# 5. Climate change mitigation potential of woodfuels

This chapter reviews some of the options for greenhouse gas mitigation using woodfuels, focusing on the costs incurred in relation to the carbon that is saved or substituted under various bioenergy systems. A brief summary of the costs of such systems is given, followed by comments on the measurement of greenhouse gas impacts. Selected greenhouse gas mitigation measures that rely solely or primarily on woodfuels are presented in later chapters. In general, mitigation occurs when woodfuels substitute for fossil fuels or where there is greater efficiency in the application of biomass technology.

The measures reviewed here are not intended to be exhaustive; nor do they cover all sectors or applications, although in general they encompass the main short-term options. The site-specific nature of bioenergy means that such estimates cannot easily be extended or applied in specific contexts; therefore, they are representative only of the overall options within a sector and do not necessarily point to any particular project portfolio that might be pursued. The final chapter gives some national-level examples on a portfolio basis in order to provide a sense of how a set of measures or programmes might be applied in a given country.

## COSTS OF BIOENERGY SYSTEMS

Given the many options available, the cost of bioenergy systems cannot easily be summarized in the way in which other renewables, such as wind and solar, can be. Table 29 presents investment costs for stationary applications of commercial systems using combustion or gasification for heat ($MW/kW_{thermal}$) and power ($MW/kW_{electrical}$).

In some cases, costs are expected to come down considerably once large-scale systems are commercialized. Note that performance changes with the quality of biomass supply; for example, in some cases the incineration of waste wood results in lower efficiency due to the considerable variation in the combustion properties of wastes and the difficulty of controlling for variations during operation.

The feedstock cost depends on a variety of site-specific factors such as labour costs, transportation costs and the availability of logistical infrastructure. One set of estimates for the EU for 2010 showed costs for residues ranging from €2.1 to €3.1 per GJ and from €1.8 to €3.7 per GJ for woody crops grown in forest plantations (Hansson and Berndes, 2009). The delivered cost will be considerably lower in most developing countries due to low labour costs but logistics and transport will tend to be uncertain and/or more expensive. An analysis in Tanzania estimated costs ranging from US$0.53 to US$1.46 per GJ (€0.43 to €1.18 per GJ

TABLE 29

**Summary of estimated efficiencies, costs and deployment of bioenergy systems**

| Process or method | Applications | Capacity range | Net efficiency (lower heating value)*(%)* | Investment cost | Deployment status |
|---|---|---|---|---|---|
| **Combustion** | | | | | |
| Heat | Domestic (modern furnace) | 1–5 MW$_{th}$ | 65–90 | 300–700 €/kW$_{th}$ | Increasing use of modern furnaces and prepared biomass (pellets) |
| Combined heat and power | District heating, industrial uses | 1–10 MW$_{e}$ | 80–100 (system) | 1500–2000 €/kW$_{e}$ | Widely deployed in Europe and North America |
| Stand-alone | Waste incineration | 20–100s MW$_{e}$ | 20–30 (electrical) | 2000–2500 €/kW$_{e}$ | Low efficiency for mass burning/ incineration |
| | High-efficiency designs | 20–100s MW$_{e}$ | 30–40 (electrical) | 1500–2000 €/kW$_{e}$ | Widely used in northern Europe |
| Co-firing | Existing coal plants | 5–20 MW$_{e}$ | 30–40 (electrical) | ~250 €/kW$_{e}$ + cost of existing plant | Widely deployed |
| **Gasification** | | | | | |
| Heat | Small-scale | <1 MW$_{th}$ | 60–90 (system) | 200–600 €/kW$_{th}$ | Commercially deployed |
| Combined-heat-and-power gas engine | Small-scale | <1 MW$_{e}$ | 15–30 | 1000–3000 €/kW$_{e}$ | Limited deployment |
| Biomass gasification combined-cycle | | 30-100 MW$_{e}$ | 40–50 | 5000–6000 €/kW$_{e}$ | Demonstration phase at smaller scales |
| | | 30-100 MW$_{e}$ | 40–50 | 1000–2000 €/kW$_{e}$ | Large-scale (long-term) |

*Source:* Adapted from Faaij, 2006.

Notes: kW$_{e}$ = kilowatts$_{electical}$; kW$_{th}$ = kilowatts$_{thermal}$; MW$_{e}$ = megawatts$_{electrical}$; MW$_{th}$ = megawatts$_{thermal}$

at current exchange rates) for fuelwood, from either woodlots or managed areas (Wiskerke *et al*., 2010).

These costs compare quite favourably with the price of steam coal in the IEA reference scenario of US$70 to $100 per tonne (€1.9 to €2.7 per GJ, assuming hard coal at 29.7 GJ per tonne). In the case of co-firing at coal plants, the woody biomass feedstock can be compared directly. Under stand-alone comparisons, however, the investment costs will be considerably lower for coal and therefore there will need to be other considerations or other sources of support based on factors such as carbon finance, a preference for smaller scale or, in the case of imported coal, concerns about energy security.

## GREENHOUSE GAS IMPACTS, LAND USE AND CARBON SEQUESTRATION

The mitigation potential of woodfuels is based on two main factors: the substitution of biomass for fossil fuels, and the sequestration of carbon in standing biomass. The main constraint that arises for substitution is the lower energy content of biomass compared to fossil fuels. This results in much higher transport costs which, together with variations in the quality of biomass, increases the uncertainty of biomass supply for a given energy production facility. It also provides the logic behind charcoal markets: the higher energy content of charcoal makes wood biomass a more tradable commodity because of its lower transport cost per unit energy. In many regions of Africa, the price of charcoal tends to vary little in relation to the distance it has travelled because, to a considerable extent, markets internalize the transport costs, as is common for internationally traded commodities (Johnson and Rosillo-Calle, 2007).

Carbon sequestration is based on the type of biomass and soils, the level of biological activity, and other physical and climatic factors. In the absence of losses, bioenergy is carbon-neutral, since the carbon released on combustion is taken up in the next cycle of the plant or tree growth. However, losses can occur in the supply chain and losses from soil and root systems can occur as a result of land-use change.

The greenhouse gas impacts of bioenergy are necessarily based on the entire lifecycle, from planting through harvesting, transport and end-use. A detailed greenhouse gas balance for specific cases is beyond the scope of this study, and the balances used here should be regarded as representative only. Land-use impacts are generally not included in these estimates, although for those options where residues are used the land-use impacts will generally be minor. The large-scale cultivation of bioenergy crops using agroforestry can have significant implications for the greenhouse gas balance where land is cleared or otherwise severely disrupted (Schubert *et al.*, 2009). Alternatively, the soil properties of marginal lands can improve under a careful management regime.

## BIOMASS-BASED ELECTRICITY GENERATION

The potential for biomass power plants depends on factors such as the available biomass supply, the minimum scale required, alternative uses of the biomass, and the geographically closest fossil-fuel competitors, which will generally be natural gas or coal. Biomass is most competitive where there is sufficient demand for heat to allow for combined heat and power production (cogeneration); in such cases the overall system efficiency can be as high as 80 to 90 percent. Biomass gasification systems can also be competitive with natural gas, although this is uncertain in the short term due to high investment costs. The IPCC's Fourth Assessment Report (IPCC, 2007) reviewed estimates for biomass electricity generation and developed a categorization according to the abatement cost, as shown in Table 30.

At current carbon prices of US$10 to $20 per tonne, somewhat less than half of the potential should be achievable; moreover, the potential is concentrated in non-OECD countries where there are opportunities for the Clean Development Mechanism (CDM) and other financial mechanisms. This is the technological/economic potential, however, and does not necessarily take into account the various issues related to implementation, deployment, infrastructure and especially the reliability of biomass feedstock supply, which almost always depends on local conditions.

TABLE 30

**Estimated 2030 mitigation potential and abatement cost for bioelectricity generation**

| Countries | Total emissions that can be saved in 2030 *($GtCO_2eq$)* | Mitigation potential by cost per $tCO_2eq$ avoided *(%)* | | | |
|---|---|---|---|---|---|
| | | <US$0 | US$0–20 | US$20–50 | US$50–100 |
| OECD | 0.20 | 20 | 25 | 40 | 15 |
| Economies in transition | 0.07 | 20 | 25 | 40 | 15 |
| Non-OECD | 0.95 | 20 | 30 | 45 | 5 |
| **World** | **1.22** | | | | |

*Source:* IPCC, 2007.

## BIOMASS CO-FIRING

Co-firing woody biomass in coal-fired power plants is a widely available and cost-effective option. Within the EU, the potential has been estimated at 0.5 to 1 EJ per year in the short term (the higher end of the range assumes use even in plants that are more than 40 years old) (Hansson *et al.*, 2009). As shown in Table 31, it has been estimated that the overwhelming majority of cost-effective abatement using co-firing is in China because of the large number of coal-fired plants that have been built there in recent years – it is easier to introduce biomass to newer plants compared with older plants. However, cost goes up over time; it more than doubles in China between 2015 and 2030 as the most cost-effective options are implemented.

In general, securing feedstock supply and ensuring proper operation are the key considerations for biomass co-firing, especially at older power plants. It should be noted that non-woody biomass as well as waste might also be used for co-firing. In some cases such sources will be cheaper, but the relatively clean characteristics of woody biomass reduce the potential for fouling the boiler equipment, additional maintenance costs and other operational problems.

## BIOMASS SUBSTITUTION AT STEEL PLANTS

There is also potential for biomass substitution in the iron and steel industries, where charcoal can replace coking coal. This potential is much smaller than in power plants due to the quantities involved and the location-specific nature of such industries. The costs, however, are negative, since biomass is cheaper than coking coal. In some regions, especially Brazil, large quantities of charcoal are already used for steelmaking; the potential in these regions is therefore limited. Nevertheless, the potential role of woody biomass in the iron and steel industries is large at the global scale; since all biomass is expected to be sourced locally, the estimates in Table 32 do not consider charcoal trade and are therefore underestimates.

## IMPROVED CHARCOAL PRODUCTION OPTIONS

Although not yielding large greenhouse gas savings in global terms, improving the efficiency of charcoal production offers local benefits by improving the delivery of

TABLE 31

**Greenhouse gas abatement and cost for biomass co-firing in coal-fired power plants**

| Region | Abatement *(MtC)* | | Cost *(US$/tonne C)* | |
|---|---|---|---|---|
| | 2015 | 2030 | 2015 | 2030 |
| United States | 47.0 | 39.2 | 33.3 | 42.7 |
| EU (selected) | 20.5 | 20.3 | 22.8 | 23.0 |
| Russian Federation | 20.1 | 14.1 | 3.9 | 10.7 |
| Japan | 6.3 | 6.4 | 48.6 | 47.7 |
| China | 329.0 | 218.0 | 10.2 | 25.8 |
| India | 37.8 | 14.5 | 8.8 | 50.3 |
| South Africa | 4.3 | 3.4 | 35.4 | 49.7 |
| Others (total) | 64.0 | 48.5 | | |
| **World** | **529** | **364** | **15** | **30** |

*Source:* McKinsey and Company, 2009.

TABLE 32

**Abatement by and costs of biomass substitution for coking coal at steel plants**

| Region | Abatement *(MtC)* | | Cost *(US$/tonne C)* | |
|---|---|---|---|---|
| | 2015 | 2030 | 2015 | 2030 |
| United States | 0.6 | 0.9 | -6.6 | -6.7 |
| Brazil | 0.6 | 0.9 | -9.2 | -9.1 |
| Rest of EU27 | 0.9 | 1.3 | -6.2 | -6.3 |
| Russian Federation | 0.7 | 1.1 | -10.5 | -10.6 |
| Japan | 1.3 | 1.9 | -6.4 | -6.5 |
| China | 7.8 | 12.2 | -11.9 | -11.6 |
| India | 1.0 | 1.7 | -9.2 | -9.2 |
| South Africa | 0.1 | 0.2 | -6.4 | -6.5 |
| Others (total) | 2.9 | 4.4 | - | - |
| **World** | **15.8** | **24.6** | **-9.8** | **-9.7** |

*Source:* McKinsey and Company, 2009.

energy services, reducing impacts on health and the environment, and saving money. In some countries, improved charcoal production is a low or negative cost measure that compares well with other mitigation options (see section on Conservation and woodfuel mitigation actions and Table 36). A wide range of technologies is available for charcoal production, from simple earth kilns to complex, large-capacity charcoal retorts.

Improved charcoal production technologies are aimed largely at increasing the efficiency of charcoal production as well as at improving the quality of the charcoal. Improved charcoal kilns can be classified into five categories: earth kilns, metal kilns, brick kilns, cement or masonry kilns, and retort kilns. These are differentiated mainly by their technical sophistication and investment cost. Table 33 shows the main characteristics of each of the five categories.

The more complex designs are less labour-intensive and include semi-automated operations. In addition, by-products in the high-cost designs are often just as important as, and sometimes more important than, the charcoal produced. The low-cost, simpler designs are particularly suitable for developing countries, where labour is usually abundant.

While most of the low-cost improved charcoal kilns have demonstrated high efficiencies under test conditions, none has been substantially disseminated, largely because of the nature of charcoal production in many developing countries and the surprisingly high efficiency of traditional kilns under field conditions. Earth kilns were once thought to be a grossly inefficient technology, but a 1984–1985 study in Sudan indicated that their efficiency was comparable with improved brick and metal portable kilns. Table 34 shows the efficiency of various low-cost kilns.

The critical factors in determining the efficiency of traditional designs appear to be operational skill and the moisture content of the utilized wood. The

TABLE 33
**Main characteristics of various categories of charcoal kilns**

| Kiln type | Typical capacity | Yield *(%)* | Cost *(US$)* | Where used |
|---|---|---|---|---|
| **Earth** | | | | |
| Mound | 5–100 $m^3$ | 10–25 | Very low | Many developing countries |
| Casamance | Variable | 25–31 | 200 | Cameroon, Ghana, Malawi and Senegal |
| Pit | 3–30 $m^3$ | 30–35 | Very low | Sri Lanka, United Republic of Tanzania and other developing countries |
| **Metal** | | | | |
| Mark V | 300–400 kg | 20–25 | 2 000–5 000 | Uganda |
| Oil drum | 12–15 kg | 23–28 | Low | Kenya, the Philippines |
| **Brick** | | | | |
| Beehive and half-orange | 9–45 kg | 25–35 | 150–500 | Argentina, Brazil and Malawi |
| **Cement or masonry** | | | | |
| Katugo | 70 kg | 25–30 | 8 000 | Uganda |
| Missouri | 350 kg | 25–33 | 15 000 | United States and other developed countries |
| **Retort** | | | | |
| Cornell | 1–3 tonnes | 22–33 | 40 000 | Norway and other developed countries (smaller prototypes tried in Ghana and Zambia) |
| Lamboitte | 3 000–20 000 tonnes per year | 30–35 | 0.5 million – 2 million | Australia, France, Côte d'Ivoire and other developing countries |

*Source:* UNCHS, 1993.

TABLE 34
**Conversion efficiencies of earth and pit kilns**

| Kiln type | Percentage recovery, oven-dried wood | Percentage recovery, air-dried wood |
|---|---|---|
| Casamance earth kiln | 31 | 27 |
| Metal channel earth kiln | 29 | 25 |
| Modified metal channel kiln | 25 | 21 |
| Earth mound kiln (control) | 25 | 21 |
| Pit kiln | 15 | 13 |

*Source:* UNCHS, 1993.

presence of a chimney that ensures optimum draught conditions also appears to be important.

A large proportion of charcoal production in developing countries is carried out as a semi-illegal, part-time activity – the wood used is often procured illegally. Consequently, few charcoal-makers are willing to invest in improved charcoal kilns because of the risk of punitive official measures and taxes. Consequently, dissemination of improved charcoal techniques to the informal sector has proved difficult. Improved charcoal production technologies have been more successful in areas where production is undertaken on a commercial basis, such as in Malawi.

Another area where the cost-effectiveness of charcoal, and its energy efficiency, can be improved is in transportation. Given charcoal's fragility, excessive handling and transporting over long distances can increase the amount of fines to up to 40 percent, greatly reducing its economic value. Distribution in bags helps to limit the production of fines and also provides a convenient, measurable quantity for both retail and bulk sales.

## TRADITIONAL BIOMASS: IMPROVED COOKING STOVES

With more than two billion users of traditional biomass worldwide, the energy savings and emission reductions potential of improving the efficiency of cooking stoves is enormous. Another factor is the sustainability of the biomass resource: harvesting that exceeds the maximum that can be regenerated in a given region has been labelled "non-renewable" under the CDM and has been subject to greater limitations in carbon finance. Calculating the emission reductions from improved management requires the estimation, verification and monitoring of the biomass supply, but data are normally difficult to obtain.

Estimates of emission reductions from improving the efficiency of traditional cooking stoves are uncertain, since the underlying data are either unavailable or subject to considerable fluctuation. The number of users and the types of equipment and their energy consumption are not well known. Thus, the estimates shown in Table 35 have a wide range. The estimates of costs include only those related to the cost of the stove and fuel; neither other costs nor emission reductions from improved forest management are considered.

TABLE 35

**Estimated emissions abatement from improved cooking stoves**

| Country/region | Abatement *(Mt C)* | | Cost *(US$ per tonne of carbon)* | |
|---|---|---|---|---|
| | Low | High | Low | High |
| India | 33 | 150 | -1 | 6 |
| Sub-Saharan Africa | 52 | 190 | -3 | 4 |
| Other Asia/Pacific | 29 | 67 | -1 | 8 |
| Other Americas | 11 | 52 | - | - |
| **Total** | **125** | **459** | | |

*Source:* Bhattacharya and Jana, 2009; Bhattacharya, 2009; Bond and Sun, 2005.

TABLE 36

**Mitigation options analysed in forest and woodfuels sectors, Mexico**

| Interventions | Area *(million ha)* | Mitigation *($MtCO_2eq$/yr)* | Investment *(US$ million)* | Net cost/benefit *(US$/$tCO_2eq$)* |
|---|---|---|---|---|
| **With negative cost/benefit ratio** | | | | |
| Efficient charcoal production | 2.8 | 11.3 | 416 | -20 |
| Forest management | 9.0 | 4.2 | 148 | -13 |
| Improved stoves | | 10.0 | 434 | -2 |
| Biomass electricity (wood-based) | 12.0 | 17.1 | 11 250 | -2 |
| **Subtotal** | **23.8** | **42.5** | **12 248** | |
| **With positive cost/benefit ratio** | | | | |
| Fuelwood co-firing | 0.1 | 2.0 | 454 | 7 |
| Afforestation | 1.6 | 7.0 | 1 084 | 8 |
| Reforestation and restoration | 4.5 | 7.7 | 2 229 | 9 |
| Wildlife management | 30.0 | 9.8 | 169 | 18 |
| Payment for environmental services | 5.0 | 2.3 | 923 | 18 |
| **Subtotal** | **41.1** | **28.7** | **4 859** | |
| **Total** | **64.9** | **71.2** | **17 187** | |

*Source:* Johnson *et al.*, 2009.

## CONSERVATION AND WOODFUEL MITIGATION ACTIONS

Recently, expectations have been raised about payments for reduced deforestation, improved forest management, afforestation and forest restoration and forest conservation activities through carbon credits for REDD-plus (‘reduced emissions from deforestation and forest degradation’ plus conservation, sustainable management of forests, enhancement of forest carbon stocks). In some circumstances the potential income from carbon credits under bioenergy options will outweigh the income from REDD options. One study in Tanzania found that the mean annual increment was too low to make carbon sequestration through forestation a profitable exercise under the CDM, but short-rotation woodlots provided employment and were cost-competitive in the supply of a bioenergy feedstock (Wiskerke *et al*., 2010). In such semi-arid regions, small-scale bioenergy production could be a useful way to earn carbon credits (as a fossil-fuel offset) while also improving energy services.

In a national context, woodfuel options tend to compare favourably with land management options aimed at conservation. In Mexico, an evaluation of various forest-based climate change mitigation options found that, in some cases, bioenergy options had a negative cost/benefit ratio (i.e. the benefits outweighed the costs); conservation options tended to be more costly because there was less certainty of a stable revenue stream than in the case of a marketable commodity (Table 36).

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