Chapter 10

Bioenergy (other than Wood)

COMMENTARY

Introduction

Biomass resources are potentially the world’s largest and most sustainable energy resource, comprising approximately 220 billion oven-dry tonnes (odt) (or c. 4 500 EJ) of annual primary production; the annual bioenergy potential is about 2 900 EJ, although only a fraction could realistically be used on a sustainable basis and at competitive prices. Estimates of the future potential contribution of bioenergy range from 67 to 450 EJ per annum.

Bioenergy is a broad term embracing a large range of feedstock. It can be classified into three main categories: (i) woodfuels, (ii) agrofuels, and (iii) fuels derived from urban waste. Bioenergy can also be classified according to a chosen technology route: (i) traditional applications (e.g. firewood and charcoal) and (ii) modern uses (e.g. electricity generation and combined heat and power (CHP)). Modern applications are rapidly replacing traditional uses, in particular in industrial countries, e.g. in Finland and Sweden 15–20% of their primary energy is generated from biomass. Bioenergy is not a transition fuel as it has often been portrayed, but a fuel that will continue to be the prime source of energy for many people for the foreseeable future.

Comparison with the WEC Survey of Energy Resources 2001 Commentary

It is not possible to do justice in a few pages to such a complex issue as bioenergy. The SER 2001 commentary (Rosillo-Calle, 2001) presented an overview of bioenergy with particular attention to the use of residues, modernisation efforts to upgrade bioenergy and a brief discussion of its potential role in climate change mitigation. It also highlighted the main reasons why bioenergy had become increasingly important in the previous decade; such issues are still largely valid today. The present commentary is slightly different, e.g. the word ‘biomass’ has been replaced by ‘bioenergy’, for the sake of clarity; after a brief note on wood fuels, agrofuels and municipal solid waste (MSW) (the last named was excluded from previous commentaries), the text concentrates primarily
on non-woody biomass. It also assesses some of the most recent technological, policy and legislative changes, all of which are playing key roles in the successful penetration of bioenergy as a cost-effective and competitive energy option.

**Continuing Difficulties with Data and Classification of Bioenergy**

Previous commentaries have highlighted the problem of the lack of good-quality data. In recent years, thanks to considerable efforts by some international agencies (e.g. FAO, IEA) and national governments, data have improved significantly, particularly in industrialised countries. In poorer countries there are still serious problems and lack of data continues to hamper sound decision-making. This is largely caused by lack of financial and human resources for adequate data collection and analysis and by the informal nature of traditional bioenergy. Many WEC member countries are unable to produce adequate and reliable data on bioenergy or cannot supply any data at all.

The problem is particularly acute in respect of economic data, which are not readily available or are quoted in a way that makes comparisons very difficult. The inability to fully address the indigenous biomass resource capability and its likely contribution to energy and development is still a serious constraint on the full realisation of bioenergy’s potential.

A further constraint is confusion with respect to terminology. FAO has been attempting to address this problem for some considerable time and after many consultations a document is currently being finalised which will hopefully solve some of these problems (see FAO/WE, 2003). It is a difficult problem because bioenergy is an integral part of many cultures. FAO classifies bioenergy into three main groups according to the nature of the biomass: (i) woodfuels; (ii) agrofuels and (iii) municipal by-products (see Fig. 10.1). FAO/WE (2003) contains a more detailed discussion of terminology. Bioenergy can also be classified according to the technological route: (i) traditional bioenergy (firewood, charcoal, residues) and (ii) modern bioenergy (associated with industrial wood residues, energy plantations, use of bagasse, etc.); see, e.g. Goldemberg and Coelho (2003).

This chapter deals primarily with ‘bioenergy other than wood’. This term includes agricultural and livestock residues and herbaceous crops grown specifically for energy purposes, but excludes woody biomass (wood and wood-based residues, including sawmill waste and black liquor) and forest plantations grown specifically for energy, all of which are discussed in Chapter 9. However, the implications of large-scale plantations (herbaceous and woody crops) are briefly discussed.

**Bioenergy Potential**

There have been many attempts to quantify bioenergy potential, but difficulties arise owing to its complex and varied nature: ranging from resource availability to economic, technological, ecological, social, cultural and environmental factors. In addition, there is considerable uncertainty with regard to the potential role of dedicated energy forestry/crops, since residues (all sources) have a much more limited potential. The plantation potential ranges from 100 Mha to over 1 300 Mha. A recent study (IPCC-TAR, 2001) has estimated the global bioenergy potential from plantations at 440 EJ/yr (10.12 billion toe); it assumes that all agricultural lands not needed for food production (1.28 billion ha or 9.70% of total land) would be used for forest plantations.

Biomass resources are potentially the world’s largest and most sustainable energy source. Previous commentaries have quoted a potential renewable resource comprising 220 billion odt (or about 4 500 EJ) of annual primary production and an annual bioenergy potential of about 2 900 EJ, although realistically only 270 EJ could be considered available on a sustainable basis and at competitive prices (Hall and Rao, 1999). Various scenarios have estimated the potential contribution from bioenergy for
the period 2025–2050 at between 67 and 450 EJ for the research focus (RF) scenario, and from 28 to 220 EJ for the demand driven (DD) scenario. The share of total final energy demand lies between 7 and 27% (Hoogwijk et al., 2001). Thus, the problem is not availability of biomass resources but the sustainable management, competitive and affordable delivery of energy to those who need it to provide them with modern energy services. This implies that both production and use of bioenergy must be modernised.

Bioenergy is not a transition fuel as it has often been portrayed, but a fuel that will continue to be the prime source of energy for many people for the foreseeable future. For example, an IEA (2002) study concluded: ‘Over 2.6 billion people in developing countries will continue to rely on biomass for cooking and heating in 2030… this is an increase of more than 240 million from current use. In 2030 biomass use will still represent over half of residential energy consumption…’.

**Current Contribution**

Bioenergy is the most important renewable energy (RE) resource and currently provides about 55 EJ, mostly in the form of woody and herbaceous residues. In future, energy plantations are, as stated above, expected to play an

---

### FIGURE 10.1  Biofuel classification scheme proposed (Source: FAO/WE (2003)).

<table>
<thead>
<tr>
<th>Production Side, Supply</th>
<th>Major Commodities</th>
<th>User Side, Demand Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Woodfuels</td>
<td>WOODFUELS</td>
<td>Solid: Fuelwood (wood in the rough, chips, sawdust, pellets), Charcoal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid: Black liquor, Methanol, Pyrolitic oil</td>
</tr>
<tr>
<td>Indirect Woodfuels</td>
<td></td>
<td>Gases: Products from gasification and pyrolysis gases of above fuels</td>
</tr>
<tr>
<td>Recovered Woodfuels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel crops</td>
<td>AGROFUELS</td>
<td>Solid: Straw, Stalks, Husks, Charcoal from agrofuels</td>
</tr>
<tr>
<td>Agricultural by-products</td>
<td></td>
<td>Liquid: Ethanol, Raw vegetable oil, Oil diester, Methanol, Pyrolitic oil</td>
</tr>
<tr>
<td>Animal by-products</td>
<td></td>
<td>Gases: Biogas, Producer gas, Pyrolysis gases from agrofuels</td>
</tr>
<tr>
<td>Agroindustrial by-products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Municipal by-products</td>
<td>MUNICIPAL BY-PRODUCTS</td>
<td>Solid: Municipal solid wastes (MSW)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Liquid: Sewage sludge, Pyrolytic oil from MSW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gases: Landfill gas, Sludge gas</td>
</tr>
</tbody>
</table>

---

269
increasing role, with their future contribution being increasingly for modern uses.

**Agricultural and Livestock Residues**

These are currently the main sources of non-wood bioenergy and will continue to be so in the short to medium term. The expected increase of bioenergy consumption, particularly in its modern forms, could have a significant impact not only in the energy sector, but also in the drive to modernise and diversify current agricultural activities, with the consequent development of rural societies. A reliable and affordable supply of energy is a key prerequisite for socio-economic development.

Residues are a large and under-exploited potential energy resource, and offer many opportunities for better utilisation, as a large proportion of them are readily available and represent a good opportunity at low costs. With proper management, residues can lead to greater productivity in agriculture. There have been many attempts to estimate global production and use of residues, e.g. Woods and Hall (1994) estimated it as 93 EJ (c. 2.14 billion toe), although assessments vary considerably.

There are a number of important factors which need to be addressed when considering the use of residues for energy. First, there are many other competing uses, e.g. for animal feed, erosion control, animal bedding, fertilisers (dung), etc. Secondly, there is the problem of agreeing on a common methodology for determining what is and what is not a recoverable residue, e.g. estimates of livestock residues often vary by a factor of five.

Many residues would be difficult to utilise and thus the most reasonable approach would be to concentrate efforts on the more promising, e.g. sugarcane, corn, rice husks, etc. together with plantations.

As an example, more than 300 million tonnes of bagasse is produced worldwide and mostly used as fuel in sugarcane mills. The energy content of 1 tonne of bagasse (50% moisture content) is 2.85 GJ/tc (tonne cane) milled. This excludes barbojo (tops and leaves), which represents the largest part of the sugarcane (55%) and which is currently mostly burned off or left to rot in the fields. In Brazil alone, the cogeneration potential ranges from 4 GW using conventional technologies to 47 GW by 2025 with BIG/GT (biomass-integrated gasification gas-turbine). The importance of sugarcane does not only stem from its potential as an energy crop, but from the many other products that can be obtained simultaneously, e.g. sugar, ethanol and other by-products such as yeast, fertilisers, etc.

The use of livestock residues is more controversial. In view of concerns about environmental and health hazards, it is questionable whether animal manure should be used as an energy source on a large scale, except in specific circumstances. In addition, the variations in quantification are so large that figures are often meaningless. One of the most important developments of the past decade has been the use of poultry litter in combustion plants. Poultry litter is refuse from broiler houses and contains materials such as wood shavings, shredded paper or straw, mixed with droppings. The material has a calorific value of between 9 and 15 GJ/tonne, with a moisture content varying between 20 and 50%, depending on husbandry practices. Currently there is about 150 MW installed capacity worldwide (75 MW in the UK and over 50 MW in the USA) and it is growing rapidly, generating new economic, energy and environmental benefits from a resource largely wasted in the past.

**Plantations**

The potential of energy forestry/crops has sometimes been overstated. This stems from the assumption that large-scale energy plantations would be established primarily on degraded lands. However, recent studies have questioned this, as a key to producing low-cost energy forestry/crops is good-quality land (http://bioenergy.ornl.gov/reports/fuelwood/chap5.html). This study also shows that plantations aimed at generating electricity can be financially viable only when local conditions are favourable and/or the costs of conventional fuels are high.

2004 Survey of Energy Resources
Overall, it seems that large-scale energy plantation predictions are unlikely to be achieved; a more likely scenario would be closer to 300–500 Mha, despite the potential availability of land\(^1\). There are various reasons for this:

- degraded land is less attractive than good-quality land owing to higher costs and lower productivity, although the importance of bringing degraded land into productive use is recognised;
- capital and financial constraints, particularly in developing countries;
- cultural practices, mismanagement, perceived and potential conflict with food production, population growth, etc.;
- productivity would have to increase far beyond what may realistically be possible, although large increases could be achieved;
- increasing desertification problems and the potential impact of climate change on agriculture, which at the present time are too unpredictable;
- emerging energy alternatives (e.g. clean coal technology, wind power, etc.);
- water constraints.

**Municipal Solid Waste**

Previous commentaries have excluded a discussion on MSW owing to: (i) the nature of MSW, which comprises many organic and non-organic materials; (ii) the difficulties and high costs associated with sorting such material, making it unlikely as a candidate for RE except for disposal purposes; (iii) re-use of MSW was mostly for recycling; (iv) MSW disposal was mostly undertaken in landfill sites or incineration plants.

However, in the past few years important changes have taken place which make MSW more attractive; it is now recognised as an RE resource, although this is still debatable. MSW has been included in this commentary for the following reasons: (i) recognition of its increasing role as a potential energy source: e.g. in the EU about 7% of RE originates from MSW and this share is expected to grow; (ii) stringent environmental legislation in many countries, which has cut pollution from MSW-fuelled plants considerably, thus making it more acceptable from an energy and environmental point of view. For example, in the USA emissions from waste-to-energy (WTE) plants have been cut from 4 260 g toxic equivalent (TEQ) in 1990 to 12 g TEQ in 2000.

It is difficult to give reliable figures on total energy generated from MSW as this varies considerably, depending on the nature of this resource. This is further complicated by differences in the amount of MSW generated in different countries, and between rural and urban dwellers within individual countries (e.g. 314 kg/yr per capita in Japan, 252 kg/yr in Singapore or 170 kg/yr in Brazil). Its composition, and hence its potential as an energy source, varies considerably but generally it contains from 8 to 12 MJ/kg.

Rogner et al. (2001) have estimated the global economic energy potential from MSW at about 6 EJ (c. 138 mtoe). The USA alone produces about 240 million tonnes/yr of MSW. Worldwide, approximately 130 million tonnes of MSW are combusted annually in over 600 WTE plants in 35 countries to produce electricity and steam for heating and other industrial applications (Themelis, 2003).

Yet, despite increasing efforts to deal with this problem, in particular through WTE plants, hundreds of millions of tonnes of MSW still end up in landfills, emitting enormous amounts of GHG. Current RD&D on MSW focuses on ways to minimise waste, material recycling, energy recovery and landfill of the non-biodegradable fractions. The utilisation of the biodegradable fraction of MSW as a bioenergy is, in most countries, intimately linked with waste-management policies and public perceptions.

**Transportation Fuels**

In the past few years there have been important advances in the field of alternative transportation fuels, primarily ethanol and biodiesel: these are briefly described below.

---
\(^1\) This could change if carbon trading (CT) becomes a significant factor.
Ethanol fuel. The past 2 years have seen important changes in this area including: (i) a rapid increase in ethanol fuel production, particularly in the USA (from 31.9 billion litres in 2001 to over 38 billion litres in 2003); (ii) an increasing number of countries running or planning ethanol fuel programmes (see Fig. 10.2); (iii) increasing interest in flexible fuel vehicles (FFVs), including in Brazil: this offers considerable flexibility to both the producers and consumers of ethanol fuel; (iv) disappointing advances in the field of cellulose-based ethanol, with costs remaining a stumbling block; (v) direct electrochemical conversion in fuel cells.

Biodiesel. The production of biodiesel has increased dramatically in the past few years, particularly in the EU. Both the automobile industry and the biodiesel producers have played a major role in developing the technical and normative prerequisites. Blends of up to 20% (B-20) can be used in almost all diesel engines; B-20 does not require any engine modifications and provides the same payload capacity and range as conventional diesel, whilst increasing the engine lubricant consumption significantly. Higher blends can also be used in most modern engines with little or no modifications, although some material compatibility and warranty issues with higher blends have not yet been fully resolved.

The EU leads the world in the production and use of biodiesel, with a current installed capacity of over 2.3 billion litres; biodiesel supplies over 1% of the diesel market. The most important biodiesel producer and consumer is Germany, where production has increased from about 79.5 million litres in 1998 to nearly 1.26 billion litres in 2003\(^2\). It was expected that by the end of 2003 there would be about 1 700 service stations selling biodiesel in Germany alone (www.ufop.de).

Biodiesel production in the USA has also increased rapidly, mainly as a result of support from government and soybean producers, together with environmental pressures. But this market is still small compared to the EU, at just over 61 million litres in 2001, although the market is potentially very large. For example, the American Biofuels Association (ABA) considers that with government incentives comparable to those provided for ethanol, biodiesel consumption could reach 7.5 billion litres or about 8% of diesel consumption, primarily to power bus fleets, heavy-duty trucks and agricultural vehicles, mostly in blends of about 20%.

The US Department of Energy is currently developing a low-cost biodiesel from mustard seed that could add a further 5–10 billion US gallons (20–38 billion litres), if the research proves successful. The estimated costs are about US$ 1.00/gal (0.26 cents/l).

Technological Developments

Despite the fact that many technologies have reached the demonstration and validation stage and have shown that both small and large-scale applications are possible, technological advances have not been matched by economics. This is partly due to high costs of raw materials, low productivity, a large range of conversion technologies, competition from other energy sources, etc. Nonetheless, technological advances are opening up many new opportunities, and there are already many mature technologies that can meet such criteria, without being necessarily more expensive than fossil fuels (if all costs are internalised).

Combustion technology is already proven, while other more advanced technologies such as gasification are still at the development stage. Current interest centres on CHP and co-firing. Co-firing with fossil fuels has received considerable attention, particularly in the EU and the USA, and is emerging as one of the most important alternatives for large-scale biomass utilisation, if current technical, economical and cultural barriers can be overcome.

The driving force in co-firing is coal and the need to reduce GHG. Coal is abundant and will

\(^2\) Includes plants under construction and due to enter operation in 2003.
continue to be used, but needs to meet increasingly stringent environmental goals: biomass offers a good and cheap alternative. Blends of 15–25% biomass with coal have been widely tested and it has been shown that bioenergy can provide about 15% of the total energy input, with only feed intake systems and burner modifications. Current interest is to reach a 40% blend and also in co-firing with natural gas, coal and biomass. In countries with large reserves of coal and abundant biomass resources, co-firing is one of the most important and promising alternatives for using bioenergy on a large scale.

Co-firing in existing coal-fired power plants makes it possible to achieve greater efficiency in converting biomass into electricity, e.g. 33–37% when fired with coal. There are also important environmental benefits, e.g. lower

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (2001)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>150 million litres/yr (current production – all uses)</td>
<td>Plan for 2-5% blend nationwide by 2010, corresponding to 1–2 billion litres/yr production</td>
</tr>
<tr>
<td>Brazil</td>
<td>12.6 billion litres (2002)</td>
<td>Could increase production significantly if carbon trading and exports take off</td>
</tr>
<tr>
<td>Canada</td>
<td>240 million litres/yr (current production – all uses)</td>
<td>Target 1.35 billion litres/yr by 2010</td>
</tr>
<tr>
<td>China</td>
<td>3 billion litres/yr (current production – all uses)</td>
<td>Plan to produce additional 3 billion litres/yr from maize, sweet sorghum, cassava and sugarcane</td>
</tr>
<tr>
<td>EU-15</td>
<td>Over 2 billion litres of ethanol</td>
<td>Plan to increase ethanol significantly. Will need 8.5 - 14 billion litres/yr by 2010. Potentially a large market</td>
</tr>
<tr>
<td>India</td>
<td>1.8 billion litres/yr (current production – all uses)</td>
<td>Plan for 5% blend, trial at 300 refuelling stations, initial demand 350 million litres/yr</td>
</tr>
<tr>
<td>Mexico</td>
<td>70 million litres/yr (current production – all uses)</td>
<td>Programme to produce 1.3 billion litres/yr</td>
</tr>
<tr>
<td>South Africa</td>
<td>385 million litres/yr from coal and gas, 40 million litres from cane</td>
<td>Plan for 12% blend nationwide; plan to increase fermentation ethanol from cane</td>
</tr>
<tr>
<td>Thailand</td>
<td>150 million litres/yr (current production – all uses)</td>
<td>Plan for 10% blend, using molasses, cassava, and sugarcane, corresponding to 0.7 billion litres/yr</td>
</tr>
<tr>
<td>USA</td>
<td>About 11.2 billion litres (2003)</td>
<td>Large expansion programme; over 16 billion litres by 2005 and c.20 billion litres in 2015. Mostly from maize</td>
</tr>
<tr>
<td>Others: Colombia, Cuba, Peru, Central America, Ethiopia, Malawi, etc.</td>
<td>Large potential, ranging from a few million litres to hundred millions</td>
<td>Mostly ethanol from sugarcane to be blended with gasoline in various proportions. Some ethanol-diesel blends. Malawi blends 15% since 1982. Other programmes are at various stages.</td>
</tr>
</tbody>
</table>

**FIGURE 10.2** Summary of current ethanol production and plans for bioethanol fuel use.
sulphur emissions, about 30% reduction in NOx (see www.eren.doe.gov/biopower/), in addition to significant savings in plant and infrastructure investment, etc.

The past 2 years have failed to produce any major development in gasification and generally the performance of many plants has been rather disappointing, as they have failed to produce the expected results. A new and promising research area is the production of hydrogen via gasification.

Policies and Legislative Changes

Policies serve as the framework within which objectives and targets are set at the national and regional level to ensure sustainable production, marketing and use of bioenergy. Unfortunately bioenergy is often neglected in political, economic and social agendas. Bioenergy involves many factors, ranging from production, preparation, transportation, and conversion of raw materials for distribution and utilisation to final use, and this complicates matters.

Nonetheless, a growing number of countries have introduced legislation or have some specific policies to deal with the various aspects of bioenergy; generally, however, it does not receive the same benefits as conventional energy sources (Trossero, 2003). Despite the growing number of countries supporting bioenergy, much is still needed to integrate it into mainstream energy systems.

Legislative measures have a key role to play. Without a legal framework, bioenergy will not penetrate the energy market on any significant scale, as recent experience shows. For example, the EU uses a mixture of incentives to promote RE, ranging from government-guaranteed purchase prices for RE electricity (e.g. in Germany, Denmark and Spain) to competitive mechanisms (e.g. in Ireland and the UK). The EU has also approved specific legislation to promote alternative fuels [COM (2001) 547]. The driving force for the support of biofuels in the EU is the Commission’s Green Paper: Towards a European Strategy for the Security of Energy Supply [COM (2000) 769], which introduced the objective of alternative fuels supplying 20% of the road transport sector by the year 2020.

In the USA the most important pieces of legislation to promote RE, particularly liquid biofuels, include: (i) the Alternative Motor Fuels Act of 1988 (AMFA), which created incentives for the production of vehicles designed to operate on any combination of fuel alcohols and gasoline; (ii) the Energy Policy Act of 1992 (EPAct); (iii) the Clean Cities Program (CCP), designed to encourage communities to coordinate the voluntary acquisition of alternative fuels vehicles (AFVs); (iv) the Clean Air Act Amendments (CAAA) which requires that certain regions use oxygenated, reformulated gasoline in cities where smog levels are high, etc. The law stipulated that a certain percentage of oxygenates must be from renewable sources.

Many countries have also introduced stringent legislation to deal with MSW and hence the growing interest in it as an energy resource, particularly in industrialised countries, e.g. the EU Directorate (EU, 1999/31/EC) requires all biodegradable materials to be reduced by 65% to the 1995 level by 2016; legislation also requires landfilling of combustible material to be phased out by 2010. In the USA, as a result of the introduction in 1995 of the Maximum Available Technology (MACT), led by the Environmental Protection Agency (EPA) of the US Congress, pollution from WTE is currently at the same level as any other comparable plant.

Social Changes

Previous commentaries estimated that bioenergy consumption in rural areas of developing countries (including all types of biomass and all end-uses) was roughly 1 tonne per person per year, and about 0.5 tonne in semi-urban and urban areas (15% moisture, 15 GJ/t); this is still generally valid today. There are many differences: e.g. bioenergy per person per year averages 6.7 GJ in Africa; and 5.6 GJ in Latin America. It seems that while in relative terms, traditional uses of bioenergy might be declining in some parts of the world (e.g. Latin America
and Asia), in absolute terms the total amount of bioenergy is increasing, particularly as a modern energy carrier.

Consumption patterns are also changing rapidly. For example, many urban consumers in Africa are shifting to charcoal as their living standards improve; also, many consumers use bioenergy in both its traditional and modern forms. There are many variations due to the large number of factors involved, including availability of supply, climatic differences, population growth, socio-economic development, cultural factors, etc.

The past 2 years have also witnessed a growing interest in biotrade, particularly from northern Europe and Canada. In the past bioenergy was only traded locally; the fact that regions with abundant raw material can trade internationally will open up new possibilities. This is particularly important for ethanol fuel, of which currently only 10% is internationally traded, the rest being commercialised internally. This acts as a barrier to future expansion since supply remains insufficiently elastic. Increased biotrade could bring significant benefits, e.g. through the creation of stable markets, better use of underutilised biomass, income generation, and so forth.

A major challenge still remaining is how best to tackle the problems posed by the traditional uses of bioenergy, e.g. low combustion efficiency and health hazards. For bioenergy to have a future it must provide people with what they want—cheap and convenient fuels for lighting, power, etc. at an affordable price. Considerably more effort is needed to integrate policies, technologies and markets to achieve these goals. Undoubtedly bioenergy, primarily in its modern applications, will continue to play a major role in the future.

Frank Rosillo-Calle
Imperial College, London

---

3 For example, Japan is planning to blend about 5% of ethanol with gasoline (this will require about 10 billion litres/yr) but is reluctant to go ahead because currently no country can guarantee to supply that amount. Brazil is keen to supply the Japanese ethanol fuel market but Japan would not wish to rely on a single supply source. Only when a large number of countries are able to supply ethanol, will major consumers feel confident to go ahead; in other words, only when ethanol fuel becomes an internationally traded commodity.
2004 Survey of Energy Resources

References

TABLE 10.1
Bagasse: estimated potential availability—2002

<table>
<thead>
<tr>
<th>Country</th>
<th>Bagasse potential availability (thousand tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benin</td>
<td>16</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>130</td>
</tr>
<tr>
<td>Burundi</td>
<td>65</td>
</tr>
<tr>
<td>Cameroon</td>
<td>340</td>
</tr>
<tr>
<td>Chad</td>
<td>104</td>
</tr>
<tr>
<td>Congo (Brazzaville)</td>
<td>108</td>
</tr>
<tr>
<td>Congo (Democratic Republic)</td>
<td>212</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>554</td>
</tr>
<tr>
<td>Egypt (Arab Republic)</td>
<td>3 651</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>935</td>
</tr>
<tr>
<td>Gabon</td>
<td>59</td>
</tr>
<tr>
<td>Guinea</td>
<td>82</td>
</tr>
<tr>
<td>Kenya</td>
<td>1 751</td>
</tr>
<tr>
<td>Madagascar</td>
<td>105</td>
</tr>
<tr>
<td>Malawi</td>
<td>850</td>
</tr>
<tr>
<td>Mali</td>
<td>104</td>
</tr>
<tr>
<td>Mauritius</td>
<td>1 803</td>
</tr>
<tr>
<td>Morocco</td>
<td>522</td>
</tr>
<tr>
<td>Mozambique</td>
<td>554</td>
</tr>
<tr>
<td>Nigeria</td>
<td>22</td>
</tr>
<tr>
<td>Senegal</td>
<td>310</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>23</td>
</tr>
<tr>
<td>Somalia</td>
<td>652</td>
</tr>
<tr>
<td>South Africa</td>
<td>9 019</td>
</tr>
<tr>
<td>Sudan</td>
<td>2 424</td>
</tr>
<tr>
<td>Swaziland</td>
<td>2 200</td>
</tr>
<tr>
<td>Tanzania</td>
<td>608</td>
</tr>
<tr>
<td>Togo</td>
<td>16</td>
</tr>
<tr>
<td>Uganda</td>
<td>522</td>
</tr>
<tr>
<td>Zambia</td>
<td>759</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>1 843</td>
</tr>
<tr>
<td><strong>Total Africa</strong></td>
<td><strong>30 343</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>Bagasse potential availability (thousand tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honduras</td>
<td>1 043</td>
</tr>
<tr>
<td>Jamaica</td>
<td>571</td>
</tr>
<tr>
<td>Mexico</td>
<td>16 538</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>1 206</td>
</tr>
<tr>
<td>Panama</td>
<td>489</td>
</tr>
<tr>
<td>St Kitts and Nevis</td>
<td>65</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>340</td>
</tr>
<tr>
<td>United States of America</td>
<td>10 641</td>
</tr>
<tr>
<td><strong>Total North America</strong></td>
<td><strong>53 523</strong></td>
</tr>
<tr>
<td>Argentina</td>
<td>5 477</td>
</tr>
<tr>
<td>Bolivia</td>
<td>978</td>
</tr>
<tr>
<td>Brazil</td>
<td>76 829</td>
</tr>
<tr>
<td>Colombia</td>
<td>8 224</td>
</tr>
<tr>
<td>Ecuador</td>
<td>1 614</td>
</tr>
<tr>
<td>Guyana</td>
<td>1 079</td>
</tr>
<tr>
<td>Paraguay</td>
<td>375</td>
</tr>
<tr>
<td>Peru</td>
<td>2 771</td>
</tr>
<tr>
<td>Suriname</td>
<td>33</td>
</tr>
<tr>
<td>Uruguay</td>
<td>23</td>
</tr>
<tr>
<td>Venezuela</td>
<td>1 940</td>
</tr>
<tr>
<td><strong>Total South America</strong></td>
<td><strong>99 343</strong></td>
</tr>
<tr>
<td>Bangladesh</td>
<td>746</td>
</tr>
<tr>
<td>China</td>
<td>28 426</td>
</tr>
<tr>
<td>India</td>
<td>63 650</td>
</tr>
<tr>
<td>Indonesia</td>
<td>7 009</td>
</tr>
<tr>
<td>Japan</td>
<td>593</td>
</tr>
<tr>
<td>Malaysia</td>
<td>359</td>
</tr>
<tr>
<td>Myanmar (Burma)</td>
<td>326</td>
</tr>
<tr>
<td>Nepal</td>
<td>359</td>
</tr>
<tr>
<td>Pakistan</td>
<td>10 805</td>
</tr>
<tr>
<td>Philippines</td>
<td>6 480</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>65</td>
</tr>
<tr>
<td>Taiwan, China</td>
<td>567</td>
</tr>
<tr>
<td>Thailand</td>
<td>20 987</td>
</tr>
<tr>
<td>Vietnam</td>
<td>2 901</td>
</tr>
<tr>
<td><strong>Total Asia</strong></td>
<td><strong>143 273</strong></td>
</tr>
<tr>
<td>Unspecified</td>
<td>851</td>
</tr>
</tbody>
</table>

(continued on next page)
### Table 10.1 (Continued)

<table>
<thead>
<tr>
<th>Region</th>
<th>Bagasse Potential Availability (thousand tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Europe</td>
<td>851</td>
</tr>
<tr>
<td>Iran (Islamic Republic)</td>
<td>652</td>
</tr>
<tr>
<td>Total Middle East</td>
<td>652</td>
</tr>
<tr>
<td>Australia</td>
<td>18,300</td>
</tr>
<tr>
<td>Fiji</td>
<td>1,090</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>172</td>
</tr>
<tr>
<td>Western Samoa</td>
<td>7</td>
</tr>
<tr>
<td>Total Oceania</td>
<td>19,569</td>
</tr>
<tr>
<td>Total World</td>
<td>347,554</td>
</tr>
</tbody>
</table>

COUNTRY NOTES

The Country Notes on Bioenergy reflect the data and comments provided by WEC Member Committees in 2003, supplemented where necessary by information provided for the 2001 and 1998 editions of the WEC Survey of Energy Resources.

Albania

Municipal solid waste
Quantity of raw material available 405 toe

Argentina

Municipal solid waste
Quantity of raw material available 5.5 million tonnes
Sugarcane bagasse
Quantity of raw material available 5.9 million tonnes
Ethanol installed capacity 6 237 TJ/yr
Ethanol fuel productionb 2 525 TJ
Electricity generating capacity 182 061 kW
Electricity generation 131 031 TJ
Direct use from combustion 37 028 TJ
Total energy production 170 584 TJ
Agricultural residues
Quantity of raw material available 5.4 million tonnes
Electricity generating capacity 81 916 kW
Electricity generation 1 186 TJ

a The figure shown corresponds to the Ciudad Autónoma de Buenos Aires and 31 municipalities of the Province of Buenos Aires. This area produces 40% of the country’s total waste.

b Raw material used: molasses.

Generally, the use of biomass resources takes place in a dispersed way, except for bagasse, mostly used as fuel in the cane sugar mills for electricity and steam production. Part of the bagasse is also used by the paper industry as raw material. Vegetable wastes mainly include harvest residues (straw and stem from maize, wheat, rice, etc.) and from the manufacturing of food products (rice chaff, peanut shells, etc.).

Municipal waste corresponds to the rubbish from the residential, commercial and public service sectors collected by the municipal services and have almost been totally used for ecological landfill.

Lately ‘biodiesel’ has aroused high expectations, but so far production on an industrial scale has not been achieved.

Australia

Municipal solid waste
Quantity of raw material available 6.9 million tonnes
Yield of solid fuel 9 GJ/tonne
Electricity generating capacity 103 700 kW
Sugarcane bagassea
Quantity of raw material available 11.4 million tonnes
Yield of solid fuel 9.3 GJ/tonne
Electricity generating capacity 368 600 kW

a Data refer to 1997.

For MSW, generation is 98 700 kW from landfill gas and 5 000 kW from MSW gasification (SWERF plant, Wollongong).

Sugar industry generation includes the Rocky Point sugar mill cogeneration plant, which uses some wood waste in the non-crushing season.

Approximately 80 megalitres/yr ethanol is produced.

Biodiesel production is relatively low and is estimated to be below 20 million litres in 2002.

The Bureau of Rural Sciences has developed a bioenergy atlas for Australia.

Austria

Municipal solid waste
Quantity of raw material available 1.5 million tonnes
Electricity generation 9 028 TJ
### 2004 Survey of Energy Resources

<table>
<thead>
<tr>
<th>Country</th>
<th>Biomass Type</th>
<th>Quantity of Raw Material</th>
<th>Direct Use from Combustion</th>
<th>Total Energy Production</th>
<th>Yield of Biogas</th>
<th>Biogas Produced</th>
<th>Electricity Generating Capacity</th>
<th>Electricity Generation</th>
<th>Total Energy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Other biomass</td>
<td>6.0 million tonnes</td>
<td>31,565 TJ</td>
<td>56,623 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Biodiesel capacity(^a)</td>
<td>1,125 TJ/yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Municipal solid waste</td>
<td>1.1 million tonnes</td>
<td>4,435 TJ</td>
<td>13,463 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Electricity generation</td>
<td>76,600 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Total energy production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolivia</td>
<td>Animal dung</td>
<td>3,270 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolivia</td>
<td>Sugarcane bagasse</td>
<td>10,458 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolivia</td>
<td>Crop residues</td>
<td>307 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Botswana</td>
<td>Municipal solid waste</td>
<td>1,420 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Municipal solid waste</td>
<td>20.0 million tonnes</td>
<td>443,556 TJ</td>
<td>1,364,633 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Electricity generation</td>
<td>76,600 kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Total energy production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Data refer to 2001.
\(^b\) Yield of biogas = 0.0230274 GJ/tonne
\(^c\) Biogas produced = 427,38 TJ
\(^d\) Electricity generating capacity = 47,631 kW

### Belgium

**Municipal solid waste**

- Quantity of raw material available: 1.1 million tonnes
- Electricity generation: 76,600 kW
- Total energy production: 200,841 TJ

### Bolivia

**Animal dung**

- Direct use from combustion: 3,270 TJ

**Sugarcane bagasse**

- Direct use from combustion: 10,458 TJ

**Crop residues**

- Direct use from combustion: 307 TJ

### Botswana

**Municipal solid waste**

- Direct use from combustion: 1,420 TJ

### Brazil

**Municipal solid waste**

- Quantity of raw material available: 20.0 million tonnes
- Biogas production capacity\(^a\): 1,640 TJ/yr

### Bulgaria

Production of energy sector raw materials could open up new possibilities for forestry and agriculture, contributing to employment in rural areas, increasing the standard of living and incomes through development of energy cultures, promoting RE based on biomass, regional support through co-financing of RE projects, and processing and marketing of agricultural production for RE.
In the long term CHP usage of biomass has the largest potential amongst all forms of RE. The advantages of biomass usage, based on new technologies, can be seen in the utilisation of biogas. Therefore, a campaign for the promotion and support of decentralised bioenergy installations is of special importance. Such installations could combine different technologies.

Unfortunately so far there are no installations in Bulgaria for biogas generation. There are at the moment at least two factors stimulating research into biodiesel fuels usage in the area of transport: the decreasing supply of oil and the negative influence of transport vehicles on the environment. It is known that the transport sector has considerable effects on the environment. During the last 10 years its share in global warming has increased from less than 20% to more than 25%.

In Bulgaria basic oils are obtained from sunflowers and, in small amounts, from rape, soya and corn. In earlier years oils were also produced from flax, castor oil, etc. The Bulgarian oil extraction enterprises have an annual production capacity of 750 000 tonnes of oil-bearing seeds, of which on average about 50% is utilised. The Bulgarian enterprises are equipped for reprocessing sunflower oil, but they can also reprocess rape oil. As sunflower oil is preferred for food purposes, the more likely raw material for future production of biodiesel will be rape oil and in small amounts lower-quality sunflower and other plant oils. For the 2000/2001 season, 90 000 decares of rape were sown and harvested, and during the 2001/2002 season 250 000 decares were sown. (Methanol production through the distillation of bio-products from corn, beetroot or potatoes is also a future possibility for the replacement of conventional fuels).

**Canada**

*Municipal solid waste*

| Quantity of raw material available | 21 million tonnes |

**Chapter 10: Bioenergy (other than Wood)**

Biogas production 9 200 TJ
Electricity generating capacity 85 300 kW
Electricity generation 2 421 TJ
Direct use from combustion 8 820 TJ
Total energy production 20 441 TJ

**Crop residues—corn**

| Quantity of raw material available | 20 million tonnes |

**Crop residues—cereal grain**

| Quantity of raw material available | 25 million tonnes |

**Various—wheat**

| Ethanol production capacity | 466.4 TJ/yr |
| Yield of ethanol | 7.2 GJ/tonne |
| Ethanol production | 466.4 TJ |

**Various—corn**

| Ethanol production capacity | 466.4 TJ/yr |
| Yield of ethanol | 7.8 GJ/tonne |
| Ethanol production | 63.6 TJ |

Data refer to 1999.

**Côte d'Ivoire**

Data concerning the use of biomass energy (apart from wood and charcoal) are unavailable. To resolve this problem, a strategy is being devised to collect data on production and consumption of all forms of biomass.

There is a programme for restructuring the institutional framework of renewable energies and a project concerning the inventory and the evaluation of agricultural and industrial wastes.

Natural biomass, agricultural waste and industrial waste constitute the potential renewable energies for direct use.

Biomass energy in different forms (firewood, charcoal by city dwellers, agricultural and industrial wastes) is consumed by 78% of the population.

The agricultural and industrial energy resources are estimated at more than 4 mtoe/yr. They constitute an important source of energy and essentially come from palm oil, manufactured wood, coffee, rice and sugarcane.
The principal technologies used for the conversion of biomass into energy are carbonisation, gasification and fermentation.

**Croatia**

**Municipal solid waste**
Quantity of raw material available 1.1 million tonnes

**Crop residues—wheat straw**
Quantity of raw material available 0.25 million tonnes

**Crop residues—maize stalks**
Quantity of raw material available 0.51 million tonnes

**Crop residues—barley straw**
Quantity of raw material available 0.03 million tonnes

**Crop residues—from fruit growing**
Quantity of raw material available 0.16 million tonnes

Data refer to 1996.

**Czech Republic**

**Municipal solid waste**
Quantity of raw material available 1.6 million tonnes
Biogas production 15 TJ
Electricity generation 702 TJ
Direct use from combustion 4 429 TJ

**Agricultural residues—straw**
Quantity of raw material available 2.7 million tonnes
Electricity generating capacity 131 000 kW
Electricity generation 2 235 TJ
Total energy production 13 698 TJ

**Agricultural residues—slurry, etc.**
Quantity of raw material available 24 PJ
Biogas production 1 138 TJ
Electricity generating capacity 20 000 kW
Electricity generation 374 TJ
Total energy production 1 490 TJ

**Agricultural residues—other veg. waste**
Electricity generating capacity 70 kW
Electricity generation 51 TJ
Total energy production 764 TJ

**Fish oil**
Quantity of raw material available 191 TJ
Electricity generation 65 TJ
Total energy production 75 TJ

**Sewage sludge**
Quantity of raw material available 3 PJ
Biogas production 330 TJ
Electricity generating capacity 7 000 kW
Electricity generation 111 TJ
Total energy production 823 TJ

**Landfill gas and municipal waste gas**
Quantity of raw material available 1 PJ
Biogas production 286 TJ
Electricity generating capacity 5 000 kW

**Denmark**

**Municipal solid waste**
Quantity of raw material available 9.5 million tonnes
Electricity generating capacity 275 000 kW
Electricity generation 5 098 TJ
Heat production 21 164 TJ
Total energy production 31 843 TJ

**Agricultural residues—straw**
Quantity of raw material available 2.7 million tonnes
Electricity generating capacity 131 000 kW
Electricity generation 2 235 TJ
Total energy production 13 698 TJ

**Agricultural residues—other veg. waste**
Electricity generating capacity 70 kW
Electricity generation 51 TJ
Total energy production 764 TJ

**Fish oil**
Quantity of raw material available 191 TJ
Electricity generation 65 TJ
Total energy production 75 TJ

**Sewage sludge**
Quantity of raw material available 3 PJ
Biogas production 330 TJ
Electricity generating capacity 7 000 kW
Electricity generation 111 TJ
Total energy production 823 TJ

**Landfill gas and municipal waste gas**
Quantity of raw material available 1 PJ
Biogas production 286 TJ
Electricity generating capacity 5 000 kW
### Egypt (Arab Republic)

#### Municipal solid waste
- **Quantity of raw material available**: 2.4 million tonnes
- **Electricity generation**: 79 TJ

#### Sugarcane bagasse
- **Quantity of raw material available**: 1.4 million tonnes
- **Ethanol production capacity**: 456.25 TJ/yr
- **Biodiesel production capacity**: 22.83 TJ/yr
- **Total energy production**: 479.08 TJ

#### Cotton stalks
- **Quantity of raw material available**: 1.2 million tonnes

#### Rice straw
- **Quantity of raw material available**: 3.4 million tonnes

#### Animal dung
- **Quantity of raw material available**: 6 million tonnes
- **Biogas production capacity**: 40 TJ/yr
- **Yield of biogas**: 4.1 GJ/tonne
- **Biogas production**: 15 TJ
- **Direct use from combustion**: 15 TJ

#### Sewage sludge
- **Quantity of raw material available**: 2.4 million tonnes
- **Electricity generating capacity**: 18 000 kW

### Finland

#### Municipal solid waste
- **Quantity of raw material available**: 0.4 million tonnes
- **Electricity generating capacity**: 50 000 kW
- **Electricity generation**: 770 TJ
- **Direct use from combustion**: 1 130 TJ
- **Total energy production**: 1 900 TJ

#### Biogas
- **Electricity generation**: 0.1 TJ
- **Direct use from combustion**: 0.5 TJ
- **Total energy production**: 0.6 TJ

#### Landfill gas
- **Electricity generating capacity**: 3 000 kW
- **Electricity generation**: 40 TJ
- **Direct use from combustion**: 150 TJ
- **Total energy production**: 190 TJ

#### Wastewater
- **Electricity generating capacity**: 6 000 kW
- **Electricity generation**: 90 TJ
- **Direct use from combustion**: 324 TJ
- **Total energy production**: 414 TJ

### France

#### Municipal solid waste
- **Quantity of raw material available**: 11.2 million tonnes
- **Electricity generation**: 8 867 TJ
- **Direct use from combustion**: 27 018 TJ
- **Total energy production**: 35 885 TJ

#### Agricultural residues
- **Biogas production**: 220 TJ
- **Direct use from combustion**: 3 208 TJ
- **Total energy production**: 3 428 TJ

#### Biofuels
- **Ethanol production**: 2 415 TJ
- **Biodiesel production**: 11 214 TJ
- **Total energy production**: 13 629 TJ

#### Landfill gas
- **Biogas production**: 8 080 TJ

#### Other waste
- **Biogas production**: 4 667 TJ
**2004 Survey of Energy Resources**

The above data relate only to metropolitan France and exclude overseas departments (DOM).

In the DOM, 2002 production from bagasse was 1,224 TJ electricity and 4,442 TJ heat.

**Germany**

*Municipal solid waste*

<table>
<thead>
<tr>
<th></th>
<th>852,000 kW</th>
<th>11,200 TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas production</td>
<td></td>
<td>9,600 TJ</td>
</tr>
<tr>
<td>Biogas production capacity</td>
<td>160 MW</td>
<td></td>
</tr>
<tr>
<td>Electricity generating capacity</td>
<td>88 GWh</td>
<td></td>
</tr>
</tbody>
</table>

**Landfill gas**

<table>
<thead>
<tr>
<th></th>
<th>142 MW</th>
<th>88 GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity generation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sewage sludge gas**

<table>
<thead>
<tr>
<th></th>
<th>75 MW</th>
<th>732 GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity generation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Liquid biofuels**

<table>
<thead>
<tr>
<th></th>
<th>500,000 tonnes/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant capacity</td>
<td></td>
</tr>
</tbody>
</table>

**Other biogas**

<table>
<thead>
<tr>
<th></th>
<th>200 MW</th>
<th>74 GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity generation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data refer to 2001.

**Ghana**

*Agricultural residues*

<table>
<thead>
<tr>
<th></th>
<th>0.135 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coconut shell and husk</td>
<td></td>
</tr>
<tr>
<td>Groundnut shells</td>
<td>0.0475 million tonnes</td>
</tr>
<tr>
<td>Rice straw and husk</td>
<td>0.12 million tonnes</td>
</tr>
</tbody>
</table>

Data refer to 1990.

**Greenland**

*Municipal solid waste*

<table>
<thead>
<tr>
<th></th>
<th>214 TJ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuel production capacity</td>
<td></td>
</tr>
</tbody>
</table>

**Hong Kong, China**

*Municipal solid waste*

<table>
<thead>
<tr>
<th></th>
<th>2.8 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of raw material available</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>281 TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuel production</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>83 TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td></td>
</tr>
</tbody>
</table>

**Waste from fishing industry**

<table>
<thead>
<tr>
<th></th>
<th>38.62 GJ/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield of biodiesel</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>12.33 TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel production</td>
<td></td>
</tr>
</tbody>
</table>

Data refers to 2001.

**Hungary**

*Municipal solid waste*

<table>
<thead>
<tr>
<th></th>
<th>0.258 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of raw material available</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>19,908 TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid fuel production</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>114 TJ/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel production capacity</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>38 GJ/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield of biodiesel</td>
<td></td>
</tr>
</tbody>
</table>

A town gas plant uses landfill gas from the nearby Shuen Wan landfill site as process fuels to crack naphtha to produce town gas.

Biogas is also utilised at sewage treatment works (STW): (1) at Shatin STW to supply a dual fuel 1,120 kW engine for generating electricity (on-site application); (2) at Shatin and Taipo STWs to fuel boiler plant to maintain temperature of sludge digestion process; (3) at Taipo STW to supply a dual fuel engine which drives a process airblower.

Landfill gas engines with a total capacity of 6,384 kW have been installed in three strategic landfill sites (WENT, NENT and SENT) to generate electrical power for on-site usages. There is an additional 373 kW capacity at two other sites (Tseung Kwan O and Jordan Valley). Four of these sites also use landfill gas for heating in the leachate treatment process.

Data on electricity and heat generated by landfill gas in 2002 are not available.
Chapter 10: Bioenergy (other than Wood)

Ireland

Municipal solid waste
Electricity generating capacity 14 732 kW
Electricity generation 324 TJ

Israel

Municipal sewage
Electricity generating capacity 1 000 kW
Electricity generation 28.8 TJ

Industrial sewage
Electricity generating capacity 500 kW
Electricity generation 9 TJ

Italy

Municipal solid waste
Quantity of raw material available 3.7 million tonnes
Biogas productionb 7 970 TJ
Electricity generating capacity 499 545 kW
Electricity generation 30 204 TJ
Direct use from combustion 600 TJ
Total energy production 38 774 TJ

Agricultural residues
Biodiesel production 3 627 TJ
Biogas productionb 64 TJ
Electricity generating capacity 7 946 kW
Total energy production 3 691 TJ

Sewage sludge
Biogas productionb 55 TJ
Electricity generating capacity 7 772 kW

Farm slurries
Biogas productionb 118 TJ
Electricity generating capacity 2 110 kW

Food industry by-products
Electricity generating capacity 222 000 kW
Electricity generation 11 599 TJ

Crop residues
Direct use from combustion 39 600 TJ

Data refer to 2001.

a Includes biogas from dumping ground.
b All used to generate electricity. In order to avoid duplication, the related electricity production is excluded.

Iceland

Municipal solid waste
Direct use from combustion 45 TJ

Indonesia

Sugarcane bagasse
Quantity of raw material available 6.5 million tonnes

Agricultural residues—rice husk
Quantity of raw material available 14.3 million tonnes

Agricultural residues—coconut shells
Quantity of raw material available 1.1 million tonnes

Agricultural residues—coconut fibre
Quantity of raw material available 2.0 million tonnes

Agricultural residues—palm oil residues
Quantity of raw material available 8.5 million tonnes

Iran (Islamic Republic)

Municipal solid waste
Quantity of raw material available 15.33 million tonnes
from electricity generation while electricity generating capacity includes the capacity of biogas-fired power plants.

**Japan**

**Municipal solid waste**

- **Quantity of raw material available**
  - Sugarcane bagasse: 51 million tonnes
  - Sludge: 0.2 million tonnes

- **Electricity generating capacity**
  - Sugarcane bagasse: 829 000 kW
  - Sludge: 27 000 kW

**Sugarcane bagasse**

- **Electricity generating capacity**
  - 829 000 kW

- **Electricity generation**
  - 19 800 TJ

**Rice bran/soy oil waste**

- **Biodiesel generating capacity**
  - 231.1 TJ/yr

- **Biodiesel production**
  - 35.4 TJ

**Sludge**

- **Biogas production capacity**
  - 3 601.6 TJ/yr

- **Biogas production**
  - 1 693.4 TJ

**Jordania**

**Municipal solid waste**

- **Quantity of raw material available**
  - 1.095 million tonnes

- **Electricity generating capacity**
  - 1 000 kW

- **Electricity generation**
  - 19 800 TJ

- **Direct use from combustion**
  - N TJ

Jordan has adopted a special programme for bioenergy by which pre-feasibility studies for the utilisation of MSW for electricity generation have been prepared since 1993 through cooperation with GEF.

The outcome of these studies resulted in implementing the first biogas project in Jordan and in the region with a capacity of about 1 MW of electricity. This project is owned, operated and maintained by the Jordan Biogas Company (JBCo), and is going to be expanded up to 5 MW by the year 2005. The Greater Amman Municipality is actively working in this field, where several waste treatment projects, including bioenergy power plants, on a commercial/private finance basis are in hand.

**Korea (Republic)**

**Municipal solid waste**

- **Electricity generating capacity**
  - 12 358 kW
- **Electricity generation**
  - 740.8 TJ

**Rice bran/soy oil waste**

- **Biodiesel generating capacity**
  - 231.1 TJ/yr
- **Biodiesel production**
  - 35.4 TJ

**Sludge**

- **Biogas production capacity**
  - 3 601.6 TJ/yr
- **Biogas production**
  - 1 693.4 TJ

**Latvia**

**Municipal solid waste**

- **Quantity of raw material available**
  - 0.28 million tonnes

- **Electricity generating capacity**
  - 2 100 kW

- **Electricity generation**
  - 36.1 TJ

**Rice bran/soy oil waste**

- **Biodiesel generating capacity**
  - 93.5 TJ/yr

- **Biodiesel production**
  - 37.4 TJ

**Sludge**

- **Biogas production capacity**
  - 60.5 TJ/yr

- **Biogas production**
  - 36.1 TJ

- **Electricity generating capacity**
  - 2 100 kW

- **Electricity generation**
  - 36.1 TJ

At present Latvia does not sort its municipal waste (0.47 million tons a year) and therefore the solid waste (0.28 million tons a year) is not used for incineration.

In Riga, the capital of Latvia, biogas is obtained from the total unsorted garbage mass, which is used to generate electricity.

The production capacity of ethanol is 8 000 tonnes/yr but that of biodiesel is 2 500 tonnes/yr. There is no legislation in Latvia at the moment on the use of bioethanol and biodiesel fuel. Since the costs of bioethanol and biodiesel fuel are higher than the costs of fossil fuels, they are not used in practice, apart from research and experimentation.
Lebanon

*Municipal solid waste*
Quantity of raw material available 1.44 million tonnes

Lithuania

Straw
Quantity of raw material available 0.004 million tonnes
Direct use from combustion 105 TJ

Luxembourg

At the present time the government is preparing a study for the evaluation of biomass resources and their exploitation.

Mexico

*Sugarcane bagasse*
Quantity of raw material available 12.6 million tonnes

Production of bagasse includes non-fuel burning. All fuel use of bagasse occurs in the sugar and pulp and paper industries. The Balance Nacional de Energía shows that in 2002, 84 081 TJ (11.9 million tonnes) of bagasse was consumed by the sugar sector for energy purposes and 212 TJ (30 000 tonnes) in the pulp and paper sector, including autoproduction of electricity. Bagasse consumed for non-energy purposes was about 3 385 TJ (479.8 thousand tonnes).

The production and consumption of biogas is about 301 TJ and the principal use is for electricity generation. The only sectors that produce and consume biogas are food, beverages and tobacco (97 TJ) and the municipal sector (204 TJ). Gross electricity generation from biogas is about 12 GWh.

Monaco

*Municipal solid waste*
Quantity of raw material available 0.07 million tonnes
Electricity generating capacity 2 600 kW
Electricity generation 26 TJ
Direct use from combustion 72 TJ
Total energy production 98 TJ

Data refer to 1996.

Morocco

*Animal dung*
Biogas production capacity 4.00 TJ/yr
Yield of biogas 0.56 GJ/tonne
Biogas production 4.00 TJ

Data refer to 1996.

Nepal

*Agricultural residues*
Quantity of raw material available 1.05 million tonnes
Solid fuel production capacity 0.51 TJ/yr
Yield of solid fuel 12.56 GJ/tonne
Solid fuel production 13.15 TJ
Direct use from combustion 13.15 TJ

*Dung*
Quantity of raw material available 1.96 million tonnes
Solid fuel production capacity 0.29 TJ/yr
Yield of solid fuel 10.90 GJ/tonne
Solid fuel production 20.08 TJ
Biogas production capacity 0.36 TJ/yr
Yield of biogas 10.90 GJ/tonne
Biogas production 1.33 TJ
Total energy production 21.41 TJ

Netherlands

*Municipal solid waste*
Electricity generation 10 296 TJ
## 2004 Survey of Energy Resources

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td>1 085 TJ</td>
</tr>
<tr>
<td>Total energy production</td>
<td>11 381 TJ</td>
</tr>
<tr>
<td><strong>Landfill gas</strong> Biogas production</td>
<td>2 763 TJ</td>
</tr>
<tr>
<td><strong>Sludge</strong> Biogas production</td>
<td>2 041 TJ</td>
</tr>
<tr>
<td><strong>Fermentation</strong> Biogas production</td>
<td>5 632 TJ</td>
</tr>
</tbody>
</table>

### New Zealand

**Landfill**
- Quantity of raw material available | 744.55 TJ |
- Electricity generating capacity | 9 000 kW |
- Electricity generation | 223.37 TJ |

**Sewage**
- Quantity of raw material available | 385.05 TJ |
- Electricity generating capacity | 11 340 kW |
- Electricity generation | 115.42 TJ |
- Direct use from combustion | 190.00 TJ |
- Total energy production | 305.42 TJ |

### Paraguay

**Sugarcane bagasse**
- Quantity of raw material available | 0.36 million tonnes |
- Ethanol production capacity | 861.6 TJ/yr |
- Yield of ethanol | 1.303 GJ/tonne |
- Ethanol production | 295.4 TJ |

**Agricultural residues—cotton**
- Quantity of raw material available | 0.285 million tonnes |
- Electricity generation | 9.3 TJ |
- Direct use from combustion | 4 089.9 TJ |
- Total energy production | 4 099.2 TJ |

### Philippines

**Municipal solid waste**
- Electricity generation | 6 TJ |

**Sugarcane bagasse**
- Electricity generation | 6 518 TJ |

**Crop residues—coconut**
- Electricity generation | 7 046 GWh |

**Crop residues—rice**
- Electricity generation | 2 934 GWh |

**Animal**
- Electricity generation | 146 GWh |

### Poland

**Agricultural residues—manure**
- Biogas production | 1 054 TJ |

**Agricultural residues—straw etc.**
- Quantity of raw material available | 20 million tonnes |
- Direct use from combustion | 25 063 TJ |

**Industrial waste**
- Direct use from combustion | 13 970 TJ |

**Other**
- Direct use from combustion | 3 641 TJ |

### Portugal

**Municipal solid waste**
- Quantity of raw material available | 1 million tonnes |
- Electricity generating capacity | 81 000 kW |
- Electricity generation | 1 840 TJ |
Romania

*Municipal solid waste*

Direct use from combustion N TJ

Senegal

*Municipal solid waste*

Electricity generating capacity 20 000 kW

*Agricultural residues—peanut shells*

Electricity generating capacity 22 000 kW

*Biomass potential (per annum)*

<table>
<thead>
<tr>
<th>Peanut shells</th>
<th>197 500 tonnes (221 MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmetto shells</td>
<td>1 740 tonnes</td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td>250 000 tonnes (20 MW)</td>
</tr>
<tr>
<td>Rice husks</td>
<td>217 212 tonnes</td>
</tr>
<tr>
<td>Sawdust</td>
<td>3 000 m³</td>
</tr>
<tr>
<td>Millet/Sorghum/Maize stalks</td>
<td>4 052 900 tonnes</td>
</tr>
<tr>
<td>Typha reed</td>
<td>1 000 000 tonnes</td>
</tr>
<tr>
<td>Cotton stalks</td>
<td>23 991 tonnes</td>
</tr>
<tr>
<td>Peanut haulm</td>
<td>790 617 tonnes</td>
</tr>
</tbody>
</table>

Serbia & Montenegro

*Municipal solid waste*

Quantity of raw material available 33 600 TJ

*Agricultural residues*

Quantity of raw material available 58 400 TJ

*Orchard*

Quantity of raw material available 15 000 TJ

*Vineyard*

Quantity of raw material available 6 400 TJ

Slovakia

*Agricultural residues*

Quantity of raw material available 2.4 million tonnes

Solid fuel production capacity 10 904 TJ/yr

Ethanol fuel production capacity 412 TJ/yr

Biodiesel production capacity 216 TJ/yr

Biogas production capacity 560 TJ/yr

Total energy produced 12 092 TJ

Slovenia

*Municipal solid waste*

Electricity generating capacity 2 776 kW

Electricity generation 43 TJ

South Africa

*Sugarcane bagasse*

Quantity of raw material available 6.974 million tonnes

Electricity generating capacity 105 000 kW

There are a number of sugar mills that use bagasse as fuel for CHP plants. Some bagasse is used as input fibre for paper.

There are two landfill sites that have, in the past, produced landfill gas: one is at Grahamstown in the Eastern Cape, the other near Johannesburg. The current status of these sites is unknown.

Afrox has a site in the Free State that produces helium. The waste gas is enriched in methane using a membrane process and is then used to fuel a generator at the plant. The installed capacity is 72 kW. The plant is not fully utilised and produces about 0.6 TJ/yr.

Other biomass estimates:

<table>
<thead>
<tr>
<th>Potential sunflower seed oil production</th>
<th>million litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassava</td>
<td>3 000</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>500</td>
</tr>
<tr>
<td>Bagasse</td>
<td>250</td>
</tr>
<tr>
<td>Molasses</td>
<td>100</td>
</tr>
</tbody>
</table>

Singapore

*Municipal solid waste*

Electricity generating capacity 135 000 kW

Electricity generation 3 994.68 TJ
### 2004 Survey of Energy Resources

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Yield of Biodiesel</th>
<th>Biodiesel Production</th>
<th>Electricity Generating Capacity</th>
<th>Electricity Generation</th>
<th>Direct Use from Combustion</th>
<th>Total Energy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>37.68 GJ/tonne</td>
<td>226.09 TJ</td>
<td>22 450 kW</td>
<td>517.50 TJ</td>
<td>14 621.18 TJ</td>
<td>20 208.90 TJ</td>
</tr>
<tr>
<td>Sorghum straw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat straw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In addition, bagasse, maize, sorghum and wheat residues could be used to provide bioenergy. The potential has not been fully explored.

### Spain

**Municipal solid waste**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Quantity of raw material available</th>
<th>Electricity generating capacity</th>
<th>Electricity generation</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop residues—dry fruit shells</strong></td>
<td>18.4 million tonnes</td>
<td>2 240 kW</td>
<td>35.77 TJ</td>
<td>1 255.08 TJ</td>
<td>1 290.85 TJ</td>
</tr>
<tr>
<td><strong>Crop residues—grape and olive</strong></td>
<td>50 900 kW</td>
<td>1 426.01 TJ</td>
<td>5 950.41 TJ</td>
<td>7 376.42 TJ</td>
<td></td>
</tr>
</tbody>
</table>

**Agricultural residues—other**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Quantity of raw material available</th>
<th>Electricity generating capacity</th>
<th>Electricity generation</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agricultural residues—wheat</strong></td>
<td>1 900 TJ</td>
<td>64 687 kW</td>
<td>1 545.16 TJ</td>
<td>365.34 TJ</td>
<td>8 078.91 TJ</td>
</tr>
</tbody>
</table>

### Swaziland

**Sugarcane bagasse**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Quantity of raw material available</th>
<th>Electricity generating capacity</th>
<th>Electricity generation</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biogas production</strong></td>
<td>1.32 million tonnes</td>
<td>5 000 TJ</td>
<td>1 100 TJ</td>
<td>26 300 TJ</td>
<td></td>
</tr>
</tbody>
</table>

### Sweden

**Municipal solid waste**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Quantity of raw material available</th>
<th>Electricity generating capacity</th>
<th>Electricity generation</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biogas production</strong></td>
<td>2.46 million tonnes</td>
<td>5 000 TJ</td>
<td>1 100 TJ</td>
<td>26 300 TJ</td>
<td></td>
</tr>
</tbody>
</table>

**Agricultural residues—wheat**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Yield of Ethanol</th>
<th>Ethanol Production</th>
<th>Electricity generating capacity</th>
<th>Electricity production</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sludge</strong></td>
<td>125 GWh</td>
<td>338 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Switzerland

**Municipal solid waste**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Quantity of raw material available</th>
<th>Electricity generating capacity</th>
<th>Electricity generation</th>
<th>Direct use from combustion</th>
<th>Total energy production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ethanol production capacity</strong></td>
<td>4 844.13 TJ/yr</td>
<td>26.79 GJ/tonne</td>
<td>4 844.13 TJ</td>
<td>226.09 TJ</td>
<td>16 880 TJ</td>
</tr>
</tbody>
</table>

**Biodiesel production capacity**

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Yield of Biodiesel</th>
<th>Biodiesel Production</th>
<th>Electricity Generating Capacity</th>
<th>Electricity Generation</th>
<th>Direct Use from Combustion</th>
<th>Total Energy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sludge</strong></td>
<td>125 GWh</td>
<td>338 TJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Other

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>744 GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generation</td>
<td>78 TJ</td>
</tr>
<tr>
<td>Direct use from combustion</td>
<td>2 197 TJ</td>
</tr>
<tr>
<td>Total energy production</td>
<td>2 275 TJ</td>
</tr>
</tbody>
</table>

### Taiwan, China

#### Municipal solid waste

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>9.4 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield of biogas</td>
<td>0.38 GJ/tonne</td>
</tr>
<tr>
<td>Biogas production</td>
<td>334 TJ</td>
</tr>
<tr>
<td>Electricity generating capacity</td>
<td>265 000 kW</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>17 698 TJ</td>
</tr>
<tr>
<td>Total energy production</td>
<td>18 032 TJ</td>
</tr>
</tbody>
</table>

#### Sugarcane bagasse

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>0.53 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capacity</td>
<td>60 980 kW</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>4 142 TJ</td>
</tr>
<tr>
<td>Direct use from combustion</td>
<td>2 824 TJ</td>
</tr>
<tr>
<td>Total energy production</td>
<td>6 966 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—paddy husk

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>2.986 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capacity</td>
<td>80 100 kW</td>
</tr>
<tr>
<td>Electricity generation</td>
<td>2 526.034 TJ</td>
</tr>
<tr>
<td>Direct use from combustion</td>
<td>32 506.08 TJ</td>
</tr>
<tr>
<td>Total energy production</td>
<td>35 032.114 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—oil palm shell

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>0.151 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generating capacity</td>
<td>1 636.95 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—coconut shell

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>0.092 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td>143.44 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—cassava rhizome

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>3.155 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td>29 057.14 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—corn cob

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>0.232 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td>4 185.28 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—sorghum leaves & stem

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>0.22 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct use from combustion</td>
<td>0.423 TJ</td>
</tr>
</tbody>
</table>

#### Agricultural residues—palm oil

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>4.03 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel production capacity</td>
<td>213 TJ/yr</td>
</tr>
<tr>
<td>Yield of biodiesel</td>
<td>7.91 GJ/tonne</td>
</tr>
<tr>
<td>Biodiesel production</td>
<td>71 TJ</td>
</tr>
</tbody>
</table>

### Thailand

#### Municipal solid waste

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>11.56 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas production capacity</td>
<td>51.25 TJ/yr</td>
</tr>
<tr>
<td>Yield of biogas</td>
<td>10.98 GJ/tonne</td>
</tr>
</tbody>
</table>

#### Agricultural residues—palm oil

<table>
<thead>
<tr>
<th>Quantity of raw material available</th>
<th>4.03 million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel production capacity</td>
<td>213 TJ/yr</td>
</tr>
<tr>
<td>Yield of biodiesel</td>
<td>7.91 GJ/tonne</td>
</tr>
<tr>
<td>Biodiesel production</td>
<td>71 TJ</td>
</tr>
</tbody>
</table>
2004 Survey of Energy Resources

**Agricultural residues—tapioca**
- Quantity of raw material available: 16.87 million tonnes
- Ethanol production capacity: 18.08 TJ/yr
- Yield of ethanol: 4.5 GJ/tonne
- Ethanol production: 1.5 TJ

**Other—animal waste**
- Quantity of raw material available: 13.67 million tonnes
- Biogas production capacity: 405.51 TJ/yr
- Yield of biogas: 4.56 GJ/tonne
- Biogas production: 385.23 TJ/tonne

**Other—waste water**
- Biogas production capacity: 994.84 TJ/yr
- Yield of biogas: 9.6 GJ/tonne
- Biogas production: 826.06 TJ/tonne

- Total quantity of MSW after recycling process (recycle ratio = 18%).
- Kampangsan landfill site.
- Phuket province.
- Capacity of biodiesel plant = 20 000 litres/day.
- Capacity of plant = 5 000 litres/day.
- Yield of biogas production from swine waste, volatile solid yields from other animal wastes are as follows (GJ/tonne volatile solid): cattle = 6.45; buffalo = 6.01; chicken = 5.08; elephant = 5.06.
- 95% of total capacity.

**Turkey**

**Municipal solid waste**
- Electricity generating capacity: 1 400 kW

**Agricultural residues—vegetal waste**
- Quantity of raw material available: 1.846 million tonnes

**Industrial waste**
- Electricity generating capacity: 19 000 kW

**Biogas**
- Electricity generating capacity: 7 200 kW

**Animal waste**
- Quantity of raw material available: 3.763 million tonnes

**United Kingdom**

**Poultry litter, meat and bone, straw, farm waste and short-rotation coppice**
- Production: 355 ttoe
- Input to electricity generation: 283 ttoe
- Direct use from combustion: 72 ttoe

**Sewage gas**
- Production: 184 ttoe
- Input to electricity generation: 130 ttoe
- Direct use from combustion: 53 ttoe
- Electricity generating capacity: 96 MW
- Electricity generation: 397 GWh

**Landfill gas**
- Production: 892 ttoe
- Input to electricity generation: 879 ttoe
- Direct use from combustion: 14 ttoe
- Electricity generating capacity: 472.9 MW
- Electricity generation: 2 679 GWh

**Waste and tyres**
- Production: 763 ttoe
- Input to electricity generation: 672 ttoe
- Direct use from combustion: 91 ttoe

**Municipal solid waste combustion**
- Electricity generating capacity: 278.9 MW
- Electricity generation: 958 GWh

**Other**
- Electricity generating capacity: 165.7 MW
- Electricity generation: 870 GWh

**Wastes**
- Electricity generation: 494 GWh

- Comprises municipal solid waste, general industrial waste and hospital waste.
- Biodegradable part only.
- Includes the use of farm waste digestion, waste tyre, poultry litter, meat and bone and straw combustion, and short-rotation coppice.
- Includes the use of farm waste digestion, poultry litter combustion, meat and bone combustion, straw and short-rotation coppice.
- Non-biodegradable part of municipal solid waste plus waste tyres.

**Landfill gas.** Landfill gas exploitation has benefited considerably from the Non-Fossil Fuel Obligation (NFFO) and this can be seen from the large rise in the amount of electricity generated.
generated since 1992. Further commissioning of landfill gas projects under NFFO will continue to increase the amount of electricity generated from this technology. In 2002, 13 new schemes came on line under NFFO.

**Sewage sludge digestion.** In all sewage sludge digestion projects, some of the gas produced is used to maintain the optimum temperature for digestion. In addition, many use CHP systems. The electricity generated is either used on site or sold under the NFFO.

**Short-rotation coppice.** Short-rotation willow coppice development is now becoming well established with demonstration projects underway in Northern Ireland and England. Under Northern Ireland’s second Non-Fossil Fuel Renewable Energy order for electricity, two projects were live at the end of 2002.

In England, Project ARBRE in south Yorkshire was contracted under NFFO 3 to generate 10 MW of electricity of which 8 MW were to be exported to the local grid. This project has run into difficulties and has recently (2002/2003) been sold to new owners who are currently evaluating their options on taking the project forward.

**Straw combustion.** Straw can be burnt in high-temperature boilers, designed for the efficient and controlled combustion of solid fuels and biomass to supply heat, hot water and hot air systems. There are large numbers of these small-scale batch-fed whole bale boilers. The figures given are estimates based partly on 1990 information and partly on a survey of straw-fired boilers carried out in 1993–1994. A 31 MW straw-fired power station near Ely, Cambridgeshire was commissioned in 2000 and has been exporting electricity since September of that year.

**Waste combustion.** Domestic, industrial and commercial wastes represent a significant resource for materials and energy recovery. Wastes may be combusted, as received, in purpose-built incinicators or processed into a range of refuse-derived fuels (RDF) for both on-site and off-site utilisation.

**Chapter 10: Bioenergy (other than Wood)**

Nineteen WTE plants were in operation in 2002 burning MSW, RDF and general industrial waste (GIW).

Waste can be partially processed to produce coarse RDF which can then be burnt in a variety of ways. By further processing the refuse including separating off the fuel fraction, compacting, drying and densifying, it is possible to produce an RDF pellet. The pellet has around 60% of the gross calorific value of British coal.

The generation of MSW has been split between biodegradable sources and non-biodegradable sources using information on calorific values of the constituent parts. Approximately 66% of generation from MSW was estimated to be from biodegradable sources.

**General industrial waste combustion.** Certain wastes produced by industry and commerce can be used as a source of energy for industrial processes or space heating. These wastes include general waste from factories such as paper, cardboard, wood and plastics.

A survey conducted in 2001 has highlighted that although there are six WTE plants burning GIW, these are all MSW facilities. As no sites are solely burning GIW for heat or electricity generation, this feedstock is being handled under the MSW category.

**Specialised waste combustion.** Materials in this category include scrap tyres, hospital wastes, poultry litter, meat and bone and farm waste digestion. The large tyre incineration plant with energy recovery did not generate in 2002. Although part of waste tyre combustion is of biodegradable waste, because there is no agreed method of calculating the small biodegradable content, all the generation from waste tyres has been included under non-biodegradable wastes when calculating renewables eligible for the Renewables Obligation (RO) and the European Union’s Renewables Directive (RD).

One poultry litter combustion project started generating electricity in 1992, a second began in 1993. Both of these are NFFO projects. In addition, a small-scale CHP scheme began generating towards the end of 1990. However, this has
now closed due to new emissions regulations. A further NFFO scheme started generating in 1998 at Thetford, Norfolk, and during 2000 a Scottish Renewable Order (SRO) began to generate. During 2000–2002 one of the earlier poultry litter projects was fuelled mainly by meat and bone. A new poultry litter scheme became fully operational in 2001.

There was a farm waste digestion project generating electricity under the NFFO but it ceased to operate post-2002.

Co-firing of biomass with fossil fuels. Co-firing of biomass with fossil fuels is now eligible under the RO, the first time that any RE initiative has included co-firing. As the purpose of this was to enable markets and supply chains for biomass to develop, and not to support coal-fired power stations, the following limits are placed on co-firing:

- only electricity generated before 1st April 2011 will be eligible;
- from 1st April 2006 at least 75% of the biomass must consist of energy crops.

Co-firing of biomass fuel in fossil fuel power stations is not a new idea. Technically it has been examined and proven to various degrees in power stations worldwide. It has not been considered at the large power station scale in the UK until fairly recently but a number of utilities are now investigating use of a range of biomass products at various coal-fired power station sites. The ability of coal station furnaces to cope with the introduction of such biomass is dependent on a number of factors including biomass composition and furnace design. Current trials are planned to look at possible substitution at up to 20% on a thermal basis. However, the scale of implicit fuel preparation and plant transport systems may limit the scope for substitution in addition to coal furnace considerations. The 2002 data for biomass include biomass use at one UK coal-fired power station, although other stations have begun to burn biomass in 2003.


---

### United States of America

**Municipal solid waste**

Quantity of raw material available: 146.2 million tonnes

Biogas production capacity: 145 895 TJ/yr

Electricity generating capacity\(^a\): 3 308 000 kW

Electricity generation\(^a\): 72 651 TJ

**Agricultural residues—corn stover and wheat straw**

Quantity of raw material available: 176 million tonnes

**Corn**

Ethanol fuel production capacity: 236 834 TJ/yr

Yield of ethanol: 2.5 gal/bushel of corn

Ethanol production\(^b\): 171 553 TJ

**Other**

Ethanol fuel production capacity: 4 916 TJ/yr

Biodiesel production capacity: 9 391 TJ/yr

Yield of biodiesel: 40.2 GJ/tonne

Biodiesel production: 2 053 TJ

Electricity generating capacity\(^c\): 539 000 kW

Electricity generation\(^c\): 9 636.7 TJ

\(^a\) Includes landfill gases.

\(^b\) Includes production from corn and other.

\(^c\) Includes agricultural residues.

---

### Uruguay

**Sugarcane bagasse**

Quantity of raw material available: 0.05 million tonnes

Electricity generation: 24.3 TJ

Direct use from combustion: 477 TJ

**Agricultural residues—sunflower husks**

Quantity of raw material available: 0.01 million tonnes

Direct use from combustion: 164.4 TJ

**Agricultural residues—rice husks**

Quantity of raw material available: 0.21 million tonnes

Electricity generation: 8.8 TJ

Direct use from combustion: 558.6 TJ

Data refer to 2001.