

## CHAPTER 2 -- CARBON SEQUESTRATION THROUGH BIOMASS ENERGY

United States agriculture could sequester of large amounts of carbon in another way - by producing corn and other sources of biomass that would serve as a source of energy. Biomass would be carbon-neutral because it would sequester carbon while the plant matter was growing and then would release approximately the same amount of carbon as the biomass was converted into energy. The combined effect of the original sequestration and the subsequent release of carbon would approximate a zero net release of carbon into the atmosphere. Compared to the large net releases of carbon in the burning of conventional fossil fuels, conversion to use of biomass as an energy source would offer a large overall reduction in the net amounts of carbon dioxide (CO<sub>2</sub>) released into the atmosphere per unit of energy.

The ability of biomass resources to meet the energy needs of the United States is still being investigated. Private companies, mostly lumber mills and paper companies, using their wood waste products, are already using biomass to generate energy. Estimates of energy capacity generated from biomass range from 7000 to 10,000 MW. Increased competition in the energy industry and technological advances in biomass power generation are likely to increase the potential amounts of energy from biomass. If these increases in biomass capacity replace some of the energy supplied by fossil fuels, CO<sub>2</sub> emissions can be avoided. Fossil fuels emit 1,634 MMTCE every year (DOE, 1997). Generating power from biomass, rather than fossil fuels, will help the United States meet the Kyoto reduction requirement of 577 MMTC per year.

Biomass must prove economically viable before companies will begin their own projects. Establishing comparative prices is difficult because costs rely heavily on site-specific factors such as energy demand, the availability of suitable biomass, and proximity of the power plant to the biomass source. Current estimates of cost range from \$1.95 - \$3.50 per million British thermal Unit (Btu) (Moore, 1996) to \$0.05 - \$0.08 per kilowatt-hour (kWh) for heat and \$0.08 - \$0.15 per kWh for electricity (IEA). The price and competitiveness of biomass energy could be affected by subsidies, working both for and against it, and other price mechanisms designed to charge energy users for their emissions. Federal legislation—the Public Utilities Regulatory Policy Act (PURPA)—mandates renewable energy purchases among electric utilities. Another federal law, the Energy Policy Act, grants income tax credits of 1.5 cents / kWh for renewable energy generation and 10% for businesses with solar and geothermal technology equipment. Renewable energy subsidies fall short of conventional energy subsidies, but the gap is closing. In 1989, total subsidies for energy were \$38 billion, with 58% allocated to fossil fuels and two percent to renewable energy. In 1992, energy subsidies were \$9 billion (\$1995), with 23% allocated to electricity, 22% to natural gas, 14% to coal, 12% to oil, 11% to nuclear, eight percent to conservation, six percent to ethanol, and five percent to other renewables (Sissine, 1996).

Biomass crops grown for energy have many environmental benefits as well as drawbacks. Biomass energy generation requires large amounts of land for growing crops to supply adequate amounts of fuel. According to the DOE, a 150 MW advanced biomass power station would require energy crops grown on 100 square miles or 25,000 hectares of land. Therefore, 50,000 MW would require 33,000 square miles or over 8,300,000 hectares of land—approximately one percent of the total land area of the United States (Patterson, 1994). Intensive agricultural

practices could also result in decreased diversity and soil degradation which could lead to heavy chemical use, further degrading the soil quality. Using conservation techniques when growing energy crops, though, would stabilize agricultural soils, protecting them from erosive forces and contributing to the organic matter content in the soil. Energy crops will also help improve water quality by slowing runoff of soils (and chemicals) into nearby water sources and by filtering the water that percolates through the ground.

Taking account of all these factors, biomass appears a promising means of sequestering large amounts of carbon at a cost less than energy reduction or energy substitution. Indeed, production of biomass is today gaining more attention as an energy option.

### **I. A Brief History Of Biomass**

Biomass is already being used to a limited extent but where it is being applied it is not for purposes of carbon sequestration. Indeed, biomass was the first energy source. Humans burned wood to heat homes and cook food. Many developing countries still depend on biomass to supply most of the energy needed for heating and cooking. As industrialized civilization advanced, humanity moved from using renewable biomass to non-renewable fossil fuels. Both biomass and fossil fuels, such as coal, oil, and natural gas, are pools of stored carbon. But fossil fuels are considered non-renewable because of the time required to regenerate their supply. Patterson illustrates this energy potential well, commenting, “If you leave appropriate biomass for a few million years under suitable temperatures and pressures, it becomes coal” (Patterson, 1994).

Worldwide, biomass accounts for 15% of the energy supply. But, biomass is much more significant as a power supply in developing nations than in industrial nations. Biomass supplies 70-90% of the energy needs of Africa; in China, 32% (BRIC, 1999); in Brazil, 33% (Patterson, 1994). In contrast, the United States gets only four percent of its energy from biomass (BRIC, 1999). But, in the United States technology could increase the feasibility and efficiency of growing biomass as an energy crop and converting biomass to a more carbon neutral energy supply.

The United States currently has the ability to produce 10,000 MW of generating capacity with the wood and agricultural waste that is already available. If the production of energy crops on unused farmland were added to the existing supply of biomass, the potential may exceed 50,000 MW of generating capacity in the 2-3 decades (Moore, 1996). This would avert the release of 90 MMTC from the burning of conventional fossil fuels. Such a reduction of carbon emissions would equal 8 percent of the total current annual additions to world carbon dioxide from the United States (Moore, 1996).

Biomass comes from organic material, mainly plants. Plants, through photosynthesis, take up carbon. The plants convert carbon dioxide into organic carbon, which provides plants with the energy to grow. The more they grow, the more carbon dioxide they absorb. When the plant dies, bacteria and fungi decompose the plant, converting the organic carbon back into its inorganic form—carbon dioxide. If the plant material can be harvested before it falls to the ground or dies, then the carbon remains stored in the plant material. This stored carbon has energy potential, available for human use. Once the plants are harvested, biomass can be converted to energy by burning the dried plant material

directly (or turning it into a gas) to generate electricity or heat. Additionally, biomass can be converted into a gas or a liquid fuel for powering automobiles or other types of engines (see Figure 2.1).

Energy crops that could be grown specifically for use in bioenergy processes include alfalfa, wheat, corn, sugar cane, soybeans, grasses, and short-rotation woody crops (SRWC)—which are fast growing trees like willow and poplar. It is possible to use plants from the water, along with the plants from the land, as energy sources. Algae—like land plants—sequester carbon through photosynthesis. Algae can be found in the ocean or in freshwater lakes, ponds, and streams. Algae also can be grown, or “farmed,” in man-made ponds.

## **II. Agricultural Sources Of Biomass**

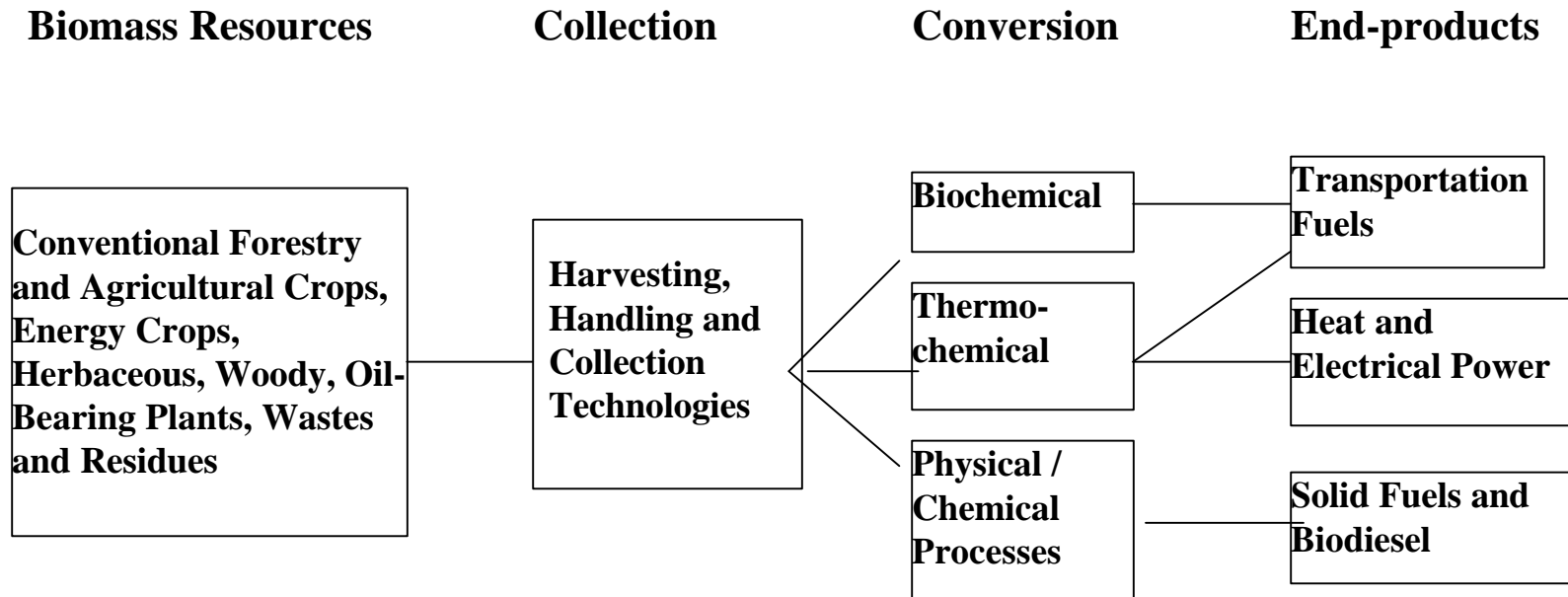
More research has been focused on biomass as a fossil fuel substitution technique than as a carbon management or sink technique, but biomass techniques have great potential for increasing the carbon sequestration both in the United States and internationally. Idle cropland or surplus agricultural land can be planted with biomass energy crops, creating a new sink not only in the growing plant material but in the soil as well. Agricultural residues, left behind through conservation tillage practices, also can be gathered and used as a biomass fuel source. Even if only five percent of the above-ground residues were used (about 25 MMT residues or 10 MMTC), 1,093 MMT of (above and below) ground residues (437 MMTC) would remain available for soil C-sequestration (Lal, 1998).

Currently there are about 14 million hectares—about 15% of the total cropland in the United States—of idle, surplus, or fallow agricultural land in the United States (Moore, EPRI). Much of this land is purposely not planted by farmers, who are paid by the federal government not to plant. Some of this land is classified as highly erodible or environmentally sensitive and gets protected under the Conservation Reserve Program (CRP). According to the Office of Technology Assessment, in the Potential Environmental Impacts of Bioenergy Crop Production, the United States spends about \$10 billion per year on these farming subsidies. Rather than encouraging farmers not to produce, these subsidies could be used to encourage farmers to plant energy crops.

Currently, agricultural residues from crops and animal dung tend to dominate the supply of biomass energy stock, along with forestry residues like woodchips and sawdust. Other residues come from industries producing timber, food, and fiber (Patterson, 1994). Municipal solid waste and industrial waste provide another source for fuel. A third source is the dedicated energy crops. These include the perennial grasses, such as switchgrass, miscanthus, alfalfa, and reed canary grass; the short rotation woody crops, such as willow, poplar, black locust, silver maple, and eucalyptus; the sugar crops, such as sugar cane, sugar beet, and sweet sorghum; the starchy crops, such as corn; and the oil crops, such as soybeans, rape seed, sunflower, and palms (see Lal 1998; Patterson, 1994).

Dedicated energy crops are selected for particular attributes—namely maximum energy yield—depending on where the land is located (DOE, 1997). The amount of energy contained in plants depends on the species of wood or plant and the amount of moisture in the plant. The water

Figure 2.1 Uses of Biomass



\*source: IEA Bioenergy Website

causes the “energy density” of the fresh plant to be very low compared to other fuels, or to dried wood, and makes transporting the crop heavier and more difficult. So biomass is dried to create a product that has a higher energy content for its weight. Oven-dried biomass contains roughly 19 GJ (gigajoules) per ton. For comparison, bituminous steam coal has an energy density of 26 GJ per ton.

### **III. Uses Of Biomass For Energy Generation**

Energy can be generated from biomass in a number of different ways. Most simply is direct burning of biomass, which creates steam for a steam turbine generator. The United States already utilizes this technology and currently generates 6.5 GW (gigawatts or million kilowatts) from agricultural and forestry residues and two GW from urban refuses. This method of energy production can be inefficient because of relatively high costs and the relatively small size of the plants and their power output (Patterson, 1994).

Biomass also can be ‘co-fired’ with coal. This is a process where, because of the similarities between biomass and coal biomass can be burned in coal-fired plants already in operation, with only minimal modifications (Patterson, 1994). This is beneficial for existing coal plants in that mixing coal with biomass will help reduce the sulfur emissions resulting from coal-fired plants and help meet sulfur emission reduction levels. A ‘co-fired’ plant also reduces the risks, namely crop failure, for biomass power plants. By creating a plant that can use coal as an alternative, power can still be supplied while working out the problems with a biomass system. Once the system runs smoothly, the plant can move to using solely biomass as fuel (Patterson, 1994).

A promising area for energy generation from biomass is gasification—the production of a gas from the biomass that can be used in generating fuel for diesel engines and gas turbines, among others. Roughly 80% of biomass is ‘volatiles’ or the gases and vapor (that can be used as fuel) released when biomass is heated to 500-600 degrees Celsius. The remaining 20% can be combined with oxygen to form carbon monoxide and with water vapor to form hydrogen, both of which are combustible (Patterson, 1994). These gases can then be used to fuel gas turbines to generate electricity. The high energy heat waste or exhaust from the gas turbine can also be used to power a steam turbine, in a ‘combined cycle’ making the process more efficient (Patterson, 1994).

Another power generating technique for biomass is pyrolysis – the creation of biocrude, a liquid fuel. By heating the biomass and limiting the oxygen, very little oxidation occurs. As the biomass breaks down, it produces vapor products that exist in a liquid state at room temperature. The advantage of this technique is that the fuel can be produced at any time of the year, stored, and transported (Patterson, 1994).

There are several biomass energy projects using some of these energy conversion techniques already underway in the United States, the European Union, Scandinavia, and Brazil (Table 2.1). In the United States, the DOE has teamed with universities, power companies, and private groups to fund programs in Vermont, Minnesota, New York State, and Iowa. Projects are already underway in Hawaii and in California.

In Burlington, Vermont, DOE and USDA teamed up for the Vermont Biogas Gasifier Project. A part of the McNeil Generating Station at the Burlington Electric Department, the 50MW wood-fired gasifier converts 200 tons of biomass per day. The wood chips are heated to form a clean gas, which is burned in a boiler. Minnesota's AgriPower Project formed a cooperative of

**Table 2.1 Biomass Energy Projects**

Burlington, Vermont	Gasifier – McNeil Station, Burlington Electric Department
Minnesota	AgriPower Gasifier – alfalfa growers cooperative
New York State	The Salix Consortium – cofiring with willow
Iowa	Chariton Valley – cofiring with switchgrass
Maui, Hawaii	Biomass Gasifier – Hawaii Commercial and Sugar Company
Brazil	CHESF
Vaernamo, Sweden	Bioflow Ltd

alfalfa farmers to collect alfalfa, separate the leaves from the stems and sell the leaves as feedstock and the stems as biomass energy. The project has planned for a biomass gasifier to be built nearby that will generate 75 MW of electricity.

In New York State, the Salix Consortium is growing willow and developing it as a commercial energy crop. Power companies will co-fire the willow with coal in their stations, using about 10-20% biomass. In southern Iowa, the DOE has teamed with Chariton Valley Resource Conservation and Development, Inc., to study the use of switchgrass as an energy crop. The switchgrass will be co-fired with coal at the Alliant Power Company's generating station to produce 35 MW of power, five percent of the plant's total capacity (DOE, 1999).

Hawaii has a gasifier in operation that operates on wood and sugar cane bagasse. Located on Maui at the Paia Mill of the Hawaii Commercial and Sugar Company, the project was a joint effort by the DOE and the Pacific International Center for High Technology Research (PICHTR) to further study on a energy process technology design called Renugas (Patterson, p. 45). In Anderson, California, Wheelabrator Shasta Energy operates a 50 MW plant. The plant uses logging residues, tree chips, and mill wastes as biomass energy sources.

Electricity use in 1990 was 11,600 TWh (terawatt hours or billion kilowatt-hours) and is expected to increase to 23,000 TWh in 2020 (Patterson, 1994). Biomass will be able to account for only a small portion of that demand, but some carbon dioxide emissions will still be averted. A target of 50,000 MW of biomass power represents only seven percent of energy use in 1990. If this much biomass power were displacing conventional coal-fired energy, it would eliminate about 90 million tons of carbon emissions per year (Patterson, 1994).

In 1992, the annual fuel uses for on-farm activities were 1.6 billion gallons of gasoline, 3.1 billion gallons of diesel, and 0.6 billion gallons of LP gas (Lal et al., 1998). More of these fossil fuels could be replaced with renewable fuels. About five percent of the country's corn crop is currently converted into about a billion gallons a year of ethanol, used as an additive to make gasoline cleaner burning. Each gallon of biofuel produced could save roughly 0.5 gallons of oil (Lal et al., 1998).

Converting idle cropland to the production of biofuels could contribute significantly to carbon sequestration and "fossil carbon offset." Lal et al. provide current estimates of the energy savings generated by replacing fossil fuels with biofuels. Growing short-rotation woody crops on 10 Mha of land, and assuming a net carbon assimilation rate of five tons/hectare/year, 10 Mha will assimilate 50 MMTC/yr. The energy substitution factor from fossil fuel to biofuel is usually 0.7. Thus the net carbon saving from replacing fossil fuels with biofuels may equal 35 MMTC/yr.  $(10 \text{ Mha}) \times (5 \text{ t/ha/yr}) \times (0.7) = 35 \text{ MMTC/yr}$  (Lal et al., 1998). Additionally, the conversion of idle land to cropland results in the soil sequestering 4 MMTC/yr.

#### **IV. Economic Feasibility Of Biomass**

Growing dedicated energy crops for biomass power can be cost-effective, especially when combined with the byproducts or residues from crops. But biomass crops can also require relatively high levels of management. If the crops require too much nitrogen fertilization, this will increase the cost significantly. The estimated cost of biomass fuel is \$1.50-3.00/GJ, while the current electricity prices are \$14/GJ (Patterson, 1994).

Location of the power plants should be near the sources for energy crops to avoid incurring excessive transportation fees. This condition is important because of the low energy density of biomass, especially when it hasn't been dried. Price mechanisms are used to penalize energy sources for emissions and should be an incentive for the buyer to purchase low-carbon or renewable sources of energy. But the estimates vary so widely, from \$20 per ton to \$320 per ton, that it is difficult to know what incentives would be required to stimulate wider use of biomass energy.

Energy from biomass will also face tough competition in the future, due to the relatively low prices of coal, oil, and natural gas (Table 2.2). By keeping resource costs low, biomass sectors may be able to stay competitive. For a 50,000 MW plant that uses 20 million hectares of crops, assuming a yield of 12 dry tons per hectare, the cost is comparable to the upper range of the recent natural gas prices (Moore, 1996).

With a 50,000 MW plant, a new agriculture market would be created worth \$12 billion per year in U.S. farm sector income (Moore, 1996). Using cropland for biomass is potentially management-intensive. Cost of fertilizers, irrigation, and labor may be high, or at least enough to reduce competitiveness with other energy sources.

Today's actual cost of producing biomass fuels from dedicated crops is estimated to be between \$1.95 and \$3.50 per million Btu. In comparison, natural gas currently costs electric utilities \$1.25 to \$2.25 per million Btu, and coal, \$0.90 to \$1.35 (Table 2.3) (Moore, 1996). However, if the

value of carbon reductions is factored into the calculations, the cost of biomass energy may be less than natural gas or coal.

**Table 2.2 Fuel Prices**

<b>Fuel Source</b>	<b>1996 Price</b>	<b>2010 Price (adjusted to 1996 \$)</b>
Crude Oil	\$20.48 a barrel	\$20.81 a barrel
Natural Gas (wellhead price)	\$2.24 per thousand cubic ft	\$2.31 per thousand cubic ft
Coal (minemouth price)	\$18.50 per ton	\$15.05 per ton
Electricity	6.9 cents per kilowatt hour	5.9 cents per kilowatt hour

\*source: Jay Hakes, Administrator, EIA, Statement to House 2/4/98

**Table 2.3 Fuel Production Costs**

<b>Fuel</b>	<b>Cost to Produce (per million Btu)</b>
Coal	\$0.90 to \$1.35
Natural Gas	\$1.25 to \$2.25
Biomass	\$1.95 to \$3.50

\*source: (Moore, 1996)

The capital costs for biomass power plants are as follows: Investment costs of \$1,500/kW over five plants and \$1,300/kW over ten plants. The total investment in ten plants would be \$500-700 million. The total electricity generating capacity of the United States in 1990 was 690,000 MW.

Another estimate prices biomass energy at 10.1 cents/ kWh. If new technologies are implemented, the price falls to 8.4 cents / kWh. If CO<sub>2</sub> capture and disposal methods are employed, the price falls to 8.0 cents/kWh. This price is just slightly above the cost of electricity, according to EIA, of 6.9 cents (\$1996) per kWh (Table 2.2) (EIA, 1999).

## **V. Further Benefits Of Biomass Sources Of Energy**

Biomass has low emissions of nitrogen oxide and sulfur dioxide. According to the EPA, the burning of agricultural residue releases 0.2 MMTCE of methane—approximately 0.1% of U.S. methane emissions for 1996 (EPA, 1998, p. ES-13) and 0.1 MMTCE of nitrogen oxide (ES-9).

Growing energy crops also puts idle lands and idle farmers back into production and creates jobs in these rural communities. Here in the United States and in other industrial nations, notably Great Britain, the government pays farmers to leave land idle so that food prices will not fall below the level to sustain farming. Because the power plants likely would be built near the fields where the energy crops grow, the biomass system would provide additional jobs for the people in rural or depressed areas in the construction and operation of the facility. The facility may generate an energy surplus, which the community can then sell or use itself.

Biomass may also be a promising energy source for developing nations as well. They already have the raw materials at hand, the available land on which to plant additional energy crops, and the labor to work the crops. Funding and new technology to generate electricity from biomass will enable these developing countries to provide jobs while preserving a local culture, increase their power supply, and possibly generate a surplus of electricity which they can sell as a commodity.

Developing countries also need a technology transfer to improve soil quality and production. As examined below in Part II, the Clean Development Mechanism established under the Kyoto Protocol is an important potential source of capital and technology for biomass projects in developing countries.

Biomass from residue has the advantage of using waste products to generate energy, helping to alleviate a growing problem of waste disposal, without adding an enormous cost. Not only is this economically efficient, but it creates a market for waste and could provide a source of income for communities.

## **VI. Environmental Problems With Biomass**

Biomass, if not managed properly, can have its drawbacks. It can promote monoculture by encouraging one particularly successful crop for energy generation and result in a lack of biodiversity in a region. If the property is not managed well, it can contribute to soil degradation and may lead to the overuse of chemicals. Should a crop fail, prospects for energy generation will fall dramatically.

Biomass crops are also largely site-specific and depend heavily on growing conditions and transportation needs. Whether a project is located at high or low latitude will dictate how much sun they have, how intense the sun is, and how seasonal the temperatures are in the region. Rainfall and other water supply issues will also impact the project's crops. These conditions will control the pace of growth, affecting the crop's biomass content. According to Patterson, conifers will produce five to six oven-dried tons per hectare per year (odt/ha/y); willow will provide 10 odt/ha/y; poplar, 12 odt/ha/y; and eucalyptus, 10-15 odt/ha/y. Harvesting and storage issues also depend on seasons and weather. "The fuelling regime must plan an appropriate schedule for harvesting, to optimize both the growth obtained and the amount of fuel that must be stored for a period lasting at least months" (Patterson, 1994).

Biomass also requires a good deal of land to produce energy crops. In some developing countries, this is a resource that could be easily utilized. In industrialized countries, the availability of land is an issue. According to U.S. DOE, a 150 MW advanced biomass power station would require energy crops grown on 100 square miles or 25,000 hectares of land. Therefore, 50,000 MW would require 33,000 square miles or over 8,300,000 hectares of land—approximately one percent of the total land area of the United States (Patterson, 1994). But there is still underproductive land that could be put to use.

According to the Office of Technology Assessment in the Potential Environmental Impacts of Bioenergy Crop Production, the substitution of energy crops for conventional row crops, if properly managed, will generally improve soil quality, reduce soil erosion and runoff, reduce the use of agricultural chemicals (fertilizers, pesticides, herbicides, fungicides), improve local air quality, and improve wildlife habitat (p. 23).

## **VII. Marine Biomass**

One possible way to increase the carbon sequestration potential of the ocean is to fertilize the surface waters with iron. The growth rate and amount of algae may depend upon iron. In general, the abundance and productivity of phytoplankton in the ocean depends a great deal on nutrients—especially nitrogen, phosphorous, and iron. Nitrogen is released by decaying organic matter and taken up by plants. Less is known about the role of iron in the ecosystem, but iron is often rate-limiting for nitrogen-fixation in the oceans (DOE, 1999, p. 6-11). According to a recent DOE report, applying 500 kg of iron to 72 km<sup>2</sup> in the equatorial Pacific resulted in a thirty-fold increase in phytoplankton biomass, a dramatic shift in species composition and elevated carbon fixation rates (p. 3-11).

Some private organizations are studying this technique to increase fish harvest. Two projects currently exploring the fertilization option are Ocean Farming, Inc., which is trying to increase the yield of tuna in the Marshall Islands and MARICULT, a European government and industry partnership which wants to increase the fish harvest in the coastal zone (p. 3-10). Such projects can include carbon sequestration as a benefit of their investments. The major problem facing such a venture as Iron Fertilization is the uncertainty of the consequences – both short-term and long-term. Research on iron fertilization is sparse, and the ecological impacts—the community and the food web structure, species diversity, and water quality—are unknown (p. 3-11). In addition, humankind’s knowledge of the ocean and the life within it, especially the deep sea, is very limited.

Algae can also be “farmed”—grown in man-made ponds—using aquaculture techniques, although little research has been done in this area. Algae are also being examined as sources of nutrients and for alternative biomass uses such as a potential energy crop—namely “biodiesel.”

Just as in the terrestrial environment, photosynthetic processes in oceans and ponds absorb carbon dioxide from the atmosphere. The phytoplankton—microscopic marine plants—fix CO<sub>2</sub> through photosynthesis. The zooplankton—microscopic marine animals—consumes the phytoplankton, and then fish and other organisms consume the zooplankton. As these organisms die or excrete waste, the organic carbon sinks to the ocean bottom where bacteria remineralize the detritus

into CO<sub>2</sub>. This is referred to as the “biological pump” (DOE, 1997 p. 3-3). Two other ocean cycles, the “solubility pump” and the “carbonate pump” also work to absorb CO<sub>2</sub>. The solubility pump is a result of thermal variation, while the carbonate pump refers to the secretion and deposition of calcium carbonate (DOE, 1997, p. 19), the building block of the reefs. Coral reefs in fact do double duty, as they have symbiotic algae living within the coral animal.

Algae can be grown in manufactured ponds just about anywhere there is open land and plenty of sunlight (the southwest United States and Africa, for example), and it can be grown in fresh or salt water (DOE, 1999, p.6-4). In Africa, man-made ponds have already proven the ability to sustain algae “farms.” Alga is a simple organism and can be manipulated genetically to produce desired attributes (DOE, 1999, p.6-5). As with other genetically manipulated species, care must be taken not to mix these manufactured pond algae with natural species, or to introduce them into the wild.

Algal biomass can contribute to carbon sequestration not only by substituting for fossil fuels in energy production, but by increasing the amount of carbon it absorbs (see Table 2.5). According to a recent report from DOE,

The capacity of some blue-green algae to thrive essentially as monocultures in waters of high alkalinity creates the possibility of much more effective CO<sub>2</sub> sequestration than would be possible with other photosynthetic systems. The chemical hydration rate of CO<sub>2</sub> increases with pH, as does the amount of inorganic carbon that can be dissolved in aqueous solution. Alkaline ponds have the potential to trap virtually all of the smokestack CO<sub>2</sub> emissions as well as the major pollutant gases SO<sub>2</sub> and NO<sub>x</sub>. Accumulation of biomass can be optimized by pH manipulations that suppress the biomass-consuming activities of respiring organisms (DOE, 1999, p. 6-6 and 6-7).

The role of the oceans in the global carbon cycle is not yet well understood, but it is estimated that 2.2 GtC/year is currently sequestered by the oceans (p. 1-4) and that the ocean stores 40,000 GtC. The estimated annual exchange between the oceans and the atmosphere is 85 GtC (DOE, 1997).

**Table 2.4 Biomass Strategies**

<b>Method</b>	<b>Carbon Sequestration Potential (MMTCE/year)</b>
Agricultural energy crops	136-218

Iron Fertilization	
Martin	545-817
Spencer	272
NAS	490-817
Algae Farming	
DOE	27

## **VII. Conclusion**

In searching for ways to reduce greenhouse gas emissions and move towards meeting the emissions reduction requirements, the United States should seriously examine the option of using biomass as a renewable energy supply to increase carbon sequestration and to offset fossil fuel burning. Biomass energy technology is already in use, although much improvement in efficiency and competitiveness is needed. The research and development is ongoing but deserves increased attention and funding as a viable option, not only for controlling greenhouse gas emissions, but for future sustainable energy generation as well.

Broad, extensive research is needed in all areas of biomass energy, including algae farms, as well as marine science research in ocean carbon cycles and iron fertilization. An emphasis should be placed on environmental and natural resource protection to ensure that current natural sinks are intact. Enhancing the health of the natural sinks is extremely important, especially in the marine environment. Coral reefs have been the focus of study for a long time, but particular attention might be paid to their role for climate change.

The federal government should encourage private citizens to utilize these opportunities for carbon sinks through incentives. Private corporations should also be encouraged to participate in research and development through regulatory and financial incentives. Possibilities for additional research include:

1) Enhancing the methods used to obtain energy from biomass. Most biomass power now in use *burns* biomass. Research into the gasification of biomass might make the energy supply more efficient and cost-effective.

2) Studying the value of those energy crops that are most useful for biomass energy generation, as well as those that are most cost-effective.

3) Iron fertilization of oceans—how much can we increase the sequestration potential? How does this action affect the ecosystem?

4) Growing algae in artificial ponds—How much land will it require? How cost-effective is it compared to energy crops or food crops?

## REFERENCES

- Biomass Resource Information Clearinghouse. Retrieved on April 14, 1999 from [www.rredc.nrel.gov/biomass](http://www.rredc.nrel.gov/biomass).
- Crookshank, Steven L. (1999) Carbon Sinks and the Kyoto Protocol. American Petroleum Institute. Discussion Paper #091. Policy Analysis and Strategic Planning Department.
- Dovring, Folke. (1988) Farming for Fuel: The Political Economy of Energy Sources in the United States. New York: Praeger Publishers.
- Energy Information Administration. Retrieved on 29 March 1999 from [www.eia.doe.gov](http://www.eia.doe.gov).
- Hakes, Jay. (1998) "Statement of Jay Hakes, Administrator, Energy Information Administration, Department of Energy before the Committee on Science, United States House of Representatives, February 4, 1998."
- Howes, Mick. (1995) Farmers, Forests, and Fuel: Towards a new biomass energy strategy for Sri Lanka. London: Intermediate Technology Publications.
- Lal, R., J.M. Kimble, R.F. Follett, C.V. Cole (1998) The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Chelsea, MI: Ann Arbor Press.
- MacPherson, George. (1995) Home-grown Energy from Short-rotation Coppice. Ipswich, UK: Farming Press.
- Miller, Alan S., Irving M. Mintzer, and Sara H. Hoagland. (1986) Growing Power: Bioenergy for Development and Industry. World Resources Institute.
- Moore, Taylor. (1996) "Harvesting the Benefits of Biomass." Electric Power Research Institute website. Retrieved from [www.epri.com/EPRI\\_Journal/may\\_june96/biomass.html](http://www.epri.com/EPRI_Journal/may_june96/biomass.html).
- National Renewable Energy Laboratory (July 1994) Biofuels: Project Summaries. Produced for the Department of Energy by NREL, Golden, Colorado.
- Patterson, Walt. (1994) Power from Plants: The Global Implications of New Technologies for Electricity form Biomass. The Royal Institute of International Affairs, Energy and Environment Programme. London: Earthscan Publications Ltd.
- Sissine, Fred J. (1996) "Renewable Energy: A New National Outlook?" Science Policy Research Division, Crest – Center for Renewable Energy and Sustainable Technology. Retrieved from [www.crest.org/pub](http://www.crest.org/pub).
- Sourie, J.-C. and L. Killen, eds. (1986) Biomass: Recent Economic Studies. London: Elsevier Applied Science Publishers.

- Smith, W. Ramsay. (1982) Energy from Forest Biomass. New York: Academic Press.
- Swezey, Blair G., and Yih-huei Wan. () “The True Cost of Renewables: An Analytic Response to the Coal Industry’s Attack on Renewable Energy.” National Renewable Energy Lab, Golden CO. Retrieved from [www.nrel.gov/research/ceaa/pubs/ceed/ceed.html](http://www.nrel.gov/research/ceaa/pubs/ceed/ceed.html).
- U.S. Congress. Office of Technology Assessment (Sept. 1993) “Potential Environmental Impacts of Bioenergy Crop Production – Background Paper.” (OTA-BP-E-118). Washington, D.C.: U.S. Government Printing Office.
- U.S. Department of Energy. Office of Energy Research. (1997) “Carbon Management: Assessment of Fundamental Research Needs.”
- U.S. Department of Energy. Office of Science. Office of Fossil Energy. (1999) “Carbon Sequestration: State of the Science.”
- U.S. Department of Energy. Retrieved on 7 March 1999 from [www.doe.gov](http://www.doe.gov).
- U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation (2122) (1998) “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996.” Document # EPA 236-R-98-006

### **Other Sources**

- Biopower Program website. ([www.eren.doe.gov/biopower](http://www.eren.doe.gov/biopower))
- Efficiency and Renewable Energy Network website ([www.eren.doe.gov](http://www.eren.doe.gov))
- Electric Power Research Institute website ([www.epri.com](http://www.epri.com))
- National Renewable Energy Laboratory website ([www.nrel.gov](http://www.nrel.gov))