Cooling the greenhouse with bioenergy

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Global warming caused by burning fossil fuels could be reduced by the use of biomass for energy. This strategy could be more effective than sequestering carbon by growing more trees.

MOST proposals for reducing global warming have focused on the need to plant more trees in forest reserves, the idea being that carbon dioxide absorption would continue until the trees mature, say for 40–100 years. Although it is recognized that this is not a permanent solution, this 'carbon sequestration' strategy buys time to develop alternative energy sources. Little attention has been paid to another approach to combat global warming, that of substitution of energy derived from biomass for fossil-fuel energy[1]. If biomass is grown for energy, with the amount grown equal to that burned for a given period, there would be no net build-up of carbon dioxide in the atmosphere because the amount released in combustion would be compensated for by that absorbed by the biomass during photosynthesis. The potential for reducing carbon dioxide emissions in this way depends on the fuel displaced and on the efficiency with which energy can be produced.

Suppose that the conversion efficiencies are equal. Then a gigajoule (GJ) of biomass substituted for coal would reduce emissions by the carbon content of 1 GJ of coal, about 0.025 tonnes of carbon (tC). Because biomass, with a heating value of 20 GJ per tonne, is 50% carbon, growing 1 GJ of biomass sequesters 0.025 tC. Thus, substituting biomass for coal would be equivalent to carbon sequestration in its effect on atmospheric CO_2. Substituting biomass for petroleum or natural gas would be less effective than carbon sequestration, as these fuels contain less carbon per GJ. Although efficiencies for biomass with commercially available conversion technologies are typically less than for fossil fuels, development of energy-conversion technologies should improve this situation.

Modernization

Although little research and development has been committed to 'modernizing' biomass, there have been serious efforts to 'modernize' coal; much of this technology could be transferred to biomass strategies. The most promising near-term option involves adapting to biomass simplified integrated gasifier/combined-cycle (IGCC) technology (using gas turbines in combined cycles) being developed for power generation with coal[2]. This technology makes it possible to achieve, at the modest scales needed for biomass power generation, efficiencies higher than those for large coal steam-electric power plants. Biomass versions of this technology should involve lower unit capital cost, allowing it to compete with coal steam-electric power in many circumstances[3,4]. Biomass versions of simplified IGCC technology could be commercialized more quickly than the corresponding coal versions, because the latter require techniques for sulphur removal that are not yet commercially tested, whereas biomass contains negligible sulphur.

Although they are not competitive at today's low oil prices, synthetic fuels need to be developed to avoid overdependence on oil imports when prices rise once more. The technology for making methanol from biomass is similar to that being developed for coal, as are the conversion efficiencies. Methanol derived via thermochemical processes from biomass, as well as ethanol derived via enzymatic hydrolysis of lignocellulosic feedstocks, could be competitive with gasoline by the year 2000, if the necessary technologies are developed[5–7].

Although harvesting, transport and processing requirements make biomass for energy much more costly than growing trees to sequester carbon, energy sales revenues can be taken as a credit against cost. Because the prospects are good that biomass-derived electricity and liquid fuels can be produced competitively, the net cost of offsetting CO_2 emissions by substituting biomass energy for fossil fuels could often be near zero or even negative, and thus lower than the cost of offsetting CO_2 emissions by sequestering carbon in trees[1].

Biomass can play a larger role in reducing global warming when used to displace fossil fuel than when used for sequestration, in part because land can be used indefinitely in displacing fossil CO_2 emissions, whereas CO_2 removal ceases at forest maturity in the 'sequestration' strategy. Also, when biomass is produced for energy markets, producers will seek to maximize the harvestable annual yield rather than the total amount of carbon that can be sequestered in a mature forest. This goal shift will lead them to choose short-rotation woody or herbaceous crops, for which annual yields are 2–3 times as large as for long-rotation species[8–10]. Futhermore, herbaceous crops can often be grown at relatively high productivity on crop and pasture lands where the soil and climate conditions are not particularly favourable for growing trees.

Finally, when biomass is used as a fossil-fuel substitute, the land that can be used for biomass production is not restricted to new areas of land for planting 'energy' crops. Agricultural and forest residues that can be economically recovered and low-quality wood resources from existing forests, for example, are potential sources of biomass energy.

In many temperate-zone forests, annual removals of trees are much less than annual growth. Although much of the unharvested stock is too low in quality for traditional forest-products markets, it is well-suited for energy applications, and removal of the low-quality woodstock can simultaneously lead to enhanced yields of high-quality wood[11]. This increased productivity of high-quality wood in regrowth forests can help ease pressures to exploit original-growth forests, thereby allaying environmental concerns. In practice, the relative contributions to biomass energy — supply of residues, increased production from existing forests and plantation energy crops — will be determined by economics, availability of water and land resources, and constraints posed by environmental concerns.

Potential

The alternative global CO_2 emission projections advanced by the response strategies working group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC)[12] provide a useful context in which to assess the potential for offsetting fossil CO_2 emissions with biomass energy. Global CO_2 emissions could be reduced to half the 1985 level by 2050 by supplementing the response measures of the RSWG "Scenario B" (involving a reversal of deforestation and emphasis of efficient energy use and natural gas) with biomass energy production sufficient to displace by 2050 5.4 Gt per year of carbon from fossil-fuel combustion[1]. This might plausibly be achieved by displacing coal with biomass — about one-third of which might come from various agricultural and industrial biomass residues and two-thirds from biomass plantations. Such residues are prime candidates for the first bioenergy systems. The required amount of plantation biomass might be achieved with 600 million hectares of plantations at an average productivity of 12 dry tonnes per ha per year.

This productivity is consistent with what has been achieved only at modest scales. But considering that the era of modern scientific silviculture began only around 1970[8], and that the growing of herbaceous crops for energy purposes is even more embryonic, this average productivity might plausibly be achieved on a large scale by the middle of the next century. For comparison, average productivities of wheat in the United Kingdom and maize in the United States have more than tripled since the mid-1940s; at present maize yields from 24 million hectares in the United States average 7.5 tonnes per ha per year of grain plus an equal quantity of residues[1]. The annual yield of sugar cane, averaged over 17 million hectares of cane harvested globally in 1987, was about 35 dry tonnes per ha per year of total above-ground harvestable plant matter. Moreover, the targeted productivity corresponds to a 0.4% efficiency for converting solar energy into recoverable biomass energy, which is low compared to the practical maximum photosynthetic efficiency under field conditions (5%)[13] and what has been attained under optimal field conditions (2.4% for Napier grass).

The land area targeted for biomass energy crops in 2050 is large, equivalent to 15 and 40% of the amount of land now in forests and croplands, respectively. Yet estimates of the amount of tropical land potentially available for reforestation are of the order of 800 million hectares[14]. Moreover, some of the 1,500 million hectares of tropical grasslands in the world could be used for energy crops such as perennial grasses; at present half this area is burned off each year[15]. Considerable land might also be available for energy crops in industrialized countries. In Europe, 15 million hectares of cropland or more would be taken out of production if agricultural surpluses and European Community expenditures on agricultural subsidies were bought under control[9]. In the United States, 30 million hectares of cropland are left idle to reduce production or conserve land; this area could double over the next 25 years. Such considerations suggest that the productivities and land areas associated with this biomass energy scheme are plausible, though ambitious.

The chief uncertainty about the development of biomass for large-scale energy production is whether high productivities can be achieved sustainably over wide areas without damaging the environment. One concern of environmentalists is that biomass energy will reduce biological diversity[16]. Certainly, if monoculture biomass plantations were to replace old-growth natural forests there would be substantial loss of biodiversity. But plantations could be established on deforested or degraded lands, and short-rotation tree crops and various perennial grasses would be an improvement on annual row-crop agriculture.

Experiments in Sweden have shown that in most forests trees grow at rates far below their potential and that nutrient availability is often the most important limiting factor. Under nutrient-optimized conditions all tree species investigated have achieved about the same total biomass yield per unit of light intercepted during the growing season[17]. Thus, growing trees under nutrient-optimized conditions could make it possible to achieve high yields with existing species and clones, facilitating the incorporation of pest resistance and other desirable characteristics, and the maintenance of a diverse landscape mosaic. Nutrient-induced yield increases can be achieved without nutrient leaching when good forest management is practiced. But achieving sustainable high yields this way requires matching nutrient applications to the varying need for nutrients[17,18].

At present, monocultures are favoured for energy crops, in large part because management techniques are being adapted from monocultural systems for agriculture. Achieving sustainable production and maintaining biological diversity may require polycultural strategies (for example, mixed species with various planting configurations and harvesting methods) for biomass production in many areas.

The nutrient status of afforested lands might be maintained both by recycling nutrients and by choosing suitable mixed species and clones[19]. The promise of the latter is suggested by 10-year trials in Hawaii, where yields of 25 dry tonnes per ha per year have been achieved without nitrogen fertilizer when *Eucalyptus* is interplanted with nitrogen-fixing *Albizia* trees[20].

Achieving high levels of biological diversity requires maintaining some land in a natural condition. Experience in Sweden suggests that maintaining a modest fraction of forest area in reserves is adequate for this purpose. But research is needed to find out how best to achieve desirable levels of biological diversity under the wide range of conditions where biomass might be grown for energy.

Conclusions

In conclusion, the growing of biomass for energy provided by modern energy-conversion systems would enable biomass to play much wider roles in coping with greenhouse warming than is possible with the growing of trees solely for carbon sequestration. Although carbon-sequestering strategies will be important where the biomass cannot be practically harvested for energy, or where the creation of new forest reserves is deemed desirable for environmental or economic reasons, biomass energy strategies will usually be preferred. Moreover, as biomass energy should often be cheaper than fossil-fuel energy, these strategies will be easier to implement than many other proposed strategies for reducing greenhouse warming.

Bioenergy industries have already been launched in several countries. Nevertheless the techniques and technologies for growing biomass and converting it into modern energy carriers must be more fully developed. If the research and development needed on sustainable production and conversion of biomass is given high priority, and if policies are adopted to nurture the development of bioenergy industries, these industries will be able to innovate and diversity as they grow and mature. □

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