10. Research, development, demonstration and deployment

This chapter reviews selected issues in research, development, demonstration, deployment and implementation of woodfuel use in climate change mitigation that need to be considered to meet end-user needs.

ESTIMATED BLACK CARBON EMISSIONS FROM TRADITIONAL BIOMASS

There are only a few studies on black carbon (soot) emissions from the household use of biomass for cooking. Based on measurements by Muhlbaier-Dasch (1982) on eleven types of wood, Streets *et al.* (2001) assumed a value of 1 g per kg of black carbon emissions for the combustion of residential biofuels. Bond *et al.* (2004) estimated the black carbon emission factor to be 0.3 to 1.4 g per kg for wood; 1.0 g per kg for crop residues as well as charcoal; 0.5 g per kg for animal dung; and 0.2 g per kg for charcoal-making.

Reddy and Venkataraman (2002) estimated black carbon emissions in India of 0.41 g per kg for wood, 0.47 g per kg for agricultural residues and 0.25 g per kg for dung. In a more recent study, Venkataraman *et al.* (2005) reported measured values of black carbon emissions of 0.48 to 0.55 g per kg for wood, 0.64 g per kg for crop residues and 0.12 g per kg for animal dung. Roden *et al.* (2006) measured emissions from biofuel cooking stoves during a field study in Honduras; average black carbon emissions were 1.5 ± 0.3g per kg.

Cao *et al.* (2007) used measured values of emissions for crop residues in preparing an inventory of black carbon emissions in China; they were 0.52 g per kg for rice and wheat straw; 0.78 g per kg for corn stover; and 0.82 g per kg for cotton stalk. MacCarty *et al.* (2008) reported black carbon and organic matter emissions, and global warming impact, of a charcoal stove and the following four types of wood-fired cooking stoves: three-stone stove; improved stove (Rocket stove); natural draft gasifier stove; and forced-draft gasifier stove. Table 43 shows that black carbon emissions varied widely.

The emission factors of pollutants from stoves depend on various parameters involved in the combustion process, such as the type of fuel, the type and design of the burner, and the operating conditions (Bhattacharya and Salam, 2002). It is almost impossible, therefore, to cite a definitive value. A simplifying assumption is that black carbon emissions per kg of fuel are the same for both traditional and improved stoves and therefore vary according to the fuel used, as follows:

- wood-fired stoves – 1 g per kg;
- crop-residue-fired stoves – 0.75 g per kg;
- dung-fired stoves – 0.25 g per kg.

TABLE 43
Black carbon emission factor for five stoves

Stove type	Emission factor *(g/kg)*
Three-stone	0.88
Rocket stove	1.16
Natural draft gasifier stove	0.28
Forced-draft gasifier stove	0.06
Charcoal stove	0.20

Source: MacCarty *et al.*, 2008.

TABLE 44
Black carbon emissions from biofuel combustion in the residential sector

Energy source	Black carbon emission *(Gg/year)*	Share of global black carbon emissions *(%)*
Wood	880	11.1
Crop residues	393	4.9
Animal waste	208	2.6
Coal	480	6.0
Total	**1 961**	**24.7**

Source: Bond *et al.*, 2004.

In one of the earliest studies of global black carbon emissions, Streets *et al.* (2001) estimated black carbon emissions from the total combustion of all biofuels – wood, crop residues and animal dung combined – using a single emission factor. Bond *et al.* (2004) used separate emission factors for different biofuels used in the residential sector (Table 44). Ventakaraman *et al.* (2005) presented estimates of black carbon emissions from biofuel combustion in India and elsewhere in Asia as well as the 1995 global total using measured values of emissions; the reported global values for wood, crop residues and animal dung were 670 to 820, 230 to 260 and 20 to 50 gigagrams (Gg) per year, respectively.

HOUSEHOLD BIOMASS: CLEAN COOKING DEPLOYMENT STRATEGIES

There is no universal strategy for disseminating clean cooking options. As noted by Barnes *et al.*, (1994), each stove programme "will face a distinctive set of challenges and benefits, depending on local conditions". National strategies for reducing black carbon emissions from residential cooking will need to take into account a wide range of country-specific barriers, constraints and opportunities. The following elements could be considered in the formulation of such strategies.

- The large-scale mitigation of black carbon emissions from residential cooking requires serious government commitment and a national-level programme with policies and targets. The provision of clean cooking options, similar to rural electrification and infrastructure development, needs to be part of the national development agenda. Recent success in Brazil in introducing an improved cooking stove programme appears to be due at least partly to the enthusiasm and commitment of a local politician.

- The large-scale dissemination of improved stoves requires public-sector investment in building capacity, raising awareness and developing technology. Experience in China suggests that government support is also needed for certification systems to standardize stove designs (Sinton *et al.*, 2004).
- Improved cooking stove programmes tend to fail in regions where poor families build their own stoves and collect their fuels free of charge. In such regions, government or donor money could be used to subsidize the cost of improved stoves (Barnes *et al.*, 1994).
- A great deal of effort is often needed to convince users that better options than traditional cooking stoves exist. Thus, a systematic and sustained campaign for creating awareness about the importance of cleaner options is vital. Involving non-governmental organizations and women's groups in these campaigns is also important.
- To be readily accepted, improved stoves must meet the actual needs and preferences of users.
- Improved stoves must be clean and efficient – if the first few users are convinced of the benefits, their positive experiences will draw more users to cleaner options.
- To attract first-time users the stoves must "look" modern. The effectiveness of such an approach to marketing can be seen in the success of new stoves being sold commercially (e.g. the Oorja and Rocket stoves being marketed in India).
- Since many of the potential users earn very low cash incomes (e.g. less than a dollar a day), the initial cost of clean options should be as low as possible; a subsidy may be required.
- The acceptance of improved stoves depends on women's opportunities for paid labour; less time spent on fuelwood collection means more time for income generation. Creating such employment opportunities would thus contribute towards the success of improved-stove programmes.
- Involving private-sector entrepreneurs in building and marketing stoves will ensure a rapid response to user complaints and generate benefits in the form of additional employment.

AN ADVANCED TECHNOLOGY OPTION: WOOD GASIFICATION

Wood can be transformed readily into a synthetic gas (syngas) through a gasification process. Municipalities and the industrial sector are looking for ways to reduce the disposal costs associated with biomass wastes and to produce electricity and other valuable products from them. Biomass gasification has not reached the level of commercial demonstration but shows a great deal of promise.

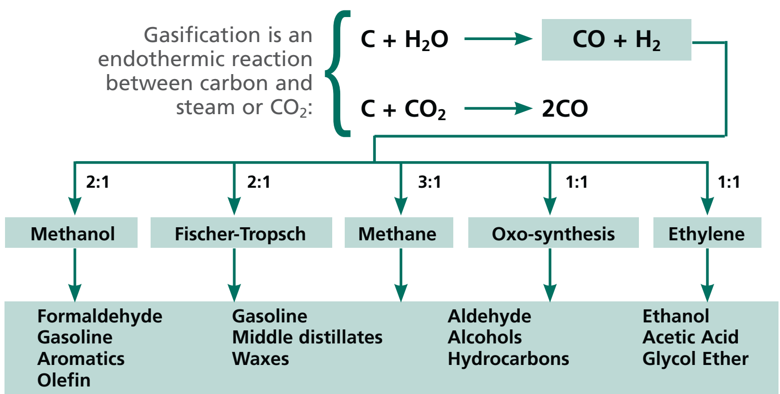
Gasification is an energy technology that can convert low-value feedstock into high-value products, helping to reduce dependence on foreign oil and natural gas and providing a clean, renewable source of energy. Syngas can be burned directly to produce electricity or further processed to produce liquid fuels, chemicals, substitute natural gas or hydrogen. The basic process and some of the possible products are shown in Figure 3.

Most gasification processes use biomass feedstock injected with oxygen and steam into a high-temperature, pressurized reactor so that the chemical bonds of the feedstock are broken. The resulting reaction produces syngas – a mixture of hydrogen and carbon monoxide – and small amounts of other gases and impurities such as sulphur, mercury, particulates and trace minerals that are removed by cleaning (carbon dioxide can also be removed at this stage). The cleaned syngas can be used for a wide range of purposes, including the production of substitute natural gas – methane – which can be used in the same way as natural gas. Syngas from wood contains tar (a mixture of hydrocarbon compounds) and other impurities; cleaning tar from syngas is an unresolved problem.

Gasification is the foundation for converting biomass to transportation fuels via one of two basic paths. In one, the syngas undergoes a Fischer-Tropsch reaction to convert it to a liquid product. In the other – the methanol-to-biofuel process – the syngas is converted to methanol, which is then converted to liquid biofuel by reacting it over a bed of catalysts.

The advanced biomass-to-power technology allows the continued use of biomass without the high level of emissions associated with conventional biomass burning. This is because in gasification power plants the pollutants in the syngas are removed before the syngas is combusted. In conventional combustion technologies the pollutants must be captured after the exhaust gas has passed through the boiler or steam generator.

FIGURE 3
Basic process scheme: gasification of biomass



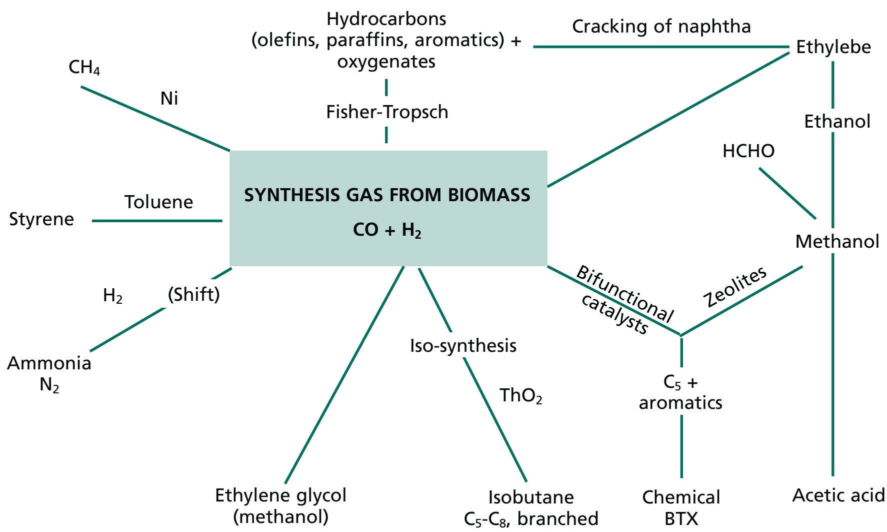
The clean syngas can also be combusted directly (i.e. without conversion to methane) in gas turbines to generate electricity with very low emissions. The gas turbines used in these plants are generally derivatives of the gas turbines in jet engines adapted for use with syngas for power production. These turbines are able to operate on syngas with high levels of hydrogen (typical 50 percent hydrogen by volume). Hot discharge gas from the turbines can be circulated through a heat recovery steam generator, providing additional electricity-generation capacity via a steam turbine (this is called a combined-cycle unit).

Steam recovered from the gasification process is superheated in the heat recovery steam generator to increase the overall efficiency output of the steam cycle. The full cycle, called the integrated gasification combined cycle, includes a gasification plant, two types of turbine generators (gas and steam), and the heat recovery steam generator. It is a clean and efficient power production system producing nitrogen oxides at levels lower than 0.03 kg per basic emission of coal power generation; combined cycle efficiencies can exceed 65 percent.

It is also possible to use the gas turbine to compress air; this reduces the capital cost of the plant and decreases the amount of power required to supply oxygen in the combustion processes.

Producing more than one product at a time (co-production or "polygeneration") such as the simultaneous production of electricity, steam and chemicals (e.g. methanol and ammonia) is also possible and in some cases improves the plant's financial performance (Figure 4).

FIGURE 4
Main chemicals from synthesis gas



Source: Wender, 1986

Gasification enables the use of biomass to produce electricity with significantly reduced environmental impacts compared to traditional combustion technologies. The reasons for this include the following:

- Syngas is cleaned before combustion – gasification plants therefore produce significantly fewer quantities of noxious air pollutants such as nitrogen oxides and sulphur dioxide.
- Gasification enables the recovery of available energy from low-value materials (e.g. municipal solid waste), thereby reducing the environmental impacts of biodegradation as well as disposal costs.
- The by-products of gasification (e.g. sulphur and ashes) are non-hazardous and are readily marketable.
- Gasification plants use significantly less water than coal combustion plants, and can be designed as zero-liquid water discharge facilities.
- In the last five to ten years, coal gasification for electricity production has reached commercialization, with over 90 installations and 60 manufactures around the world.

The main advantages of gasification are:

- high electrical efficiency;
- the substitution of natural gas or diesel in boilers;
- the distribution of power generation where power demand is low;
- the substitution of gasoline/diesel in internal combustion engines.

The gasification of biomass is not yet commercially viable; to penetrate the market its costs must be lowered considerably. The first successful demonstration of biomass gasification at an industrial scale was at Värnamo in Sweden (the test programme ended in 1999). On the basis of a recent feasibility study, the energy company E. ON Sverige identified 20 potential locations for plants in Sweden.