plus added costs representing the additional shift reactor capacity. The cost of the additional shift reactor capacity has been estimated by scaling according to incremental volume flow of $H_2 + CO$ using a 0.65. power factor and assuming a baseline cost of US$ 9.67 million for a flow of 8,819 kmol/hr [64].

[e] The cost for oxygen plants (in million 1994 US$) is assumed to be 0.279 x $(tO_2pd)^{0.712}$, where tO_2pd is the plant capacity in tonnes of 99.5 per cent pure O_2 per day. This is based on estimates of the cost of 95 per cent pure O_2 plants sold by Air Products Company for use in integrated coal-gasifier/gas turbine facilities [59]. The plants produce O_2 at 3.7 MPa and include 20 minutes of gaseous oxygen storage. For plant sizes of 1,000 tO_2pd or larger, the use of dual trains is assumed, each providing 50 per cent of the capacity. CH_3OH or H_2 production requires an O_2 purity of 99.5 per cent (or higher). It is assumed that capital cost increases by 15 per cent to produce O_2 of 99.5 per cent purity instead of 95 per cent purity [60].

[f] H_2S recover is required with the coal system. This cost has been scaled using a 0.7 power factor according to the feed rate of dry coal from a baseline cost of US$ 53.9 million for a coal feed rate of 7,982 tonnes per day.

[g] Compressor cost is assumed to be US$ 965/kW of required capacity. The cost here refers to the cost of the compressor used to raise the pressure of the syngas before it enters the CH_3OH synthesis loop.

[h] The reformer cost includes costs for boiler feed-water pumps, steam drum, induced-draught and forced-draught fans, all internal heat exchangers, including exchangers to cool the reformate to ambient temperature, desulphurizing vessels, local piping, controls, instrumentation, analysers, initial catalyst charge and water-treating equipment. For the natural gas case, the cost is based on an estimate of Moore [64]. For the other cases, the reformer cost is scaled (using 0.57 power) according to the total heat exchange duty of the reformer, including all preheating, after-cooling and steam raising associated with the reformer. The total duty in the natural gas case is 767.8 MW for CH_3OH, 560.13 for H_2.

[i] No shift reactor is required with natural gas. For the coal gasifier case, the shift reactor costs are included in the cost of high-temperature gas cooling equipment. For the biomass case, the shift reactor cost is scaled according to the volume flow of $H_2 + CO$, assuming a baseline cost of US$ 9.67 million for a flow rate of 8,819 kmol/hr and a scaling factor of 0.65 [64].

[j] For Union Carbide's Selexol process, leaving approximately 2 per cent CO_2 in the exit gas. Costs are scaled according to volume of CO_2 removal raised to the 0.7 power. The baseline estimate is $15.3 million for 810 kmol/hr CO_2 removal [65].

[k] Estimated cost with the ICI low-pressure CH_3OH synthesis process, including the make-up compressor, recycle compressor and synthesis loop equipment. A cost estimate of US$ 71.02 million is assumed for a facility with production capacity of 2,012 tonnes/day [64]. The costs for other capacities have been scaled using a 0.66 power factor [66].

[l] Compressors are assumed to cost US$ 965/kW capacity.

[m] Assuming use of the Gemini-9 PSA system from Air Products, which removes CO_2 and H_2O in a first bed and produces a fuel gas of 99.999 per cent pure H_2 out of a second bed. The estimated cost for the natural gas case is US$ 33.04 million for an H_2 production rate of 8,474 kmol/hr [64]. For the other cases, costs are scaled according to the H_2 production rate raised to the 0.7 power. The cost excludes the recycle compressor.

[n] The installed cost (in 1994 US$/kWe) for a condensing-extraction steam turbine co-generation system, including a waste heat boiler, is assumed to be 4,076 x $(MWe)^{-0.374}$, where MWe is the electricity-generating capacity of the facility. This is based on estimates of the cost for steam bottoming cycles in the range 20-40 MWe for gas turbine/steam turbine combined cycles [67].

[o] Assumed to be 25 per cent of the sum of other installed hardware costs [56][64].

[p] The following percentage of installed equipment costs (given by Wyman and others [56] for Ch_3OH production) are adopted here: contingencies, 20 per cent; owners' costs, fees and profit, 10 per cent; working capital, 10 per cent.

[q] Start-up costs are assumed to be 5 per cent of installed hardware costs.

[r] The following costs for land, developed from estimates of Wyman and others [56], are assumed: for biomass and coal facilities, land cost (million 1994 US$) is 453 x $(tpd)^{1.147}$, where tpd is the dry feed capacity in tonnes per day; for the natural gas case, the land cost (in 1994 US$) is assumed to be $0.19 per GJ/yr of natural gas feed capacity.

[s] Assuming levelized costs for delivered feedstocks of US$ 2.15/GJ for biomass chips, US$ 4.4/GJ for natural gas and US$ 1.55 for coal. It is expected that the price of plantation biomass will be no higher than this in many parts of the world by 2010. The assumed natural gas and coal prices are levelized prices for 2010-2035 based on prices projected for United States industrial customers in 2010 [35] escalated for 25 years thereafter at rates of 1.0 per cent per year for natural gas and 0.5 per cent per year for coal.

[t] The costs for catalysts and chemicals for the biomass and coal cases are those estimated by Wyman and others [56] scaled linearly by the production rate.

[u] For external electricity input, a cost of US$ 0.05/kWh is assumed. External heat input is charged at US$ 4.3/GJ. Table XVII.4 shows the quantities of electricity and heat required.

[v] Labour costs are based on Wyman and others [56]. For natural gas, Wyman's estimate is used directly. For solid feedstocks, the following relationship for annual labour costs was derived from two biomass cases of different capacities considered by Wyman and others: million $ = 953 x $(dtpd)^{0.959}$.

[w] Based on Wyman and others [56], maintenance is assumed to be 3 per cent of installed hardware costs, general overhead is 65 per cent of labour and maintenance and direct overhead is 45 per cent of labour.

[x] Annual capital charge rate of 15.1 per cent is assumed, based on average financial parameters for major United States corporations during 1984-1988 (9.91 per cent real rate of return on equity, 6.2 per cent real rate of return on debt, a 30 per cent debt fraction, a 44 per cent corporate income tax), a property and insurance rate of 1.5 per cent per year and a 25-year plant life. For land and working capital, the annual capital charge rate is taken to be 9.91 per cent/yr, the corporate discount rate.

[y] This is the price of natural gas at which the total levelized cost of fuel from natural gas would equal the total levelized cost of fuel from the alternative feedstock (biomass or coal).

[z] This is the price at which the cost of fuel produced from biomass at US$ 2.15/GJ would equal the total levelized cost of fuel from coal.

The cost of MeOH from biomass is US$ 12.0/GJ (see table XVII.5 and figure XVII.4). The cost of MeOH from coal is only 10 per cent less than the cost from biomass, even though the assumed reference feedstock price is 28 per cent less for coal than for biomass and the coal plant is five times as large as the biomass plant. At the average 1990 natural gas price for United States industry (US$ 3.4/GJ) the production cost for MeOH from natural gas would be US$ 8.8/GJ, 27 per cent less than for the biomass case shown. However, natural gas prices are expected to rise in most parts of the world. At the reference natural gas price of US$ 4.4/GJ for 2010-2035, MeOH from natural gas would be 16 per cent less costly than MeOH from biomass at US$ 2.15/GJ.

In some regions (e.g. some developing countries) biomass-derived MeOH would probably be competitive with that from natural gas. For example, it is estimated that 1.7 EJ/yr of biomass (enough to provide 1.0 EJ/yr of MeOH) could be produced on 4 million hectares of plantations in the north-east of Brazil at a cost of US$ 1.6/GJ or less.* Producing MeOH there from biomass at this price and shipping it to Rotterdam would cost the same as producing it in Europe from natural gas costing US$ 5.4/GJ, 21 per cent above the reference natural gas price.** MeOH imports of 1 EJ/yr would be able to support 60 million fuel-cell-powered cars in Europe (about half of the total number of private cars in the European Union at present), and the benefits to rural development of such a biomass fuels industry in Brazil (and other developing countries) could be significant [35].

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*Carpentieri et al. [31] estimate that 12.6 EJ/yr of biomass could be grown at an average productivity of 12.5 tonnes/ha/yr on 50.5 million ha of plantations in the Brazilian north-east, at an average cost of US$ 1.65/GJ. This total potential production includes 1.7 EJ/yr that could be grown at an average productivity of 20.7 tonnes/ha/yr on the better available lands at a cost of US$ 1.32/GJ. These costs include 85 km of transport to the conversion facility but do not include the cost of shipping. Shipping costs have been estimated by Perlack and Wright [32] to be US$ 5.50/dry tonne, or US$ O.28/GJ of biomass. Thus the total cost of 1.7 EJ/yr of biomass (including shipping) would be US$ 1.6/GJ delivered to the conversion facility.

**For biomass feedstock costing US$ 1.6/GJ, the plant-gate cost of MeOH would be US$ 11.1/GJ. For delivery to Rotterdam, the cost of oceanic transport must be added to this production cost. The cost C (in US$/GJ) of oceanic transport of CH_3OH via large (250,000 dead-weight tonnes) tankers fuelled with fuel oil costing P (US$/barrel) for a round-trip distance of RT nautical miles is given by the United States Department of Energy [33] as follows:

$$C = 2.18 \cdot RT \cdot 10^{-5} + 2.67 \cdot 10^{-2} + 1.55 \cdot P \cdot RT \cdot 10^{-7} + 2.59 \cdot P \cdot 10^{-5}.$$

For transport from the Brazilian north-east to Rotterdam, $RT = 12{,}000$ nautical miles. Moreover, the United States Department of Energy [34] projects that the cost of residual fuel oil for transport in 2010 will be US$ 3.47/GJ, or US$ 23/bbl. Thus the transport cost would add US$ 0.3/GJ to the cost of producing MeOH, bringing the total cost of MeOH produced from biomass in the Brazilian north-east and delivered to Rotterdam to US$ 11.4/GJ, which would be competitive with MeOH produced in Europe from natural gas priced at US$ 5.4/GJ.

(b) Costs of producing hydrogen

Estimates of the levelized costs of H_2 produced from biomass, coal and natural gas, derived in the same manner as for MeOH, are also given. The production cost for biomass-derived H_2 is about 20 per cent less than for MeOH.

The estimated cost of producing H_2 from biomass is less, by a factor of 2 or more, than the cost of H_2 derived electrolytically from water using wind or photovoltaic power sources, assuming that the long-term cost reduction goals for these power sources can be met [24, 26].

H_2 and MeOH derived from biomass costing US$ 2.15/GJ (reference feedstock price) become competitive with these fuels derived from natural gas at roughly the same natural gas price (US$ 5.9/GJ and US$ 5.8/GJ, respectively). The price of biomass at which H_2 and MeOH derived from biomass can compete with these fuels derived from coal (reference price of US$ 1.55/GJ) are US$ 2.25/GJ and US$ 1.4/GJ, respectively.

If global environmental costs associated with fuel production and use (e.g. net CO_2 release) were internalized, the economics of biomass-derived MeOH and H_2 production would improve relative to the fossil fuel options.

(c) Consumer costs

The costs seen by the consumer differ from production costs because of the extra costs of delivering the fuel and the characteristics of the vehicle that uses the fuel.

While the cost of producing H_2 from biomass or natural gas is about 25 per cent less than that of producing MeOH, the cost of H_2 delivered to consumers is only about 6 per cent less than that of MeOH, largely because of the expense of compressing H_2 to high pressure at the refuelling station (figure XVII.5 and table XVII.6). But because H_2-fuelled FCVs would be more energy-efficient than MeOH-fuelled FCVs, the cost of H_2 fuel per v-km would be only four-fifths as much as for MeOH (figure XVII.6 and table XVII.6). Going one step further and considering the total cost of owning and operating the vehicle (in US¢/km) tips the balance slightly in favour of MeOH, because H_2-fuelled FCVs would probably have higher first costs (figure XVII.7). However, for both fuels, the total cost of owning and operating a vehicle that consumes biomass-derived fuel is only 2 per cent more than the total cost if natural gas-derived fuel is consumed. Prospectively, in 10-20 years time, biomass can start to displace fossil fuels in the transport sector at an added cost that would be hardly noticeable to the consumer.

5. Summary

Biomass-derived MeOH and H_2 offer substantial improvements over conventional biofuels such as ethanol (EtOH) derived from maize and rape methyl ester derived from rapeseed because (a) they can be produced more efficiently from a given amount of land and with fewer adverse environmental impact and (b) they are well-suited for use in clean and efficient fuel cell vehicles. Biomass-derived MeOH and H_2 could make major contributions to energy requirements for road transportation when used in fuel cell vehicles. Such systems offer attractive economics in the post-2010 time-frame and the potential for very low emissions of both local air pollutants and low net CO_2 emissions if the biomass is grown sustainably. The development of technologies for producing MeOH and H_2 from biomass should be coordinated with efforts to develop FCVs. The FCV represents an extraordinarily attractive market for biomass producers, and FCV developers should not hesitate to introduce their new products out of concern about the availability of fuels suitable for use in FCVs, in light of the prospect of large potential renewable supplies of cost-competitive biomass-derived MeOH and H_2.

Table XVII.6. Summary of estimated delivered retail fuel prices[a]

(1994 United States dollars per gigajoule)

Cost component	Energy carrier						
	Reformulated gasoline[b]	**MeOH**			**H_2**		
	Crude oil	Biomass	Natural gas	Coal	Biomass[a]	Natural gas	Coal
Feedstock cost	4.0	2.15	4.40	1.55	2.15	4.40	1.55
Cost components for delivered fuel	(US$ 24.65/bbl)						
Production[c]	7.25	12.05	10.14	10.87	9.36	7.69	9.55
Transport to filling station[d]	1.06	2.04	2.04	2.04	0.54	0.54	0.54
Filling station cost[e]	0.65	1.29	1.29	1.29	4.72	4.72	4.72
Delivered retail price	**8.96**	**15.37**	**13.46**	**14.19**	**14.61**	**12.94**	**14.80**
[US$/litre gasoline equivalent[e]]	[0.31]	[0.54]	[0.47]	[0.49]	[0.51]	[0.45]	[0.51]
[US$/gal gasoline equivalent[f]]	[1.18]	[2.03]	[1.78]	[1.88]	[1.93]	[1.70]	[1.95]
	ICEV	FCV			FCV		
Fuel cost per unit of service[f, g] (US¢/km)	2.84	2.06	1.81	1.89	1.69	1.48	1.69

[a] Excluding retail fuel taxes.

[b] Based on a projected crude oil price in the United States of $24.65/bbl in 2010 [35].

[c] Production costs for Ch_3OH and H_2 derived from biomass, natural gas and coal are from table XVII.5. For reformulated /gasoline, with 0.132 GJ/gal, the production cost per gallon is 0.9 x ($/bbl crude) 0/42 + 0.27 + 0.16, where 0.9 is the fraction of a gallon of gasoline derived from crude oil, 42 is gal/bbl, $0.27/gal is the estimated cost of refining standard formula gasoline and $0.16/gal is the additional cost for refining reformulated gasoline [68].

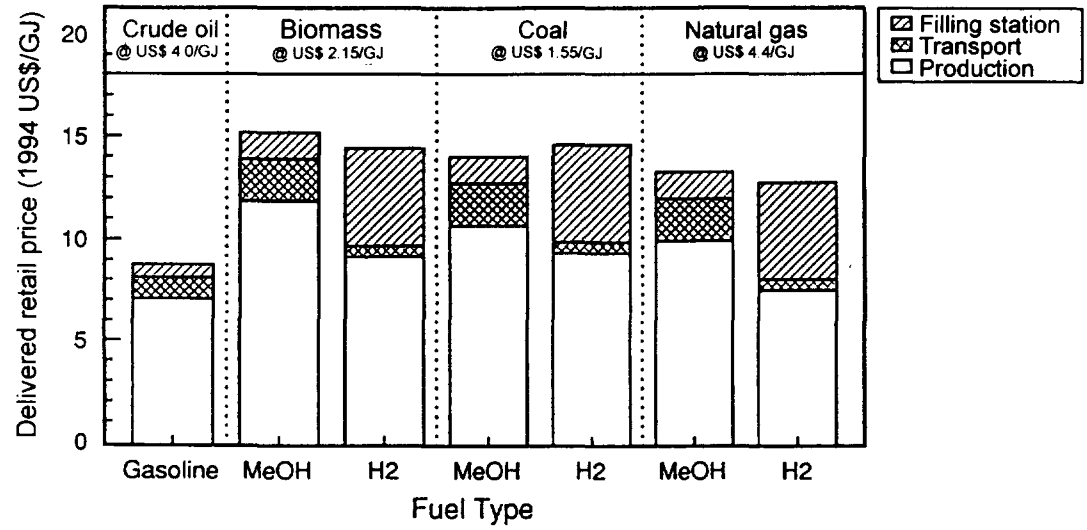
[d] See ref. [24].

[e] The fuel price in United States dollars per unit volume of gasoline equivalent is calculated as the US$/GJ price times the HHV of gasoline (0.035 GJ/litre 0.132 GJ/gal).

[f] This is the fuel price (in US$/litre) divided by the gasoline-equivalent fuel economy (km/litre). The assumed ICEV is a year 2000 version of the Ford Taurus, having a fuel economy of 11.0 km/litre (25.8 mi/gal) when operated on reformulated gasoline. The FCV version of this automobile would have a gasoline-equivalent fuel economy of 26.1 km/litre (61.5 mi/gal) when operated on MeOH and 30.4 km/litre (71.6 mi/gal when operated on compressed H_2 [24].

[g] Fuel cell vehicles for MeOH and H_2; internal combustion engine vehicles for reformulated gasoline.

Figure XVII.5. Estimated retail price, excluding retail taxes, of MeOH and H_2 produced from biomass, coal and natural gas



Note: Estimated retail price, excluding retail taxes, of MeOH and H_2 produced from biomass, coal and natural gas.

Figure XVII.6. Estimated fuel cost to consumer per vehicle-km of transport service (See table XVII.6 for details)

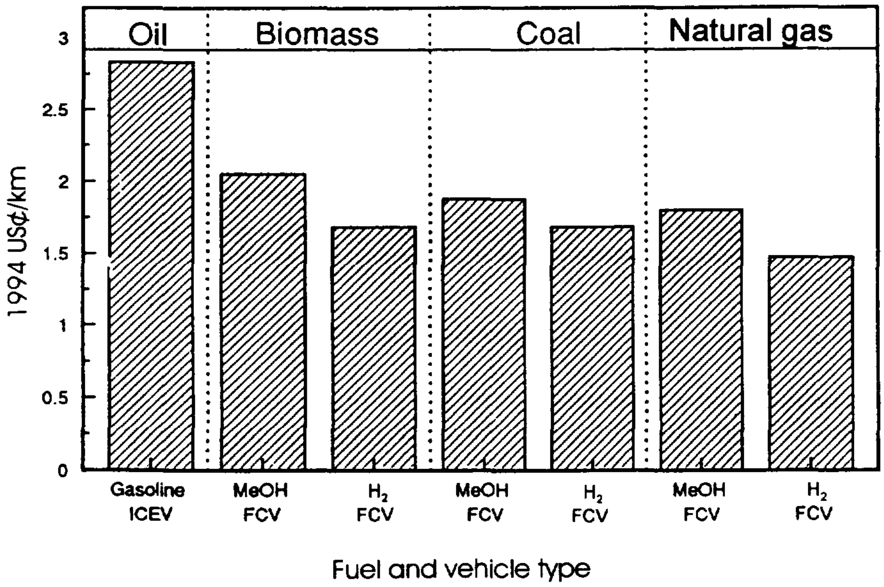
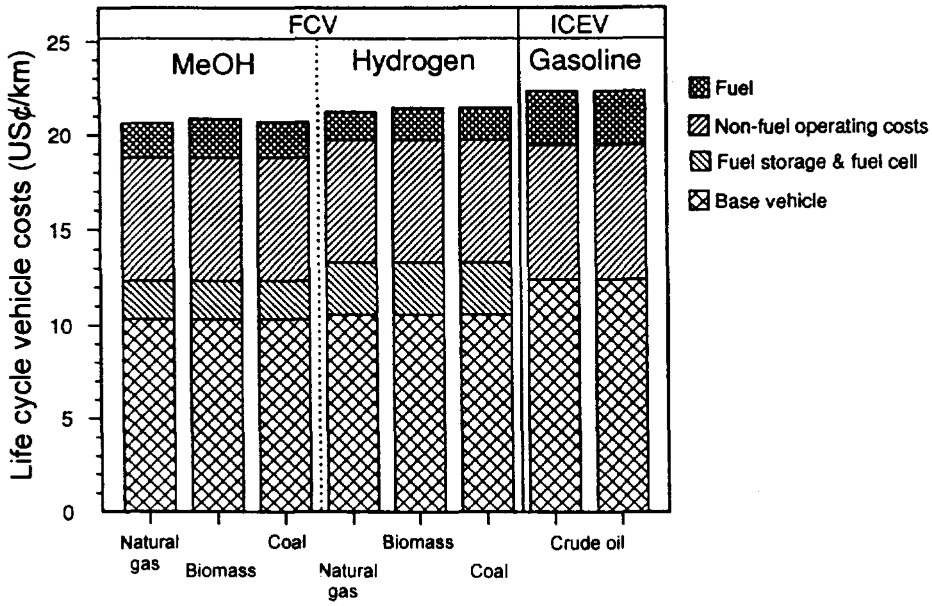


Figure XVII.7. Estimated life-cycle costs for FCVs fuelled with MeOH and H_2 derived from alternative feedstocks, with a comparison to the life-cycle costs of an ICEV fuelled by reformulated gasoline (Fuel costs are drawn from table XVII.6)



Source: I. M. Ogden, E. D. Larson and M. A. DeLuchi, *A Technical and Economic Assessment of Renewable Transportation Fuels and Technologies* (Washington, D.C., United States Congress, Office of Technology Assessment, 1994).

C. Biomass supply issues

To this point, the discussion of the economics of electricity and fuels production from biomass has assumed that a substantial biomass resource would become available. In this section, some issues pertaining to the availability of biomass and its cost, are considered, along with some potential positive socio-economic roles for biomass industries in developing countries.

1. Availability of land

Developing countries have potentially large economically exploitable biomass resources. In the IPCC energy scenario that envisions a biomass-intensive supply future [1], developing countries provide two thirds of the biomass resources used globally for commercial energy-some 50 EJ in 2025, consisting of agricultural and industrial residues, biomass sustainably recoverable from forests and biomass grown on dedicated plantations. In such a scenario, deforested or otherwise degraded lands that are not needed for food production might be targeted for biomass plantations in developing countries. One estimate of the availability of such lands is that 2077 million hectares of tropical lands are degraded, of which 758 million hectares can potentially be reforested [37] (see table XVII.7). The fact that many successful plantations in developing countries have been established on degraded lands [38] suggests that it is possible to deal successfully with the challenges of revegetating these lands with energy crops.

Table XVII.7. Geographical distribution of tropical degraded lands and potential areas for reforestation

(Millions of hectares)

Region	Logged forests	Forest fallows	Deforested watersheds	Desertified drylands	Total
Latin America	44	85	27	162	318
Africa	39	59	3	741	842
Asia	54	59	56	748	917
Total	**137**	**203**	**87**	**1,650**	**2,077**
Suitable for reforestation		203	87	331	621

Source: A. Grainger, "Estimating areas of degraded tropical lands requiring replenishment of forest cover", *International Treecrops Journal*, vol. 5, 1-2 (1988) and "Modelling the impact of alternative afforestation strategies to reduce carbon emissions", *Proceedings of the Intergovernmental Panel on Climate Change Conference on Tropical Forestry Response Options to Climate Changes*, Report no. 20P-2003, Office of Policy Analysis, United States Environmental Protection Agency, Washington, D.C., 1990.

While the use of degraded lands would appear to be a potentially important and attractive option for biomass energy crops, concerns about future food supplies could mean that large land areas will not after all be available for biomass production for energy purposes in some developing regions. Indeed, some analysts have concluded that it will be difficult to expand food production enough in developing countries to keep up with population growth, largely for environmental reasons [39, 40]; they call attention, for example, to the recent downturn in world cereal production per capita [41].

The outlook for future food production may not be so bleak, however. Dyson [42] points out that the main reason for the recent decline in world cereals production per capita has been the reduction in the amount of land committed to cereals production, especially in the United States, Canada and Latin America, as a result of extremely low world prices for cereals. Potentially, productivity improvements could make it possible to meet world food requirements to the middle of the next century with little or no expansion of cropland [43, 44]. If the long-term sustainability of input-intensive agricultural practices can be demonstrated, food requirements need not significantly limit the use of land for energy crops.

A recent preliminary analysis of the biomass production potential of Latin America, Africa and Asia [45] suggests that land resources may well be sufficient to support a biomass-intensive energy future in developing countries without compromising food production needs. To estimate the land required for food production, this study used United Nations [46] population projections for the year 2025, assumed increases in cereal yields commensurate with recent historical trends for each region and allowed for an increase in domestic food production for each country such that currently unsatisfied minimum calorie requirements would be met by 2025. It was found that after allowing for the required expansion in cropland, substantial land resources remained that were potentially suitable for biomass plantations.

Ravindranath and Hall [47] conducted a comprehensive study of the prospects for large-scale commercial biomass energy in India, where high population density presents a particularly pressing challenge for food. They suggest that by increasing cropland under irrigation, expanding the application of organic and inorganic nutrient inputs and increasing reliance on high-yield varieties, food production can more than keep pace with population growth rates and there will be no need to increase the area of land under cultivation. Indeed, such advances helped food production per capita to increase from 1970 to 1990 in India despite a 60 per cent growth in population and an unchanged area of land under cultivation.

2. *Cost of plantation-grown biomass*

Since no plantations now exist for growing biomass for energy, costs of plantation-grown biomass must be estimated based on experience with similar agricultural enterprises, such as growing trees for pulp and paper. A United States Department of Energy/Department of Agriculture study [48] estimates the costs of producing plantation biomass in the United States at various levels of supply, with current and future biomass plantation technology as projected by bioenergy researchers at the Oak Ridge National Laboratory. A related study carried out by the United States Environmental Protection Agency [49] estimates biomass prices under the same technical assumptions about yields and costs but also takes into account the effects of land use competition, which leads to higher land rents and thus higher biomass prices. In the latter study it is estimated that with current biomass plantation technology (not yet commercial but as demonstrated in field trials), some 3 EJ/yr of plantation biomass could be produced in the United States at prices up to US$ 2.15/GJ, and that the potential supply at this price would increase to 8 EJ/yr with plantation technology projected for the year 2020.

In many developing countries, the growing season is longer than in the United States, so biomass production costs can be expected to be lower. An extensive study of the potential production of plantation-grown biomass was conducted for the north-east of Brazil [30] based on detailed surveys of bioclimatic characteristics and experience gained from existing eucalyptus plantations. The study concluded that more than 12 EJ of biomass could be produced using only land deemed sub-optimal for agriculture, at a cost of less than US$ 2/GJ. The study of biomass production potential in Africa, Latin America and Asia referred to above [37] found that it may be possible for 60 EJ per year to be produced at this cost in 2025, of which 20 EJ could be produced at a cost as low as US$ 1.50, if 10 per cent of the land area that is not forest, not wilderness and not needed for food production in 2025 were to be used for biomass energy plantations.

3. *Jobs and infrastructure for rural areas*

In addition to making available energy at competitive costs, biomass plantations offer the social benefit of directly providing jobs in rural areas of developing countries, helping to stem unsustainable urban migration. Based on large-area (tens of thousands of contiguous hectares) commercial eucalyptus plantations in north-east Brazil, Carpentieri and others [30] estimate that the employment generation is from 1.9 to 3.6 direct jobs per square kilometre. While this level of employment is fairly modest, the availability of low-cost electricity from biomass could catalyse rural industrialization, attracting further employment-generating activities to rural areas, specifically energy-intensive industries that frequently offer well-paying jobs.

It is sometimes argued that if large energy-consuming industries are not already established in rural areas there would be no market for the electricity that would be produced by large (tens of megawatts of installed capacity) biopower plants, a classic chicken-and-egg problem. However, a rural industrialization strategy propelled by biopower would not necessarily require a high level of coordination between biopower plant construction and the construction of energy-consuming factories in rural areas, although such coordination would be desirable. If initially there is not enough local demand to utilize all the electricity being generated, the excess could be transported by wire to urban centres (as hydroelectricity is transported from remote sites in many countries today). Even though this electricity would not be as cheap as that made available near the plant site, the extra electric transmission costs should not be prohibitive, because biopower plants would provide mainly baseload power and transmission lines would therefore tend to operate at a high capacity factor, thus reducing unit transmission costs. This is in contrast to the reverse situation, where centralized power plants near urban centres are used to provide electricity for dispersed rural consumers who typically have sporadic demand profiles; in this situation the transmission lines are often poorly utilized and unit transmission costs are high.

A rural industrialization effort that starts by building privately owned biopower plants can provide a substantial tax base for supporting local infrastructure-building, if the taxation system is designed such that most if not all of the revenues are used for this purpose instead of being diverted to the urban sector. Rural areas can draw on such a tax base to help finance the building of infrastructure that would attract a wide range of energy-using industries, infrastructure for conventional public services (schools, hospitals etc.) and effective programmes for serving basic needs of the poorest, such as small-scale biogas energy systems for villages [50]. As biopower plants begin to attract power-consuming firms to rural areas, these firms could further add to the rural tax base.

Rural-based industries could be taxed in various ways. The taxation method chosen will reflect cultural preferences as well as considerations of economic and administrative efficiency. In the United States, property taxes on businesses and homes are levied to support much local infrastructure-building. A property tax levied on a rapidly growing capital-intensive industry such as the electric power industry could provide an enormous tax revenue base. To illustrate the potential magnitude of the revenue base, without passing judgment on the relative merits of property taxes vs. other taxation instruments, suppose that a 1.5 per cent property tax were levied on biopower production facilities. (A 1.5 per cent/yr tax on the installed capital cost is a typical rate for investor-owned power plants in the United States.*) Such a tax applied to a 113 MWe BIG/ISTIG power plant would amount to a surcharge of only US$ 0.0027/kWh (i.e. roughly 6 per cent) (see table XVII.2), but the tax revenues would amount to US$ 1.9 million per year, or $59 million over the 30-year life of the plant. Such a locally based revenue stream for the support of rural development might be more attractive politically than the alternative of direct government funding, at least from the standpoint of the urban taxpayer.

D. Conclusions

The results of several recent studies that have explored energy supply scenarios for the twenty-first century suggest that biomass could play an important role in sustainably meeting energy needs [1, 51, 52]. A unifying assumption for all of these scenarios is that biomass technologies must be modernized to make them economical. The analysis presented in this paper of the costs of biomass-derived electricity not in OCE and fluid fuels suggests that modest technological advancements will make biomass competitive with fossil energy sources in the first decades of the next century. In many developing countries, important ancillary benefits derive from the development of a biomass-based energy economy since biomass is domestically available and its production is labour-intensive and based in rural areas. These benefits justify the expansion of modernized biomass-based energy not only as a response to the threat of climate change and fossil resource depletion, but also as part of a strategy for global sustainable development.

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*This is the value of the tax levelized over the life of the plant.

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XVIII. THE EXTERNAL COSTS OF ELECTRICITY GENERATION: A COMPARISON OF GENERATION TECHNOLOGIES

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Abstract

Electricity generation, like any economic activity, leads to costs that can be grouped in two categories: (a) private or internal and (b) external. Private costs are those paid by the buyers and sellers of energy within the market system. The external costs, however, are not included in the market price mechanism as they accrue to third parties other than the buyer and the seller. External costs include environmental external costs and non-environmental external costs.

There are two conditions for the existence of external costs:.(a) market failure, or the inability of markets to account for the cost of environmental impacts of energy generation and the market structure and (b) government or policy failure, or the policies that cause private generators to pay either higher or lower costs than they would if these interventions did not exist. A third reason can be added for the existence of non-environmental externalities: energy security, or certain costs faced by society as a result of overreliance on imported energy.

Section A introduces the concept of external costs and benefits. Section B looks at the environmental externalities of energy generation. The procedure is to develop the methodology to estimate what are known as externality adders, i.e. a monetary value for the environmental costs and benefits associated with selected generation technologies, expressed in pence per kilowatt-hour. The result is an "adder" because, in principle, the sum can be added to the private cost of generating electricity to obtain a measure of the "full" or "social" cost. The selected generation technologies are conventional coal, wind power, small-scale hydro, energy crops, incineration of municipal solid waste and energy recovery from landfill. The data reported are based on the application of the technologies in Scotland, but the methodology can be applied anywhere.

Section C takes a brief look at the non-environmental externalities including the general theory and evidence from the United Kingdom, including the non-fossil fuel obligation, a system for encouraging energy generation from nuclear fuels and renewable resources. Section D discusses various strategies for internalizing external costs of conventional forms of energy, including emission taxes and tradable emission permits.

Introduction

In the light of increasing energy demand and the unwanted environmental impacts of fossil fuels, biomass energy sources are one of the alternative renewable resources in developing countries. Despite this, biomass and other renewable energy sources face difficulties in gaining a place in the energy market. This paper aims to introduce a methodological framework within which the costs of environmental impacts from different fuel sources can be compared.The methodology is illustrated with an example from the United Kingdom, more specifically Scotland. Although such an exercise is not within the scope of this paper, the environmental cost estimates can be added to the financial costs of different fuel sources to enable a complete comparison. In short, the paper aims to provide decision makers with a more comprehensive analysis tool than simply the financial concerns.

Section A introduces the concept of external costs and benefits, which are the fundamental basis of monetizing the environmental impacts of economic activities. Section B outlines the concept of environmental externalities, a methodology for estimating and comparing the social cost of electricity generation by different fuels, namely wind, small-scale hydro, energy crops, landfill with energy recovery, municipal solid waste incineration and conventional coal. The methodology is illustrated by a case study of energy production in Scotland.

Section C gives a brief overview of the non-environmental externalities, including the general theory, and experience from the United Kingdom, including the NFFO, which is a system for encouraging energy generation from nuclear fuels and renewable resources.

Section D discusses various strategies for internalizing the external costs of conventional forms of energy, such as emission taxes and tradable emission permits.

A. The concept of external costs and benefits

Electricity generation, like any economic activity, leads to costs that can be grouped in two categories:

- Private (internal) costs
- External costs.

Private costs plus external costs equal social costs.

The internal costs of generating a kilowatt-hour of electricity are those borne by the generator and hence reflected in the market price charged to consumers. The external costs of generating a kilowatt-hour of electricity are those borne by society, which are not compensated by the generator or user of electricity and which are therefore not included in the market price. Such external costs would include both environmental damages due to electricity generation (environmental externalities)* and distortions to various fuel cycles due to government intervention, market failure and energy security (non-environmental externalities).

Full social cost pricing implies that both private and external costs and benefits are included in the pricing of the electricity. So it is necessary to identify the external costs and include them in the market price. The relevant formula for electricity expresses price as the sum of three marginal costs.**

$$P = MPC + MEC + MUC$$

where P = optimal price of electricity, MPC = marginal private cost of generation and transmission, MEC = marginal external cost of generation and transmission and MUC = marginal user cost. MUC, which is designed to capture the cost in the future of using up a unit of a non-renewable resource today

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*Some environmental damages are internalized by regulations, e.g. limits on SO_2 emissions from power stations. Thus these costs will be borne by the power generator and will no longer be an externality.

**Price is determined with reference to the cost of an additional unit, which is referred to in economics as a marginal unit. In the case of electricity, this is the cost of producing one more unit of electricity.

(it is a scarcity premium) is not covered in this paper. In general, markets will internalize user costs since producers will be aware of future scarcity. But user cost can be important in project appraisal where optimal prices are being determined at the outset.

MEC consists of both environmental and non-environmental externalities, so the relevant formula is:

$$MEC = MEE + MNEE$$

where *MEC* = marginal external cost, *MEE* = marginal environmental externality and *MNEE* = marginal non-environmental externality.

Environmental and non-environmental externalities can have both a positive and a negative sign. This depends on whether they increase or decrease the costs borne by the generator. For example, a subsidy given to nuclear energy lowers the costs paid by a nuclear generator but is borne by society through higher taxation. It is, therefore, external to the price of electricity. The value of this subsidy should be added to the marginal private costs to increase the price of nuclear energy to obtain a true estimate of marginal social cost. But the United Kingdom domestic coal premium (abolished after March 1993), under which electricity generators were obliged to buy a certain amount of domestic coal, increased the costs paid by a generator. In this case, the full social cost pricing would be calculated by subtracting the cost of this distortion from the current price of coal.

B. The concept of environmental externalities

The conventional market does not account for the cost of environmental impacts of economic activities including energy generation. There are two conditions for the existence of external costs:

- *Market failure*. For most environmental goods and services, markets simply do not exist. This leads to their over exploitation, including the assimilative capacity of the environment.

- *Government or policy failure*. The policies that alter the cost of energy generation or the price of electricity so as to increase the environmental impacts of generation and overuse of natural resources include input subsidies, output price controls physical output targets, exchange controls and tariffs.

The methodology adopted here is the application of economic valuation techniques to estimate what are known as "externality adders". This adder approach has two attractions:

- It permits a direct comparison between the generation technologies in terms of their environmental impacts.

- It permits some comparison with the private costs of generation.

Externality adders enable these comparisons by reducing varied impacts to a common unit: money. In turn, the monetary unit reflects the individuals' preferences in the market-place or preference for non-market outcomes, which can be inferred from behaviour in other markets or from direct expression (in surveys, for example) of willingness to pay for environmental goods and services.

1. Methodology

This subsection presents a methodology for estimating the environmental externalities of different generation technologies and comparing them with each other step by step. The methodology can be applied anywhere in the world and for any generation technology provided that the necessary information is available. It is illustrated with an example of the choice of generation technology in Scotland.

(a) Identify the potential environmental impacts of energy generation

Each energy generation technology, whether different fuels are used or the same fuel is processed in different ways, has environmental impacts on air, water and land and creates noise, odour and visual intrusion. Details of detecting and measuring these environmental impacts were presented in Chapter XV. What is especially important for the externality adders methodology is to determine, as a first step, the effect of these environmental impacts on receptors or stock at risk, including human populations, forest stock, number and type of buildings, crops and fisheries.

(b) Distinguish generic, semi-generic and site-specific externalities

The second step is to categorize the environmental impacts into generic, semi-generic and site-specific externalities.

An externality is said to be generic when a given amount of "emission" has, broadly speaking, the same amount of "impact" regardless of where it is emitted. In other words, the impact of a unit of pollutant emitted will not be altered by the receptors it affects. For example, a unit of a greenhouse gas such as CO_2 is assumed to make the same contribution to global warming damage wherever in the world it is emitted.

An externality is site-specific when a given amount of emission has a different amount of impact, depending on where it is emitted. Thus the impact is entirely conditional upon which receptor is affected. Examples are disamenity, visual intrusion, noise and odours. Noise and visual intrusion will, accordingly, depend on the site characteristics, in terms of the existing landscape, the background noise and the distance from the source. Although at a global scale these externalities are negligible, they usually have very significant impact on the local population and hence on public policy for the siting of renewable and conventional generation technologies.

Semi-generic externalities fall between the two categories above. Thus the damage to biodiversity may be highly site-specific but resulting in the loss of biodiversity could contain some generic elements. Other semi-generic externalities include the damage from conventional air pollutants such as SO_2, NO_x and particulate matter. These gases can travel in the atmosphere, creating damage at a distance from the area where they are emitted. Transfer matrices exist showing how much SO_2 and NO_x fall on to Europe from a European country [1].* Although the evidence shows particulates to lead to semi-generic externalities, there are no data to show the magnitude of this impact.

The differences among these three categories have implications for the way the externality adders are calculated. Moving from generic to site-specific externalities, the degree of generalizability declines. For some site-specific externalities such as visual intrusion, generalization is not possible at all.

Another way to categorize externalities is by whether they are fixed or variable. For variable externalities, the size of the externalities depends directly on the output of the plant. For instance, greenhouse gas emissions are directly related to the fuel input, e.g. biomass, to the power station. For fixed externalities, by contrast, the impact is related to the existence of the plant, regardless of its size. For instance, visual intrusion is directly related to the existence of the power station building or wind

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*"Europe" refers to the countries within the boundaries of the Economic Commission of Europe.

turbines and plant capacity has no significant effect. The case study in this paper [2] concentrates on generic and semi-generic air pollution.

(c) Carry out a life-cycle inventory of each technology

A fuel cycle is characterized by all of the stages of processing energy, from its extraction through various conversion processes to the distribution of electricity to consumers. The externalities of using fossil fuels for electricity production have typically been analysed by considering the whole fuel cycle. This ensures a genuine comparison between different fuel cycles.

The use of renewable biomass (whether energy crops or solid waste) has many of the same features as the use of fossil fuels and is therefore amenable to the same type of analysis. However, other renewable energy technologies such as wind turbines and hydropower differ significantly from thermal generation based on heat engines. In particular, wind and water are naturally occurring "fuels" at the point of use, so there is no upstream fuel cycle, in the sense of the fuel extraction, transportation and processing required for combustion. The fuel cycle is therefore straightforward, consisting of only the wind turbines or hydropower plant and any extension of the electricity distribution network required to link the turbines to the electricity grid.

Neither the (non-biomass) renewable power plant nor the power line are polluting, in the usual sense of emitting chemical substances into the environment during operation. At first sight, it might therefore be thought that these fuel cycles will have no impacts resulting from chemical pollution. However, emissions of this type are involved in the processes required to manufacture and construct the generation and transmission equipment. These processes are the "life cycles" of the equipment used in the renewable "fuel cycles". The distinction between "fuel cycle" and "life cycle" analysis is frequently obscured in the literature but is important in this analysis. Whereas the fuel cycle follows the energy flow from resource to final user, the life cycle follows the material involved in any product or equipment, from cradle to grave.

Since for renewable power plants, it is the non-operational parts of the life cycle that are the major emitters of chemical pollution, these sources need to be included if chemical pollution due to renewables is to be analysed. This should not be interpreted as meaning that the operation of wind turbines and hydropower plants is free of all environmental externalities: indeed, noise, visual and other amenity effects may be of concern, as mentioned above.

A typical life-cycle inventory of an energy-generating technology has the following stages:.resource extraction; resource transportation; materials processing; component manufacture; component transportation; plant construction; plant operation; plant decommissioning and product disposal. It is necessary to determine the boundaries for these stages before the life-cycle inventory is estimated. The following are issues related to the boundary problem:

- The spatial boundary of the analysis is determined by the range of the effect. For example, acid deposition is a regional problem, and greenhouse gas emissions are a global problem.
- For some of the pollutants considered, there are natural as well as anthropogenic emissions, and it would clearly be wrong to treat the impacts of natural emissions as energy externalities. The correct approach, used here, is to estimate the marginal impacts due to anthropogenic emissions as the basis for valuation. This is especially a problem for global warming. The enhanced greenhouse effect that is predicted to cause global warming arises only because of variations in natural cycles in the atmosphere/surface ocean/biosphere system attributable to (a) the combustion of fossil fuels,

introduces new carbon into the system and (b) reductions in the pool of carbon in the biosphere due to deforestation.

All fossil fuel combustion is therefore implicated in global warming, but biomass combustion contributes only to the extent that the biomass is not sustainably produced. The commonest methodological approach, which is used here, is that it is non-sustainable agricultural or forestry practices that are responsible for the carbon emissions. Biomass combustion is then treated as having zero CO_2 emissions, the actual emissions being assumed to be balanced by uptake of CO_2 in photosynthesis at the biomass source.

The life-cycle analysis yields emission factors for the energy technologies, i.e. units of emissions per kilowatt-hour of electricity generated.

(d) Identify the displaced fuel source and the baseline for renewable energy technologies

In the comparative analysis of renewable and conventional fossil fuel energy generation, the.assumption is made that each unit of electricity produced by the renewable energy replaces electricity that would have been produced by a conventional technology. In other words, since the scientific evidence shows that renewable energy is less environmentally damaging than conventional fuel sources, it should be credited with the benefit of avoiding the environmental impacts from conventional technologies. Thus, the external cost of conventional energy generation becomes the external benefit of renewable energy generation.

The conventional generator that will be displaced is called the displaced fuel source. The displaced fuel source may vary both daily and seasonally. At times of high demand, even the less efficient (and therefore usually more polluting) plant is used, so that, in general, the benefits of displacing pollution might be expected to be higher in winter and during the day.

At any given time, the identity of the displaced electricity source will be largely independent of the new renewable source. However, averaged over the whole year, the electricity displaced will be a function of the daily and seasonal availability of different sources. Plants that burn energy crops, solid wastes or landfill gas all have a high availability with no particular seasonal or daily variation. However, wind and hydropower rely on natural resources that are variable. Hydropower is winter-peaked, as, to a lesser extent, is wind power. However, the extent of this effect is difficult to estimate, and there is no reason to believe that wind or hydropower will displace electricity from fuels other than other renewables.

At the penetration rates envisaged for new renewable sources for the near future, the intermittency of some of the sources does not have any significant effects for the electricity system as a whole [3], so considerations of additional backup plant etc. are not important.

In the case study presented here, it is assumed that the displaced fuel source is the source at the bottom of the merit order in the electricity grid system. For many countries, including the United Kingdom, this source is coal used in a conventional power station with minimum environmental controls. The case study uses the Cockenzie coal-fired power plant in Scotland as the displaced fuel source. This plant uses a high-sulphur (1 per cent) coal and it has a low efficiency factor and no sulphur or nitrogen abatement technologies.

"Baseline" is what would have taken place in the absence of the renewable technology. Comparison between two alternatives in economic terms should refer to a baseline case where none of the alternatives take place. This is also known as the with/without principle of cost-benefit analysis, which is applicable mainly to generation technologies where land use and waste are involved. If a given technology involves a particular land use, then the baseline is what would have happened without the technology. The same problem arises with energy from waste technologies, where it is necessary to identify what would have happened to the waste without the technology. The following are the baselines identified for the case study presented here:

Renewable technology	*Baseline*
Wind	No wind technology, i.e. externalities are zero
Small-scale hydropower	No hydro technology, i.e. externalities are zero
Energy crops	Land left fallow
Landfill gas combustion	Landfill with flaring of gas
Municipal solid waste	Landfill with flaring of gas
Agriculture and forestry waste	Landfill with flaring of gas

Once the baseline scenarios have been identified, they too must be quantified in terms of external costs and benefits. Thus landfill gas combustion must be compared with the emissions that would have arisen if the gas had been flared instead. This is because what matters is the net change in externalities as a result of the provision of renewable technology. Thus, for example, it would be incorrect to compare the externalities of an incineration plant with a situation of zero externalities, since even without the incinerator society would have had to find some way to dispose of its waste.

The emission factors presented in the case study are life-cycle emissions from each energy technology net of the emissions from baseline (see table XVIII.1).

Table XVIII.1. Emission coefficients
(Grams per kilowatt-hour)

	Generic pollutants			**Semi-generic pollutants**		
Energy	**CO_2**	**CH_4**	**N_2O**	**SO_2**	**NO_x**	**Particulates**
Wind	7	0.03	0.001	0.08	0.04	0.003
Hydro	12	0.04	0.001	0.12	0.07	0.004
Energy crops	45	0.4	0.02	0.12	1.2	0.1
MSW Combustion	451	-35.9	-	1.28	2.07	0.14
Landfill gas combustion	-	0.02	0.03	0.013	2.80	-0.1
Coal-fired power plant	945	3.2	0.07	7.8	4.1	0.34

Source: Centre for Social and Economic Research on the Global Environment (CSERGE), Economies for the Environment Consultancy (EFTEC) and Eyre Energy Environment (EEE), *Assessing the Environmental Costs and Benefits of Renewable Energy Technologies in Scotland*, report prepared for the Scottish Office, Industry Department, Edinburgh, 1994.

(e) Unit monetary costs of environmental externalities

Economic valuation techniques are used to measure people's preferences for environmental goods and services (for a detailed examination of these techniques, see Freeman [4] and Pierce and others [5]). These measurements are used to estimate the environmental externalities as categorized above. For generic and semi-generic externalities, the dose-response function is the most widely applied technique. This technique first sets out the physical relationship between a unit of pollutant (dose) and the environmental impact it causes on a given receptor (response). The impact is then valued either by using market values (e.g. value of crop loss at international prices or hedonic house price technique) or by estimating what people are willing to pay to avoid that impact or willing to accept in compensation for it (e.g. contingent valuation and contingent ranking methods).

The rest of this section presents the valuation techniques used by the Commission of the European Communities research programme [6] which are also used in the case study to estimate the cost of semi-generic air pollution externalities. For all receptors but forests, it is assumed that even the first unit of pollutant causes damage, i.e. there is no threshold effect. The analysis for forests assumes that there will be no environmental damage to forests (zero response) until a certain level of pollution is reached, beyond which environmental damage occurs. This causes forest damage to be much smaller than damage to other sectors.

- *Human health.* The monetary damage estimate is based on the value of a statistical life (VOSL), medical expenses, the value of working days lost and willingness to pay to avoid respiratory symptoms. VOSL is estimated by using a combination of surveys and other techniques to estimate the value of a reduction in the risk of dying.

- *Buildings.* The damage cost estimate is based on the cost of repair and maintenance of damaged buildings and materials, i.e. the estimate is the result of a clean-up (replacement) cost approach. The cost for historic buildings will be higher than just the clean-up cost owing to the cultural and social values attached to such buildings. These have not, however, been estimated.

- *Crops.* Damage attributable to acidifying pollutants is estimated by using the market value of crop yield loss at international market prices.

- *Forests.* Damage is estimated from the market value of timber growth loss at international prices. The value of the forests as a recreation source and carbon sink is not estimated.

- *Fresh water.* Acidification of fresh waters reduces the commercial fish catch and the recreational value, especially for angling. However, this loss has not been quantified in the current literature. Instead, the cost of liming fresh water lakes as a remedy to acidification is used.

Generic externality, i.e. global warming, estimates for the environmental externalities of greenhouse gases are taken from a study by Fankhauser [7]. That study uses a Monte Carlo simulation to calculate costs over four decades between 1991 and 2030. It treats the discount rate as a random variable with lower and upper limits of 0 per cent and 3 per cent and a best estimate of 0.5 per cent. Unlike most other studies, it uses expected values rather than best estimates. This reflects the fact that global warming damage is not distributed symmetrically but skewed to the right since extreme events will have very high costs. This use of expected values generates slightly higher damage costs than some other studies. But the use of expected values and a low discount rate seems entirely justified in view of the consensus that a conservative principle should be adopted when dealing with high-risk outcomes such as global climate change.

Table XVIII.2 summarizes the methodology outlined above. Table XVIII.3 shows the estimates of environmental externalities due to pollutants emitted from the United Kingdom. As mentioned above, the estimates for generic externalities (CO_2, CH_4 and N_2O), include the impact of United Kingdom emissions on the whole world, while the estimates for semi-generic externalities (SO_2, NO_x and particulates smaller than 10 μ in diameter) include the impact of United Kingdom emissions on Europe (Economic Commission for Europe region).

Table XVIII.2. Methodology for estimating externality adders

External cost (£/kWh)	Factor (tonnes/kWh) x (£/tonne)
External cost of renewable energy (A)	Emmission factor x unit monetary cost
External cost of displaced fuel source (external benefit of renewable energy) (B)	Emission factor x unit monetary cost
Net externality adder for renewable energy	B-A

Note: If step C produces a negative number, the external cost of renewable energy is greater than that of displaced fuel and the adder should be added to the market price. If step C produces a positive number, the external cost of displaced fuel is greater than that of renewable energy and the adder should be subtracted from the market price.

Table XVIII.3. Unit monetary costs of environmental externalities in Europe per pollutant emitted in the United Kingdom

(Pounds sterling per tonne)

	Pollutant					
Receptor	**CO_2**	**CH_4**	**N_2O**	**SO_2**	**NO_x**	**PM_{10}[a]**
Human health				1,849-3,672	2,659-3,008	3,450-12,116
Buildings				436	290	229
Crops				32	NQ	NE
Forests				3	NQ	NE
Fresh waters				1	0	NE
Global warming	4	72	614	NQ	NE	NE
Total	**4**	**72**	**614**	**2,321-4,144**	**2,949-3,298**	**3,679-12,345**

Sources: Adapted from Commission of the European Communities, *Externalities of Fuel Cycles "ExternE" Project*, prepared for the DG XI, Brussels, 1995; and S. Fankhauser, *Evaluating the Social Costs of Greenhouse Gas Emissions*, CSERGE working paper GEC 94-01, 1994.

Notes: The ranges for the health damage estimates from SO_2, NO_x and particulates are due to different air pollution dispersion modelling. PM_{10} = particulates smaller than 10μ in diameter, NQ = not quantified and NE = no effect.

Finally, Table XVIII.4 presents the external cost adders for renewable energy technologies, the external benefit from the displaced fuel source and the net externality adders for renewable energy technologies. The externality adder for the conventional coal-fired plant is shown for comparison. As the table shows, all renewable energy technologies have positive externality adders, i.e. net external benefits, when compared to the baseline and the displaced fuel source. Therefore, the value of the adder should be subtracted from private (financial) costs to estimate the full cost price. On the other hand, the net externality adder for a conventional coal-fired power plant is negative, i.e. there are net external costs. In this case, the value of the adder should be added to private (financial) costs to estimate the full cost price.

Table XVIII.4. The externality adders: results
(Pence per kilowatt-hour)

Energy generation technology	**External cost of renewable energy (A)**	**External cost of displaced fuel source (external benefit of renewable energy) (B)**	**Net externality adder for renewable energy (B-A)**
Wind	0.03-0.05	3.55-5.4	3.5-5.4
Hydro	0.06-0.08	3.55-5.4	3.5-5.3
Energy crops	0.44-0.59	3.55-5.4	3.1-4.8
Landfill gas combustion	0.79-0.81	3.55-5.4	2.8-4.6
MSW combustion	0.89-1.32	3.55-5.4	2.7-4.0
Coal-fired power plant	3.55-5.4	0	(-3.55)-(-5.4)

Note: The numbers in the final column are rounded up or down to the nearest first decimal point.

Source: Centre for Social and Economic Research on the Global Environment (CSERGE), Economies for the Environment Consultancy (EFTEC) and Eyre Energy Environment (EEE), *Assessing the Environmental Costs and Benefits of Renewable Energy Technologies in Scotland*, report prepared for the Scottish Office, Industry Department, Edinburgh, 1994.

Table XVIII.4 also shows that the renewable energy technologies can be ranked according to the size of external benefits in descending order:.wind, small-scale hydro, landfill gas combustion and MSW incineration. The results are sensitive to the assumptions about technologies but not limited to the prevailing conditions in Scotland.

C. Non-environmental externalities of electricity generation

"Non-environmental externalities" is a term used to define distortions to various energy markets due to government intervention, market failure and energy security. There are three potential types of non-environmental externalities:

- Market failure in this context refers to the distortions brought about by market behaviour such that society faces higher costs than a generator or distributor does. They can be overcome by using shadow-pricing to force the private generator to bear the full costs. The first instance of non-environmental externality market failure is information asymmetry in the labour market, which means that workers in risky occupations are not fully compensated by higher wages. If this is the case, inherently risky fuel cycles would be paying too low a price for their workers. A second effect of labour market imperfections is geographical rigidity, which means that certain areas experience worse unemployment than the national average. This imposes a cost on society, which can be overcome by shadow-pricing job losses as more detrimental in these regions. Fuel cycles that make workers unemployed in these areas are passing this cost on to society. A third market failure is the public good nature of roads, so that fuel cycles that make a heavy demand on roads are not charged for this, although society faces the cost of congestion, road accidents and road surface damage. This can be overcome by various techniques of marginal cost road pricing. A fourth possible market failure arises from the lack of competition in the energy market, which means that the average price for electricity may be higher than the price that would prevail if competition existed.

- Government intervention failure includes policies that cause private generators to pay either higher or lower costs than they would if these interventions did not exist. These include both direct and indirect subsidies to certain fuel cycles, such as current government spending on R and D, tax allowances for oil and gas exploration and liabilities faced by governments rather than by the nuclear industry. Generators also face direct and indirect taxes that may distort decisions in favour of a fuel. Examples of such taxes in the United Kingdom are the fossil fuel levy and fixed contracts at above market prices with certain fuels.

- Energy security externalities arise since society faces certain costs from overreliance on imported energy. This overreliance may place importing countries at the risk of supply interruptions, which themselves have high costs (outages, lay-offs etc.). The energy security costs can be both political (country A does not wish to be at the mercy of country B, which supplies it with energy) and economic (interruptions of supply cause welfare losses due to unmet demand and energy-price-induced recession). This suggests that a security premium should be added to the price of any fuel that has to be imported.

This simple typology hides a number of complications. First, it is important that in calculating market failure and government intervention, double-counting is avoided. If a government intervenes to "internalize" a market failure, then it would be double-counting to include both distortions. Indeed, the distortions may (depending on the efficiency of the government intervention) cancel each other out. For example, subsidies paid to the coal industry, which constitute government intervention, may be in place to overcome the market failure of labour market imperfections in coal-mining regions.

Secondly, since the main concern is with the current price of new, i.e. marginal, generating capacity, it is important to look carefully at past government expenditures to determine what role any subsidy plays. In a static context, past R and D may be a sunk cost that affects the average price of generating capacity but not the marginal cost. However, within a dynamic context this may not be the case. Past government spending on wind power R and D, for example, will lower the cost of future wind farms, and this will affect marginal prices.

Thirdly, since the concern is with the optimal price for electricity generation, only expenditures that would have been undertaken by a private firm without any subsidy are of interest. Thus even if data on government expenditures for electricity generation exist, the value of the subsidy is not necessarily the total level of expenditure. The value of the subsidy is the amount of expenditure that would have been undertaken by the generator if government spending was zero, i.e. the amount of private expenditure "displaced" by public expenditure. However, this distinction is often difficult to make in practice. For example, one reason for government investment in research is its "public good" nature, which means that the government is making an investment that private firms may benefit from, although for strategic or technological reasons they are reluctant to make this investment.

The rest of this section presents an example of government intervention in the energy market in the United Kingdom. The example has relevance to the utilization of fossil fuels, nuclear energy and renewable technologies in energy generation. The scope and the length of this paper do not allow for a full investigation of other types of non-environmental externalities (see [8] for a detailed analysis of the non-environmental externalities in the United Kingdom energy market).

1. An example of non-environmental externalities from the United Kingdom: the non-fossil fuel obligation and the fossil fuel levy

The non-fossil fuel obligation (NFFO), which was first introduced in 1989, encourages nuclear energy and renewables by mandating a certain amount of non-fossil fuel energy to be bought by regional electricity companies (private regional electricity suppliers) at a price higher than the market level. This price premium, funded by the fossil fuel levy (FFL), acts as a subsidy. As the largest non-fossil generator, the nuclear industry gets the bulk of the subsidy. Thus a non-environmental externality in the nuclear fuel cycle is created, as in its absence nuclear power would be more expensive.* Whether or not the NFFO and FFL act as a non-environmental externality to the renewable fuel cycle is more complex, since it may be that this spending would not have been undertaken by the private sector. Finally, there is the issue of whether or not these government interventions are correcting for certain environmental externalities, primarily the environmental damage of fossil fuels.

The latest Order (NFFO-3) was issued in December 1994 to secure 627 MW of new electricity generating capacity from a range of renewable energy sources [9]. This Order, which covers the period 1 April 1995 to 31 March 2014, was renamed the Non-Fossil Fuel Obligation Renewables Order to separate it from the nuclear industry. NFFO-3 is especially important because its time-frame extends beyond 1998, the year until which the European Commission initially approved NFFO. The Commission sees NFFO for the nuclear industry as unfair State aid and is against its extension beyond 1998. The longer time-frame for the renewable order shows that the European Commission does not have any objections to NFFO for renewable energy.

NFFO not only sets the capacity of electricity supply that must be provided by nuclear and renewable generators but it also sets the price at which this capacity will be purchased. As a result, non-fossil-fuel generators are not only assured that their output will be bought, but they also receive supported prices for their product. Purchasing power from the renewable energy sector.is arranged collectively on behalf of the regional electricity companies by the Non-Fossil Purchasing Agency (NFPA). NFPA buys NFFO capacity at a price above the average price for electricity. The average price paid at the end of 1993 was around 6.8 p/kWh for renewables and 5 p/kWh for nuclear. Under NFFO-3, the average price for renewables fell to 4.35 p/kWh. This shows a move towards the market price for electricity [9].

The difference between the pool price for electricity and the price paid by NFPA to the generators for electricity supplied under NFFO is funded through the FFL. The levy is applied to sales of electricity to the final customer. It is set as a percentage of the value of all leviable electricity sold in England and Wales, where leviable electricity is defined as electricity generated by United Kingdom fossil fuel and nuclear power stations. Thus it does not include renewables or power imported from France.

NFFO had two purposes regarding nuclear power: (a) to increase the cash flow to Nuclear Electric and (b) to help fund inherited liabilities.** These purposes have been criticized as being designed to insulate the industry from fair competition since both are actions that would be taken by the private company in the absence of the government intervention. Thus, it can be concluded that NFFO for the nuclear industry is a type of non-environmental externality.

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*However the net subsidy received by the nucelar industry must take note of the fact that electricity generated by nuclear power is also charged the fossil fuel levy. By contrast, electricity from renewable sources both receives the NFFO subsidy and does not pay the fossil fuel levy.

**Inherited liabilities refer to the cost of treating waste fuel and decommissioning reactors inherited from the public sector by the private company, Nuclear Electric, when it was formed in 1990.

The total liabilities of Nuclear Electric* will be £14.3 billion by March 1998 (in October 1992 prices). Therefore, even if all of the levy collected until 1998, i.e. £9.1 billion, is used to meet the liabilities, the second purpose of the levy–to fund inherited liabilities–cannot be achieved. The Trade and Industry Committee recommended that Nuclear Electric cease to receive income from the FFL and that it cease to be responsible for discharging inherited nuclear liabilities. Instead the levy and the liabilities could be vested in a trust fund.

For renewables, the results of the first order by the then Department of Energy (now part of the Department of Trade and Industry) showed that there have been 75 projects with which regional electric companies concluded contracts [10]. Entirely new projects, which could not have gone forward without the benefit of the above-market price available within the NFFO, account for over half of the projects and over two thirds of capacity. Therefore it is unclear whether NFFO creates a non-environmental externality for renewables, since the government spending in this case does not replace private expenditure. However, in the long run, government intervention through NFFO is intended to make all renewables competitive without a subsidy.

D. Strategies for internalizing external costs

Electricity generation impacts all three environmental media: air, water and land. The scale of this impact varies with the type of fuel and/or technology used. The basis of internalizing external costs is the full-cost pricing. The principle requires that the price of a good or service should fully reflect its total cost of production, including the cost of all resources used. Thus the use of air, water, or land for the emission, discharge or storage of wastes is as much a use of resources as are other labour and material inputs.

The first step in environmental policy should be to remove government failure, i.e. policies that lead to over exploitation of environmental resources, including assimilative capacity. Although such an action may face political difficulties at the beginning, the gains are usually twofold. First, governments could save money by removing subsidies. Secondly, environmental quality could be improved as a result of changes in the incentives and behaviours of individuals and institutions. Even if government interventions that lead to externalities are removed and the market is left to function freely, the full-cost pricing goal cannot be achieved due to market failure. Thus, another form of government intervention is necessary. Governments have two alternatives for including external costs in the price of products:

- *Command-and-control approach.* The enforcement of environmental quality through the setting of standards that must then be adhered to. Examples of this type of environmental policy approach are widespread.

- *Market-based instruments.* Policy instruments that achieve environmental objectives by giving producers economic incentives to lower their level of pollution or their use of natural resources.

With command-and-control approaches to environmental management, a government either specifies the technology that must be used for this purpose (a technology-based standard) or sets an emissions-extraction limit that all sources must meet (a uniform-performance standard). These approaches can be effective in achieving environmental goals but tend to be unnecessarily expensive. The government would need detailed information which is already possessed by the polluters, such as cost

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*Total liabilities consist of inherited liabilities (£9.3 billion) and those arising from generation between 1990 and 1998 (£5 billion).

of compliance with the regulation. The advantages of market-based instruments over a command-and-control approach can be summarized as follows:

- Polluters vary in the ease with which they can abate pollution or reduce resource use. Those that can easily reduce emissions will have an incentive to do so. Conversely, polluters that find it very expensive to reduce pollution can carry on polluting and pay the financial penalty. However, under command-and-control.regulation, each polluter has to achieve a given standard regardless of the individual cost of doing so. The total costs of reducing pollution by a set amount are usually higher under a command-and-control-system.

- Regulations tend to set a floor as well as a ceiling to emission levels. In the command-and-control approach, there is no incentive for the individual polluter and/or resource user to do better than the uniform standard. However, with market-based instruments, where a polluter pays per unit of emissions, a dynamic incentive is retained to always reduce emissions.

- If there are many polluters, under a command-and-control-system the administrative costs of monitoring and enforcing the system can be very high indeed. Regulations work best when they are applied to a few large polluters and users. As pollution increasingly comes from many small sources, the monitoring costs increase and the effectiveness of the regulation decreases. Market-based instruments reduce much of the government's administrative costs.

- Market-based instruments can also bring in revenue. This would be the case if polluter/user prefers to pay the tax rather than see it as an incentive to reduce its environmental impacts. The twin advantages of market-based instruments, revenue raising and altering incentives to change behaviour, may seem to be in conflict. However, this trade-off depends on how individuals respond to price changes, as measured by the price elasticity of demand. To increase revenue, it is best to raise prices for polluters/users who will not change their behaviour substantially (demand with low elasticity). But to change behaviour (incentive setting), it is best to raise prices for those who will respond significantly (demand with high elasticity). The revenues collected by market-based instruments could be invested in environmental protection or used to reduce some other taxation to improve environmental behaviour.

Most market-based instruments create a win-win situation for polluters and resource users. This implies that these instruments increase the efficiency of economic activity as well as environmental performance. This is not the case with command-and-control measures.

1. Characterization of environmental policy instruments

(a) Command-and-control approach

Command-and-control approaches for the control of air pollution from energy generation fall into two broad categories: (a) those that limit emissions to the environment and (b) those that determine the technologies for generation or pollution abatement. Some examples of restrictions on emissions are the following:

- Non-transferable emissions quotas or emissions standards involve direct regulation of the amount of emissions permitted for each individual source.

- Standards for the quality of inputs, are e.g. sulphur content of fuel, an alternative to setting standards for emissions.

Some examples of restrictions on technologies are as follows:

- Technological standards for new sources are similar conceptually to regulation of emissions. They are even more inflexible, however, because they do not allow abatement cost minimization even within the individual firm.

- Technological standards for existing sources may create a bias in favour of new plants.since it may be more costly to convert existing plants to meet the new regulations than to build compliance into the design of new constructions.

(b) Market-based instruments

Market-based instruments can be grouped in two main categories:.(a) those that affect prices directly and (b) those that affect the quantity of the environmental impact directly and prices indirectly. The following are some examples of price instruments:

- Emissions tax, which in most cases is a direct charge applied to the emissions of a given pollutant. It is favoured by economists because it acts directly on the cause of environmental damage and in so doing provides a full range of incentives to reduce damage.

- Input tax, e.g. a fuel tax, which approximates an emissions tax if there is a directly proportional relationship between the input and emissions.

- Differentiated input tax, which can be used if emissions vary directly with the quality of an input. An example is a fuel tax based on the sulphur content of the fuel.

Examples of quantity and price instruments are as follows:

- Emissions quota permit switching, the principle of which is to provide a certain level of control, as under a system of non-transferable emission quotas, while allowing for the same degree of economic flexibility as under a tax-based system.

- Mixed transferable emissions quota and fee/subsidy systems, which entail a non-punitive fee on emissions above the quota and a subsidy on emissions below the quota. A non-punitive fee is a fee intended to be a realistic alternative to meeting a quota rather than a fine or penalty for non-compliance.

(c) Evaluation of environmental policy instruments

Each policy instrument, whether command-and-control or market-based, should be evaluated against the following criteria before a choice is made:

- Economic efficiency, i.e. that costs of abatement under a particular policy instrument relative to the level of emissions abatement achieved.

- Secondary benefits, i.e. the ability of a policy instrument to reduce a secondary environmental impact along with the target environmental impact. For example, many instruments adopted to reduce sulphur emissions will have affect CO_2 emissions, too.

- Administrative costs, i.e. costs accruing to the government as a result of setting up and administering the policy instrument.

- Equity, i.e. the distributional effects of policy instruments.
- Assurance, i.e. the likelihood of meeting a given level of environmental quality.

Table XVIII.5 shows how each policy instrument mentioned above scores against the evaluation criteria. The secondary benefits criterion is not presented in the table since it depends on the specific abatement technology adopted as a result of the policy instrument. The choice of policy instruments would depend not only on the general analysis presented in table XVIII.5 but also on the political, legal and economic conditions in a particular country.

Table XVIII.5. Performance of policy instruments against the economic criteria

Policy instrument	Evaluation criterion			
	Economic efficiency	**Administrative costs**	**Equity**	**Dependability**
Command-and-control approaches				
Non-transferable emissions quotas (standards)	Likely to be poor, i.e. excessive abatement costs. Variable	Depends on the number and size of polluters	No direct redistribution effect, but costs of meeting the standard may be passed on to customers. If so, then there is an equity impact on consumers according to income group	High
Standards for inputs	Likely to be poor	Lower than emission standards	As for non-transferable emissions quotas	Same as emissions standards provided that the relationship between input and emissions is known
Technological standards for new sources	Poor	Lower than others	As for non-transferable emissions quotas. Scheme may act as a.barrier to entry	High for new sources but little effect overall
Technological standards for existing sources	Poor	Lower than others	As for non-transferable emissions quotas. Scheme may favour new sources	More assurance than technological standards for new sources
Market-based instruments				
Emissions tax	Good	Variable depending on the bureaucracy and cooperation	Variable depending on the redistribution of tax revenue	Variable depending on the tax level
Input tax	Good	Less than emissions tax	Same as emissions tax	Same as emissions tax provided that the relationship between input and emissions are known
Differentiated input tax	Very similar to an input tax. The difference is that the emissions vary with the quality of the input, as well as with the quantity			
Emissions quota permit switching	Good	Could be high	Variable depending on the allocation of initial quota permits	Same as emission standards

Policy instrument	Evaluation criterion			
	Economic efficiency	Administrative costs	Equity	Dependability
Mixed transferable emissions quota and fee/subsidy systems	Good	Could be higher than permit switching	Variable depending on the allocation of initial quota permits	Variable depending on the level of fee or subsidy

E. Conclusions

The main emphasis of this paper has been a methodology for estimating the monetary values for the environmental impacts of various energy-generating fuels and technologies. Although most of the research to date has been conducted in Europe and North America, the methodology can be applied in developing countries. In the case of insufficient data, the findings from one country can be transferred to another, taking into account the differences in pollution levels and economic conditions.

The example of a non-environmental externality in this paper is one that has a positive effect on renewable energy resources, i.e. it encourages their application. There are, however, many other examples showing non-environmental externalities that favour fossil fuels and conventional technologies over renewable energy resources. In these cases, such externalities should be handled with more care.

The first step of an environmental policy should be to remove the government failure, i.e. policies that lead to the overuse of environmental goods and services.

The choice of policy for correcting a market failure should be made based on the criteria presented in the paper and the special legal and socio-economic condition of each country.

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Part five

Special papers

XIX. COMBATING DESERTIFICATION - FUEL OIL FROM JATROPHA PLANTS IN AFRICA: A SYSTEMATIC APPROACH APPLIED BY A GTZ-SUPPORTED PROJECT IN MALI, WEST AFRICA*

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Abstract

The use of plant oil as an engine fuel has a long and eventful history, and technical developments have largely been completed. The economic conditions, however, do not yet suffice to produce a breakthrough for plant oil use as fuel in most industrialized and developing countries. The approach applied by a pilot project in Mali and described in this paper tries to overcome these economic drawbacks. The primary aim of the project is not the use of plant oil from Jatropha as a fuel per se, but rather to make that fuel use into an incentive that would activate a system combining ecologic, economic and income-generating effects, the latter specifically for women. These effects could materialize only if the non-edible oil of the jatropha plant can find an economically viable use.

Since jatropha trees (*Jatropha curcas L.*) not only bear oil-rich seed, but can also be planted in the form of hedges to protect gardens and fields from foraging animals while warding off soil erosion, this would seem to be a case of positive correlation between energy production and agricultural production: the more energy that is produced by the hedgerows of jatropha, the more food production is strengthened. Of particular importance here is the recycling of the oilcake as organic fertilizer.

The technologies used in the jatropha system are the well-known hand-driven or mechanically driven oil presses and with precombustion chambers diesel engines. While various makes, the latter are already available on the local market, the presses can be produced locally at affordable prices. The project's activities focus, accordingly, on training and disseminating the relevant know-how. They do this by using local, often non-governmental institutions and by offering advice to farmers and rural communities interested in the jatropha system.

The economic analysis using the UNIDO COMFAR III program shows very positive impacts if both direct and indirect effects are considered. Even in a completely non-subsidized situation in which all investments are financed by agricultural bank credits, an internal rate of return (IRR) of about 26 per cent is achieved. The break-even analysis shows that the system becomes economically viable when the oil press is used at 25 per cent of its capacity.

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*The pilot project "Use of plant oils as fuel" is being financed by the German Ministry of Cooperation for four years and executed by GTZ. Its aim is to prove that the systematic approach is technically and economically viable and is accepted by the rural population.

Introduction

Mali is a typical Sahelian country in which, owing to its large geographical expanse spanning various climatic zones, the ecological conditions found throughout the Sahel are mirrored. Because of this, the efforts being made in Mali to derive value from oil-bearing plants can be taken as representative and used for elaborating a concept for the production and use of plant oils as fuel that is valid for the Sahel region as a whole, and even for other African countries.

The principal energy-related problem in Mali is the fact that the energy needs of its largely rural population are not adequately met. Since it is a land-locked nation without any fossil fuels of its own, it is obliged to spend enormous sums of money to meet those needs. It is also expensive to distribute the imported energy across large distances because of the poor transport infrastructure. As a result, energy prices in many rural areas are much higher than in the capital city. Many remote locations have a difficult time receiving any fuel at all.

The most pressing ecological problem in Mali is desertification, the rate of which is accelerating. It is caused by crop and livestock farming and the cutting and clearing of trees and forests, which places an excessive burden on the fragile ecosystem. This increasing desertification is disturbing the ecological equilibrium and reducing agricultural production in Mali. The associated decline in the country's ability to supply its own food and the deterioration of living conditions, especially in rural areas, are aggravating existing social and economic problems.

On the other hand, Mali is blessed with a large stock of jatropha trees (*Jatropha curcas L.*). Jatropha is a shrublike plant that is grown in the form of protective hedges around gardens and fields to keep foraging animals out of the crops. A non-edible oil, called jatropha oil, can be derived from the seeds of these plants (figure XIX.1) and used as a diesel-oil substitute in suitable engines [1, 2].

Figure XXI.1. Jatropha seeds

Experience with the collection of jatropha seed, with jatropha oil extraction, with the use of the oil in diesel engines [3] and with the use of the oilcake as organic fertilizer was gained during the project's pilot phase.

A. The jatropha system

1. Description

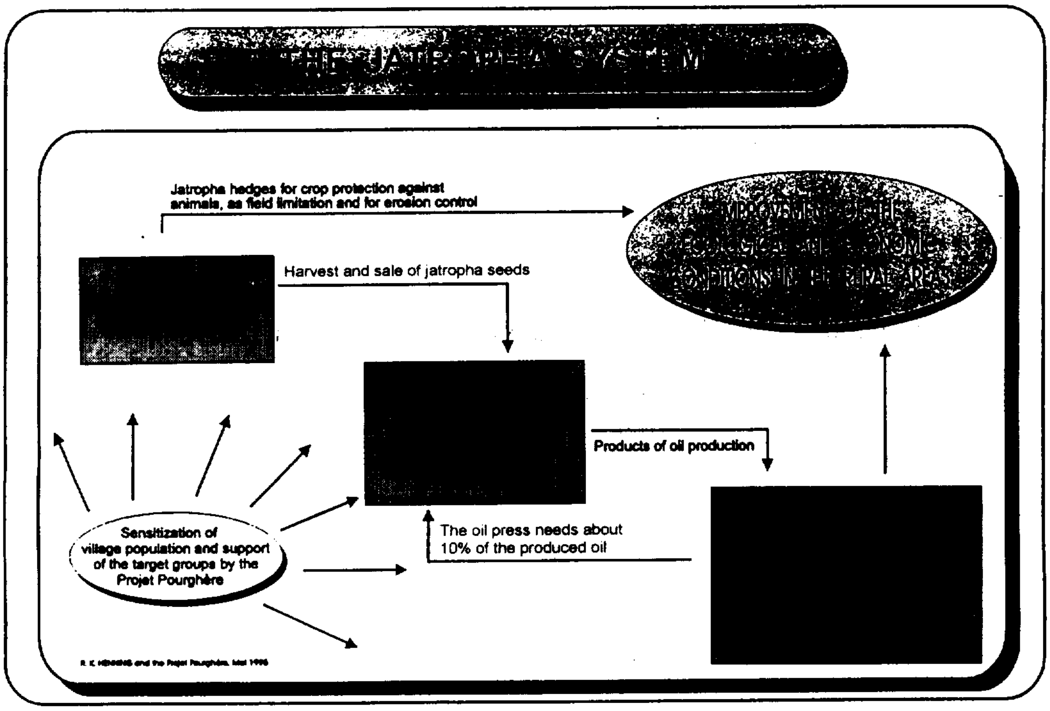
Fields and gardens are fenced in by jatropha trees planted in the form of hedges. These contain unpleasant-tasting and -smelling substances that are unpalatable to animals and therefore safe from being eaten. At the same time, the hedges guard against erosion (wind- and water-induced soil erosion).

Oil can be derived from the seeds using simple devices (hand- and motor-driven presses), and the oilcake left over can also be used as a valuable organic fertilizer (its mineral composition is similar to that of poultry manure [3]). In equivalent terms, the energy needed to produce the oil in mechanical presses amounts to less than 10 per cent of the energy in oil obtained.

After being filtered, the oil can be directly used as fuel in suitable engines [4].

The principal components shown in Figure XIX.2 have been developed and are available for use. Among the various components of the system there exist a host of social, economic, technical and health-related interdependencies, which are described below.

Figure XIX.2. Components of the jatropha system



2. *Components*

(a) *The Plant**

The Jatropha shrub or tree is a ubiquitous drought-resistant plant belonging to the family Euphorbiaceae, making it a close relative of the castor oil plant (*Ricinus* spp.) [5]. Because of its medicinal properties, it is used locally to treat illnesses. In some areas, soap is also made from the seeds. It is therefore generally well known by the population of Mali.

Protective functions

Because of its intensive and unpleasant odour and taste, animals will not eat the jatropha tree. Farmers long ago began to take advantage of this fact, using it to fence in gardens and fields. As a result, fewer crops are damaged by free-roaming cattle herds, a circumstance that greatly promotes the peaceful coexistence of livestock keepers and crop farmers. Some villages have planted up to 40 km of protective hedges nearby (in the Kita region, the average is 5 km per village) [6].

In addition to affording protection against browsing animals, the hedges mark the perimeters of fields in a permanent, indelible manner. This reduces strife between neighbours. When planted along the edges of roads, they also prevent vehicles from giving water-filled holes a wide berth and destroying crop plants in the process.

A particularly important benefit of planting jatropha hedges is erosion control. The hedges break the wind, and the plants, whose roots grow close to the surface, anchor the soil like miniature dykes, preventing it from being washed away. These miniature dykes are effective in slowing surface run-off from downpours, which are common, causing more water to penetrate into the soil and boosting harvests.

Because jatropha seed can be sold, the protective hedges acquire additional value as a quick and direct source of cash income. They are therefore planted primarily for this reason, with erosion control assuming the status of a desirable side-effect (positive feedback between energy production and agricultural production).

To improve soil quality, an improved fallow that entails the planting leguminoses was introduced by the national cotton-growing society. These fallow fields must be protected against being eaten by animals. However since the farmers are unable to afford mechanical fences (barbed wire) for this purpose, the cotton-growing society has advocated the planting of jatropha, and roughly 5,000 km of hedges were planted in 1991 alone. The plans called for another 3,000 km to be planted each year, and from 1992 to 1994, the goal was half-reached.

Harvesting the seeds

It has traditionally been a women's task to harvest the seed, and until recently, they typically transformed the seeds into soap or sold small quantities of peeled nuts at local markets. About 1 kg of nuts can be harvested every year from each meter of hedge [7], and a single person can gather as much as 5 kg an hour with a harvesting device.

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*The information given here is based on surveys, measurements and experience gained during the author's three years working for the GTZ Special Energy Programme in Mali, 1987-1990, and during two years of the present pilot project, 1993-1995. The results are presented in various reports that can be obtained from the project in Bamako and from the GTZ head office in Eschborn.

The main harvest time for the nuts is in August and September, when there is only minimal conflict with other important agricultural tasks (see figure XIX.3 [8]). It is not difficult to store the nuts, since the low relative humidity during the dry season has a preservative effect. Suitable storage facilities can be easily built using local materials.

(b) Oil extraction

The production of edible fats has a lengthy tradition in Mali (e.g. shea-butter), so the extraction of jatropha oil is not a very strange idea. However, the traditional means of extracting oil is not well suited for producing the larger quantities of oil needed to, for instance, power a mill engine (3-5 litres of oil/day). It is therefore assumed that motorized presses must be used when extracting oil as fuel for engines.

Oil presses

A modified worm-type power press that originated in India is being used for oil extraction. The modification consisted principally of replacing the original cast-iron frame with a steel-plate design so that the press can now be made with relatively simple tools in small metal-working shops. Extraction trials with physic nuts yielded very satisfactory results [9].

Jatropha Oil

Because it contains fatty acids, jatropha is quite thin-bodied and well suited for use as an engine fuel, especially at the relatively high temperatures prevailing in the countries of the Sahel. Per unit volume, its energy content is 3 per cent less than that of diesel fuel.

To use cold-pressed jatropha oil as fuel, thorough mechanical cleaning is necessary (sedimentation and filtering) [4]. The oil can be stored without problem in air-tight containers. Polymerization reactions occur if it is exposed to air, but these do not pose a serious obstacle to its use [10].

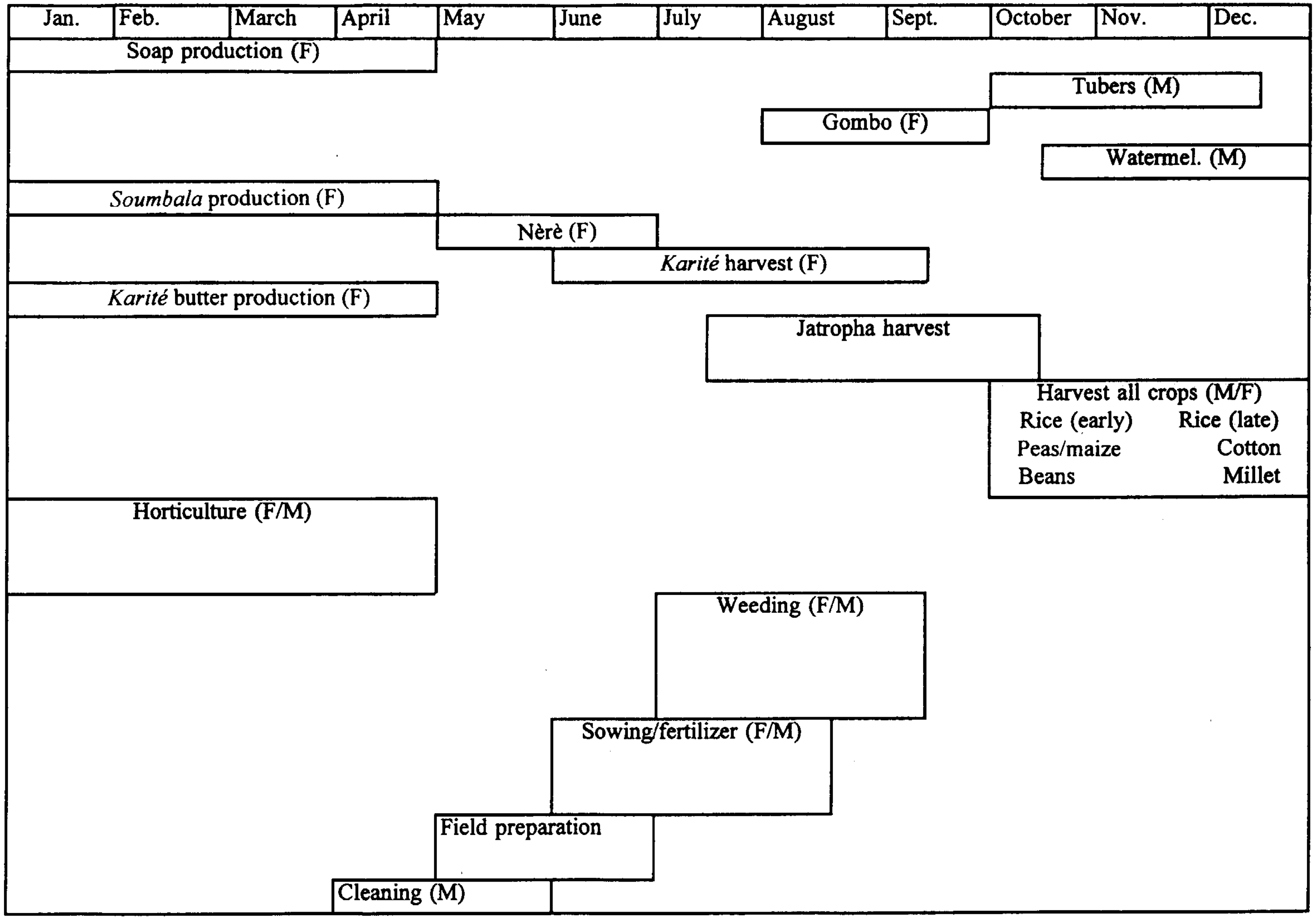
Oil cake

The oilcake that is left over as a solid residue after removal of the oil can be used as an organic fertilizer. This has great value for agriculture in the Sahelian countries (its mineral composition is roughly equivalent to that of poultry manure [3]), since the soils there are rapidly depleted of humus and chemical fertilizers are very expensive. The oilcake can be used much more cost effectively as a nitrogenous fertilizer [11]. The use of the protein-rich oilcake as animal feed is under investigation (it must first be detoxified).

Toxicity

Jatropha oil was tested for possible mutagenic properties by the University of Heidelberg in cooperation with the Heidelberg Cancer Research Center. No evidence was found of any DNA damage, so it can be safely assumed that skin contact with it will not trigger any mutagenic or carcinogenous effects [12].

Figure XIX.3. Farming calendar in the south of Mali



Source: A. Keita, *Produktion und Nutzung von Purgieröl als Kraftstoff in Mali: Sozio-ökonomische Aspekte*, study prepared for GTZ, 1992.

(c) Use of the oil

In engines

In principle, all large-volume diesel engines with precombustion chambers can be fuelled with plant oils (table XIX.1) [13]. One suitable engine type is 912W, the engines made by Deutz, which are used for subterranean mining and for tractors. Type E89 engines made by Hatz are also appropriate because of their robustness [1] [2]. The Hatz engines are especially suitable since their output (8 kW) is large enough to power village mills, and a considerable number of them are already in operation. Hatz stopped the production of its E89 engine in Germany, but a licensed production has started in India.

For use in vehicles, the company Elsbett sells its own three-cylinder engine as well as the modified OM 352 Mercedes engines. Other manufacturers are currently developing and/or testing plant-oil-compatible engines: Dieselmotorenfabrik Schönebeck (DMS), Thüringer Motorenwerke (TMW) and Indian makers of Lister-type engines. The three-cyclinder plant-oil engine [14] that has been developed and produced in small series by Elsbett may not, however, be a good choice because no service network or spare parts are available in developing countries.

For soap production

Jatropha oil lends itself to soap production (figure XIX.4). It can be used alone or in a mixture with other high-quality vegetable oils, such as shea-butter, cottonseed oil or groundnut oil. Owing to the devaluation of the CFA franc in 1994, the importation of vegetable oils to Mali for soap production has been sharply reduced, and the demand for local oils has increased.

Figure XIX.4. Local soap production

Table XIX.1. Overview of plant-oil engines

Engine make	**Deutz**	**Hatz**	**TMW**	**Elsbett**[a]	**DMS**[b]	**Lister-type (India)**
No. of cylinders	2-6	1	4-6	3-6	3-6	1
Serial production	yes	yes	yes	small series	in devlpm.	yes
Injection type	PC[c]	PC	DI[d]	DI	DI	PC
Plant oil compatibility shown by:	Test by Porsche	Test at Cologne Technical College, use by Projet Pourghère	Test by Porsche	Test at University of Siegen	Test in Brasil	Use by Projet Pourghère, test by TMW

[a] Elsbett offers its own three-cylinder engine and a modified Mercedes OM 352 engine.
[b] Licence from Elsbett.
[c] Precombustion chamber.
[d] Direct injection.

Soap production is a very important source of income for the rural women, and the soap is easily sold on local markets. The quantity of oil that can be used in rural areas as a fuel is limited, moreover, by the small number of existing engines.

Other possible uses for the oil

Jatropha seeds are used for a wide range of medicinal applications. There are also signs that compounds with insecticidal and molluscicidal properties (against the bilharzia-propagating snail) can be extracted from it. This is currently being studied by the University of Heidelberg [5][15].

B. Economics*

The basis for the economic calculation is an oil press unit managed by a women's group, which purchases jatropha seeds in the region and sells the final products and services: oil, sediment, presscake and battery charging (part of the oil is used for driving the engine).

1. Financial analysis (microeconomic)

For the purpose of financial analysis (i.e. the calculation of profitability for the owner/operator), three cases using different presses have been studied. These are the Bielenberg, the Sundhara/Lister and the Sundhara/Hatz combination. The underlying assumptions for each case are summarized in table XIX.2, the results in table XIX.3:

- The Bielenberg press, is a hand-operated press with a capacity of about 10 tonnes of seed per year. The investment costs are very low, approximately US$ 100 for the production of the press.
- The second case is a Sundhara oil expeller driven by an Indian-built Lister type engine. The investment costs are high for the press (about US$ 3.000) and relatively low for the plant-oil engine (about US$ 1.000). The engine is used half of the time for milling and the other half for oil extraction. The investment is subsidized.
- The third case is a Sundhara press with an expensive Hatz engine (about US$ 4,500). The investments are completely financed by agricultural bank credits.

(a) Bielenberg Press

The hand-operated Bielenberg press shows an IRR of 75 per cent under the conditions specified by the basic data. An IRR of 75 per cent indicates that the payback period is less than two years.

(b) Sundhara/Lister pressing unit

The Sundhara oil expeller driven by an Indian Lister-type engine shows an IRR of 49 per cent under the assumptions of table XIX.2. In this case the Sundhara expeller is given free to the women's group, which manages the press under the stipulation that the depreciation be paid into a special bank account.

The expeller unit makes four products and services: jatropha oil, oilcake, sediment from the oil filtration and battery charging, which are sold in the proportions shown in figure XIX.5.

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*This economic description is based on a study by H.-J. Wiemer in 1995 [17], who used the UNIDO COMFAR III Expert computer program for his calculation.

Table XIX.2. Basic data for financial analysis

Description	Engine type		
	Bielenberg	Lister	Hatz
Interest rate (discounting rate) (%/yr)	7	7	7
Seed processing capacity (tonnes/yr)	20	84	84
Price of seed (FCFA/kg)	50	50	50
Price of fuel (produced oil) (CFAF/litre)	–	210	210
Engine's consumption oilseeds (litres//kg)	-	70	70
Maintenance (CFAF/yr)[a]	10,000	1,100,000	50,000
Personnel (CFAF/yr)	240,000	60,000	60,000
Incl. variable costs (%)	50	–	–
Capacity factor (%)	50	25	25
1995	100	50	50
1996	100	60	60
1997	100	70	70
1998	100	80	80
1999	–	90	90
2000	–	100	100
2001			
Extraction rate (%)	20	20	20
Jatropha oil, pure	5	5	5
Sediment	75	75	75
Oilcake	–	2	2
Maximum frequency of battery loading (times/day)			
Selling price	250	250	250
Jatropha oil, pure (CFAF/litre)	75	75	75
Sediment (CFAF/kg)	15	15	15
Oilcake (CFAF/kg)			
Financing	150,000	180,000	200,000
Equity capital (CFAF)	0.1	2.0	
Subsidy (10^6 CFAF)			4.0
Long-term credit (10^6 CFAF)			10
Interest rate (%/yr)		0.2	
Short-term credit (10^6 CFAF)		17.0	
Interest rate (%/yr)			

[a] Including, for the Lister and Hatz engines, variable costs of 58 and 50 per cent, respectively.

Table XIX.3. Economic analysis of the jatropha system, comparing the Sundhara/Lister and the Sundhara/Hatz combinations

Combustion	Case	Assumption		Result				
					Macroeconomic (% ERR)		Meso-economic (% MERR)	
					Without	With	Without	With
		Direct effects	Indirect effects	Financial (% IRR)	Indirect effects		Indirect effects	
Sundhara/ Lister	1	Economic price of jatropha oil = CFAF 102/litre[a]	2/3 of the oil used for soap-making, added value: CFAF 450/litre 1/3 of the oil as fuel, local value of transport: CFAF 60/litre	49	-22	176		
	2	Economic price of jatropha oil = CFAF 122/litre[b]	2/3 of the oil used for soap-making, added value: CFAF 450 /litre 1/3 of the oil as fuel, local value of transport: 0	49	3	184		
	3	Economic price of jatropha oil = CFAF 162/litre[c]	100% of jatropha oil used as fuel, value of transport = 0	49	33	135		
	4	Meso-economic price of jatropha oil = CFAF 289/litre[d]	As for case 2	49			129	351
Sundhara/Hatz	1	Economic price of jatropha oil = CFAF 102/litre[a]	2/3 of the oil used for soap making, added value: CFAF 450/litre 1/3 of the oil as fuel, local value of transport: CFAF60/litre	26	-11	109		
	2	Economic price of jatropha oil = CFAF 122/litre[b]	2/3 of the oil used for soap making, added value: CFAF 450/litre 1/3 of the oil as fuel, local value of transport: 0	26	-	112		
	3	Economic price of jatropha oil = CFAF 162/litre[c]	100% of jatropha oil used as fuel, value of transport = 0	26	17	80		
	4	meso-economic price of jatropha oil = CFAF 289/litre[d]	As for case 2	26			62	172

[a] Price CIF border of diesel: calculated average price.

[b] Price CIF border of diesel, plus 1/3 of transportation costs in Mali, 1/3 of which is paid in foreign exchange (lorries, fuel etc.) 102 + [(90 x 1/3) x 2/3] = 122

[c] Price CIF border of diesel, plus 100 per cent of transportation costs in Mali, 1/3 of which is paid in foreign exchange 102 + (90 x 2/3) = 162

[d] Meso-economic analysis: indirect effect as for case 2; adjustment of the price of jatropha oil: for 2/3 of the oil used for soap production: 300 CFAF/litre (= estimated price for other plant oils); for 1/3 of the oil used as fuel: price of diesel oil at station (275 CFAF) multiplied by energy conversion factor (1,05); >> estimated substitution price: 289 CFAF/litre.

The sensitivity of the IRR (see figure XIX.6) shows three important facts:

- The IRR is not very sensitive to investment costs: a 20 per cent increase reduce the IRR by only 10 per cent, and vice versa.
- The influence of operating costs is very great: lowering the variable costs by 20 per cent increases the IRR by about 35 per cent. This shows that the viability/profitability is very sensitive to the operating costs, of which the purchase of the seeds is the most important.
- The final price of the products is important for the success of the commercial unit: improving revenues by 20 per cent doubles the IRR and a decreasing of them by 20 per cent reduces it to zero. That means the project is very sensitive to the market conditions for the final products.

Figure XIX.5. Partitioning of the output of the pressing unit

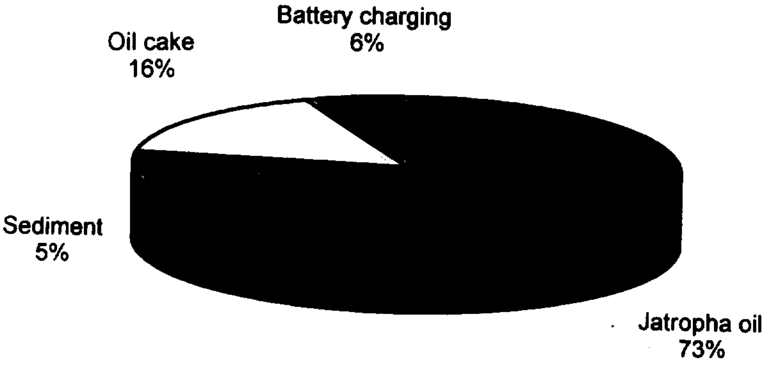
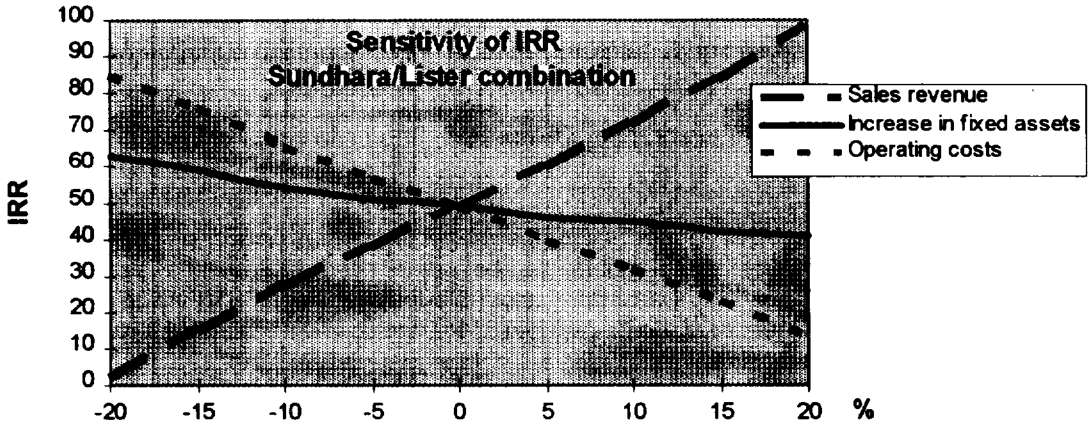


Figure XIX.6. IRR sensitivity of the Sundhara/Lister unit



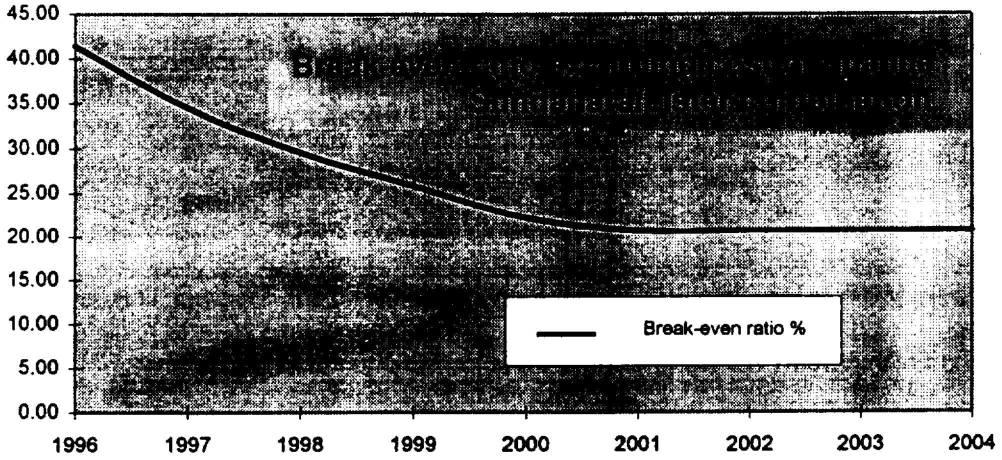
The break-even analysis, which evaluates at what percentage of operating capacity the press becomes profitable, shows that point to be 21 per cent (see figure XIX.7), which amounts to 18 tonnes of seed per year.

(c) Sundhara/Hatz expeller unit

This case differs in two important points from the preceding case, the Sundhara/Lister combination. The jatropha-oil-consuming Hatz engine is almost five times more expensive than the Lister engine, and all the investments are financed by agricultural bank credits. The effect of these stiffer conditions is a drop in the IRR to 26 per cent, which is, however, still a perfectly acceptable value for this profitability indicator.

The break-even analysis shows a break-even point at 26 per cent of full operating capacity, which amounts to 22 tonnes of seed per year.

Figure XIX.7. Break-even ratio of the Sundhara/Lister unit at a full capacity of 84 t/a (after 5 years)



2. Macroeconomic analysis

For a macroeconomic analysis, it is important to evaluate not only the costs and prices indicated in table XIX.2, but also the indirect effects:

- Agro-ecological effects due to the protective effect of the jatropha hedges against erosion and the increase in soil fertility by improving the fallow.
- Protective effect of the hedges against stray cattle.
- Improved harvests due to using the oilcake as organic fertilizer.
- Less social conflict as a result of using the hedges to delimit field borders.
- Income generated by collecting and selling seeds to the press operator.
- Income generated by producing soap from the extracted oil.
- Value of the oil as a domestic substitute fuel, which is calculated at about two thirds of the cost of the transport, storage and distribution of imported diesel oil in Mali
- The (negative) effect of the hedges owing to the land needed for their growth.

When all these supplemental indirect effects are considered, the economic rate of return (ERR) is calculated at 135 per cent. If only the next to-last effect (its value as a substitute fuel) is considered, the ERR is 33 per cent.

3. Meso-economic (regional) analysis

At the regional level, including 20-30 villages around an engine-driven oil expeller, a very important economic impact is the creation of employment. Approximately a thousand women are occupied with harvesting, drying and dehulling the seed, which gives them an income that would be typical in rural areas. There is also work for about a hundred women producing soap, and for about two people in commercializing the products (oil, soap, oilcake, other by-products).

With all the indirect effects, the meso-economic (regional) analysis (MERR) is calculated at 351 per cent. Considering only the next-to-last effect, the MERR is about 129 per cent for the Sundhara/Lister combination.

C. Socio-cultural acceptability

The studies that have been carried out to date [8][18] have assessed positively the chances of this system's being successfully implemented, provided that a cautious approach is taken. Above all, care must be taken to ensure that the women retain their traditional responsibility for harvesting and processing the physic nuts.

1. Raising the awareness of the men

Raising the awareness of men is important for two reasons. On the one hand, they must be prevented from monopolizing the jatropha business. On the other hand, it is important to placate their fears that greater economic autonomy for women could somehow threaten their status.

2. Support for women's organizations

Women's organizations function less well than those of men which have existed for a long time. Women's *tôn* (both men's and women's organizations are called *tôn*) represent a new type of organization aimed at implementing cooperative village projects. *Ci-tôn*, groups of individuals who help one another to work their fields, have adapted to the monetary system, that is, their members work for pay in the fields of those who can afford such services. Thus, a woman can find herself working on the family fields either without remuneration or else in return for wages if her husband avails himself of the services of a *ci-tôn*.

3. Management training for women

Because women lack training, they understand only poorly how technologies work, how to use them and how to service them. Even the money they earn typically winds up beyond the control of the women and is managed by the men, who have an educational head start. In the long term, the use of jatropha oil to power motor-driven mills and presses could better the economic situation of women. However, they need support in the form of management training to prevent their gains from being usurped by others.

D. Status of development policy

1. Rural energy supply

By producing and utilizing plant oil in small engines (mills, generators and irrigation pumps), rural areas can lessen their dependence on central sources for energy supplies, thus achieving a certain amount of autonomy and supply security. At the same time, their purchasing power is strengthened because less money flows out of their villages into the cities and/or the oil-producing countries to buy energy.

2. Poverty alleviation

The jatropha system can help in three ways to alleviate poverty:

- Since the prices of agricultural products are dropping worldwide and/or are being kept at an artificially low level by the agricultural policies of the industrialized countries, cotton and peanut farmers are interested in diversifying their revenue sources. By fencing their fields with jatropha hedges and selling the seed, they can bolster their incomes.

- By collecting and selling the seeds of jatropha shrubs, which require only minimal inputs when rown as a permanent crop, subsistence farmers can earn cash incomes.

- Since the trees can grow on marginal sites otherwise unsuited for agricultural production, such sites can be included in forest-planting programmes, giving landless population groups a source of livelihood.

3. Environmental and resource conservation

Rural populations can be motivated to plant protective hedges if they realize that their jatropha seed will be bought up. (After two buying campaigns in one region, the planting of jatropha hedges increased by 40 per cent [19]). In other words, the use of Jatropha oil as fuel can be seen as a vehicle for combating wind- and water-induced erosion. The cost of purchasing the seeds is probably lower than the cost of any equivalent erosion-control measures.

4. Protection of the atmosphere

The use of plant oils as a fuel is CO_2-neutral, meaning that the CO_2 released by burning the oils comes from carbon that has previously been extracted from atmospheric CO_2 by photosynthesis. Using plant oil as an energy source does not, therefore, raise the CO_2 concentration in the earth's atmosphere.

E. Conclusions

So far the experiences of the pilot project have shown that the jatropha system has seven principal effects:

- Jatropha hedges give a considerable protection against stray animals, they serve to delimit field, they improve the soil and they are an important tool in erosion control.

- The oil of jatropha seeds can be extracted at the village level. The necessary technical equipment is available.

- The oil can be used as a fuel for stationary engines (with precombustion chambers) to run grain mills, water pumps and electric generators.

- The surplus oil can be used for local soap production, which generates considerable income for rural women.

- On a regional level, the jatropha system has a considerable positive employment effect.

- The economic analysis is very positive. Even under the worst conditions (all investment and financing done by agricultural bank credits), the IRR is 26 per cent.

- Because the rural population has a financial state in the jatropha system, the system may be self-propagation, thus strengthening the fight against desertification.

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XX. OIL CROPS: REQUIREMENTS AND POSSIBILITIES FOR THEIR UTILIZATION AS AN ENERGY SOURCE

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Abstract

Although vegetable oils have been used as an energy source for centuries, they were used almost exclusively in oil lamps. Their value as a foodstuff and the availability and low price of mineral oil had for a long time kept them from being seriously considered as a potential energy source.

Now, owing to the increasing cost of fossil fuel, particularly oil, and increasing industrial energy consumption, as well as the negative impact of fossil fuel use on the environment, there is interest in a number of alternative energy sources, including vegetable oils.

The discussion in this paper focuses on the use of untreated vegetable oils, particularly rapeseed oil. The energy potential of rapeseed oil is explored first. Then, conditions under which the use of oil crops as an energy source is feasible are briefly discussed; two concepts for decentralized oil-seed processing are described and, finally, future possibilities for use of vegetable oils as a fuel source are reviewed.

Introduction

Although vegetable oil has been used as an energy source for centuries, its application was largely restricted to oil lamps. Compared with other biogenic energy sources such as wood and straw, it was rarely used as a fuel owing to its alternative value as a foodstuff.

In 1912, Rudolf Diesel said "such products will become just as important in the long term as paraffin and coal tar products are today", showing that he was aware that vegetable oil had a much wider range of potential applications. However, owing to the ready availability and low price of mineral oil, little serious thought was given to alternative fuels until quite recently.

Now, however, it is known that fossil energy sources, and mineral oil in particular, will be depleted in the foreseeable future and that the costs of their development and exploitation are rising steeply. Similarly, the negative impact of emissions into the atmosphere from the combustion of fossil fuels and the effects of these emissions on the global environment are now undisputed; one need only think of CO_2 emissions and climate change. Moreover, it must be realized that even today most of humankind does not have access to fossil fuels to improve their lives.

In view of these problems associated with the use of fossil fuels, a wide range of alternative energy sources is being considered. Among them, vegetable oils are attracting increasing interest. One thing must be made quite clear, however: the use of oil crops as an energy source is not proposed as a solution to these problems but as an ecologically reasonable and economically acceptable contribution towards meeting the demand for energy under certain circumstances.

Important economic, technical and ecological issues regarding the use of rapeseed oil as an energy source were addressed in Germany between 1991 and 1994 as part of a vegetable oil applications Project in Sachsen-Anhalt (Anwendungsprojekt Pflanzenöl [1]), which also established important principles for a reasonable energy and material cycle based on vegetable oil. This paper is largely based on these results. Besides rapeseed oil, a variety of vegetable oils, including palm oil, soya oil and castor oil, to mention but a few, are also available virtually without limit for use as an energy source. However, the amounts used in this way must always be carefully balanced against those used for foodstuffs.

This paper deals mainly with the use of untreated vegetable oils, in particular rapeseed oil, as an energy source. The possibility of using methyl esters of vegetable oils will be considered only for comparison purposes.

A. The energy potential of rapeseed oil

Oil crops will be economically viable as an energy source only if their energy potential is comparable to that of mineral oil products and if they yield considerably more energy than is required for the production of the oil.

Oil production from rapeseed crops gives rise to three main products: rapeseed oil, press cake and rape straw.

These three materials are taken into account in figure XX.1, which compares total energy yield with energy input [2]. The total energy balances revealed by studies so far differ insignificantly. Fundamentally, they all show that the ratio between energy input and energy yield cannot be better than 1:8 [3] if all real energy potentials are taken into account. However, this theoretical figure is of little use for practical calculations. According to Reinhard [3], the energy input to energy yield ratio varies as follows, depending on how the products are used:

Oil used for energy production alone	1:1.5
Oil used for energy production, press cake used as animal fodder	1:1.9
Oil and press cake used for energy production	1:2.8

In practice, these ratios can be further improved by burning the rapeseed straw; any further improvement in energy yield needed to approach the ideal ratio of 1:8 can be achieved only by highly mechanized intensive farming. However, one thing is already evident: rapeseed has an acceptable positive energy balance, which is the most important prerequisite for its use as an energy source.

A further important criterion is the energy content of the vegetable oil relative to that of mineral oil. Table XX.1 presents the energy content of diesel oil, rapeseed oil, rapeseed methyl ester and glycerine [4] for comparison. It shows that the calorific values of rapeseed oil and rapeseed methyl ester are generally somewhat over 90 per cent of the corresponding figure for diesel oil, whereas glycerine, a by-product of the process for making rapeseed methyl ester, has a much lower value, producing about 40 per cent as much heat as diesel oil.

Vegetable oils therefore meet another criterion for energy-producing applications: no major power reduction need be expected from the combustion of vegetable oils in prime movers.

When considering energy-producing applications, the composition of exhaust gas emissions, which is the most important ecological criterion, must also be included in the equation. Exceptionally thorough studies by Krahl [5] show clearly that exhausts from vegetable oil are not fundamentally worse and are in some respects better than those from diesel oil, although the various constituents of the exhaust gases must be considered separately. Figure XX.2 shows the principal constituents of exhaust gases from engines burning vegetable oil and diesel oil, respectively. It should be noted that there is no sulphur in vegetable oils and therefore no SO_2 in the exhaust gases.

Figure XX.1. Energy balance

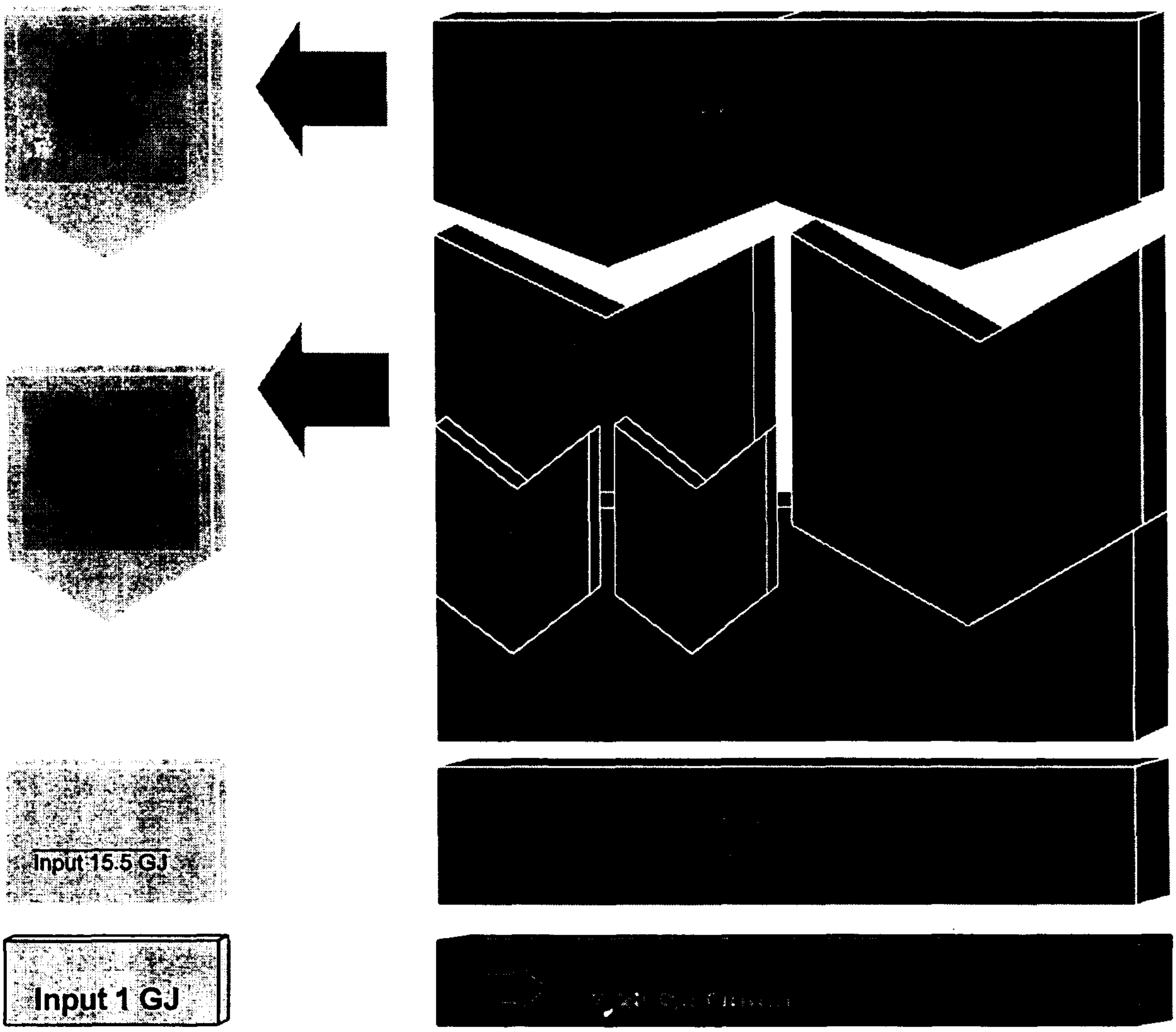
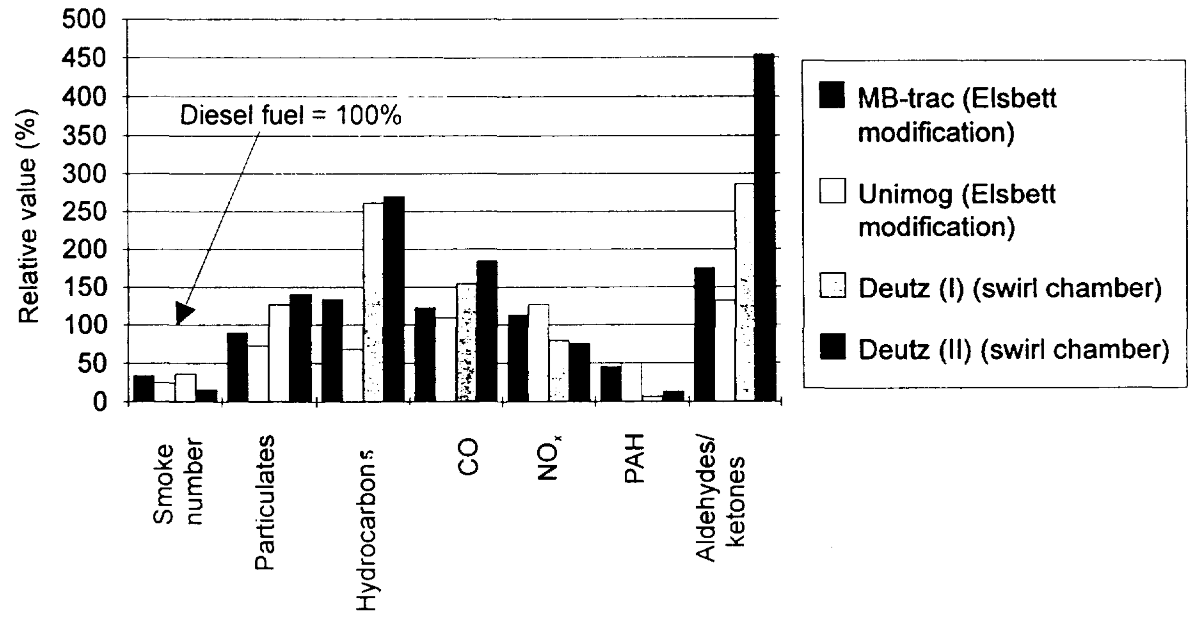


Table XX. 1. Energy value of liquid fuels

Fuel	**Heat value (MJ/kg)**
Diesel oil	42.80
Rape Oil (refined)	36.00-37.60
Rapeseed methyl ester	37.20
Glycerine	16.30

Figure XX.2. Relative emissions of four engines fuelled with rapeseed oil (diesel fuel = 100%)



A comparative ecological balance shows, moreover, that vegetable oils have the clear advantage of a closed CO_2 cycle: during growth, the plants bind just as much CO_2 as is released during combustion. There are no consumers for the CO_2 released by the combustion of fossil fuels, and this has led to the known global effects on the atmosphere.

Fears that expansion of the area under rapeseed would release sufficient N_2O (laughing gas) to change the climate have been shown to be more or less unfounded and can no longer be considered an argument against a drastic increase in land devoted to rapeseed production.

An assessment of the energy potential of rapeseed, and especially rapeseed oil in comparison to diesel fuel, shows quite clearly that rapeseed crops yield sufficient potential surplus energy and that rapeseed oil has an energy content comparable to that of diesel oil, but without the negative ecological effects.

B. Project topics

As already stated, the main purpose of using vegetable oils as an energy source must not compete with fossil fuels. On the contrary, any decision concerning such use must give absolute priority to using vegetable oils for human consumption and must take into careful account the specifics of each case, particularly because, worldwide, demand for vegetable oils of a quality suitable for human consumption cannot be met in the foreseeable future, although the situation varies greatly from region to region. A clear warning must be sounded against euphoric forecasts of the use of vegetable oil as a fuel. Such use will be reasonable only under certain circumstances in certain regions and for certain producers and users. Several examples can be mentioned:

- Set-aside land in central Europe.
- Autonomous power and fuel supplies to increase the production of foodstuffs in rural areas with inadequate fossil fuel reserves.

- Use of wild oil plants as an energy source, particularly in tropical regions.
- Establishment of closed matter-energy cycles on farms and in agricultural enterprises.
- Supply of biologically degradable fuels and lubricants for ecologically sensitive regions.

The next subsections cover the issues that have to be considered in each application to arrive at an economically and ecologically sustainable solution.

1. Agricultural Prerequisites

It is first necessary to identify the oil crop that will yield the optimal oil quality under the existing natural conditions. The yield (oil content of the seed or fruit) and the oil yield from the extraction process must be known, as must the amount of land remaining for energy production after food crop and forage production have been taken care of. Consideration must also be given to the available resources, including the machinery and manpower needed for cultivation, harvesting, transport, storage and preparation of the oil-seed or fruit, and to cultivation conditions and crop rotation. Conditions can vary immensely, ranging from intensive farming to the harvesting of wild, oil-yielding fruit that is permanently available in sufficient quantities.

2. Infrastructure

Oil crops cannot be processed and utilized until they have been harvested, but their oil must be available year-round for use as a fuel. In other words, there must be facilities for storage and for transport to storage and from there to the processing plant to bridge the period during which the crop grows and ripens, before it is harvested. Spoilage and deterioration must be kept to a minimum. Depending on the general energy situation, i.e. whether the oil is replacing fossil fuels or is the sole source of energy, the following are decisive factors: storage, transport, energy distribution, energy utilization, education of work force, communications, spare parts supply and maintenance.

3. Economic factors

The main economic factor governing the use of vegetable oil as an energy source is its price relative to that of available fossil fuels. Owing to national and regional differences, it is impossible to make a generally valid price comparison. Unless supply of mineral oil is inadequate, price will always be the decisive factor where vegetable oil and diesel oil are in direct competition.

With rapeseed oil currently costing US$ 0.35-0.55/litre in central Europe, depending on local circumstances, vegetable oil obviously stands a chance only if everything possible is done to minimize production costs. This must also be taken into account when considering the questions of finance and possible subsidies. All feasibility studies must be based on selling all of the vegetable oil and as many of the by-products as possible, reliable cost estimates and achievable prices. The controlling economic factors are summarized below:

- Availability and price of fossil fuels.
- Production costs of oil-seed or fruit.
- Costs and prices of the vegetable oils and the by-products.
- Finance and possible subsidies.

- Prevailing national and regional conditions.

4. Technical conception

The technical conception must be adapted to suit each case in order to keep investment and production costs to a minimum. This will involve considering various technological solutions for the agricultural production of the oil crop, its storage and transport, extraction of the oil and, ultimately, its use as a fuel. Decentralized systems installed and run by the producers of the vegetable oil appear to be the best answer. Such plants (oil extraction will be considered separately) should consist of small, flexible units with standardized capacities. Internal combustion engines equipped to burn vegetable oil and used, for instance, in harvesters, transport vehicles and ships or even for the generation of electricity and heat in CHP stations are the obvious means for transforming the oil into energy. However, direct combustion to produce heat may also be feasible, especially if combined with the combustion of shells, straw and press cake (if it cannot be used as cattle feed).

5. Project-related development work

The conditions attending each case may well lead to issues for which no cut-and-dried solution is available. For each case, project-related development tasks will need to be identified, some of which are as follows:

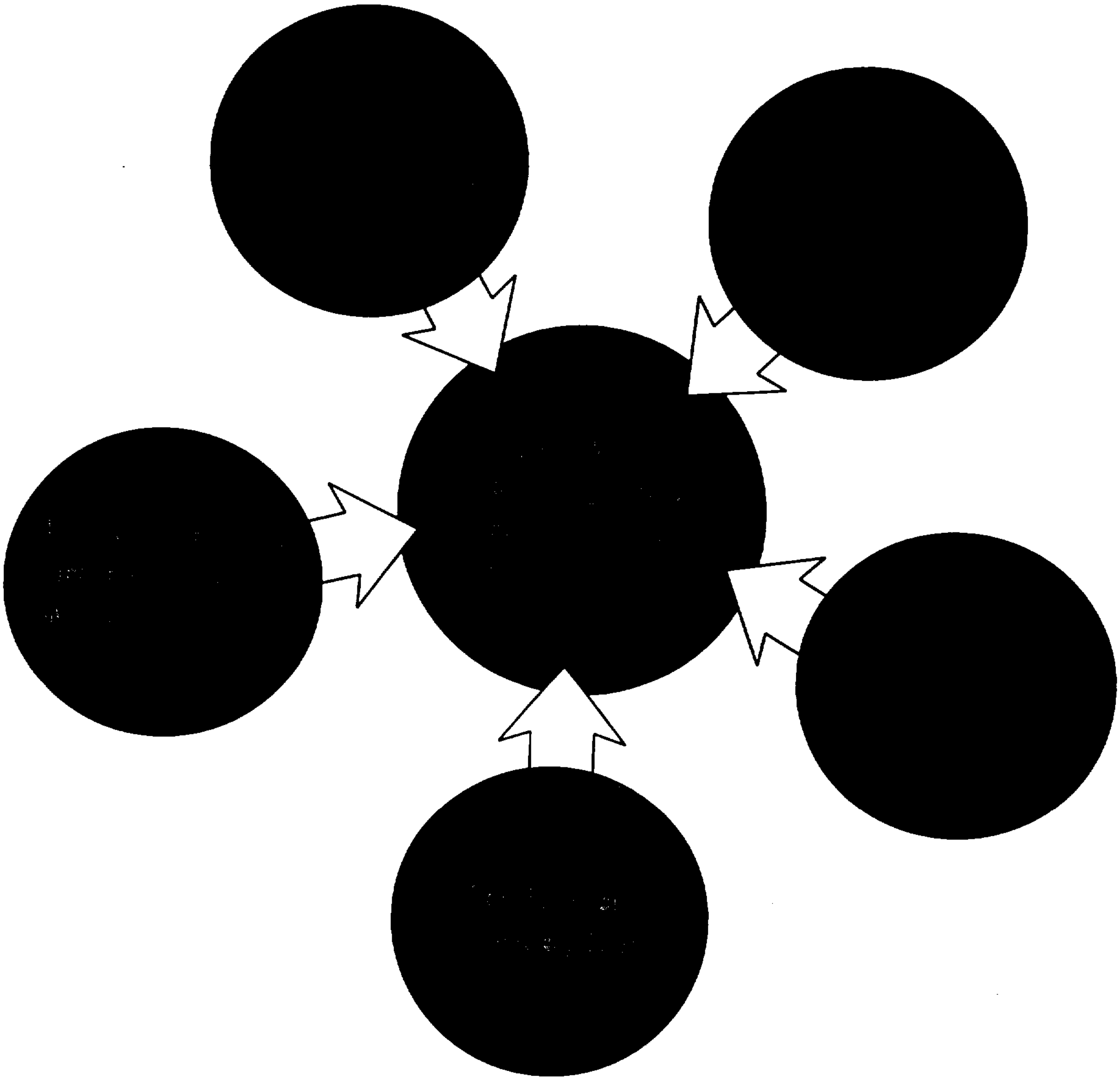
- Selection and breeding of seed to produce reliable yields.
- Creating optimal conditions for cultivation.
- Assessment of impacts on the natural environment.
- Adaptation of the equipment to kind and quality of oil produced.
- Processing of oil-yielding plants that have not been thoroughly studied.

It is evident that the use of oil crops as a basis for energy involves the coordinated solution of a whole series of problems to ensure ecological and economic success. A simple solution cannot be expected to take all specific circumstances adequately into account (Figure XX.3) and is bound to fail. The authors recommend, therefore, that for each project a feasibility study should first be conducted by a group of specialists from all disciplines to define the project and find a sustainable solution.

C. Decentralized oil extraction

The authors' work mainly involves the coordination of projects and the development and construction of decentralized oil mills and power stations Modern industrial vegetable oil extraction plants now permit very high levels of productivity. Their drawbacks are high investment costs and the need for a highly developed infrastructure. At present, such centralized plants appear to be the only economical approach to the production of methyl esters of vegetable oils for use as fuel. However, small decentralized oil mills represent an economical alternative for the production of untreated vegetable oils, especially if investment capital is restricted and demand for the processing of oil crops is high. Although many growers of oil-seed traditionally press their produce themselves, the decentralized mills must also be able to extract high yields of technically reliable products that consistently meet high quality standards. Only a thoroughly tested mill concept that takes into account the specific conditions at the place of use can satisfy this requirement.

Figure XX.3. Project topics



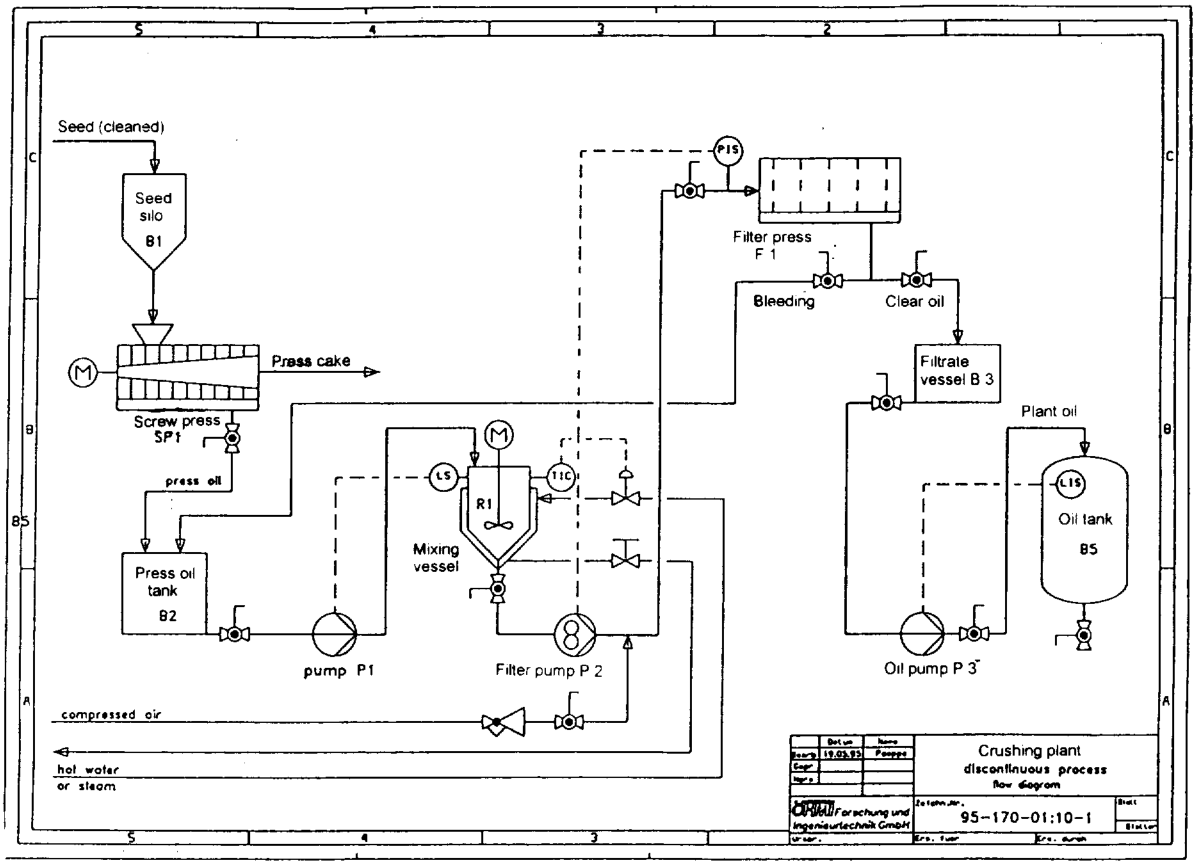
As a result of development work, two mill concepts for decentralized oil-seed processing are now available as marketable units:

- Discontinuous mills incorporating seed-processing, seed-pressing and oil-cleaning sections and having a filter press with throughput capacities of 100, 350, 700 or 1,500 kg oil-seed/hr. (see figure XX.4). Seed processing comminutes the seed to improve the oil yield above a certain press throughput and simultaneously heats it to the temperature needed for the pressing operation. It is carried out in screw-type cage presses with various seed throughput capacities. Seed particles entrained with the oil as a result of the pressing process are removed by the oil-cleaning section.

- These plants are called discontinuous because the filter press must be cleaned manually after a certain time. However, the frequency of this procedure can be reduced to once a day by selecting a suitably dimensioned filter press. Otherwise, plant operation consists only in starting up and closing down and daily checks to ensure that the plant is running smoothly.

- Continuous automatic mills with standard throughputs of 700, 1,500 and 3,000 kg oil-seed/hr with self-cleaning pressure filters. In continuous mills, the oil is cleaned in tank pressure filters that can be automated. However, this requires compressed air as an auxiliary medium. For continuous plant operation, facilities must be provided to return the pulp extracted from the oil to the seed flow upstream of the press. A filter with a dry filter cake discharge arrangement is recommended for this purpose. The seed preparation and pressing stages are analogous to those used in discontinuous mills. The investment for plants based on this concept is about 25 per cent higher than that for a discontinuous plant.

Figure XX.4. Process diagram



Which of these concept yields the best economic results will depend largely on local conditions. The factors to be considered include the variety and quality of the oil-seed, the throughput capacity, the quality of the oil and press cake end products, the operating mode of the plant and the peripheral equipment.

Prices for oil produced in decentralized mills vary considerably because many of the factors affecting them depend on local conditions.

In the vegetable oil applications Project in Sachsen-Anhalt [1], production costs of US$ 0.25/litre were calculated for a decentralized oil mill processing 300 kg rapeseed/hr with an oil yield of 35 per cent and producing press cake valued at US$ 0.14/kg. This production cost was used as a basis for the sample cost calculation for rapeseed oil shown in table XX.2 [1], in which the premiums paid under European Union agricultural policy for set-aside land had a positive effect. The calculation shows clearly that owing to the higher oil yield production costs will be lower in large-scale plants under central European conditions. Although it is unlikely to be applicable to other situations, this calculation is presented here merely to give an idea of the rapeseed oil prices that can be achieved.

Table XX.2. Sample cost calculation for rapeseed oil

Item	Unit	Decentralized mills	Large-scale plants
Cost of cultivation	US$/ha	991	991
Cost of production	US$/ha	275	173
Other cost	US$/ha	37	111
Total cost	US$/ha	1,303	1,275
Premiums for set-aside land	US$/ha	438	438
Press cake price	US$/ha	251	236
Residual cost	US$/ha	613	600
Yield	kg/ha	980	1,092
	litres/ha	1,089	1,213
Costs of production	US$/kg	0.63	0.55
	US$/litre	0.56	0.49

D. Possibilities for use as a fuel

Engines capable of operating on vegetable oil are available in Germany as a result of development work carried out mainly during the past 10 years. Although relatively few modifications are needed to permit conventional diesel engines to operate on methyl esters of vegetable oils, operation on untreated vegetable oil requires a completely different engine. The two design principles characterizing the vegetable oil engine are the swirl chamber engine and the direct injection duothermal engine. Engines designed to run on heavy oil can also be converted with little effort to burn vegetable oil.

Engines capable of running on vegetable oil and suitable for use in motor vehicles are available with outputs of up to 200 kW (table XX.3), and field testing in lorries, tractors and agricultural machinery such as forage harvesters is virtually complete. Besides the conversion of tractors and forage harvesters to vegetable oil engines, the objectives of the vegetable oil applications project [1] included the conversion of the hydraulic systems and transmissions of forage harvesters for the use of products based on vegetable oils and lubricants based on such oils. The performance of the vehicles was tested under service conditions and compared with that of vehicles equipped with diesel engines. The vegetable oil engines achieved satisfactory operating times without failure in continuous service during three harvesting seasons. When installing a vegetable oil engine in an existing vehicle, the original gear ratios must be changed to suit the characteristics of the new engine in order to optimize consumption of the vegetable oil fuel.

The tested vegetable oil engines can be installed in series-produced machines suitable for their designed-rated output without significant loss of performance, and they even proved superior in fuel consumption to the original diesel engines [1].

Engines suitable for operation on vegetable oil can also be used to generate electricity and heat on the CHP station principle. In these applications, the diesel engine is coupled to a generator and the hot exhaust gases and cooling water are used to supply heat. The waste heat has a temperature of about

100° C and is therefore mainly suitable for producing warm water. Plants using the CHP station principle are available with the outputs shown in table XX.4, although so-called heavy oil engines with outputs up to 2.5 MW are also conceivable

Table XX.3. Model numbers of engines running on vegetable oil that can be used in motor vehicles of the Thüringer Motorenwerke at Nordhausen

Model no.	Cylinders	Maximum output (DIN 70020) (kW)	Nominal engine speed (rpm)	Total swept volume (cm^3)
6P 13,5 AL	6	200	2,200	8,858
6P 13,5 A	6	165	2,200	8,858
6P 13,5	6	120	2,300	8,858
4P 13,5 AL	4	125	2,200	5,905
4P 13,5 A	4	105	2,200	5,905
4P 13,5	4	80	2,300	5,905

Table XX.4. Typical vegetable oil-based co-generation plants

Plant type	Nominal engine speed (rpm)	Approximate output		Approximatef uel consumption (litre/hr)	Total swept volume (cm^3)
		kWe	kWt		
HP TMW 45T	1,500	45	76	14.5	5.905
HP TMW 60T	1,500	60	93	19	5.905
HP TMW 70TL	1,500	70	108	22	5.905
HP TMW 90T	1,500	90	139	28	8.858
HP TMW 120TL	1,500	120	186	36	8.858
SKL 6VD 18/16 AL-2	1,500	400	500	99	..
HP TMW 150T[a]	1, 500	150	255	255	12.040
HP TMW 180T[a]	1,500	180	306	306	12.040
HP TMW 260TL[a]	1,500	260	442	442	21.910
HP TMW 320TL[a]	1,500	320	544	544	21.910

[a] Planned for 1996.

The main benefit of the CHP station principle is the high utilization, up to 80 per cent, of the energy potential of the fuel if heat extraction is optimal. Such systems are particularly useful and economical if a similar demand for heat must be met besides the demand for electrical energy. Naturally, in order to achieve acceptable prices for electricity and heat, the engine should as far as possible run continuously for a large number of operating hours per year.

If only electricity is required because there is no other source of electrical energy, the waste heat must be dissipated to the atmosphere, and the thermal efficiency drops to about 35 per cent of the energy content of the fuel.

Plants using the CHP station principle therefore require thorough planning as a basis for correct, economically sound decisions under the given conditions. Typical applications for such plants include the following:

- Self-sufficient energy supplies for hospitals, schools or hotels.
- Supplies of energy and heat for industrial and trading estates.
- Self-sufficient supplies of energy for remote villages.

The CHP stations principle yields only relatively low-grade heat. Other facilities, such as boilers, are needed to supply steam to, for instance, oil mills.

Vegetable oil can be used to generate steam in conventional boilers equipped with modified burners. Experiments have shown that vegetable oil produces somewhat more fouling on the fire side than boiler oil, so that mixing with boiler oil is necessary for small boilers. The mixing ratio varies with oil throughput and should be about 1 kg rapeseed oil to 3 kg boiler oil for an oil throughput of 25 kg/hr (boiler performance about 300 kW). The ratio can be reduced to 1:1 for larger oil throughputs (boiler performance above 1 MW). Although boilers of this capacity are currently being heated successfully with pure rapeseed oil, it is still too early for a final assessment. In principle, a vegetable oil can be burned in a conventional boiler if, in a specific case, it is economically acceptable.

Another alternative that should be mentioned for the sake of completeness: the combustion of used fats such as those used for frying in the catering industry. After they have been cleaned, these fats can be burnt in conventional boilers without difficulty. They produce flue gases with better emission values than boiler oil. A plant of this kind has been in successful operation for over three years at ÖHMI.

E. Conclusions

Nowadays, the use of vegetable oil as a fuel poses no serious technical problems, as shown in this brief review, which also tries to show, however, that such use should not aim to completely replace fossil fuels. Thorough project preparation, the main points of which have been mentioned, will reveal a wide range of applications, especially in the agricultural industry, in which oil crops and their main product, vegetable oil, can be used as an energy source to help overcome acute local energy problems economically and without ecological harm.

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XXI. THE USE OF BIOMASS ENERGY IN THE PULP AND PAPER INDUSTRY AND THE PROSPECTS FOR BLACK LIQUOR GASIFICATION COMBINED CYCLE GENERATION*

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Abstract

The world production of paper and paperboard products, which increased 3.3 per cent per year since 1980, reached 243 million tonnes in 1991 and is expected to continue to grow by about 2.5 per cent per year over the next decade. Consumption levels in 1990 ranged from 2.8 kg per capita in India to 313 kg per capita in the United States. The biggest producers of pulp are the United States, Canada and the Scandinavian countries, but much of the expansion of pulp production capacity is taking place in countries such as Brazil, Chile and Indonesia.

The pulp and paper industry has always relied on biomass as a fuel source to meet process energy demands. Kraft pulping is the most common process accounting for about two thirds of world wood pulp production. Energy recovered from burning black liquor, a lignin-rich by-product, in a chemicals recovery boiler typically provides most of the on-site demand for heat and electricity in a modern kraft pulp mill. Another important fuel source is bark and wood waste generated at the mill.

Aging recovery boilers in industrialized countries and increasing electricity/heat demand ratios are stimulating interest in alternative co-generation technologies. Most of the interest in new biomass and black liquor co-generation technologies focuses on those that would utilize gas turbines rather than steam turbines. Gas turbines are generally characterized by higher electricity/heat ratios than steam turbines, as well as lower unit capital costs.

With the black liquor and biomass gasification technologies that are now being developed and demonstrated, the energy needs of an energy-efficient kraft pulp mill could be met and 40-50 MW of baseload power would be available for export. Using, in addition, currently unused logging residues for fuel would increase that potential.

The pulp and paper industry is likely to be an important early market for advanced biomass-based co-generation technology owing to its access to biomass fuels and the potential for co-generation.

Introduction

Paper is one of the few basic materials the per capita demand for which has not become saturated [1]. For example, in the United States the increase in apparent per capita consumption**

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*This paper is largely based on L.J. Nilsson and others, "Background paper on energy efficiency and the pulp and paper industry", *Proceedings from ACEEE Summer Study on Energy Efficiency in Industry: "Partnerships, Productivity, and Environment"*, Grand Island, New York, 1-4 August 1995, American Council for an Energy Efficient Economy, Washington, D.C., and Berkeley, California, forthcoming.

**Apparent per capita consumption is domestic production plus imports less exports, divided by population.

averaged 1.8 per cent per year 1960-1980 and 1.6 per cent per year 1980-1993 [2]. The United States has the highest apparent per capita consumption of paper in the world, 313 kg in 1990. By comparison, per capita consumption in 1990 in the United Kingdom, Brazil and India was 164, 28, and 2.8 kg, respectively (table XXI.1). Total apparent consumption in the United States increased 3.0 per cent per year 1960-1980 and 2.6 per cent per year 1980-1993 [2]. The increase in world and western European consumption averaged 3.2 per cent and 3.1 per cent per year, respectively, 1971-1990. World and western European demand have been forecast to grow 2.5 per cent and 2.4 per cent per year, respectively, over the next decade [3].

Table XXI.1. Apparent per capita consumption of paper and paperboard in selected countries

Country	Consumption (kg/capita) 1980	1990	Increase 1980-90	Annual average increase (%)	Total consumption, 1990 (millions tonnes)
United States	267	313	46	1.5	78
Sweden	209	250	41	1.6	2.1
United Kingdom	121	164	43	2.6	9.4
France	115	154	39	2.5	8.7
Brazil	28	28	0.0	0.0	4.2
India	1.8	2.8	1.0	3.6	2.4

Source: FAO, 1991 *Forest Products Yearbook*, Rome, 1993, and United States Bureau of the Census, Statistical abstract of the United States, Washington, D.C., 1994.

Growing paper consumption, even with increased levels of paper recycling, is reflected in increasing primary pulp production. Kraft pulp presently accounts for about two thirds of global wood pulp production and is expected to continue to grow (table XXI.2). The most rapid growth in kraft pulp production is likely to take place in Latin America and Asia.

Table XXI.2. Estimated and projected world production of bleached and unbleached kraft pulp

(Thousands of tonnes)

Region	1990	2000	2010
North America	55,178	60,536	72,163
Western Europe	15,942	20,908	23,279
Latin America	5,376	7,809	10,322
Japan	8,721	8,296	9,195
Rest of Asia	3,004	9,713	13,847
CIS and eastern Europe[a]	4,871	3,494	4,403
Rest of world	2,165	2,711	4,490
Total world	**95,257**	**113,494**	**139,699**

Source: Ilpo Ervasti, Jakko Pöyry Consulting Oy., Vantaa, Finland.

Note: Based on forecast made for paper and paperboard grades by region and accounting for increased levels of paper recycling.

[a] Commonwealth of Independent States.

1. Energy use

The pulp and paper industry is one of the most energy-intensive industrial sectors. In the United States, for example, the energy intensity (expressed in megajoules per dollar value of shipments) of the paper and allied products industry was 21 in 1991, making it the second most energy-intensive industry group in the manufacturing sector. The ratio of electricity/heat demand has been increasing steadily in the pulp, paper and paperboard industry. In the United States, this trend is reflected, for example, in a near doubling of purchased electricity between 1972 and 1993 and a 7 per cent decrease in total purchased energy. The trend towards higher electricity/heat ratios is being driven by increasing electrification (in part to meet more stringent environmental regulations), combined with thermal energy efficiency improvements. As a result there is growing interest in the industry in electricity conservation and in co-generation technologies characterized by higher electricity/heat production ratios.

The pulp and paper industry can be distinguished from most other manufacturing industries by its extensive use of biomass fuels and co-generation. Self-generation of energy (i.e., the use of biomass) in the United States amounted to 56 per cent of the industry's total energy use in 1993, up from 40 per cent in 1972 [2]. The most recent survey data indicate that about 50 TWh of electric power was co-generated in the United States pulp and paper industry in 1991 [4]. This is equivalent to about half of the total electricity consumed.

2. Environment

Concern about the environment, manifested in changing market demand and more stringent environmental regulation, is one of the most important drivers of technological change in the pulp and paper industry. While requiring capital expenditures, environmental concerns have also given the industry a competitive advantage vis-à-vis paper substitutes, since the industry produces recyclable products from renewable resources using relatively few non-renewable inputs. Environmental issues associated with pulp and paper manufacture include solid waste disposal; emissions to water of chlorinated organic compounds or adsorbable organic halogens (AOX), including dioxins and furans, chemical/ biological oxygen demand (COD/BOD), phosphorous compounds and nitrogen; and emissions to the air of SO_x and NO_x from fuel combustion.

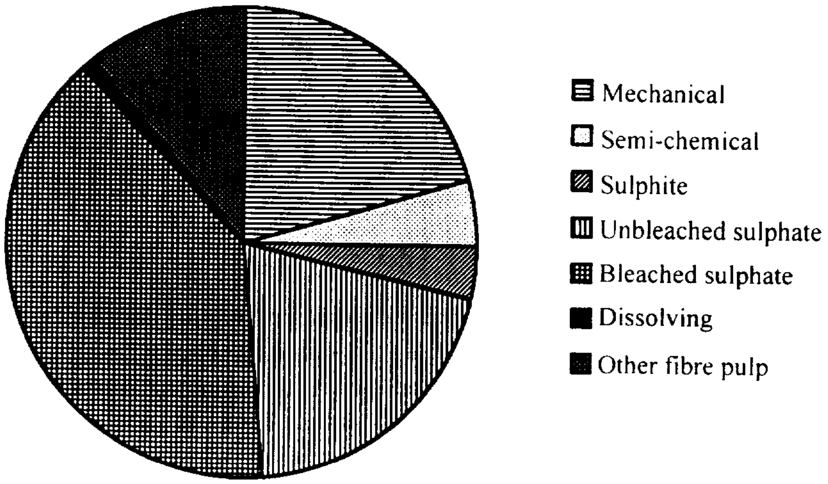
Environmental regulation to reduce AOX emissions and market demand for chlorine-free products have driven the pulp and paper industry to find alternatives to elemental chlorine as a bleaching agent. Chlorine dioxide bleaching gives much less AOX than elemental chlorine bleaching and decreases the relative amount of the highly chlorinated and potentially most toxic compounds in the AOX [5]. Swedish data show that typical AOX emissions from bleach plants using elemental chlorine in the 1970s were 8-10 kg/ADMT [5]. Emissions today are typically around or below 1 kg/ADMT from pulp mills in Scandinavia. Many modern North American mills reach the same levels. Efforts to reduce AOX emissions have resulted in a shift to elemental chlorine-free and totally chlorine-free pulp. Environmental concern has also led to increased paper recycling. The present fraction of paper being recycled in leading recycling countries like Japan, Austria and the Netherlands is slightly higher than 50 per cent [6].

A. Kraft pulping

Pulping is the process by which the fibres in the wood are separated and treated to produce a pulp. The wet pulp is converted into paper at an integrated pulp and paper-mill or is dried and transported from the pulp mill to a paper-mill. Different pulping processes are used depending on the raw material and the desired end product. The processes can be categorized as chemical, mechanical (also called high-yield), semi-chemical and chemi-mechanical. There are additional processes for extracting fibre from recycled paper.

The predominant process is the chemical process kraft (also called sulphate) pulping. Kraft pulp accounts for about two thirds of all wood pulp produced in the world and a somewhat small fraction of total pulp production, which also includes pulp from straw, bagasse, and other sources (figure XXI.1). In kraft pulping, the lignin* is dissolved in a digester, where the wood chips are cooked. The pulp yield, i.e., the mass of pulp dry substance produced divided by the mass of wood dry substance input, is 40-50 per cent and 50-65 per cent, for bleached and unbleached kraft, respectively. The energy content of the dissolved lignin and other organic compounds is used to produce heat and electricity for the process.

Figure XXI.1. World pulp production by type in 1993 (including wood pulp and other fibre pulp)



Source: FAO, *1993 Forest Products Yearbook*, Rome, 1995.

The name kraft has its origin in the German word for strength, reflecting an important characteristic of this type of pulp. In the kraft process, a mixture of sodium hydroxide and sodium sulphide in an alkaline solution with a pH of 13-14 is used to pulp the wood. An alternative chemical process to kraft pulping is sulphite pulping, which uses sulphite or hydrogen sulphite as the active chemical in an aqueous acidic or neutral solution. In either the kraft or sulphite process, wood chips are impregnated with the pulping liquor and then heated under pressure for a few hours in a digester to dissolve the lignin. The fibres are separated from the spent pulping liquor from which process chemicals and energy are recovered in both the kraft and the sulphite processes. The remaining discussion in this paper refers to kraft pulping.

The fibre line in the kraft process [7] is shown schematically in figure XXI.2. Following the debarking and chipping of the pulpwood, the chips are screened for size before being fed to the digester. The digestion may be batch or continuous. The wood chips are first treated with steam (in the presteaming vessel) to drive air from cavities and replace it with steam. When the chips meet the somewhat colder mixture of pulping chemicals (sodium hydroxite and sodium sulphide, known as white

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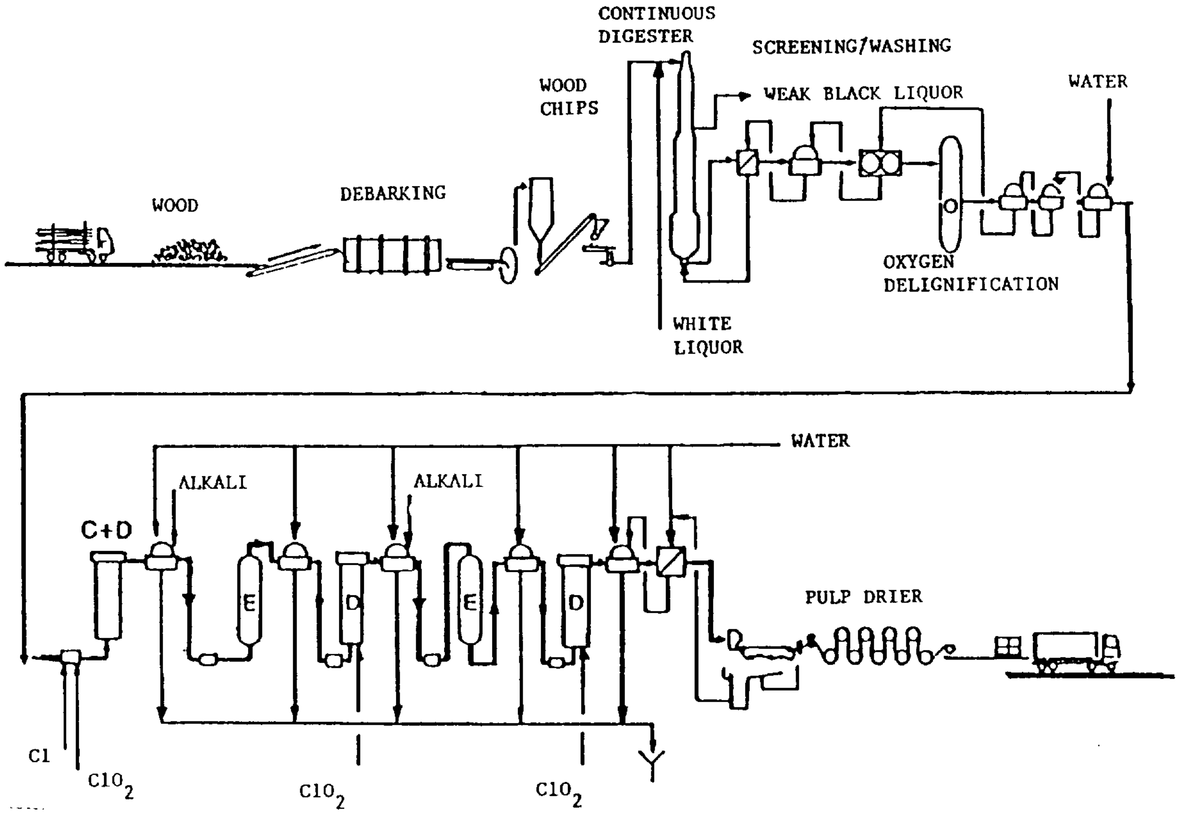
*The main chemical components of wood are cellulose, hemicellulose and lignin. The lignin acts as a binder for the wood fibres.

liquor) at 80-90° C, the steam condenses, creating an underpressure that facilitates impregnation of the chips with white liquor. The chips are heated for 1-1.5 hours up to the desired cooking temperature, where they remain for another one hour or more. The target temperature is usually 165-175° C. Higher temperatures increase chemical reaction rates, but above about 180° C, pulp quality degrades and steam demand increases.

Figure XXI.2. Kraft pulping fibre line

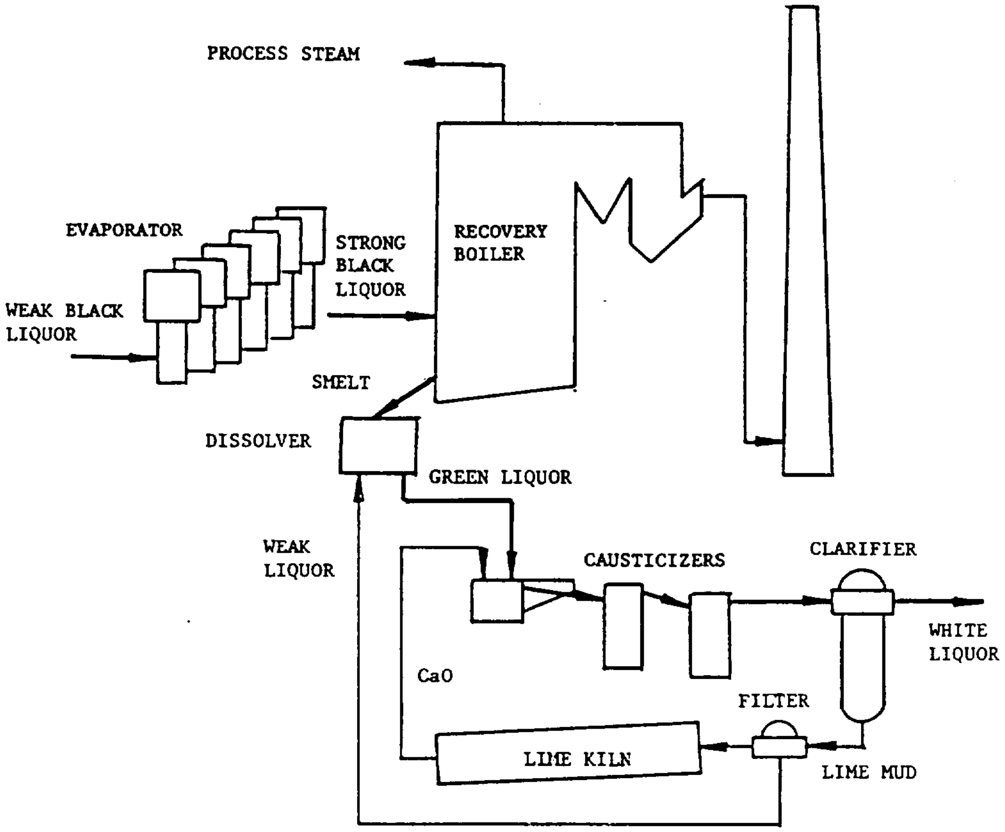


After the digester, the fibres are separated from the spent pulping liquor through several stages of countercurrent washing. Heat is recovered from the digesters as condensate and flash steam. The pulp is then screened, often bleached, and then pumped to the paper-mill or dried before being shipped from the pulp mill.

Bleaching increases the brightness of the pulp by decolourizing, degrading and dissolving the coloured components. It is done in several steps using oxidants to degrade and decolourize the lignin and sodium hydroxide to degrade the lignin (by hydrolysis) and aid in its dissolution [8]. The principal oxidants and (in parentheses) their common identifier in the industry are chlorine (C), chlorine dioxide (D), oxygen (O), hypochlorite (H), hydrogen peroxide (P) and ozone (Z). Sodium hydroxide is identified by the symbol E, for caustic extraction. A common bleaching sequence in the 1980s was C_DE_ODED, where the subscript refers to the chemical used to augment the primary chemical in a particular stage. Modern pulp mills use oxygen delignification to remove more lignin after digestion and before bleaching, thereby reducing the amount of bleaching chemicals required and the bleach plant effluent emissions. Today, a typical sequence for totally chlorine-free pulp might be oxygen delignification followed by ZE$_o$P.

The spent pulping liquor, known as weak black liquor, is evaporated to increase the solids content (organic compounds and pulping chemicals) from 10-20 per cent to 60-75 per cent and then goes to the chemicals recovery section of the mill. It is burned there in a Tomlinson recovery boiler (figure XXI.3). Steam generated in the boiler is used to produce electricity and process steam in a turbine with steam extraction at low and intermediate pressures. The pulping chemicals are recovered from the bottom of the boiler as a smelt of sodium sulphide and sodium carbonate, which is then dissolved in water to form green liquor. The green liquor reacts with an aqueous solution of calcium hydroxide (formed by mixing calcium oxide-lime-with water) in the causticizer, converting the sodium carbonate to sodium hydroxide and thereby regenerating white liquor for the pulping process. The precipitate from the causticizer, calcium carbonate-called lime mud-is burned in a lime kiln to regenerate calcium oxide.

Figure XXI.3. Kraft chemicals recovery cycle



Note: For details on kraft pulping, see T. M. Grace and E. W. Malcolm, eds., *Pulp and Paper Manufacture, Vol. V, Alkaline Pulping* (Atlanta, Georgia, TAPPI, 1989).

B. Kraft pulping and energy efficiency

The bleached and unbleached kraft pulping processes are essentially the same, except bleached kraft is cooked to achieve a higher level of delignification in the digester and the pulp is bleached. The pulp is then dried in a market pulp mill, whereas it is converted into dried paper at an integrated mill. As in most industries, new or modernized plants typically use less energy than old plants. The industry has been more effective in reducing steam demand than electricity demand in new and retrofitted mills, which has contributed to the trend of increasing electricity to heat ratios (table XXI.3).

Table XXI.3. Comparison of specific energy use in kraft pulp mills

	Including Powerhouse[a]		Excluding Powerhouse[a]		
Mill	Steam demand (GJ/ADMT)	Electricity demand (kWh/ADMT)	Steam demand (GJ/ADMT)	Electricity demand (Wh/ADMT)	Electricity/ heat[b] (kWh/GJ)
1960 U.S. mill[c]	24.5	920	22.3	756	34
1980 U.S. mill[d]	20.2	780	16.3	656	40
Average 1988 Swedish[e]	15.2	840	-	-	55[e]
Best 1988 Swedish[e]	12.4	720	-	-	58[e]
Model mill 1980[f]	12.2	740	11.7	680	58
Model mill 2000[f]	7.8	640	7.8	580	84

[a] Powerhouse energy demand is the co-generation plant's parasitic energy consumption.

[b] Electricity/heat ratio is based on steam and electricity demand including powerhouse because separate estimates of powerhouse steam and electricity consumption were not available.

[c] A. Subbiah and others, "Energy analysis of a kraft pulp mill's potential for energy efficiency and advanced biomass co-generation", *Proceedings of the 17th Industrial Energy Technology Conference,* April 1995.

[d] E .D. Larson, "Biomass gasifier/gas turbine co-generation in the pulp and paper industry", *Journal of Engineering for Gas Turbines and Power,* vol. 114 (1992).

[e] Steam data for average and best 1988 Swedish mills, from ÅF-IPK, "Energy use in the pulp and paper industry 1988", report to the energy committee of the Swedish Forestry Industries Association, 1989.

[f] Data for the model mill 2000 are from B. Warnquist, "Massa-och paplerslinjer med tillgänglig processteknik år 2000", Swedish Board for Industrial and Technology Development, report 1989-10-24, 1989. The model mills show what is considered to be technically and economically feasible in a greenfield mill with 1980- and 2000-vintage technology, respectively. The model mill 2000 is still based on the kraft process but uses extended modified cooking, oxygen delignification and elemental chlorine-free bleaching.

The main steam users in a kraft pulp mill include the digesters, the evaporators and the pulp drier (or, alternatively, the paper machine in an integrated mill) (figures XXI.2 and XXI.3). These three unit processes account for about three quarters of the steam use in most market pulp mills.

Electricity demand is more evenly distributed throughout the mill than steam demand. Most electricity is used in pumps and fans: 40-45 per cent and 15-20 per cent of the total, respectively, according to a detailed electricity audit of two Swedish mills [9]. Most of the installed fan capacity is in the dryer, lime kiln and boilers. The main electricity-using machine drives are found in the woodyard and the pulp screening plant. Other electricity uses are present at an integrated mill: stock preparation and the paper machine may each account for 200-300 kWh/ADMT of electricity demand in a linerboard mill [10]. Table XXI.4 presents a breakdown of energy use in two United States mills and in two hypothetical model mills to illustrate the development in energy use over time and to give an indication of the potential for efficiency improvements. The United States mills are described in more detail by Larson [11] and Subbiah and others [12]. The two model mills represent what a large Swedish consulting firm considers possible using 1980-vintage and 2000-vintage technology in a greenfield mill.*

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*The primary objective for the model mill work has been to develop input to the Swedish government long-term energy planning.

Table XXI.4. Comparison of unit-level steam and electricity demands for bleached kraft pulp production[a]

	Steam (GJ/ADMT)				Electricity (kWh/ADMT)			
	US60[b]	US80[c]	M80[d]	M00[d]	US60[b]	US80[c]	M80[d]	M00[d]
Woodyard	-	-	0.3	0.1	..	25	75	75
Digester	4.57	2.89	2.5	1.5	..	43	50	40
Washing	-	-	-	-	..	..	40	10
Screening	-	-	-	-	212	103	45	20
Oxygen delignification	0.43	-	0.35	0.7	..	47	60	85
Bleaching[e]	1.15	0.51	1.35	0.15	185	42	120	60
Screening and storage	-	1.08	-	0.2	-	74	50	40
Drying and baling	5.92	3.94	3.25	2.15	174	153	130	110
Black liquor concentration	5.26	4.33	3.75	2.95	-	66	25	30
Powerhouse	2.50[f]	3.91	0.50	-	-	125	60	60
Causticizing and lime kiln (excl. fuel)	0.31	-	0.15	-	141	42	35	45
Waste water treatment	-	-	-	-	..	-	35	30
Other	4.41[a]	3.51[h]	-	..	208[i]	61[j]	15	35
Total	**24.55**	**20.16**	**12.15**	**7.75**	**920**	**780**	**740**	**640**

[a] Note that different accounting principles complicate comparisons at the unit level. For example, the high electricity use in causticizing and lime kiln in the US60 mill suggests that it includes electricity use in black liquor evaporation.

[b] Mills built in the 1960s in the United States. (A. Subbiah and others, "Energy analysis of a kraft pulp mill's potential for energy efficiency and advanced biomass co-generation", *Proceedings of the 17th Industrial Energy Technology Conference*, April 1995.)

[c] Mills built in the 1980s in the United States (E. D. Larson, "Biomass gasifier/gas turbine cogeneration in the pulp and paper industry", *Journal of Engineering for Gas Turbines and Power*, vol. 114 (1992).)

[d] Hypothetical mills that would use the best available technologies in 1980 (M80) and 2000 (MOO) (B. Warnquist, "Massa-och papperslinjer med tillgänglig processteknik år 2000", Swedish Board for Industrial and Technology Development, report 1989-10-24, 1989.) The model mills show what is considered to the technically and economically feasible in a greenfield mill with 1980- and 2000-vintage technology, respectively. The model mill 2000 is still based on the kraft process but uses extended modified cooking, oxygen delignification and elemental chlorine-free bleaching.

[e] The US80 mill has a three-step bleaching sequence and the other mills have five-step bleaching.

[f] Consists of 1.44 GJ/ADMT and 1.06 GJ/ADMT to utilities and soot blowing, respectively.

[g] Consists of 2.34 GJ/ADMT, 1.01 GJ/ADMT and 1.06 GJ/ADMT to deaerator, water heater and chiller.

[h] Consists of 1.75 GJ/ADMT, 0.70 GJ/ADMT and 1.06 GJ/ADMT to deaerator chiller, and other, respectively.

[i] Consists of 164 kWh/ADMT and 44 kWh/ADMT to utilities and water plant, respectively.

[j] Consists of 16 kWh/ADMT, 25 kWh/ADMT, 5 kWh/ADMT, 2 kWh/ADMT and 14 kWh/ADMT to water supply, air supply, chiller/HVAC, odour control and miscellaneous, respectively.

C. Biomass-based combined heat and power generation

In addition to being the feedstock for pulp and paper production, biomass is also an important energy resource for the industry. For example, black liquor and solid biomass residues (bark and hog fuel) generated at the mill and used for energy accounted for about 55 per cent (1.5 EJ, more than two thirds of which was black liquor) of all the energy consumed by the United States pulp and paper industry in 1993. Purchased fossil fuels amounted to about 1 EJ, or 40 per cent of total fuel consumption. In the Swedish pulp and paper industry in 1991, purchased fuels accounted for about 15 per cent of total fuel consumption and about 85 per cent was domestic wood fuels, two thirds of it was black liquor. With an estimated production of 140 million tonnes of kraft pulp in 2010 (Table XXI.2), the energy contents of the black liquor would be about 3.2 EJ.*

The industry also has access to residues of pulpwood harvesting, some of which can be removed from the forest without serious environmental consequences.** One estimate of the amount of environmentally recoverable forest residues (applicable in the south-eastern United States) is some 0.15 tonnes/tonne pulpwood [11]. The estimate of 0.15 tonnes of residue, if applied to the total world pulpwood consumption,*** corresponds to about 47 million dry tonnes of biomass, or an additional 0.93 EJ per year of biomass. The available biomass from residues and thinnings may be much higher for some mills. A detailed study at one United States mill indicated that the amount available was equivalent to the total amount of pulpwood consumed at the mill [13].

All black liquor and most mill residues are used at mill sites to fuel co-generation systems providing steam and electricity for on-site use. In 1991, the United States pulp and paper industry generated a total of 54 TWh of electricity, which met 56 per cent of its electricity needs [14]. Essentially all of this power was produced in steam-Rankine cycles, with black liquor accounting for about 43 per cent and bark and wood chips for about 18 per cent of the fuel input to the boilers [14, 15]. The remaining 39 per cent came from fossil fuels.

The energy implications of alternative biomass-fuelled co-generation technologies for the industry are discussed next.

1. *Existing co-generation technology*

The average heating value of spent pulping liquors in the United States is equivalent to 23 GJ/ADMT chemical pulp, and it accounts for 73 per cent of the biomass-derived fuels used in the pulp and paper industry today. The concentrated black liquor in the kraft pulping process is now burned in Tomlinson recovery boilers, to (a) recover process chemicals in the form of sodium sulphide and sodium carbonate and (b) generate steam from combustion of the contained organic matter. The recovery boiler is thus an integral part of the process and of the mill's steam and power system. The cost of a recovery boiler for a 1,200 ADMT/day bleached softwood kraft pulp mill firing 2,000 tonnes black liquor/day is about US$ 65 million [16]. An entire chemical recovery system costs about US$ 100 million, about one sixth of the total cost for a 1,200 ADMT/day bleached kraft market pulp mill [17]. The recovery boiler is a primary reason for the capital intensity and economies of scale associated with kraft pulp mills.

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*Assuming 1.5 tonnes black liquor per tonne pulp and an energy content of 15 GJ/tonne black liquor.

**The impact on soil nutrients and organic content are key concerns associated with the removal of logging residues. Recycling ash from the mill back to the forest may be necessary or desirable to minimize long-term nutrient depletion [18, 19]. Removing residues for energy might actually be beneficial in areas with high nitrogen deposition from air poullution [20].

***Pulpwood consumption in 1993 was 460 million m^3, or about 310 million tonnes, assuming 675 kg dry matter/m^3 [21].

In a recovery boiler, droplets in a black liquor spray-dry, pyrolyze and burn. The inorganic chemicals are extracted as a smelt at the bottom of the boiler. Steam is usually produced at about 60 bar and 450° C and fed to one or more back-pressure steam turbines from which some process steam is extracted at 10-12 bar and the rest exhausts at 4-5 bars. Bark, hog fuel, and other fuels are fired in separate boilers to raise steam, which typically augments the steam from the recovery boiler.

The electricity/heat production ratio for a conventional back-pressure steam turbine is about 0.23 (60 kWh/GJ) with no intermediate extraction and about 0.15 (40 kWh/GJ) with an intermediate extraction [22]. These electricity/heat ratios are relatively well matched to the steam and electricity needs at older kraft mills (table XXI.3). However, increasing electricity/heat demand ratios are motivating interest in alternative co-generation technologies.

Electricity/heat ratios can be increased to some extent by increasing boiler pressures and temperatures. For example, 60-80 kWh/GJ can be achieved with steam conditions of 105 bar and 520° C [22]. The overall ratio of electricity to heat output may also be increased by using a condensing extraction steam turbine in which some of the steam is expanded to subatmospheric pressure to produce additional power and then condensed. Condensing power can also be produced by adding a separate condensing steam turbine after the back-pressure turbine. The technology of choice depends on the specific energy balance and relative fuel and electricity prices for each mill.

There are several reasons for industry interest in alternatives to the Tomlinson recovery boiler/steam turbine systems, in addition to limitations on the electricity/heat ratios that can be achieved. The black liquor handling capacity of the recovery boiler is typically the bottleneck to expanding overall production capacity at a mill, and adding incremental recovery boiler capacity (as many mills would like to do) is prohibitively capital-intensive. (Recovery boilers are built large to take advantage of economies of scale.) Other drawbacks of Tomlinson recovery boilers include dangerous explosions that can occur when water or wet black liquor inadvertently contacts the smelt, as well as emissions of odorous and acid gases. Furthermore, a large fraction of the existing recovery boilers were installed between 1965 and 1975. In the United States it is expected that 70 per cent of all recovery boilers will need some type of major rebuild or replacement in the next decade [23].

2. *Future co-generation technology*

Most interest in new biomass co-generation technologies focuses on those that would utilize gas turbines rather than steam turbines. Gas turbines are generally characterized by higher electricity/heat ratios than steam turbines, as well as lower unit capital costs. The key requirement for using biomass in a gas turbine is a clean gaseous fuel. Thus, there is significant development work on technologies for converting black liquor or biomass residues into combustible fuel gas,* and on the clean-up systems that would be needed to enable use of the gas in gas turbine cycles.

(a) Black liquor gasification

Black liquor gasification [24, 25] is attracting considerable interest from industry today, primarily because gasifiers are expected to allow cost effective incremental recovery of chemicals. In the longer term, full-scale black liquor gasification/gas turbine co-generation systems should offer higher overall energy efficiency, higher electricity-to-heat ratios, and lower emissions than recovery boiler/steam turbine systems.

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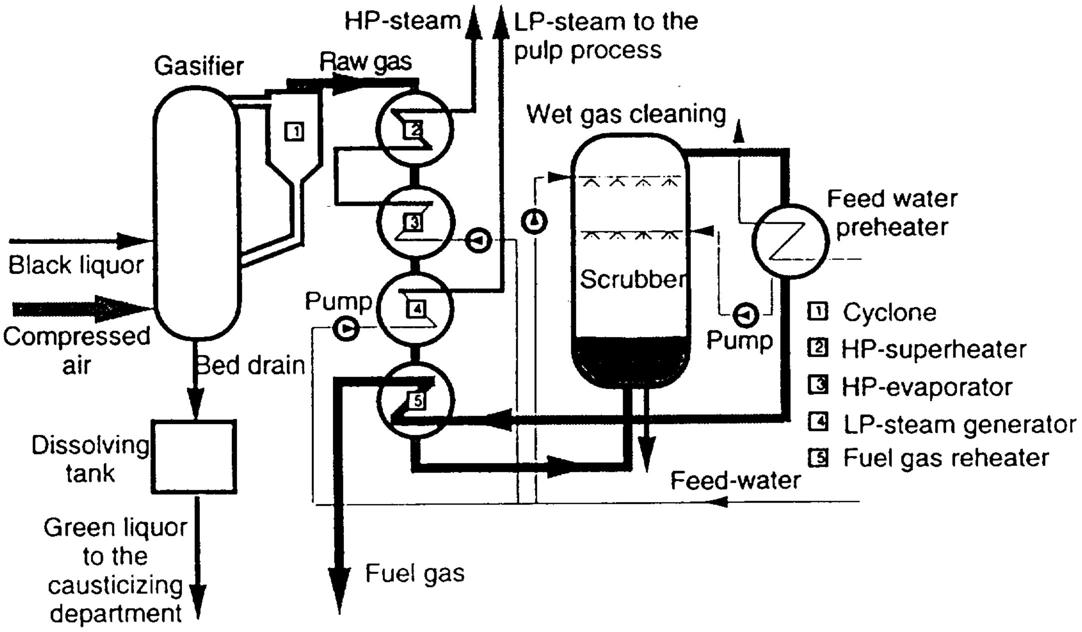
*Hydrogen and carbon monoxide are the most important combustible components in most fuel gases from gasifier. The full composition of the gas depends on the design and operating conditions of the specific gasifiers.

Gasification processes are categorized as low-temperature/solid-phase (below approximately 750° C) or high-temperature/smelt-phase (above approximately 900°C). They produce fuel gas with HHV of 3-4 MJ/Nm^3 (with air as the gasifying agent) or 8-9 MJ/Nm^3 (with oxygen or with indirect heating) [25]. With either gasifier, clean-up of the fuel gas is required to recover inorganic chemicals that may leave the gasifier with the gas, to prevent damage to the turbine and to meet emissions regulations.

The main feature of the low-temperature gasification processes are that they employ fluidized-bed gasification. Solid sodium carbonate is precipitated out during gasification and forms the bed material. Some 70 per cent or more of the sulphur in the black liquor leaves as H_2S gas, which then is scrubbed from the gas (figure XXI.4). Manufacturing and Technology Conversion International (MTCI) and Asea Brown Boveri (ABB) are two leading developers of low-temperature gasifiers. The MTCI design is an indirectly heated fluidized bed (with in-bed heater tubes). The ABB design (figure XXI.4) is an air-blown circulating fluidized bed. MTCI is testing a 50 tonne black liquor solids/day gasifier at Weyerhaeuser's kraft pulp mill at New Bern, North Carolina. ABB has been testing a 2-4 tonne/day pilot gasifier in Sweden since 1991 and is planning a 50-100 tonne per day demonstration unit in the United States.

Figure XXI.4. Low-temperature/solid-phase, circulating fluidized-bed black liquor gasifier (ABB Type) with wet gas clean-up

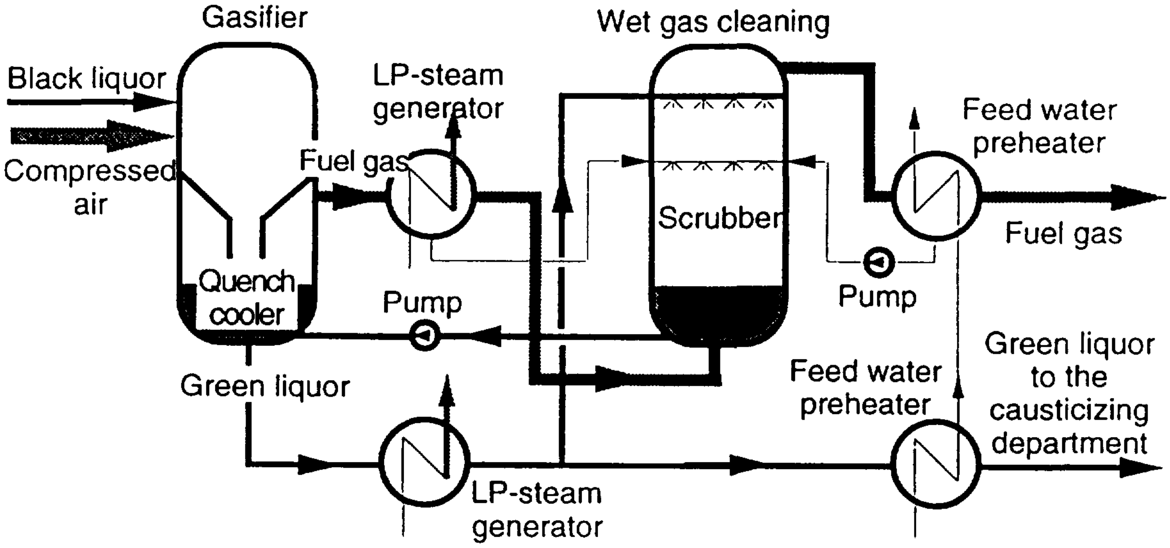


Source: N. Ihren, "Optimization of black liquor gasification systems", licentiate's thesis, Royal Institute of Technology, Stockholm, 1994.

One of the main difficulties associated with low-temperature processes is that they must operate within a narrow temperature window: high enough to achieve satisfactory gasification rates and tar destruction but low enough to avoid softening of the bed material, leading to agglomeration. Closed-cycle operation of mills could lead to accumulation of potassium and chloride in the bed material. If not removed, these elements will lower the melting point of the bed and further narrow the temperature window.

High-temperature gasification uses an entrained flow reactor (figure XXI.5). Inorganic chemicals (sodium carbonate and sodium sulphide) are recovered as a smelt similar to that from a recovery boiler. About half the sulphur leaves as H_2S in the fuel gas. The high-temperature reactors give higher rates of carbon conversion than with the low-temperature design. Kvaerner Pulping is the leading developer of the high-temperature technology. An atmospheric pressure unit having a capacity of 75 tonnes/day is operating commercially at a Swedish mill in parallel with a recovery boiler to boost chemicals recovery capacity. Kvaerner has also operated a pressurized (6-7 tonnes/day capacity) gasifier with a gas clean-up system at a Scandinavian mill since February 1994 [26]. Large atmospheric pressure units-250 tonnes/day-are now being offered on commercial terms for incremental capacity increases. Weyerhaeuser recently placed the first commercial order with Kvaerner Pulping. Tampella, a Finnish equipment supplier to the pulp and paper industry, undertook limited pilot-scale tests beginning in 1991 with a 2-3 tonnes/day gasifier. However, the unit is no longer being operated, and Tampella's activities are at present limited to fundamental studies [27].

Figure XXI.5. High-temperature/smelt-phase, entrained-bed black liquor gasifier with quench (Kvaerner-type) and wet gas clean-up



Source: N. Ihren, "Optimization of black liquor gasification systems", licentiate's thesis, Royal Institute of Technology, Stockholm, 1994.

Note: Pressurization of the gasifier facilitates recovery of heat at higher temperature and pressure.

The higher rate of carbon conversion is an important advantage of the high-temperature gasifiers. However, there is some concern about the materials and corrosion problems associated with operating at high temperatures. Higher concentrations of potassium and chloride as a result of mill downtime are likely to be an advantage in high-temperature gasifiers since they increase the reactivity of the black liquor [26, 28]

(b) Bark and wood waste gasification

Black liquor is the most abundant biomass energy source at a kraft pulp mill, providing 20-25 GJ/ADMT. However, bark and wood wastes also make important contributions at most mills.

Typically, 5-10 per cent of the pulpwood that enters a mill is bark and other residues, corresponding to roughly 200 kg of dry substance, or 4 GJ/ADMT pulp. The recovery of logging residues might add another 8 GJ/ADMT, so that bark and wood waste might make up 12 GJ/ADMT, or 50 per cent of the energy value of the black liquor.

A handful of large (>30 MW biomass input) atmospheric-pressure, air-blown wood-chip gasifiers are operating commercially today, most of which supply fuel gas to lime kilns at kraft pulp mills. Pressurized and other advanced gasifier designs are the focus of demonstration efforts of biomass integrated gasifier/gas turbine (BIG/GT) technology in several countries [29]. The first BIG/GT system to be built was a 6 MWe and 9 MWt (20 MW biomass input) combined cycle district heating co-generation facility in Värnamo, Sweden. Testing of that system began in 1994 and is ongoing. Other planned demonstration efforts include a commercial-scale combined cycle in north-east Brazil that will be partially financed by the Global Environmental Facility [30]. An Enviropower wood-waste gasifier coupled with a combined cycle based on General Electric's Frame 6B turbine producing more than 50 MWe is planned for construction beginning late next year at the Summa Paper Mill of Enzo Gutzeit Oy, one of Finland's largest paper producers [31]. Several demonstration projects in the 8-20 MWe range have recently been announced in the European Union, and two projects receiving partial backing from the Department of Energy are ongoing in the United States.

(c) Electricity exports from kraft pulp mills

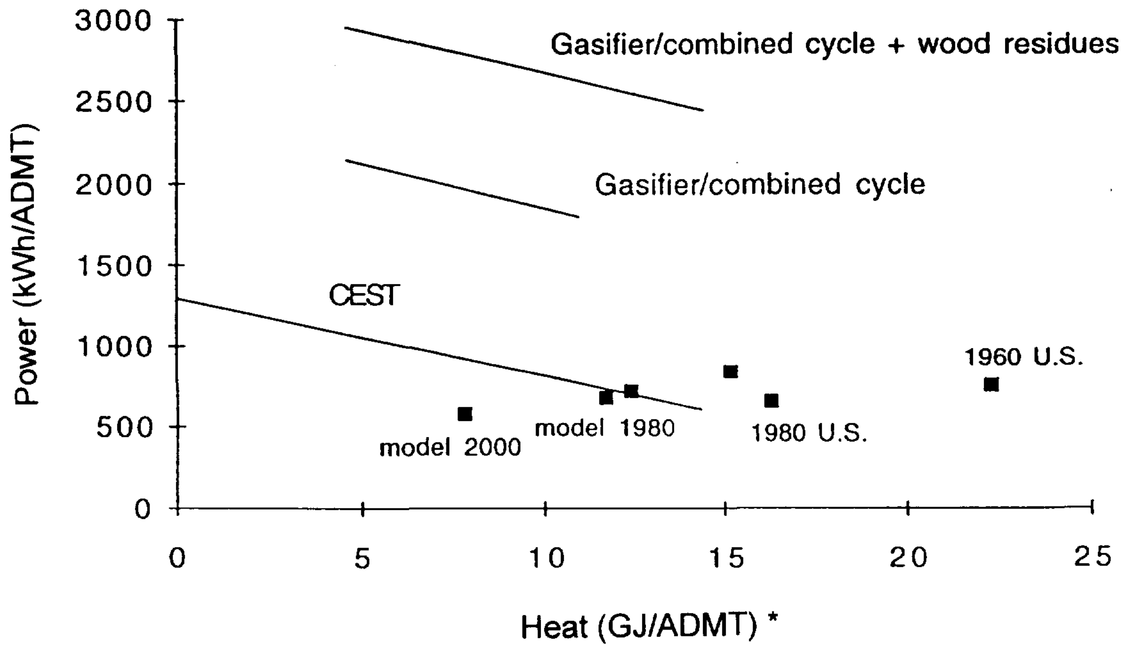
Mills with kraft pulp production might become significant electricity exporters if they were to adopt full-scale black liquor and biomass gasification gas turbine technologies [11, 16, 24, 32]. Commercial biomass gasifier/gas turbine systems might be commercially available by the end of the decade. The commercialization of systems using black liquor gasification will probably require somewhat longer, because gasifier/gas clean-up technology is at a less mature stage for black liquor than for woody biomass.

The potential impact of alternatives to existing co-generation systems using back-pressure steam turbines can be appreciated from an examination of three configurations of black liquor/biomass co-generation systems at a kraft pulp mill, assuming biomass fuel availability of 21 GJ/ADMT of black liquor and 4 GJ/ADMT of bark: (a) biomass and recovery boilers are used, but a condensing-extraction steam turbine (CEST) replaces the back-pressure system; (b) black liquor and biomass gasifiers fuel a gas turbine/steam turbine combined cycle; and (c) the same as the previous system, but assuming the supplemental availability of 8 GJ/ADMT of logging residues as fuel.

Figure XXI.6 from Subbiah et al. [12] summarizes the estimates of electricity and steam production for each case. Varying electricity/heat ratios can be generated with the CEST and gas turbine technologies to match the particular energy demands of a mill. Mill demands correspond to those shown in table XXI.3 for alternative mills.

The CEST option in the full co-generation mode (maximum process steam production) generates about 600 kWh/ADMT electricity and 14.4 GJ/ADMT steam. With this technology, an efficient kraft mill can be essentially energy self-sufficient. With option (b), the integrated gasification/gas turbine combined cycle using mill residues, 1,800 kWh/ADMT and 11 GJ/ADMT would be generated in the full co-generation mode. Further reductions in steam demand would be needed compared to option (a). Assuming these can be achieved, there would be about 1,100 kWh/ADMT, or 35-45 MW of baseload power (at a 1,200 ADMT/day mill), available for export from the mill after meeting on-site demands. The value of the excess electricity (assuming US$ 0.05/kWh revenue) would be US$ 55/ADMT, which is significant relative to the value of the primary product, pulp. (Bleached kraft pulp prices in recent years have been US$ 400-800/ADMT. The same system but including use of logging residues (option (c)) would generate 2,440 kWh/ADMT and 14.5 GJ/ADMT in the full co-generation mode and would thus provide still greater electricity revenues. The economic viability of the gas turbine options would need to be examined carefully, but some preliminary assessments [11, 16] show potentially attractive returns.

Figure XXI.6. Steam and electricity production potential (net of co-generation plant) at a kraft pulp mill from bark (4MJ/ADMT) and black liquor (21 MJ/ADMT) fuels using alternative co-generation technologies



Note: Steam and electricity demands (excluding powerhouse, table XXI.3) for alternative mill technologies are also shown. The co-generation technologies are the condensing-extraction steam turbine (CEST) and black liquor/bark integrated gasification/gas turbine combined cycle (black liquor and bark are gasified separately). For the latter technology, two lines are shown. The upper line assumes the use of 8 MJ/ADMT of forest or other biomass residues in addition to the 25 MJ/ADMT of fuels assumed for the lower line and for the CEST case. For details of the calculations, see A. Subbiah and others, "Energy analysis of a kraft pulp mill's potential for energy efficiency and advanced biomass co-generation", *Proceedings of the 17th Industrial Energy Technology Conference*, April 1995.

*1 GJ = 1.055 MM Btu.

Assuming an average electricity production of 2,000 kWh/ADMT of bleached, semi-bleached and unbleached kraft pulp and a global production of 140 million ADMT of kraft pulp per year, the total annual electricity production would be 280 TWh. This is probably more than double the amount of electricity self-generated by the pulp and paper industry today.

D. Discussion and conclusion

The development of black liquor gasification is at present motivated primarily by non-energy factors. Incremental enlargement of recovery boiler capacity, the bottleneck in many existing mills, is generally not economic, but incremental addition of black liquor gasification is feasible. This is the initial market for black liquor gasifier developers. The fact that non-energy issues are driving the development an implementation of black liquor gasification technology illustrates an important point: energy efficiency improvement, either through new technology development or simple off-the-shelf technologies, is not a primary objective in the industry but will often synergistically accompany gains in productivity, environmental performance, capital utilization and other higher priority factors.

At present, there is little incentive for existing mills to pursue improved steam use efficiency: when less steam is used, more electricity must be purchased, because the electricity/steam production ratio of a back-pressure steam turbine is more or less fixed. The introduction of new co-generation technology is required to overcome this problem, but such retrofits are costly when equipment has not yet reached the end of its useful life. The necessary rebuild or full replacement of ageing recovery boilers over the next decade, however, will create a window of economic opportunity in which to introduce new technology

Pulp production is also expected to grow rapidly in, for example, Asia and South America. Production capacity increases in these regions, and elsewhere, should be based on best available technology. This could have important effects, not least in terms of reduced environmental impacts. Improved end-use energy efficiency might also facilitate significant improvements in on-site co-generation. The pulp and paper industry is in the unique position of being able to rely on its own internally generated fuels from renewable biomass resources to a large extent: a modern kraft pulp mill can be entirely self-sufficient in energy and perhaps even export biomass-generated power to other users. Raymond [33] reports that energy experts at some companies think that within two decades many pulp mills will derive as much value from energy ventures as from the pulp itself.

Advanced biomass-based co-generation systems, which would be much more efficient than existing systems, are undergoing rapid development. Such systems are likely to be commercial by around the turn of the century. The pulp and paper industry is a prime initial market for such systems because it has biomass fuels available on-site and because it will be expanding production capacity and retiring or rebuilding many of its ageing chemical recovery boilers and much of its co-generation equipment during the next decade or so. Deregulation of electricity markets may give the industry an opportunity to market renewable electricity directly. Alternatively, the industry might divest its energy assets and become primarily a supplier of biomass fuels without adding much value to them. It would probably benefit in either case, so it should take a leadership role in developing and commercializing such technologies.

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Part six

Summary report on consensus and conclusions

CHIEF RAPPORTEUR' S SUMMARY

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The symposium covered a variety of interesting subjects, beginning with a comparison of biomass energy production and potential uses in different regions. It also provided specific country case studies about the present situation and trends in biomass energy utilization (volume II). Technological aspects discussed included the production of biomass resources, their conversion into energy carriers and technology transfer to developing countries. This was followed by an analysis of financial resources available and mechanisms for funding biomass projects. Finally, discussion was devoted to environmental effects and ways to incorporate those effects into economic analyses comparing biomass with fossil and other fuels. Some relatively successful biomass projects under development were described.

A. Consensus

Consensus was achieved in the following areas:

- There are real social advantages to be obtained from increasing the efficient use of biomass energy. The fact that a significant amount of biomass resources is being used with very low efficiency means there is a significant potential for sustainable expansion of biomass energy services.

- The main argument for biomass should rest on its convertibility to modern energy carriers.

- Available biomass resource production and conversion technologies have significant potential for improvement. However, such improvements must be accompanied by the further development of biomass energy markets, which are largely underdeveloped in both developed and developing countries.

- It may be advisable to pursue two paths of biomass energy development: (a) provide rural energy services for poor people using local biomass resources; and (b) develop the larger market constituted by middle income, urban population (this path will provide better returns, better opportunities for financing and allow for significant advances in the commercialization of biomass technologies). A number of dual-track strategies could be pursued: small/large industrial applications; traditional/modern energy carriers; incremental system upgrades/technological leaps; project financing/broader based programme financing; and residue resource development/plantation development. Interest groups that can focus their attention on any one of these strategies should be formed in future meetings.

- Despite the potential of biomass energy, there are still many barriers to its successful development:

    - Lack of appropriate government policies on energy pricing, taxes, subsidies and the environment and lack of political will to privatize energy supplies. In particular, biomass cannot presently compete extensively with fossil fuels unless subsidies are provided or externalities are incorporated into national or global environmental policy measures.

  - Constraints on commercial financing for medium and large projects in most developing countries. Securing funds depends on the ability of a developing country to meet the criteria of financiers as well as some flexibility on the part of investors, and backing by multilateral funds and banks. There is, however, still a shortage of grants for carrying out assessments and demonstrations of non-conventional applications.

  - Limited national capabilities in institutions, policy and technical areas.

  - The diverse applications of biomass technologies, which vary with each country's potential, tradition and experience.

- Areas that need verification or clarification include the following:

  - Most participants felt that the trade-off between food and fuel production did not pose a major issue in most countries. Also the claim by some participants that biomass production for energy purposes would take up too much land in the Asia and Pacific region was said by the majority of participants to be an unsubstantiated claim. Both issues require further verification.

  - It is possible to continue to pursue the R and D path, developing more sophisticated and cost-effective technologies, and it also is possible to pursue a learning-by-doing path, with more modest, yet readily available, technologies. Both paths may be appropriate, and neither should be completely excluded.

B. Conclusions

Participants arrived at a number of conclusions:

- There was a need to properly evaluate and incorporate all the externalities into order to draw a fair economic comparison between biomass and fossil fuels.

- Temporary subsidies for most promising learning-by-doing projects could contribute significantly to the successful implementation of new approaches.

- Biomass energy planning could follow a double path:

  - Large projects for urban, middle-class markets could be commercially viable and attract commercial financing from domestic and foreign sources.

  - Small projects are better suited to rural areas. While these projects are based on social considerations, they are one way to promote biomass. They usually rely on grants, which are not superabundant.

- A natural follow-up of this symposium would be the preparation of another meeting devoted to a specific project. It would include a complete cost evaluation, so as to promote interest among potential financiers and donors.

- Industrial projects financed by multilateral or bilateral organizations should include a biomass energy component. This would be an innovative means of financing enhanced utilization of biomass energy.

- Biomass uses should be promoted in a continuing public campaign, and the results of this symposium could form part of the information input to that campaign.

Finally, approval and acceptance by the United Nations of the IPCC-95 recommendations would provide an opportunity for the development of biomass energy resources and uses. One of those recommendations was that a significant amount of biomass should be used as a primary source of energy. That would force biomass energy planners to pay more attention to the market. Decisions to increase the use of biomass must be made as soon as possible, without undue worry about potential mistakes. The effort will require identifying the best technologies, persuading policy makers, quantifying the environmental and social advantages of biomass energy and facilitating relationships between foreign investors, private local entrepreneurs, utilities and governments officials.

Annex

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