3. Bioenergy production

Many processes are available for producing bioenergy, from burning sticks and branches for cooking and heating to gasification of wood chips for transport fuel production. Energy producing systems may be compared in terms of energy efficiency, installation costs, carbon emissions, labour intensiveness or any range of costs and benefits. The appropriateness of different systems, however, will depend largely on existing structures and markets rather than isolated production assessments.

Recently, there has been much discussion of the presumed benefits of bioenergy in terms of carbon dioxide emissions. It should be noted, however, that bioenergy is only a renewable and sustainable form of energy under certain conditions (Perley, 2008). To maintain the carbon dioxide balance, biomass harvest must not exceed growth increment, and carbon dioxide emitted during production, transportation and processing must be taken into account. The conversion efficiency of the product should be considered together with its end use to limit the risk of policy failure.

The appropriateness of different bioenergy production systems in economic, environmental and social terms will depend to a large extent on national and local circumstances. In planning a bioenergy strategy, analysis of different options and their broad impacts should be carried out to ensure that policy objectives will be met.

SOLID WOODFUELS

While the use of wood for cooking and heating is as old as civilization, the efficiency of this energy source varies according to production systems. Open fires convert only about 5 percent of wood's potential energy. Traditional wood stoves increase this efficiency to about 36 percent, and charcoal-based systems are between 44 and 80 percent efficient, depending on the furnace design and charcoal production method. The modern wood pellet stove delivers about 80 percent efficiency for residential use (Mabee and Roy, 2001; Karlsson and Gustavsson, 2003).

A number of technologies are currently in use or under development for industrial-scale bioenergy production. These include power boilers for heat recovery, combined heat and power (CHP) systems for the production of both heat and electrical power, and gasifier systems for advanced energy recovery.

Steam-turbine power boilers designed to work primarily with bark can be added to sawmills as an alternative to beehive burners or other apparatus to dispose of waste. Heat from power boilers can generate steam, which can be used for electricity generation using turbines or to meet process requirements. Recovery boilers are used in a similar way in pulp and paper mills, to recycle black liquor and recover pulping chemicals, as well as to produce steam to drive the pulping process. The efficiency of a steam-turbine power boiler is generally about 40 percent (Karlsson and Gustavsson, 2003). The historically low cost of fossil fuels has not provided sufficient incentive for installing electrical generation capacity in mills.

In CHP facilities, steam produced is used to supply other industrial processes or support district heating grids for residential, institutional or industrial facilities. The recovery of both heat and power from the process can significantly increase the efficiency of operations. When the most recent technology is used, and flue-gas recovery and recycling incorporated, efficiency can rise to between 70 and 80 percent (Karlsson and Gustavsson, 2003).

The carbon efficiency of wood-based combined heat and power systems is generally high in relation to non-renewable energy sources and most other biofuels. Spitzer and Jungmeier (2006) found that heat production from a combined cycle power plant operating on wood chips produced only 60 g CO_2 equivalent for each kilowatt of energy produced. A similar plant using natural gas produced about 427 g.

New technologies that use gasification have been reported to be much more efficient for energy recovery in terms of electricity generation than traditional combustion in a power boiler. An integrated gasification combined cycle may increase efficiencies to about 47 percent and, theoretically, to 70 or 80 percent using CHP. Significant technical hurdles remain, however.

Gasification technology has been suggested as a means to provide small-scale power delivery suitable for villages and small-scale industry. Small-scale plants represent an appropriate technology, since they are cheaper, spare parts are more easily accessible, and repairs can be carried out on site (Knoef, 2000). In Cambodia, Abe *et al*. (2007) found that although biomass gasification provided cheaper power than diesel generators, consistent supply and barriers to growing wood were key constraints. The profitability of the small-scale plants set up as commercial enterprises has also been found to be marginal, and highly dependent on both energy prices and biomass input costs (Knoef, 2000). Wu *et al.* (2002) reach similar conclusions from work done in China and suggests that medium-scale plants may be more appropriate where financial considerations are of principal importance.

Wood pellet furnaces, using the most advanced technologies for energy conservation and recovery, have become an attractive technology option. Wood pellets are originally produced from wood waste (such as sawdust and shavings), rather than whole logs, and thus can be viewed as an integrated part of forest product manufacturing. The raw material is dried, mechanically fractioned to size, and extruded under intense pressure into pellets. Modern small-scale wood pellet furnaces are the most effective tool for bioenergy production on the small-scale.

LIQUID BIOFUELS

Biofuels include a range of liquid and gaseous fuels derived from biomass. "First-generation" biofuels are derived from food-crops and include sugar- and starch-based bioethanol and oilseed based biodiesel. "Second-generation" biofuels are derived from non-food crop agricultural and forestry products and make use of the lignin, cellulose and hemicellulose components of plant matter. Technology for processing the lignin component is still under development.

Recently, high oil prices have led to increased interest in liquid biofuels. Because of their lower price and more advanced state of development, those derived from food-crops are drawing the greatest attention. It is expected that in the medium-term, future technological advances will increase the competitiveness of second-generation biofuels. Currently, many governments are looking to biofuels as a way of reducing reliance on oil imports and reducing greenhouse gas emissions. For example, the Biofuels Initiative goals of the United States Department of Energy include making cellulosic ethanol costs competitive with gasoline by 2012, and replacing 30 percent of current levels of petrol consumption with biofuels by 2030 (UNECE/FAO, 2007).

First-generation liquid biofuels

First-generation liquid biofuels are manufactured from a range of crops that are relatively specific to geographic location. In temperate regions, rapeseed, corn and other cereals are used as biofuel feedstock, whereas in tropical regions, cane sugar, palm oil, and, to a lesser degree, soybeans and cassava are used. Sugar cane is not a widespread crop within OECD countries, among which only Australia and the United States rank as major producers. Sugar beet is, however, grown in many OECD countries and although production is primarily devoted to food products, this may change in the future.

The technologies for production of ethanol from sugars and starch have been refined and developed over the years. Brazil and the United States have made particular advances in these technologies, with Brazil focusing on sugar fermentation, and the United States on starch hydrolysis and fermentation. A number of countries in Asia and the Pacific have well-developed and expanding sugar-cane production systems, notably the Philippines, India, Pakistan and Thailand. An advantage of sugar cane use is that bagasse, the cellulosic component of the sugar-cane stalk, can be used to generate energy for production of bioethanol, thus increasing overall carbon and energy efficiency.

Production of oilseed crops is globally more widespread than sugar crop production. Oilseed crops are used in the production of biodiesel through a process known as transesterification. Production of oilseed crops, however, requires optimal soil and growing conditions. This may limit increases in production or result in the conversion of forest land that is suitable for cultivation of oilseed crops.

Europe has dominated the biodiesel industry to date, generating around 90 percent of global production using rapeseed oil as the main feedstock. Malaysia and Indonesia are currently the world's largest producers of palm oil. In 2006, Malaysia had an estimated 3.6 million hectares of oil-palm planted, while Indonesia had around 4.1 million hectares (FAO, 2007c). Estimates of current areas under palm oil cultivation vary considerably, however, and some sources report much higher figures than those collected by FAO (Butler, 2007a).

The development of biofuels and the palm oil industry is particularly relevant in Asia, given the steep projected increase in energy demand in the region. There are disputes over lands being converted to oil palm, with claims being made that expansion of oil-palm plantations in Malaysia and Indonesia has often been at the expense of recently logged over forest areas, valuable rainforests or carbon-storing peat swamps. In Southeast Asia, 27 percent of oil-palm plantations are located on drained peat lands (Hooijer *et al*., 2006). The related emissions contribute significantly to global greenhouse gasses.

Recently, the use of other oilseed plants, such as *Jatropha* spp., has been explored as a feedstock for biodiesel production. *Jatropha* is a genus of more than 100 species including shrubs and trees, originating in the Caribbean and now found throughout the tropics. The seeds of *Jatropha curcas* produce oil that is increasingly used for biodiesel production, particularly in the Philippines and India. The plant is hardy, grows well on marginal lands and can also be used to restore degraded lands. These characteristics suggest that *Jatropha curcas* production, if carefully managed, may be expanded without directly competing with natural forests or high-value agriculture lands used for food production.

Second-generation liquid biofuels

Second-generation technologies under development are expected to produce economically competitive liquid biofuels that can be used for transport from cellulosic feedstocks, including both agricultural residues and wood. It is anticipated that the technology for commercially competitive conversion of cellulose to liquid biofuels will be available within ten to fifteen years (Worldwatch Institute, 2007). Demonstration scale production is already under way (see www.iogen.ca), with bioethanol being the cellulosic liquid biofuel closest to commercialization. The United States Government is currently investing in small-scale cellulosic biorefineries (US Department of Energy, 2008).

Agricultural residues are likely to be among the lowest-cost liquid biofuel feedstocks. Bagasse and residues from the production of cereals, including maize, wheat, barley, rice and rye, are among the feedstocks that can be used to generate bioethanol. However, only about 15 percent of total residue production would be available for energy generation after accounting for needs related to soil conservation, livestock feed and factors such as seasonal variation (Bowyer and Stockmann, 2001). As bioenergy production increases, agricultural residues may become more important biofuel feedstocks, and their availability could increase through improved management practices.

Residues from the forest products industry and wood from forest plantations provide other potential sources of feedstock for commercial cellulosic biofuel production. Today, only a small proportion of liquid biofuels are forest-based, but the development of an economically viable process for producing cellulosic liquid biofuels could lead to the widespread use of forest biomass in the transport sector.

Two basic technologies are being developed to convert wood to liquid fuels and chemicals: biochemical conversions and thermochemical conversion (gasification or pyrolysis). In biochemical conversion, wood is treated using enzymes to release hemicellulose and cellulose as sugars. These sugars can then be further converted to ethanol or other products. The lignin residue is also converted to other products, or used to provide heat and power for the plant's operation or for sale.

In gasification, wood and bark are heated in the minimum presence of oxygen to produce a mixture of carbon monoxide and hydrogen, which, after clean-up, is referred to as synthesis gas (syngas). Syngas may be further converted to liquid transportation fuels. Pyrolysis is the process of treating wood at a lower temperature, in the absence or minimum presence of oxygen to convert wood to char, non-condensable gases and pyrolysis oils. Pyrolysis oil may be used directly for fuel or refined into fuel and chemicals.

Currently, biochemical conversion technologies require clean wood chips (without bark), which could draw on the same wood resources as pulp mills. Thermochemical conversion, however, can use a mix of wood and bark.

An interesting prospect is that of biorefineries, which are expected to produce not only heat and power, but also transportation fuels and industrial products. Modern pulp mills, which in some cases are net producers of heat and power, can be described as prototypes of biorefineries. The vision is that pulp mills will go from being large energy consumers and producers of only pulp and paper, to being producers of pulp and paper, as well as heat, electricity, transportation fuels and speciality chemicals. There is potential for adjusting the product mix to market situations, thus optimizing the profit made from a given amount of wood (UNECE/FAO, 2007).

It is probable that second-generation processes will be more profitable when integrated into existing manufacturing facilities, such as paper mills, that produce or have access to low-cost or by-product biomass (Global Insight, 2007). Cellulosic ethanol production is likely to be limited outside the United States, Europe, and Brazil due to the limited size of the expected markets and the availability of imports.

At present, the United States is among the most advanced countries in terms of cellulosic conversion. Support there is being given for the development of integrated forest biorefineries that would be added to existing pulp mills and produce renewable bioenergy and bio-products from forest and agricultural materials (UNECE/FAO, 2007). Current efforts are in three focal areas:

- seeking cost-effective processes to separate and extract selected components from wood prior to pulping for use in producing liquid fuels and chemicals;
- using gasification technologies to convert biomass, including forest and agricultural residues and black liquor, into a synthetic gas, which is subsequently converted into liquid fuels, power, chemicals and other high-value materials;
- enhancing forest productivity, including developing fast-growing biomass plantations designed to produce economic, high-quality feedstocks for bioenergy and bio-products.

The development of technologies for production of biofuels from cellulosic sources holds great promise for the use of wood in energy production. The fact that advanced technologies will be required, however, places constraints on the global availability of systems to convert wood and other cellulosic feedstocks into liquid fuels. The Institute for Agriculture and Trade Policy has warned that patent policy and the cost of patent royalties and licensing fees will influence the adoption of biofuels (IATP, 2007). In addition to the technological and economic issues, an understanding of patent policy on biomass and biofuels production is of crucial importance in understanding how biofuel technologies might contribute to sustainable development.

Countries and private companies considering the production of second-generation liquid biofuels from cellulosic biomass face an uncertain, if potentially lucrative, future. The development of technologies for the competitive production of liquid fuels from wood will require time and significant investment in research. Considerable investment is also needed for large-scale facilities, especially for gasification. It should be noted that the high oil prices in the early 1980s resulted in a number of gasification plants for the production of methanol from wood, particularly in a number of European countries. These, however, were eventually undercut by lower oil prices (Faaij, 2003). The risks associated with investment in second-generation liquid biofuels are relatively high; therefore most developing countries will probably explore other options fully before embarking on this venture.