IEA Bioenergy

Task 38

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IEA Bioenergy
Task 38
"Greenhouse
Gas Balances
of Biomass and
Bioenergy Systems"

Second edition
compiled and edited
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Answers to ten frequently asked questions about bioenergy, carbon sinks and their role in global climate change

Photo courtesy of DOE/NREL, credit Warren Gretz

Introduction

Global climate change is a major environmental issue of current times. Evidence for global climate change is accumulating and there is a growing consensus that the most important cause is humankind's interference in the natural cycle of greenhouse gases (IPCC, 2001; Broadmeadow and Matthews, 2003). Greenhouse gases get their name from their ability to trap the sun's heat in the earth's atmosphere – the so-called greenhouse effect. Carbon dioxide (CO_2) is recognized as the most important. Since the turn of the 20th century the atmospheric concentration of greenhouse gases has been increasing rapidly, and the two main causes have been identified as:

- burning of fossil fuels;
- land-use change, particularly deforestation.

Emissions of greenhouse gases to the atmosphere during the 1990s due to burning fossil fuels have been estimated at 6.3 gigatonnes of carbon (GtC) per year. (1 GtC = 10^9 tonnes carbon.) During the same decade, the conversion of 16.1 million hectares of the world's forests to other land uses, mostly taking place in the tropics, resulted in the release of 1.6 GtC per year (FAO, 2001). Overall, the amount of carbon in the atmosphere is estimated to have increased by 3.3 GtC per year, with the remaining carbon being taken up about equally by the oceans and the terrestrial vegetation (IPCC, 2000a).

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Obvious solutions to these problems involve reduced consumption of fossil fuels and preventing and reversing deforestation. Scientists acknowledge that using more bioenergy is one possible way to reduce dependence on fossil fuels, while encouraging management of land as a carbon 'sink' is an option for reversing deforestation or for expanding forest area.

The information set out below, in the form of answers to ten frequently asked questions, aims to:

- Introduce and explain relevant fundamental concepts.
- Clarify areas of common misunderstanding.
- Outline relevant technologies and systems that may offer potential solutions.

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1. What is the difference between CO_2 emissions from bioenergy and from fossil fuels?

Bioenergy is energy derived from biomass (BIN, 2001; EERE, 2005). Biomass may be produced from purpose-grown crops or forests, or as a byproduct of forestry, sawmilling and agriculture. Biomass can be utilized directly for heat energy or converted into gas, electricity or liquid fuels.

There is a vital difference between energy production from fossil fuels and from biomass. Burning fossil fuels releases CO_2 that has been locked up for millions of years. By contrast, burning biomass simply returns to the atmosphere the CO_2 that was absorbed as the plants grew and there is no net release of CO_2 if the cycle of growth and harvest is sustained (Figure 1).

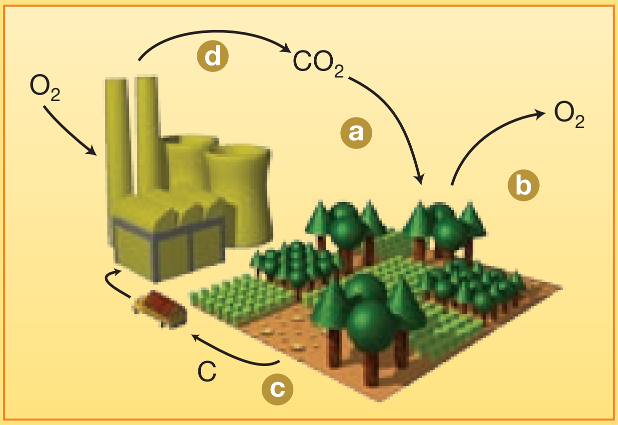

Figure 1. Illustration of the recycling of carbon as biomass accumulates in energy crops and forests and is consumed in a power station. a: CO_2 is captured by the growing crops and forests; b: oxygen (O_2) is released and carbon (C) is stored in the biomass of the plants; c: carbon in harvested biomass is transported to the power station; d: the power station burns the biomass, releasing the CO_2 captured by the plants back to the atmosphere. Considering the process cycle as a whole, there are no net CO_2 emissions from burning the biomass.

Fossil energy is usually consumed in producing bioenergy, but research shows that usually the energy used is a small fraction of the energy produced. Typical energy balances for relevant forestry and agriculture systems indicate that roughly 25 to 50 units of bioenergy are produced for every 1 unit of fossil energy consumed in production (Börjesson, 1996; Boman and Turnbull, 1997; McLaughlin and Walsh, 1998; Matthews, 2001; Elsayed et al., 2003). Producing liquid bioenergy requires more input energy, with roughly 4 to 5 units of energy produced for 1 unit of fossil energy consumed, but still reduces fossil fuel consumption overall (IEA, 1994; Gustavsson et al., 1995; Elsayed et al., 2003). (Calculation of the energy balance for liquid bioenergy production is very complicated, and of the widely varying results reported in current scientific literature, the estimates shown here represent the middle of the range and are indicative only.) Net carbon emissions from generation of a unit of electricity from bioenergy are 10 to 20 times lower than emissions from fossil fuel-based electricity generation (Boman and Turnbull, 1997; Mann and Spath, 2000; Elsayed et al., 2003).

2. How can trees and forests act as a carbon sink?

The term 'sink' is used to mean any process, activity or mechanism that removes a greenhouse gas from the atmosphere (UNFCCC, 1992). Vegetation and forests exchange large amounts of greenhouse gases with the atmosphere. Plants capture CO_2 from the atmosphere through photosynthesis, releasing oxygen and part of the CO_2 through respiration, and retaining a reservoir of carbon in organic matter. If stocks of carbon are increased by afforestation or reforestation, or carbon stocks in croplands or forest stands are increased through changes in management practices, then additional CO_2 is removed from the atmosphere. For example, if an area of arable or pasture land is converted to forest, additional CO_2 will be removed from the atmosphere and stored in the tree biomass. The carbon stock on that land increases, creating a carbon sink. However, the newly created forest is a carbon sink only while the carbon stock continues to increase. Eventually an upper limit is reached where losses through respiration, death and disturbances such as fire, storms, pests or diseases or due to harvesting and other forestry operations equal the carbon gain from photosynthesis (Matthews, 1996; Davidson and Hirsch, 2001). Harvested wood is converted into wood products and this stock of carbon will also increase (act as a sink) until the decay and destruction of old products matches the addition of new products (Questions 3 and 9). Thus a forest and the products derived from it have a finite capacity to remove CO_2 from the atmosphere, and do not act as a perpetual carbon sink (see Figures 2 and 3). By substituting for fossil fuels, however, land used for biomass and bioenergy production can potentially continue to provide emissions reductions indefinitely.

If a forest area is harvested and not replanted, or is permanently lost due to natural events like fire or disease, then the carbon reservoir that has been created is lost. In contrast, the benefits provided by bioenergy substituting for fossil fuels are irreversible, even if the bioenergy scheme only operates for a fixed period. Frequently a distinction is made concerning the so-called 'permanence' of measures based either on carbon sinks or on replacement of fossil fuel with bioenergy. This is discussed in the information box on "the permanence issue".

3. Does tree harvesting cancel out the carbon sink?

Forest stands managed for commercial production through periodic harvesting generally have lower carbon stocks than stands that are not harvested (Figures 2 and 3), but this harvesting should not be confused with deforestation. Deforestation implies a change in land cover from forest to non-forest land, whereas sustainable wood production involves cyclical harvesting and growing. A newly created forest

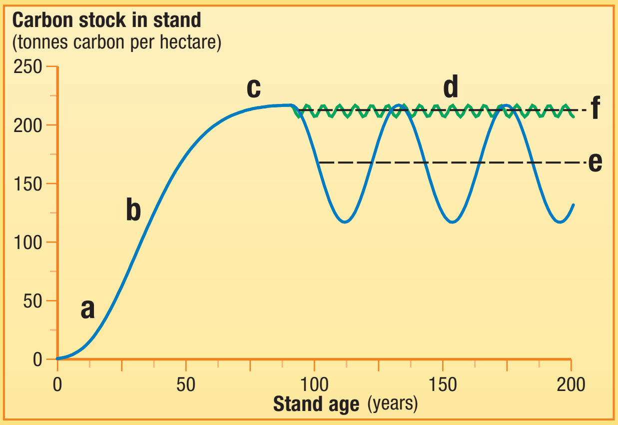

Figure 2. Carbon accumulation in a newly created stand of trees managed as a carbon sink. (A stand is a cluster of trees with similar characteristics and management history that usually makes up part of a forest. This example is based on an average stand of Sitka spruce in Britain, assumed to be planted on bare ground.) Four phases of growth or carbon accumulation can be seen: a: establishment phase; b: full-vigour phase; c: mature phase; d: long-term equilibrium phase. Looking over several decades it is evident that, following an increase in carbon stocks on the ground due to the initial establishment of the stand, carbon stocks neither increase nor decrease because accumulation of carbon in growing trees is balanced by losses due to natural disturbances and oxidization of dead wood on site. Two examples of carbon dynamics with low (dashed line – e) and high (dashed line – f) long-term equilibrium carbon stocks are illustrated. Carbon dynamics in soil, litter and coarse woody debris are ignored.

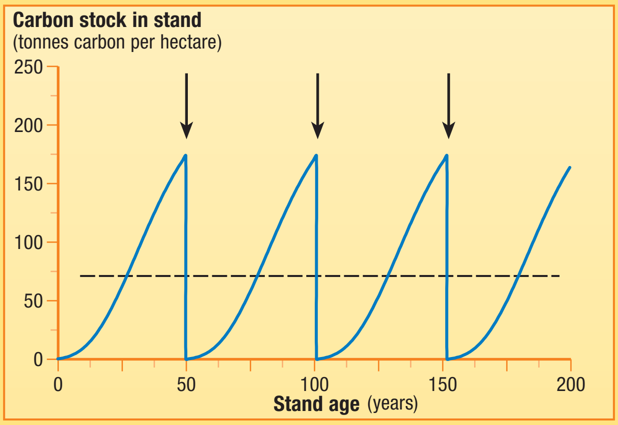

Figure 3. Carbon accumulation in a newly created commercial forest stand. Periodically the stand of trees is felled (times are indicated by vertical arrows) to provide wood products and perhaps bioenergy, and the ground is replanted with a new stand which grows in place of the old one. Looking over several rotations, it is evident that, following an increase in carbon stocks on the ground due to the initial establishment of the stand, carbon stocks neither increase nor decrease because accumulation of carbon in growing trees is balanced by removals due to harvesting of products. In practice a forest usually consists of many stands like the one in the figure, all established and harvested at different times. Averaged over a whole forest, therefore, the accumulation of carbon stocks is more likely to resemble the time-averaged projection shown as a dashed line. Carbon dynamics in soil, litter and coarse woody debris are ignored. Impacts outside the forest (wood products and bioenergy) are also excluded (see Question 3).

managed for wood production can act as a carbon sink just as surely as a newly created forest reserve, although there may be differences in the level of the ultimate carbon stock and the time horizon over which it is attained.

Wood products are themselves a carbon reservoir and can act as a carbon sink if the size of this reservoir can be increased by making use of more wood products. However, wood products may have a far more significant role to play. Because wood products are a renewable and relatively energy-efficient source of material, greenhouse gas emissions can be reduced by using wood in place of more energy-intensive materials (Figure 4). This will depend on identifying practical and technically feasible opportunities to increase the use of wood as a replacement for other materials in a range of domestic and industrial applications. For example, for some countries, research on the energy required to construct

The permanence issue

The permanence issue can be explained in a highly simplified form using the example of a factory that burns fossil fuel to meet its energy requirements, and operates for a period of 25 years. On the one hand, suppose that a new forest is created to make a carbon reservoir that will offset the total CO_2 emissions for the 25-year period. To retain this carbon sink the forested area must be maintained in perpetuity – if it is harvested or destroyed, it must be replaced. However, whatever safeguards are put in place, it is impossible to absolutely guarantee the protection of this forest against future loss due to deforestation, unplanned harvesting or natural causes such as fire or disease. The reduction in emissions achieved is therefore potentially reversible and cannot be guaranteed to be permanent. On the other hand, if the factory is converted to consumption of bioenergy instead of fossil fuels to meet its energy requirements over the same 25-year period, then the reduction in emissions from the factory over the period cannot be undone and is therefore permanent.

At the local scale, when deciding on how to manage a particular area of land to mitigate greenhouse gas emissions, the permanence issue will not always be relevant because landowners will not have equally practical options to choose between involving either bioenergy production or carbon sinks. The former option would commonly be a business decision to develop new bioenergy crops and forests to supply a bioenergy facility and permanently eliminate emissions from a certain quantity of fossil fuels. The latter option would encompass the management of new or existing forests, possibly to provide products such as sawlogs and paper as demanded in the market place, but crucially involving changes in management to permanently increase the level of carbon stocks.

Although not necessarily a consideration when deciding how to manage a specific area of land, the permanence issue has become extremely prominent in discussions and negotiations concerned with promoting and financing alternative measures aimed at reducing net greenhouse gas emissions at the national and international scale. Even in this context, non-permanence may not be an issue provided that any future losses of carbon stocks due to deforestation are registered when they occur using appropriate accounting and reporting procedures. However, the establishment of new forest areas in order to create carbon sinks could be seen as a liability to future generations. (See also Question 7.)

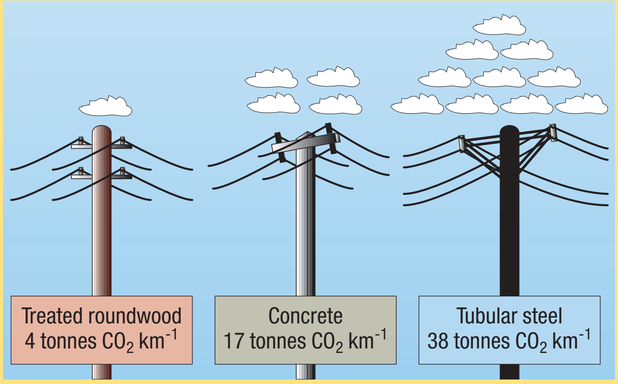

Figure 4. Illustration of potential emission reductions when substituting wood for other materials. The estimates shown are for emissions of greenhouse gases in tonnes CO$_2$-equivalent to construct one kilometre of transmission line using poles made of either treated wood, concrete or tubular steel over 60 years, and include the impact of disposal. (After Richter, 1998.)

buildings from different mixes of materials suggests that maximizing use of wood in constructing new buildings can cut emissions of greenhouse gases due to the manufacture of building materials by between 30 % and 85 % (see for example Buchanan and Honey, 1995). The heating of houses can contribute 90 % of the total greenhouse gases emitted over the lifetime of a house including its construction. Here, bioenergy for domestic heating may play a more important role. Used either as building material or fuel, the major contribution of harvested wood is through replacement of other materials or fossil fuels, rather than through the physical retention of carbon within the wood.

4. What area of land is needed to supply bioenergy to a power station?

Consider an example of a 30 MW power station using bioenergy to generate and supply electricity. (1 MW = 1 megawatt = 10^6 watts.) In Western Europe, for example, this is enough electricity for roughly 30 000 homes. The area of land that would need to be planted with dedicated bioenergy crops may be estimated at 11 250 hectares. Grown on the same land on longer rotations, forest stands achieve somewhat lower levels of productivity than energy crops. Much of the biomass produced will be used to make sawn timber, boards and paper with only a fraction of the harvested biomass – perhaps 25 % (Börjesson et al., 1997) – available directly as a supply of bioenergy. (These estimates are for wood fuel potentially generated directly on-site during harvesting. Wood fuel generated as a byproduct during sawmilling and processing can be considerable, but is not included here.) As an example, if 10 % of the biomass supplied to the power station came from forestry byproducts, and bioenergy crops were used to supply the remaining 90 %, the areas of forest and bioenergy crops may be estimated at approximately 20 000 hectares. In practice, many existing bioenergy power plants in operation produce not only electricity but also heat which can be utilized by industry or to heat buildings. This may increase overall efficiency, reducing the area of land required to deliver a certain amount of energy.

How is the area of crops calculated?

The rating of the power station is 30 MW. During the course of a year, it operates at full load for 6 000 hours. This means that the power station generates 30 x 6 000 = 180 000 MWh of electrical energy every year. If it operates with an efficiency of 40 %, then to produce 180 000 MWh of electrical energy as output every year the power station must need 180 000 / 0.4 = 450 000 MWh of bioenergy to burn as input energy. It is assumed that the biomass of the crops and forests has an energy value of approximately 4 MWh per dry tonne, after allowing for the influence of moisture content on energy value. Suppose biomass is supplied from dedicated energy crops that produce on average 10 dry tonnes of biomass per hectare per year. For this example, the area of land required would be 450 000 / (4 x 10) = 11 250 hectares. 1 hectare = 10 000 m^2.

5. What area of forest is needed to offset the CO$_2$ emissions from a power station or from running a car?

Based on the example forests illustrated in Figures 2 and 3, it would take between 3 000 and 18 000 hectares of newly established forests to take up 30 years of CO$_2$ emissions from a 30 MW fossil fuel power plant, depending on how the forests are managed. The area of forest that has been created must be managed according to the prescribed regime indefinitely, as the land is effectively committed forever to the maintenance of the reservoir of carbon that has been removed from the atmosphere. If the carbon stocks on the land are reduced

How is the area of forest calculated?

The example forest in Figure 3 sequesters a total of about 70 tonnes carbon per hectare. This can be converted to an equivalent quantity of carbon dioxide by multiplying by 44 / 12, giving 257 tonnes CO$_2$ per hectare. The example 30 MW power station would emit between 85 000 and 150 000 tonnes CO$_2$ per year, depending on the kind of fossil fuel used. Working with the lower of these two values, it would take 30 x 85 000 / 257 = 9 922 hectares of new, commercially productive forests to offset 30 years of emissions (or 17 509 ha for the higher value). Calculations based on the estimate of high long-term carbon stocks for a forest in which harvesting is avoided (about 220 tonnes carbon per hectare, Figure 2, dashed line – f) give required forest areas ranging from 3 159 to 5 576 hectares. In the examples in Figure 2 it is clear that, in fact, the full long-term carbon stocks are not attained until after 80 years. In these cases, greater forest areas would be needed if there was a requirement for the emissions to be fully offset over the same 30-year period.

for some reason, or are lost, other land must be found as a replacement. If more than 30 years of CO_2 emissions need to be offset then additional areas of forest must be created.

Note that the area of land required to supply the example power station with biomass from dedicated bioenergy crops, replacing fossil fuel indefinitely (Question 4), is comparable to estimates of productive forest land area required to remove just 30 years of atmospheric CO_2 emissions from fossil fuels.

Roughly half a hectare of trees is needed to compensate for the emissions from a car over one driver's lifetime (Cannell, 1999; Maclaren, 2000). This is a modest area of forest for an individual to create but the area of forest required would be extremely large if all of the world's car drivers tried to do this.

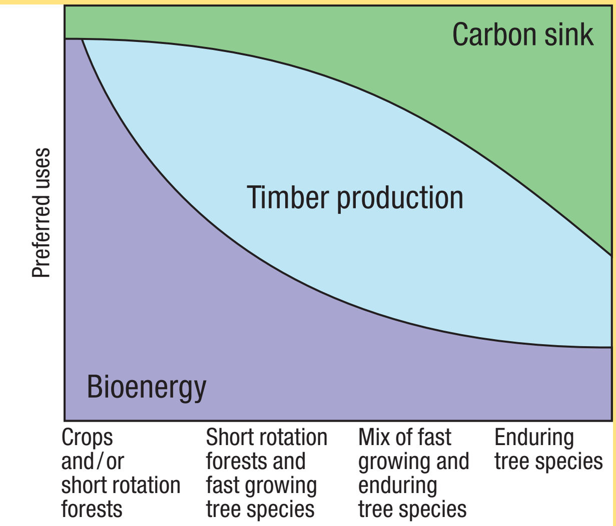

Figure 5. How choice of crops, types of tree species and management regime can be selected to achieve a mix of bioenergy production, timber production and carbon sink.

6. What types of trees and crops are best as carbon sinks or for bioenergy and wood production?

The choice of most appropriate trees or crops will be based on environmental, economic and social factors, and the objectives of a given scheme, as illustrated in Figure 5. If the aim is biomass production for energy, then maintaining high biomass productivity will be important, so biomass crops and short rotation forestry systems based on fast growing tree species will be appropriate. If the intention is to provide a mixture of pulp, wood chip and some timber from the land, then fast growing trees managed on rotations of decades will often be suitable. On the other hand, if the principal objective is to establish and maintain a long-term reserve of carbon stocks, then there is a case for maximizing the carbon stock ultimately attained and ensuring its long-term durability, rather than emphasizing rapid capture of carbon in the initial phase of the project. This will tend to favour management based on establishment of enduring tree species, perhaps involving promotion of natural regeneration and succession processes. Production of durable timber, with secondary priority given to relatively short-lived wood products, chips and pulp, will also often be achieved through management of enduring tree species, or using a combination of fast growing and enduring tree species to achieve the desired product mix.

7. Can land be managed simultaneously as a carbon sink and for bioenergy and fibre production?

Often there are opportunities for synergy between bioenergy and wood production and management for carbon sinks, particularly on a regional scale. For example, establishing a forest or crop for bioenergy on formerly cultivated or degraded land is likely to increase the carbon density above ground, while also ensuring a new biomass resource for energy and/or fibre production. Introducing alternative management in some crops and forest stands to maximize productivity may permit specified quantities of bioenergy and wood to be produced from a smaller area of land, releasing a portion of land to be managed as a forest reserve with enhanced carbon stocks.

An example of synergy is that found in an integrated production system for wood and bioenergy, in which forest stands are thinned to maximize value of wood production, and thinnings are utilized for bioenergy. Residual wood remaining after harvest and off-cut wood from sawmills and processing plants can also be utilized for bioenergy. Often, harvested wood may be used and reused in a cascade of products, ultimately being available for use as energy after it has served a useful life. A considerable share of modern bioenergy use arises from 'co-production' of wood fuel with other wood products and utilization of waste products in the forest industries. For most of the last century, wood fuel accounted for more than 50 % of the world's harvested wood (Solberg, 1996).

8. How does management of land as a carbon sink or for bioenergy production affect biodiversity and other environmental characteristics?

Changing land use can have positive or negative impacts on major environmental characteristics such as biodiversity, soil quality, landscape appearance, water availability and quality, pollution of rivers and lakes and production of toxic emissions. These are complex and site-specific issues that are beyond the scope of this leaflet, but some general observations can be made, taking the example of biodiversity.

Biodiversity increases at the ecosystem, species and genetic levels when new energy crops or forests are created on degraded land, or on intensively-managed arable land. However, forests and energy crops can only increase diversity where they replace land cover which is species-poor, while in some places their introduction may threaten valued species and habitats. Trade-offs between fuel/fibre production and carbon sinks, and maintaining biodiversity, can also occur when creating large areas of productive crops or managed forest, especially monocultures of exotic species managed on short rotations. There are management options available to address the trade-offs between production and biodiversity. These include using appropriately selected seeds or planting stock to achieve genetic diversity, and creating a patchwork of crops and multi-aged forest stands for structural diversity. Using wildlife corridors to connect fragmented habitats, altering field and felling unit sizes, minimizing chemical inputs, encouraging ground vegetation and using species and age mixtures are further examples of management options. With clear goals in terms of conservation of biodiversity, optimal compromises can be chosen between maximizing carbon sinks or biomass productivity and maintaining biodiversity.

9. How great is the potential to reduce greenhouse gas emissions by using more bioenergy and through carbon sinks in biomass?

Bioenergy in its many forms accounts for roughly 11 % of the world's consumption of primary energy, amounting to some 44 exajoules (EJ) of consumption per year. (1 EJ = 10^{18} joules.) Of this, some 6 EJ is utilized in OECD (industrialized) countries, mainly with high conversion efficiency. The remaining 38 EJ consist largely of traditional, low efficiency fuel-wood use in developing countries (IEA Statistics, 2000a, b). Increasing the contribution made by bioenergy to energy supply therefore involves improving the efficiency of existing biomass use as well as increasing the utilization of biomass. The potential global contribution of bioenergy has been estimated to be between 95 and 280 EJ in the year 2050 (Hall and Scrase, 1998), leading to a potential reduction/avoidance in emissions of between 1.4 and 4.2 GtC per year, or between roughly 5 % and 25 % of projected fossil fuel emissions for the year 2050 (IPCC, 2000b). The maximum energy that may be technically feasible to supply globally from bioenergy sources has been estimated to be in excess of 1 300 EJ (IPCC, 2000b).

The current global potential carbon sink through vegetation management has been estimated at between 60 and 87 GtC over 50 years (1.2 to 1.7 GtC per year), or 7–15 % of average fossil fuel emissions for the period 2000 to 2050 (IPCC, 1996, 2000a, b). Globally, there may be potential to promote carbon sinks in biomass over the next 50 to 100 years or more, but ultimately the scope for increasing carbon stocks in vegetation will reach its ecological or practical limits, and other measures will need to be adopted. However, in practice this potential might be achieved at the same time as realizing greater bioenergy production, with much of the future bioenergy supply probably coming from some of the newly created forests or adapted agricultural systems. The potential carbon sink in wood products is estimated to be small compared to the carbon sink in living vegetation and biomass (Winjum et al., 1998), or compared to the potential of wood products to displace fossil fuel consumption (Question 3).

How are the potential percentage emissions reductions calculated?

Estimation of percentage emissions reductions requires projections to be made of potential future CO_2 emissions from fossil fuel consumption if no action is taken. The estimates here are based on projections developed by the IPCC (2000b), focussing on scenarios which assume continued heavy dependence on fossil fuels, with minimum efforts to improve efficiency in energy consumption or to increase use of renewable energy sources. The relevant projections indicate global CO_2 emissions in the range 15 to 25 GtC in the year 2050. For example, taking an estimated emission reduction of 4.2 GtC and a projection of 25 GtC gives $100 \times 4.2/25 = 16.8\,\%$.

10. Is the technology available now for bioenergy to play a role in reducing atmospheric CO_2?

The burning of biomass as a direct source of heat and light must rank among the first of humankind's technological achievements, and it is remarkable that biomass fuel, utilized using modern technologies, may now offer one answer to the present climate change problem. Heat and power have been produced commercially from biomass residues for decades especially in the forest industry, but also for example in the sugar cane processing industry. The same basic combustion technology is still the main method for generating power from solid fossil fuels or biomass. New technologies, such as Integrated Gasification Combined Cycle and gasification combustion engine systems, are being developed to improve power production efficiency from biomass. Fast pyrolysis of biomass producing a liquid biofuel is at the pilot stage and the possibility of adapting oil burners, diesel engines and gas turbines to use this liquid fuel is being studied.

Liquid fuels produced from sugar cane, corn and rapeseed are also used on an industrial scale to replace conventional transportation fuels. The use of ethanol as a vehicle fuel is already significant in some countries such as Brazil and is increasing in the USA and European Union.

Residential district heat supply from woody biomass is now established in some countries, notably Sweden, Finland and Austria, and there is growing interest in countries such as Canada and the United Kingdom. There may also be potential to provide local sources of electricity or gas from biomass by using small-scale gasification plants or low-technology systems involving fermentation of biomass.

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IEA Bioenergy
Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD & D) programs. IEA Bioenergy aims to realize the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA Bioenergy Task 38 integrates, analyses and disseminates information on greenhouse gases (GHGs), bioenergy, agriculture and forestry from national programs of all participating countries. Emphasis is placed on the development of state-of-the-art methodologies for assessing GHG balances; demonstrating the application of established methods; supporting decision-makers in implementing effective GHG mitigation strategies. One approach employed by the Task involves the use of case studies to analyse the GHG balance of a range of bioenergy and carbon sequestration systems.

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