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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Environmental Emissions and Socioeconomic Considerations in the Production, Storage, and Transportation of Biomass Energy Feedstocks

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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ABSTRACT

An analysis was conducted to identify major sources and approximate levels of emissions to land, air, and water, that may result, in the year 2010, from supplying biofuel conversion facilities with energy crops. Land, fuel, and chemicals are all used in the establishment, maintenance, harvest, handling and transport of energy crops. The operations involved create soil erosion and compaction, particulate releases, air emissions from fuel use and chemical applications, and runoff or leachate. The analysis considered five different energy facility locations (each in a different major crop growing region) and three classes of energy crops -- woody crops, perennial herbaceous grasses, and an annual herbaceous crop (sorghum). All projections had to be based on reasonable assumptions regarding probable species used, type of land used, equipment requirements, chemical input requirements, and transportation fuel types. Emissions were summarized by location and class of energy crop. Soil loss resulting from wind and water erosion was the largest output, in tons of material, for all crop types at all locations. Relationship of soil losses to allowable loss rates was not determined. Fossil-fuel CO_2 was the second largest emission in absolute terms. Fossil fuel CO_2 emissions from production operations were lowest (per unit of biomass energy produced) for the crops and locations with the highest yield per acre. Handling and transportation emissions were lowest at the location where the average transportation distance was shortest. Soil carbon sequestration would offset fossil-fuel CO_2 emissions for periods of 45 to 65 years at four of the five locations. Biogenic emissions of volatile organic compounds (VOCs) were identified as a possibly significant emission of woody crops and unknown for perennial grasses. This study did not compare emissions from energy crops to those that would likely occur under alternative 2010 land use scenarios. However, the study did determine that significant amounts of land currently used for rowcrops, pasture, closecrops, and hayland would likely be converted to perennial grasses and woody crops. If such land uses represent likely 2010 alternatives, it can be surmized that changes on a landscape basis in soil loss, chemical use, and fossil-fuel emissions associated with energy crop production are likely to be small and may be beneficial. This report provides the first comprehensive summary of the types and possible levels of emissions that may be associated with the feedstock production component of biofuel commercialization. Further analysis is needed to evaluate the positive and negative environmental impacts of these emissions.

1. INTRODUCTION

The U.S. Department of Energy (DOE) is considering technologies that would supplement transportation fuel supplies with renewable fuels (primarily ethanol) derived from biomass feedstocks. These biomass feedstocks include forest residues, forest mill wastes, municipal solid wastes, and, most important, dedicated woody and herbaceous energy crops. The development of dedicated energy crops for conversion into liquid fuels has the potential to expand greatly the supply of alternative transport fuels. The use of domestically produced and renewably grown fuels can reduce U.S. vulnerability to foreign oil disruptions and price shocks and improve global environmental conditions by sequestering carbon, if they displace fossil fuels.

The growing of large amounts of dedicated energy crops will involve the conversion of vast acreage of the U.S. land base, including idle cropland. Among the questions that need to be addressed in developing these alternative biofuels are what kinds of energy crops can be grown in large quantities, what regions of the U.S. will be most suited for large-scale production, what will be the economic and regional impacts on agriculture and industry, and what will be the environmental emissions from large-scale biomass production.

In this initial effort the focus is on quantifying the direct environmental effects associated with the production and transport of energy crops feedstocks to hypothetical conversion facilities. Specific environmental effects that are addressed include criteria pollutants regulated by the Clean Air Act, greenhouse gases, and other effects associated with land and water. The study also qualitatively addresses effects associated with land conversion and biodiversity as well as socioeconomic issues, such as employment and health and safety.

This study evaluates and tabulates the emissions associated with growing, harvesting, and transporting energy crops based on assumptions developed by experienced energy crop researchers. The study does not attempt to compare the emissions with other possible land uses or to evaluate the impact of those emissions. That will likely be the subject of future analysis.

The analysis considers five major crop growing regions and all three classes of energy crops -- woody crops, annual herbaceous crops, and perennial herbaceous grasses. The analysis is performed for the year 2010 -- the year in which ethanol via dedicated energy crops is expected to be commercially viable. By that time the efforts from biomass selection and breeding research programs will have produced species that are both high in productivity and have increased tolerance and resistance to environmental stresses. These advances will reduce factor input requirements. It is also likely that conservation and no-till site preparation procedures will be sufficiently developed such that high survival and high crop productivity are not compromised. Reduced tillage will lower soil erosion in the early years of energy crop establishment.

Many of the assumptions on location and transportation modes and fuels were developed in conjunction with analysts at the National Renewable Energy Laboratory and Pacific Northwest Laboratory who are performing parallel analysis on biofuel conversion technologies. The format of many of the tables generated was determined by the effort to coordinate on a total fuel analysis of environmental emissions associated with alternative transportation fuel options. This study on the energy crop production component is intended, however, to stand on its own to be used for consideration of possible impacts of large scale energy crop production in different regions of the country.

2. BOUNDARY ASSUMPTIONS

2.1 REGIONS AND FEEDSTOCKS

All feedstocks evaluated in this analysis are assumed to be produced specifically for an ethanol conversion facility. Woody feedstocks from conventional forest resources are not considered and thus the environmental concerns associated with harvesting conventional forest resources are not considered. The focus for this portion of the analysis is to evaluate the environmental effects of producing and transporting sufficient energy crops to supply an ethanol conversion facility in 2010. This study is not a market penetration study but arbitrarily selects five locations for evaluation. This approach allows analysis of site-specific differences in production and transportation emissions.

The major crop production regions represented in this study include the Northeast, Southeast, Midwest, Great Plains and the Pacific Northwest (Fig. 1). Selection of a specific location within each region was based on a combination of factors that included: availability of research data on crop production, preliminary assumptions about crop production potential, and the availability of large quantities of land.[1] There was an attempt to select locations that would be representative of major regions as a whole such as the locations selected for the Southeast, Midwest/Lake States and the Great Plains. The Tifton, Georgia, location in the southeast is near the middle of the coastal plains and is a major crop production area. The Peoria, Illinois, location is near the center of the corn belt and also near cropland that would be categorized as "marginal" cropland. Within the Great Plains which extends from the Dakota's to Texas, the Lincoln, Nebraska, location was felt to be a midway location that also had good crop growth potential. Besides selecting locations to represent regions, there was an interest in selecting locations that would provide alternatives to trucking for hauling feedstocks. The locations selected for the Northeast and the Pacific Northwest met those criteria. The Portland location in the Pacific Northwest is near the midpoint of the only area (a long corridor) that would be suitable for growing energy crops without using irrigation, and also offers the opportunity to evaluate environmental effects of transporting crops by rail. The Rochester location chosen in the Northeast allows the opportunity to evaluate transporting crops by barge and was also believed to be a location where land would be suitable and available for energy crop production.

In considering the logistics of producing energy crops, there are numerous factors and points of view to consider. From the conversion facility viewpoint, assured supplies, cost and quality are high priority concerns. From a farmer's standpoint, markets, relative prices and net returns per acre are the major concerns. A complete analysis of the environmental effects of energy crop production would address both viewpoints and would include extensive economic analysis and evaluation of landowner decision making processes. Inevitably the decisions on types of land used and the crops supplied will depend on economic rather than technical decisions. However, we do not know what the future prices of farm commodities and how U.S. agricultural policy will change, and without this information evaluation of farmers' decisions is impossible. Economic sensitivity analysis to evaluate different possible scenarios was beyond the scope of this

[1]The selection of these specific locations should not be construed as a recommendation.

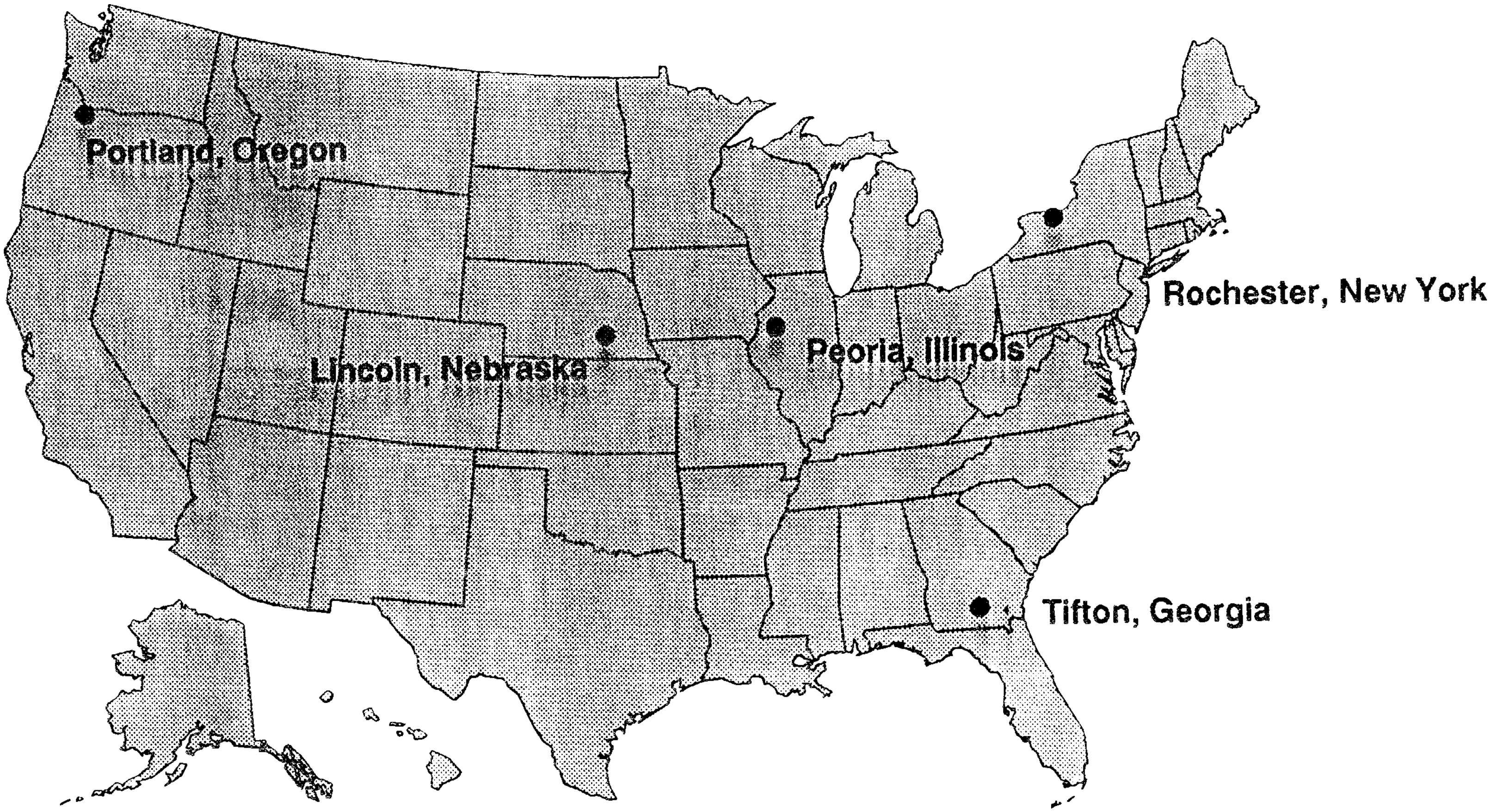

Fig. 1. Biomass-ethanol fuel cycle feedstock production locations

present study. Thus decisions on crops produced and land uses displaced were made based on the technical judgements of the writers of this report and on systematic evaluations of current land uses.

The emphasis of this report was to build scenarios that would assure a continuous year-round supply of biomass feedstocks to a conversion facility. Cost of production was not directly factored into our decisions but was indirectly incorporated into some of our baseline assumptions. For instance, crops that can produce high yields per unit of land were assumed to be preferable because available land may be limited and ability to grow the needed crops within a short distance of the conversion facility helps reduce costs, especially transportation costs. Also, land of a quality believed to be too low to produce economically viable yields was excluded from the potentially available landbase. These critical assumptions represent the current consensus of the authors of this report (who have managed energy crop research for 10 years or more) and many energy crop researchers who have conducted field trials for 5 to 20 years.

Supply, management and risk considerations lead to decisions to mix feedstock types for most locations. From the facility viewpoint a year-round supply of a uniform feedstock would be advantageous. Although some crops, such as trees, can be harvested year-round, that is not the most desirable or cost-effective management strategy for trees. Storage of grasses over an 8-12 month period is also not desirable. Warm-season perennial grasses grown in the South probably have the widest harvest window ranging from June to October. Cool-season perennial grasses can extend the herbaceous supplies from late spring to late fall. Crops such as sorghum will only be suitable for harvest in late summer or early fall. A mix of energy crop feedstocks is being assumed for several reasons. Higher overall yields can be obtained by matching crops to site characteristics. Storage losses can be minimized and labor resources more evenly utilized by producing crops with different optimal harvest windows. Risks of crop losses from pests, diseases or climate can be minimized by having a variety of feedstocks. Inclusion of two or more tree species that can be intermixed, will increase crop biodiversity and wildlife habitat.

All assumptions on feedstocks and land used are based on a current climate scenario since databases with land use designations have not been developed for future climate scenarios. It would be interesting to project how our current assumptions might change with future climate changes, however, such an analysis was entirely beyond the scope of this present study.

For this study, the chosen biomass feedstocks represent likely energy crops that would be grown for a biomass to ethanol industry. These selected feedstocks are not necessarily the optimal combination of feedstocks or represent the entire range of possible energy crops for each region. However, all three classes of cellulosic crops are represented -- woody crops, thick-stemmed perennial and annual herbaceous grasses, and thin-stemmed perennial herbaceous grasses. In all likelihood energy crops will displace some agricultural crops (e.g., corn, wheat, soybeans), hayland, pasture, and idle land under the conservation reserve and set-aside programs. This assumption is based on the observation that the vast majority of the U.S. land base that is suitable for biomass cultivation is largely cropland, pasture, or range land. Existing well-stocked forest land should not be required for producing energy crops. However, land categorized as "forest land" but with less than 55% wood canopy covered is included as land potentially available for conversion to energy crops. The amount of this type land likely to be used is expected to be small.

For the Rochester, New York, location hybrid poplar is assumed to be the principal wood crop with willow and the nitrogen fixing black locust accounting for smaller proportions. Inclusion of grasses in the Rochester energy crop mix was found to be necessary because of a lack of nearby land capability classes that could support high productivity tree production (at least five dry tons per acre each year). The Peoria, Illinois, and Tifton, Georgia, locations are assumed to produce both woody and herbaceous feedstocks. The tree crops at the Peoria location are assumed to be a combination of hybrid poplar, silver maple, and black locust. Perennial grasses (switchgrass and reed canarygrass) are assumed to account for about half of energy crop production. The annual, sorghum, is also assumed to be in the feedstock blend at Peoria. For the Tifton location, the feedstock blend is a combination of trees (sweetgum, sycamore, and black locust), switchgrass, and energy cane, a tropical grass. In Lincoln, the feedstock is assumed to be 100% perennial grasses -- a combination of a warm season grass (switchgrass) and cool season grasses (e.g., wheatgrass). The Pacific Northwest region is assumed to grow only woody feedstocks (hybrid cottonwood and red alder). Table 1 summarizes the blend of energy crop feedstocks for each production location.

In all locations, the wood feedstocks are assumed to be harvested between the months of November and March and delivered to the conversion facility in the beginning months of the year. Dormant season harvesting of trees will lead to better coppice regrowth and leave more nutrients on the site than would non-dormant season harvesting. The herbaceous perennial grasses (cool season grasses, warm season grasses, and tropical grasses) and the herbaceous annual crop (sorghum) are assumed to be harvested from mid-summer and through the Fall. With this harvesting schedule tree crops are supplied to the conversion facility in the beginning of the year and the herbaceous crops from mid-summer to the end of the year. In the Lincoln and Portland locations, where there is only one major crop type, longer biomass storage is assumed.

2.2 ENERGY CROP PRODUCTION OPERATIONS

Production operations for crop establishment, cultural management, and harvesting and storage will vary among the three broad classes of cellulosic energy crops (woody crops, perennial herbaceous crops, and annual herbaceous crops). However, it is assumed that production operations will be approximately the same across all locations for each major crop and soil type. This is not a realistic assumption because site-specific characteristics, such as soil type, vegetative cover, and nutrient content of the soil among others, must be known before site-specific management regimes can be established.[2] Even with similar input assumptions, emissions will vary by location because of differences in assumed biomass productivities and the mix of energy crops grown.

[2] Even if the variability in management inputs were included, it would not be expected to result in large differences between locations. In fact, one could expect more variability among specific sites within a general location than between locations.

Table 1. Biomass production regions, locations, feedstocks, and blends

Region/location	Feedstock blend
Northeast Rochester, New York	Trees - 32% Hybrid Poplar (60%) Willow (20%) Black Locust (20%) Perennial Herbaceous Crops - 68% Switchgrass (50%) Reed Canarygrass (50%)
Southeast Tifton, Georgia	Trees - 46% Sweetgum (50%) Sycamore (40%) Black Locust (10%) Perennial Herbaceous Crops - 54% Switchgrass (100%) Energy Cane - 10%
Midwest/Lake States Peoria, Illinois	Trees - 32% Hybrid Polar (50%) Silver Maple (30%) Black Locust (20%) Herbaceous Crops - 52% Switchgrass (75%) Reed Canarygrass (25%) Annual Herbaceous Crops - 16% Sorghum - (100%)
Great Plains Lincoln, Nebraska	Grasses - 100% Switchgrass (60%) Wheatgrass (40%)
Pacific Northwest Portland, Oregon	Trees - 100% Hybrid Cottonwood (80%) Red Alder (20%)

By selecting and breeding desirable traits and hybridizing and propagating exceptional plant material energy crop productivity is expected to increase considerably in the near future. Moreover, breeding superior crops is also expected to reduce management requirements; faster growth will reduce the frequency of weed control and greater tolerance to stresses will reduce the need for pest control. Conservation and no-till site preparation procedures are also assumed to be sufficiently developed by 2010 such that high survival and high crop productivity are not compromised. Reduced tillage will lower soil erosion in the early years of tree crop establishment and lower erosion and chemical losses associated with annual crops.

The major assumptions regarding the establishment, management, and harvesting of each major class of energy crops are highlighted below. These assumptions reflect a probable management regime for each crop in the year 2010. For example, reduced tillage and pesticide use relative to current practice is assumed. Specifically, the 2010 scenario assumes in herbicides and pesticides, compared with current practice and use, and complete residue retention. Fertilization requirements may diminish in the future, but this is not explicitly accounted for in this analysis. Factor input assumptions regarding equipment fuel use and power requirements for various operations and chemical inputs that are discussed below are summarized in Table 2 and 3. Tables 4 through 9 provide a summary of the factor input requirements for each major crop.

2.2.1 Woody Crops

Successful establishment of short rotation woody crops under current methods usually requires an application of a contact herbicide and plowing in the fall, followed by disking in the spring, the planting of cuttings, and application of pre-emergent herbicides in the spring. This sequence of activities strips the soil of ground cover and may lead to substantial erosion on hilly sites in the first two years of the life of the plantation. Under future technology (year 2010) it is likely that trees will be successfully established under an alternative regime that not only provides the necessary conditions for success but also maintains maximum ground cover. Some results of recent field studies recommend a site preparation procedure that includes strip herbicide spray (broad-kill) to define tree rows and chisel plowing or subsoiling on the defined rows (Bongarten, 1991). Fertilizers (phosphate and potash) are then spread followed by the planting of the trees. A selectively applied preemergent herbicide is then applied around the trees to control weeds. Weed control between rows is accomplished with mowings and an application of a broad-kill herbicide during the middle of the growing season. Mowing and an application of a broad-kill herbicide should be sufficient to control weeds in the second year of growth following establishment.[3] After two years of growth, canopy closure should occur eliminating the need for additional weed control. No weed control or herbicides are used during coppice rotations. Following establishment, the management of a woody crop should not be intensive, requiring only biennial nitrogen fertilizer applications and, perhaps, one application of fungicides and insecticides during each rotation. It is assumed that tree crops will grow for three rotations (of six years each) before replanting is required.

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[3]Fast growing eucalyptus plantations in Brazil only receive herbicide applications at the time of planting. This practice may become possible in the U.S. with the selection of superior clones or seed sources of trees.

Table 2. Equipment fuel use and power requirements

Implement	Field capacity	Fuel use	Power requirements
Subsoiler	3.0 ac/hr	1.4 gals/ac	19.1 hp-hrs/ac
Chisel plow	5.2 ac/hr	0.8 gals/ac	11.5 hp-hrs/ac
Mower	6.5 ac/hr	0.6 gals/ac	9.2 hp-hrs/ac
Sprayer	11.1 ac/hr	0.4 gals/ac	5.4 hp-hrs/ac
Spreader	14.6 ac/hr	0.3 gals/ac	4.1 hp-hrs/ac
Planter (trees)	1.5 ac/hr	2.8 gals/ac	39.8 hp-hrs/ac
Drill (grasses)	5.9 ac/hr	0.7 gals/ac	10.1 hp-hrs/ac
Planter (sorghum)	6.2 ac/hr	0.7 gals/ac	9.6 hp-hrs/ac
Tree harvesting	2.0 tons/hr	1.9 gals/ton	29.9 hp-hrs/ton
Perennial harvesting (grasses)	1.9 tons/hr	2.0 gals/ton	31.4 hp-hrs/ton
Forage harvesting (sorghum and energy cane)	3.3 tons/hr	1.1 gals/ton	18.1 hp-hrs/ton

Notes: Field capacities are derived from Dobbins et al. (1990) and Blankenhorn et al., (1985). Fuel use is based on an average of the Nebraska Tractor Tests (varying power and fuel consumption) for a standard enclosed cab 100 bhp diesel tractor. Fuel use is 3.7 gal/hr (12.60 hp-hrs/gal and 54% loading). A charge of 10% was included to reflect the movement of equipment and materials to the field. A charge of 2% was also added to total fuel use to account for lubricants (Liljedahl et al., 1984). Power requirements were based on a fuel efficiency assumption of 0.44 lbs/bhp-hr with diesel fuel having a density of 7.08 lbs/gal.

Table 3. Average annual chemical inputs for energy crop production by crop type

Crop Type	Fertilizers			Pesticides	
	lbs/acre				
	N	P_2O_5	K_2O	Herbicides	Insecticides/ Fungicides
Populus Spp., Sweetgum, Sycamore, Silver Maple	45.0	13.3	13.33	0.22	0.01
Black Locust, Red Alder	0	13.3	13.33	0.22	0.45
Switchgrass, Wheatgrass	81.0	60.0	60.0	0.14	0.03
Reed Canarygrass	126.0	60.0	90.0	0.10	0.03
Energy Cane	139.5	50.0	80.0	0.16	0.04
Sorghum	130.0	70.0	90.0	1.6	0.4

Notes: Pesticide amounts are in pounds of active ingredient. Inputs are averaged over the life of the crop.

Table 4. Factor input requirements for tree crop production-
***Populus* Spp., Sweetgum, Sycamore, Silver Maple, and Willow**

Activity	Material	Amount
Crop Establishment (year 1)		
Strip herbicide spray	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Mow	Diesel	0.6 gals/acre
Subsoil on strips	Diesel	1.4 gals/acre
Phosphorous and potassium spread	P_2O_5 K_2O Diesel	80 lbs/acre 80 lbs/acre 0.3 gals/acre
Plant	Diesel	2.8 gals/acre
Herbicide spray	Preemergent Diesel	1.0 lbs/acre 0.4 gals/acre
Mow (mid-year)	Diesel	0.6 gals/acre
Herbicide spray (mid-year)	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Crop maintenance (years 2 - 18)		
Nitrogen spread (biennial applications)	N Diesel	90 lbs/acre 0.3 gals/acre
Phosphorous and potassium spread (one application during each rotation)	P_2O_5 K_2O Diesel	80 lbs/acre 80 lbs/acre 0.3 gals/acre
Insecticide/fungicide spray (one application during each rotation)	Pesticide Diesel	0.05 lbs/acre 0.4 gals/acre
Mow (in year 2 only)	Diesel	0.6 gals/acre
Herbicide spray (in year 2 only)	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Harvesting operations (years 6, 12, and 18)		
Harvesting and handling	Diesel	1.9 gals/ton

Notes: N is half urea and half ammonium nitrate. Pesticide amounts are given in terms of active ingredient. Amounts are derived from Ranney and Mann (1991) and reflect reduced tillage. Herbicide amounts are based on a total use of 4.0 lbs/acre over 18 years or 1.0 lbs/acre for each of the four sprayings. Insecticide and fungicide amounts are based on a total (18 year) plantation life application of 0.16 lbs/acre or 0.05 lbs/acre for each 6 year rotation. Harvesting includes cutting, crushing, baling, moving/loading, and unloading.

Table 5. Factor input requirements for tree crop production -- Black Locust and Red Alder

Activity	Material	Amount
Crop Establishment (year 1)		
Strip herbicide spray	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Mow	Diesel	0.6 gals/acre
Subsoil on strips	Diesel	1.4 gals/acre
Phosphorous and potassium spread	P_2O_5 K_2O Diesel	80 lbs/acre 80 lbs/acre 0.3 gals/acre
Plant	Diesel	2.8 gals/acre
Herbicide spray	Preemergent Diesel	1.0 lbs/acre 0.4 gals/acre
Mow (mid-year)	Diesel	0.6 gals/acre
Herbicide spray (mid-year)	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Crop maintenance (years 2 - 18)		
Phosphorous and potassium spread (one application during each rotation)	P_2O_5 K_2O Diesel	80 lbs/acre 80 lbs/acre 0.3 gals/acre
Insecticide/fungicide spray (one application during each rotation)	Pesticide Diesel	2.7 lbs/acre 0.4 gals/acre
Mow (in year 2 only)	Diesel	0.6 gals/acre
Herbicide spray (in year 2 only)	Broad-kill Diesel	1.0 lbs/acre 0.4 gals/acre
Harvesting operations (years 6, 12, and 18)		
Harvesting and handling	Diesel	1.9 gals/ton

Notes: Pesticide amounts are given in terms of active ingredient. Amounts are derived from Ranney and Mann (1991) and reflect reduced tillage. Herbicide amounts are based on a total use of 4.0 lbs/acre over the life of the 18 year plantation or 1.0 lbs/acre for each of the four sprayings. Insecticide and fungicide amounts for N-fixing trees are based on a total 18 year plantation life application of 8.0 lbs/acre or 2.7 lbs/acre for each rotation. Harvesting operations include cutting, crushing, baling, moving/loading, and unloading. On poorer quality sites N fertilizer may be required in the establishment year.

Table 6. Factor input requirements for perennial energy crop production -- Switchgrass and Wheatgrass

Activity	Material	Amount
Crop Establishment (year 1)		
Mow	Diesel	0.6 gals/acre
Herbicide spray	Broad-kill Diesel	0.9 lbs/acre 0.4 gals/acre
Phosphorous and potassium spread	P_2O_5 K_2O Diesel	60 lbs/acre 90 lbs/acre 0.3 gals/acre
Plant	Diesel	0.7 gals/acre
Herbicide spray	Preemergent Diesel	0.5 lbs/acre 0.4 gals/acre
Crop maintenance (years 2-10)		
Nitrogen, phosphorous, and potassium spread (annual applications)	N P_2O_5 K_2O Diesel	90 lbs/acre 60 lbs/acre 90 lbs/acre 0.3 gals/acre
Insecticide/fungicide spray (once during crop life)	Pesticide Diesel	0.3 lbs/acre 0.4 gals/acre
Harvesting operations (years 2-10)		
Harvesting and handling	Diesel	2.0 gals/ton

Notes: N is half urea and half ammonium nitrate. Pesticide amounts are given in terms of active ingredient. Amounts are derived from Ranney and Mann (1991) and reflect reduced tillage. Total herbicide use is 1.4 lbs/acre over the 10 year crop life. Insecticide and herbicide use is based on an average yearly application rate of 0.03 lbs/acre. Harvesting operations include mowing, raking, baling, moving/loading, and unloading.

Table 7. Factor input requirements for perennial energy crop production -- Reed Canarygrass

Activity	Material	Amount
Crop Establishment (year 1)		
Mow	Diesel	0.6 gals/acre
Herbicide spray	Broad-kill Diesel	0.9 lbs/acre 0.4 gals/acre
Nitrogen, phosphate and potash spread	N P_2O_5 K_2O Diesel	45 lbs/acre 60 lbs/acre 90 lbs/acre 0.3 gals/acre
Plant	Diesel	0.7 gals/acre
Herbicide spray	Preemergent Diesel	0.5 lbs/acre 0.4 gals/acre
Crop maintenance (years 2-10)		
Nitrogen, phosphorous, and potassium spread (annual applications)	N P_2O_5 K_2O Diesel	135 lbs/acre 60 lbs/acre 90 lbs/acre 0.3 gals/acre
Insecticide and fungicide spray (once during crop life)	Pesticide Diesel	0.3 lbs/acre 0.4 gals/acre
Harvesting operations (years 2-10)		
Harvesting and handling	Diesel	2.0 gals/ton

Notes: N is half urea and half ammonium nitrate. Pesticide amounts are given in terms of active ingredient. Amounts are derived from Ranney and Mann (1991) and reflect reduced tillage. Total herbicide use is 1.4 lbs/acre over the 10 year crop life. Insecticide and herbicide use is based on an average yearly application rate of 0.03 lbs/acre. Harvesting operations include mowing, raking, baling, moving/loading, and unloading.

Table 8. Factor input requirements for perennial energy crop production – Energy Cane

Activity	Material	Amount
Crop Establishment (year 1)		
Mow	Diesel	0.6 gals/acre
Herbicide spray	Broad-kill Diesel	0.8 lbs/acre 0.4 gals/acre
Phosphorous and potassium spread	P_2O_5 K_2O Diesel	50 lbs/acre 80 lbs/acre 0.3 gals/acre
Plant	Diesel	0.7 gals/acre
Herbicide spray	Preemergent Diesel	0.8 lbs/acre 0.4 gals/acre
Crop maintenance (years 2-10)		
Nitrogen spread (annual applications)	N P_2O_5 K_2O Diesel	155 lbs/acre 50 lbs/acre 80 lbs/acre 0.3 gals/acre
Insecticide/fungicide spray (once during crop life)	Pesticide Diesel	0.4 lbs/acre 0.4 gals/acre
Harvesting operations (years 2-10)		
Harvesting and handling	Diesel	1.1 gals/ton
Notes: N is half urea and half ammonium nitrate. Pesticide amounts are given in terms of active ingredient. Amounts are derived from Ranney and Mann (1991) and reflect reduced tillage. Herbicide amounts are 1.6 lbs/acre or 0.8 lbs/acre for each of two applications. Insecticide and herbicide use is based on an average yearly application rate of 0.04 lbs/acre. Harvesting includes forage chopping, wagons, and blowing.		

For all woody crops, harvesting is assumed to take place in year 6 with two additional coppice cycles. The harvesting system assumed is one in which trees are felled, crushed, field dried, baled, moved, loaded, hauled, and unloaded. The bales of wood are assumed to be stored at the production site and are assumed to dry-out to a moisture level of 25% on a dry weight basis. In northern climates, wood harvested and field stored under rainy and cold conditions may have a higher moisture content. Higher moisture content would imply that more tonnage would have to be hauled by truck, rail or barge. Transportation assumptions have not yet been modified to account for possibly higher tonnages. The factor input requirements for tree crops are summarized in Tables 4 and 5.

2.2.2 Perennial Herbaceous Crops

Establishing perennials (switchgrass, wheatgrass, reed canarygrass, and energy cane) often requires plowing, disking, spreading of fertilizers, planting, and an application of a herbicide. In the future no-till establishment should be sufficiently developed to ensure high survival and high crop productivity. Under no-till establishment any existing crop cover would be mowed or reduced to a stubble. The perennial could then be planted with a drill with the spreading of fertilizers and spraying of herbicides following. The application of fertilizers and harvesting (years 2 through 10) would be the only operations associated with growing perennial crops after they have been established. These crops with the exception of energy cane are harvested as hay -- mowing, raking, round baling, moving and loading, and hauling. These operations can result in crop losses of 10 to 17% (Dobbins et al., 1990). However, the major difference between most hay crops and perennial energy crops is that harvesting is done only once or twice during the growing season. It is assumed that the perennials are reestablished after a period of 10 years (1 establishment year plus 9 production years) in all locations where they are grown. Reestablishments likely to be required less often; however, a 10 year interval takes into consideration the need or desire to establish newer seed sources with higher yields or better feedstock quality. Tables 6-7 summarize the factor input requirements for perennial grasses. Energy cane is also a perennial grass. Many of the factor input requirements for growing energy cane as well as harvesting and handling, are similar to that of sorghum. Factor input requirements for energy cane are summarized in Table 9.

2.2.3 Annual Herbaceous Crops

Plowing, disking, and application of nitrogen, phosphate and potash are required for the establishment of the annual herbaceous crop, sorghum. Sorghum also requires the application of herbicides to control weeds. However, in the future it may be possible to successfully establish annual energy crops using a conservation tillage approach, such as chisel plowing that leaves the soil partially covered. Planting follows with application of fertilizers and herbicides to control weeds. While crop yields of sorghum can be very high, fertilization requirements are also very high. It is assumed that nitrogen fertilization requirements will be 0.5% of standing biomass yield or about 155 lbs/acre. Harvesting of sorghum is assumed to take place in early Fall utilizing a forage system (forage harvester and wagons). Harvest losses are assumed to be about 5% (Coble and Egg, 1989) while storage and handling losses are assumed to be about 9%. Table 9 summarizes the annual management regime for sorghum.

2.3 ACREAGE AND HAUL DISTANCE REQUIREMENTS

Land capability data were extracted from the 1982 National Resources Inventory (NRI) for counties within 100 miles of a selected county's centroid for each of the five regional locations (SCS, 1987) (Fig. 2). The extracted NRI data were then filtered to eliminate unsuitable or incompatible land uses based on the criteria established by Graham (1991, in final review).

Land had to meet the following criteria to be included:

- It must be classified by the Soil Conservation Service (SCS) as cropland or it must have a high to medium conversion potential (to cropland).

Table 9. Factor input requirements for annual energy crop production -- Sorghum

Activity	Material	Amount
Crop Establishment (year 1)		
Mow	Diesel	0.6 gals/acre
Herbicide spray	Broad-kill Diesel	0.8 lbs/acre 0.4 gals/acre
Chisel plow	Diesel	0.9 gals/acre
Plant	Diesel	0.7 gals/acre
Nitrogen, phosphorous, and potassium spread	N P_2O_5 K_2O Diesel	155 lbs/acre 70 lbs/acre 90 lbs/acre 0.3 gals/acre
Herbicide spray	Preemergent Diesel	0.8 lbs/acre 0.4 gals/acre
Insecticide/fungicide spray	Pesticide Diesel	0.4 lbs/acre 0.4 gals/acre
Harvesting operations (year 1)		
Harvesting and handling	Diesel	1.1 gals/ton
Notes: N is half urea and half ammonium nitrate. Pesticide amounts are given in terms of active ingredient. Amounts are averages derived from Ranney and Mann (1991) and reflect reduced tillage. Harvesting includes forage chopping, wagons, and blowing.		

- It must be located in the USDA Land Resource Regions (LRR) A, J, K, L, M, N, O, P, R, S, T, U, or in the USDA Major Land Resource Area (MLRA) 53B-C, 55A-C, 56, 71, 73, 74, 75, 76, 78, 79, 80A-B, and 84. These are crop growing regions that do not normally require irrigation.

- It must be deemed capable of supporting an energy crop production rate of at least 5 dry tons/acre/year.

Land having the following characteristics was excluded:

- Land considered a riparian area (i.e., natural streambanks, manmade canals or ditch banks, natural or manmade ponds or lake shoreline, or a tidal area shoreline).

- Pasture, range or forest land with a woody canopy cover of more than 55%, if it is currently classified as pasture, range, or forest land.

- Land with a wetness limitation that was also described as being a "seasonally flooded basin or flat" or as "inland fresh meadow." (All swamp, marsh, bog, and open waters were thus excluded.)

- Cropland also secondarily classified as "horticulture" (i.e., fruit, nut, vineyard, berries, etc.), "other vegetables" (i.e., truck farms), or "aquaculture".

- Land classified with a current land use of residential, commercial, industrial, institutional, wilderness, wildlife, recreation, nature, study, research and experimentation, or roads and railways.

- Land owned by the Federal Government.

The above criteria indicated how much land was capable and suitable for producing energy crops. We can not be absolutely certain that all environmentally sensitive areas (including functional wetlands based on the most current definitions) were excluded, however the exclusions listed above were our attempt to exclude such areas from the "suitable" land base. The next step in a logical analysis sequence is to determine which land is likely to be available for energy crop production based on markets, net returns to the landowner, etc. As explained in the initial discussion of regions selected, economic analysis was beyond the scope of this analysis. Therefore availability was determined in an arbitrary but systematic manner for all regions.

Basically, we chose to limit the acreage assumed available for energy crop production to no more than 7% of the suitable land base. We noted that most secondary crops utilized 5% to 10% of the suitable landbase while the primary commodity crops often utilized 15 to 30% of the landbase. Our 7% land use penetration assumption was low enough to avoid competition with the major commodity crops yet utilize sufficient land to make energy crop production a significant part of the farm economy. At the 7% level, energy crops became approximately equivalent to the 5th most important crop (as a percentage of the suitable land base) in each location.

The 7% availability restriction was applied uniformly across land capability classes I, II, III, and IV[4]. This means, for example, the higher the percentage of land in a capability class, the higher the relative amount of energy crops to occur in that class. A disproportionately higher percentage of class III and IV land might appear to be more economically justified because of the presumption of lower land cost. However, such land produces lower yields and does not necessarily result in positive returns. Thus without detailed analysis on the interaction between land cost and yields, we felt there was no appropriate justification for limiting energy crop production to specific land classes. As a consequence, crop displacement (existing crops displaced by energy crops) was also a constant percentage for each existing crop within a land capability class. This assumption generally meant that corn, soybeans, pasture, and closecrop agriculture was affected the most by energy crops in this evaluation. Finally, there was no explicit consideration of subclass in restricting the available landbase.

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[4]We assumed that capability class V, VI, VII, and VIII would not be cropped. In many instances, these lands are being cropped. The conversion of these lands to energy crop production could be more beneficial over current practices.

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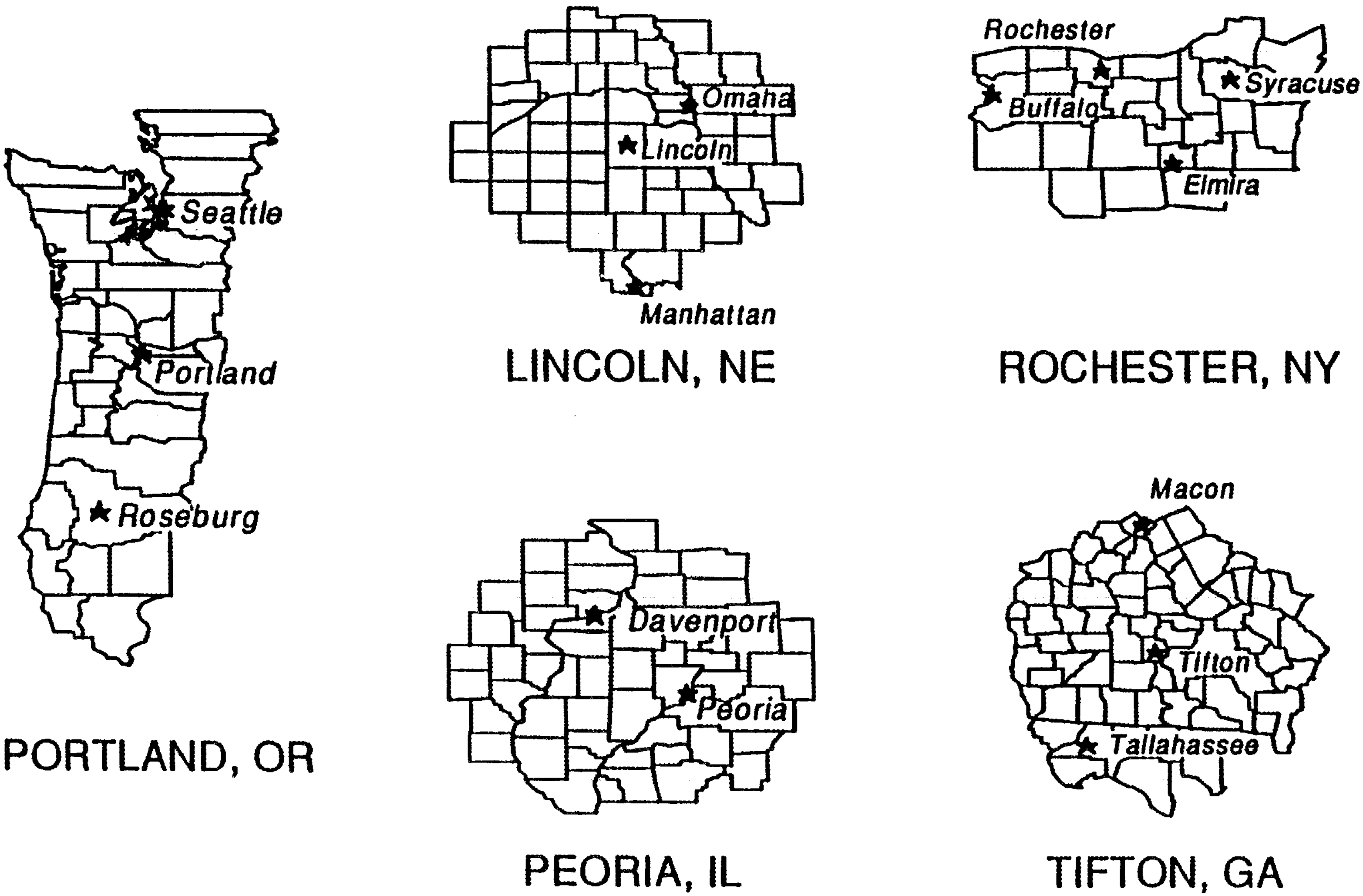

Fig. 2. Map of counties used in extracting data form the 1982 NRI

Conservation Reserve Program (CRP) land was not included in the NRI 1982 database and thus could not be explicitly included in the analysis of suitable and available land. There was access to information on the total number of acres enrolled in the CRP for each county following the 9th (most recent) sign-up, however, there was no way of determining yield potential on CRP land.

Once the proportion of land that was available in each land capability class was determined, we proceeded to determine the crop types and crop yields that would be appropriate for the available land base and to determine the actual acreage needed (Table 10). Acreage needed was obtained by back calculating from the 715,400 dry tons that had to be supplied to the facility each year, allowing for losses from harvesting and storage. Energy crop productivity data for the year 2010 were extrapolated from current experimental research results. Energy crop investigators in several parts of the U.S. were asked to provide estimates of the best yields obtainable with current technology as a function of land capability class and subclass.[5] Of course, these estimates cannot be rigorously defended, but are believed to be conservative and are based on the opinions of the best experts available. Yields beyond 2010 may increase with genetic improvements, but they may also decrease as more environmental constraints are imposed on management options.

An implication of limiting our production to a constant proportion of the suitable land base was that haul distances then varied as a function of land availability. This provided the basis for some interesting analysis on the environmental effects of different transportation modes and distances. In three cases (Peoria, Lincoln, and Tifton), the suitable landbase available within a 100 mile radius far exceeded the landbase required for supplying a 2000 ton/day ethanol conversion facility operating at 98% capacity. For those locations imposing the 7% limitation on the suitable land base resulted in the maximum haul distance varying from about 32 to 54 miles (Table 11). For the remaining two cases (Rochester and Portland), the 7% limitation on the suitable land base and topography prevented the feedstocks requirements from being met within a 100 mile radius. In these cases, a long narrow corridor provided the land required for production and the maximum haul distance varied from 120 to 220 miles (Table 11).

Since the amount of suitable land base was not the same in all regions, the proportion of the total land base used varied with each location. In the three cases where supplies could be supplied from a circular area, the proportion of total land used varied from 2.1 to 5.5% of the total land area within the maximum haul radius (Table 11). It was difficult to determine what proportion of the total land was used at the two sites supplied along a corridor. This was because our databases only summarized acreages by counties and the corridors did not correspond with county boundaries. The total acreage required was compared with the amount of CRP land currently available (Table 11). Although we do not know whether the CRP land is suitable for producing energy crops at the desired production levels, the amount of CRP land present can be interpreted to be an indicator of the amount of land not needed currently to meet agricultural

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[5]Personal communication with T. Bowersox, D. Bransby, D. Buxton, D. Frederick, W. Geyer, R. Hall, E. Hansen, P. Heilman, O. Hesterman, K. Johnson, A. Kuhl, S. Land, D. Parrish, K. Steinbeck, E. White, K. Woodward, and K. Vogel.

Table 10. Summary of energy crop production requirements

Location, species, and capability class	Acreage	Annual Productivity (dry tons/acre)	Total production (dry tons/year)
Rochester			
Trees			
Class I	4,453	6	26,718
Class II	52,336	5	261,680
Subtotal	56,789		288,398
Perennials			
Class I	1,989	8	15,912
Class II	23,393	7	163,751
Class III	86,238	5	431,190
Subtotal	111,620		610,853
Total	168,409		899,250
Tifton			
Trees			
Class I	6,985	9	62,865
Class IIe	25,342	7	177,394
IIs	8,731	5	43,655
IIw	5,793	8	46,344
Class IIIother	9,370	5	46,850
IIIw	2,683	6	16,098
Class IVw	1,193	5	5,965
Subtotal	60,097		399,171
Perennials			
Class I	5,281	10	52,810
Class II	30,283	8	242,264
Class III	9,157	5	45,785
Class IV	9,541	5	47,705
Subtotal	54,262		388,565
Energy Cane			
Class I	852	13	11,076
Class II	4,770	13	62,010
Class III	1,448	5	7,240
Class IV	767	5	3,835
Subtotal	7,837		84,161
Total	122,196		871,896

Peoria			
Trees			
Class I	10,205	8	81,640
Class IIw	14,457	8	115,656
IIother	14,457	5	72,285
Class IIIw	1,063	6	6,378
Class IVw	213	6	1,278
Subtotal	40,395		277,237
Perennials			
Class I	8,079	10	80,790
Class II	23,281	10	232,810
Class III	17,436	6	104,616
Class IV	6,485	6	38,910
Subtotal	55,281		457,126
Sorghum			
Class I	2,020	15	30,300
Class II	5,847	15	87,705
Class III	2,020	8	16,160
Class IV	744	5	3,720
Subtotal	10,631		137,885
Total	106,307		872,248
Lincoln			
LRA 2			
Class I	9,559	10	95,590
Class II	28,824	10	288,240
Class III	26,618	6	159,708
Class IV	17,206	6	103,236
Subtotal	82,207		646,774
LRA 3			
Class I	9,559	7	66,913
Class II	28,677	5	143,385
Class III	26,765	5	133,825
Subtotal	65,001		344,123
Total	147,208		990,897
Portland			
Class I	4,222	10	42,220
Class IIes	17,736	5	88,680
Class IIw	43,010	10	430,100
Class IIIw	19,443	10	194,430
Class IVw	13,743	8	109,944
Total	98,184		865,374

Table 11. Landbase variables as a function of location

Location	Percent of suitable landbase	Maximum haul distance	Percent of total landbase	Total acres required	CRP acres available
Rochester	0.07	120.0	na	168,409	14,663
Tifton	0.07	53.9	2%	122,196	110,657
Peoria	0.07	32.1	5%	106,307	131,324
Lincoln	0.07	36.7	6%	147,208	182,335
Portland	0.07	220.0	na	98,184	~5,000

Notes: CRP acreage within haul distance was approximated by taking 25% of the CRP acreage within a 100 mile haul radius for all locations except Portland. Total CRP acreage in all Pacific Northwest counties was used in evaluating possible Portland area CRP (see Fig. 2). "na" demotes not available. The percent of the total land base was not computed for these location.

production demands. This comparison suggests that theoretically, energy crop production needs could be largely supplied through the use of CRP land.

Dry weight of biomass produced and delivered was calculated with allowances for biomass losses in handling and storage. These losses differed among trees, thin-stemmed perennials, and thick stemmed grasses. Differences in percentages of material lost relate to the length of storage time that is assumed for each crop and location. The resultant dry weight equivalent of biomass lost and hauled and delivered to the conversion hopper are summarized in Table 12. This information is the basis of carbon flow calculations discussed later but does not indicate the actual quantities of material hauled. Weight of biomass material actually hauled is a function of the storage assumptions, and assumed moisture content when hauled. Moisture contents and wet weights of the material harvested, hauled and delivered are summarized in Table 13. Tree moisture content could be higher than projected if harvest and field storage occurring during cold, wet periods. Sorghum and energy cane are assumed to have the same moisture content when hauled and placed in the hopper as when harvested (233% moisture content on dry weight basis or 70% on wet basis) because of storage as silage.[6]

[6]Moisture content on a dry basis is equal to the weight of water in the fuel divided by the dry weight of the fuel. Moisture content on a wet basis is equal to the water weight of the fuel divided by the dry weight of the fuel plus the water weight of the fuel.

Table 12. Annual biomass feedstock flows and losses

Location	dry tons/year (MMBtu/year)				
	Standing Yield	Pre-haul losses	Haul	Post-haul losses	Conversion hopper
Tree crops					
Rochester	288,398 (4,902,766)	38,501 (654,519)	249,897 (4,248,247)	11,536 (357,349)	238,361 (4,052,136)
Tifton	399,171 (6,785,907)	53,289 (905,919)	345,882 (5,879,988)	15,967 (271,436)	329,915 (5,608,552)
Peoria	277,237 (4,713,029)	37,011 (629,189)	240,226 (4,083,840)	11,089 (188,521)	229,136 (3,895,318)
Lincoln	--	--	--	--	--
Portland	865,674 (14,716,458)	115,567 (1,964,647)	750,107 (12,751,811)	34,627 (588,658)	715,480 (12,163,153)
Perennial grasses					
Rochester	610,853 (9,162,795)	109,954 (1,649,303)	500,899 (7,513,492)	23,823 (357,349)	477,076 (7,156,143)
Tifton	388,564 (5,828,460)	62,170 (932,554)	326,394 (4,895,906)	13,405 (201,082)	312,988 (4,694,825)
Peoria	457,126 (6,856,890)	73,140 (1,097,102)	383,986 (5,759,788)	15,771 (236,563)	368,215 (5,523,225)
Lincoln	990,897 (14,863,455)	235,734 (3,536,016)	755,163 (11,327,439)	39,636 (594,538)	715,527 (10,732,901)
Portland	--	--	--	--	--
Energy cane and sorghum					
Tifton	84,161 (1,262,415)	8,416 (126,242)	75,745 (1,136,174)	3,156 (47,341)	72,589 (1,088,833)
Peoria	137,885 (2,068,275)	14,478 (217,169)	123,407 (1,851,106)	5,171 (77,560)	118,236 (1,773,546)

Notes: Trees crops are assumed to have 17 MMBtu/dry ton. Herbaceous perennial grasses, energy cane, and sorghum have 15 MMBtu/dry ton.

Table 13. Annual wet biomass feedstock flows and losses

Location	Wet tons	MC (%)	Wet tons hauled	MC (%)	Total hauled	Wet weight converted	MC (%)	Total converted
Rochester								
Trees	576,796	200	312,371	125		297,951	125	
Grasses	916,280	150	626,124	125		596,345	125	
Total					938,495			894,296
Tifton								
Trees	798,342	200	432,352	125		412,394	125	
Grasses	582,846	150	407,992	125		391,235	125	
E. cane	196,095	233	176,486	233		169,132	233	
Total					1,016,830			972,761
Peoria								
Trees	554,474	200	300,282	125		286,420	125	
Grasses	685,689	150	479,982	125		460,269	125	
Sorghum	321,272	233	287,538	233		275,491	233	
Total					1,067,803			1,022,180
Lincoln								
Grasses	1,486,346	150	943,953	125	943,953	894,408	125	894,408
Portland								
Trees	1,731,348	200	937,634	125	937,634	894,350	125	894,350

Notes: Moisture content (MC) is on a dry weight basis.

3. BIOMASS FEEDSTOCK EMISSIONS

Land, fuel, and chemicals are all used in the production and transport of energy crops. These factor inputs combined with production, harvesting, and transport operations create soil erosion and compaction, particulate releases, CO_2 emissions from fuel and biomass decomposition, other air emissions (CO, VOCs, NO_x, etc.), runoff containing nitrogen (N), phosphorus (P) and potassium (K) and many other direct emissions (Fig. 3). Large scale production of energy crops will also raise many secondary environmental issues related to biodiversity and sustainability. Of course, these emissions are all relative to the displacement of current land uses and crops. In many cases, the displacement of certain agricultural activities (e.g., row crops) with energy crops will result in a positive net change.

The approach used and the resultant emissions are presented in the remainder of this section. These emissions are calculated as absolute emissions and not as net emissions reflecting the displacement of current land use and crops. Emissions from energy crop production and harvesting operations are calculated from equipment use (i.e., diesel fuel), soil losses, and agricultural chemicals. Emissions from feedstock transportation are based on the consumption of low-sulfur diesel fuel. Emissions are also calculated from the biomass itself (e.g., CO_2 releases from decomposition).

3.1 EMISSIONS FROM ENERGY CROP PRODUCTION AND HARVESTING

Production and harvesting emissions most directly include those from diesel fuel for equipment operations, and those from chemicals and soil losses. Indirect emissions, such as the energy embodied in fertilizer production, are not included in the analysis but have been evaluated elsewhere (Turhollow and Perlack, 1991).

3.1.1 Emissions from Equipment Operations

Emissions from equipment operations are based on average diesel fuel consumption over a 30 year production life. A 30 year production period for tree crops with a six year rotation age and two coppice harvests would imply two crop establishments and five harvests on any given unit of land. From Table 2 (fuel use and power requirements) and Tables 4 and 5 (factor input requirements) average annual fuel consumption and power requirements are calculated and summarized in Table 14. Average annual diesel fuel use (power requirements) for tree crops range from a low of about 10.1 gals/acre (162.7 bhp-hrs/acre) in Rochester to 17.0 gals/acre (274.4 bhp-hrs/acre) in the Portland supply area. The variation is due to site differences in productivity and greater fuel use in harvesting. For perennial grasses (including energy cane), a 30 year production period would imply three crop establishment years and 27 harvest years. Average annual fuel and power requirements can be calculated as the product of specific fuel and power requirements (Table 2) and the factor input requirements for each perennial grass crop (Tables 6 to 8). The lowest fuel use and power requirements are for the Rochester site and this is due to lower overall biomass productivity. Average annual diesel fuel use (power requirements) ranges from a low of about 10.1 gals/acre (162.7 bhp-hrs/acre) in Rochester to 15.0 gals/acre (242.0 bhp-hrs/acre) in Peoria (Table 14). Finally, the annual herbaceous crop, sorghum, is

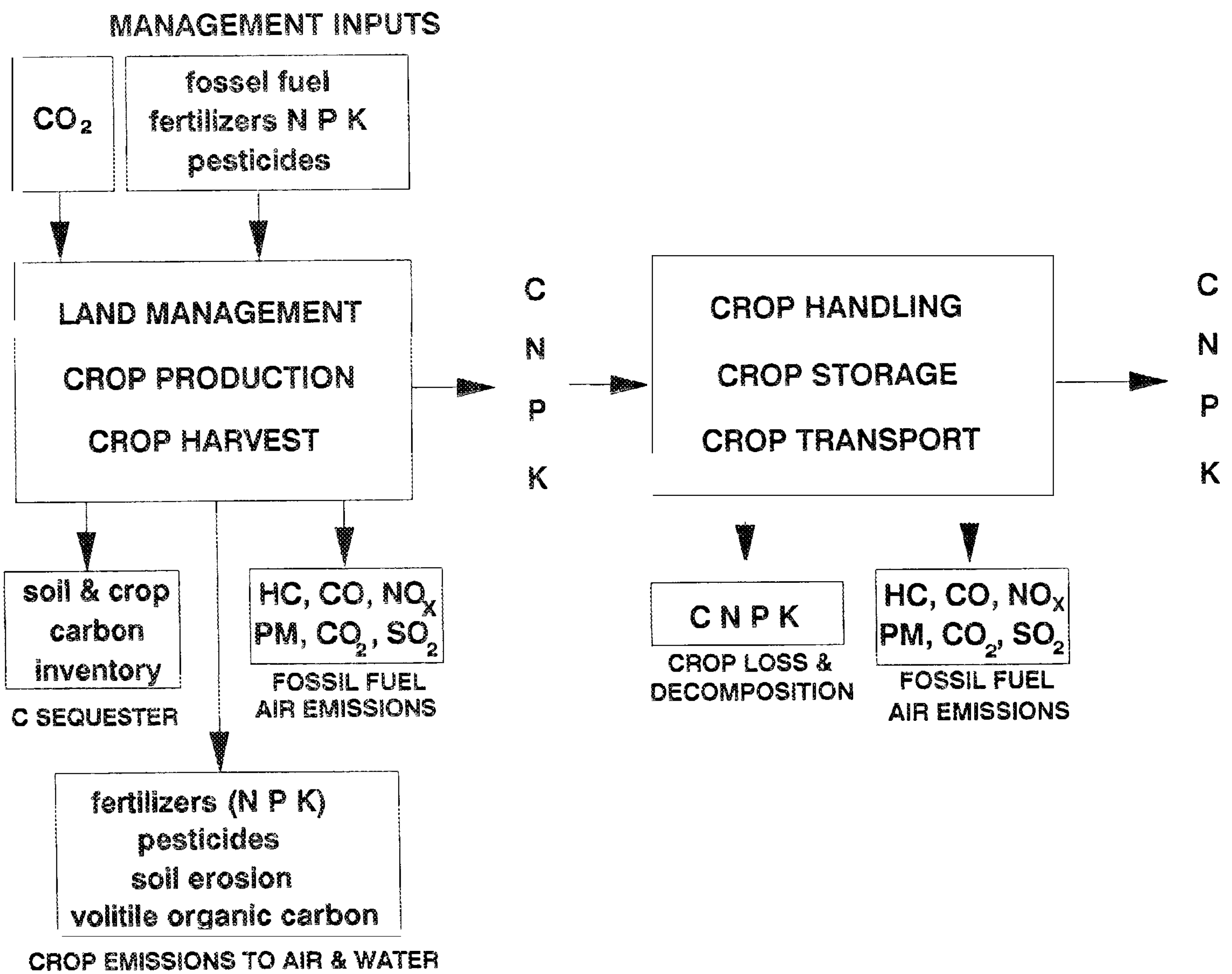

Fig. 3. Annual energy crop management inputs and environmental emissions

Table 14. Total annual diesel fuel use and power requirements

Location	Fuel use (gals/acre)	Power requirements (bhp-hrs/acre)
Tree crops		
Rochester	10.1	162.7
Tifton	10.9	174.9
Peoria	13.4	215.9
Lincoln	0	0
Portland	17.0	274.4
Perennial grasses		
Rochester	10.1	162.7
Tifton	13.1	210.6
Peoria	15.0	242.0
Lincoln	12.4	199.5
Portland	0	0
Energy cane and sorghum		
Tifton	11.4	182.9
Peoria	17.7	285.4
Notes: Fuel use requirements are based on weighted average productivities in each region.		

reestablished and harvested each year and requires in total 17.7 gals/acre of diesel fuel and 285.4 bhp-hrs/acre (Table 14). Sorghum is the most fuel intensive on a per acre basis of all the energy crops considered.

Diesel farm tractors give off a variety of airborne emissions -- hydrocarbons, CO, NO_x, particulates, CO_2, and SO_2. Emissions of VOCs and aldehydes are negligible for this equipment. Emissions of hydrocarbons, CO, NO_x, and particulates were computed as the product of average annual power requirements (Table 14), acres in production (Table 10) and per unit releases of 0.002, 0.011, 0.011, and 0.001 lbs/bhp-hr (1.1, 4.8, 4.8, and 0.5 grams/bhp-hr) for hydrocarbons, CO, NO_x, and particulates, respectively [U.S. Environemental Protection Agency (EPA) 1991]. These total emissions were then divided by annual harvested yield (Table 12 before losses) to give an estimate in lbs/MMBtu of harvested biomass. These estimates are shown in Table 15. Annual

Table 15. Total annual air emissions from farm equipment operations including harvesting

Location	Hydro-carbons	CO	NO_x	Parti-culates	CO_2	SO_2
	lbs/MMBtu of Energy Crop					
Tree crops						
Rochester	0.0046	0.0199	0.0199	0.0021	2.64	0.00083
Tifton	0.0038	0.0164	0.0164	0.0017	2.17	0.00068
Peoria	0.0045	0.0196	0.0196	0.0020	2.60	0.00082
Lincoln	--	--	--	--	--	--
Portland	0.0044	0.0194	0.0194	0.0020	2.57	0.00081
Perennial grasses						
Rochester	0.0048	0.0210	0.0210	0.0022	2.78	0.00087
Tifton	0.0048	0.0207	0.0207	0.0022	2.75	0.00086
Peoria	0.0047	0.0206	0.0206	0.0022	2.74	0.00086
Lincoln	0.0048	0.0209	0.0209	0.0022	2.77	0.00087
Portland	--	--	--	--	--	--
Energy cane and sorghum						
Tifton	0.0028	0.0120	0.0120	0.0013	1.59	0.00050
Peoria	0.0036	0.0155	0.0155	0.0016	2.06	0.00065

Notes: Emissions are from EPA, *Compilation of Air Pollution Emissions Factors*, Vol. 2, Supplement A, PB91-167692, January 1991. Releases of hydrocarbons, carbon monoxide, oxides of nitrogen, and particulates are based on factors of 0.002, 0.011, 0.011, and 0.001 lbs/bhp-hr (1.1, 4.8, 4.8, and 0.5 grams/bhp-hr), respectively. Fuel consumption is 0.44 lbs/bhp-hr. Emissions of CO_2 are based on 0.87% C/lb fuel (22.57 lbs CO_2/gal of fuel). CO_2 equivalence based on the ratio of molecular weight of CO_2 to the atomic weight of C (3.664). SO_2 emissions are based on a factor of 0.45 grams/lb fuel. VOC and aldehyde emissions are negligible. Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12). The energy content of wood and herbaceous crops are assumed to be 17 and 15 MMBtu/dry ton, respectively.

emissions from diesel tractors are essentially the same across all regions with the exception of sorghum and energy cane, which is due to higher productivity.

Emissions of CO_2 by location and crop type were computed as the product of average annual fuel consumption (Table 14), total acres in production (Table 10), and an emission factor for CO_2 of 0.87% C/lb fuel (22.57 lbs CO_2/gal of fuel). This product was then divided by annual energy production (Table 12) to yield CO_2 emissions in lbs/MMBtu.

Emissions of SO_2 by location and crop type were computed as the product of average annual fuel use (Table 14), total acres in production (Table 10), and an emission factor of 0.45 grams/lb of fuel. Dividing by annual energy production (Table 12) provides estimates of SO_2 in lbs/MMBtu (Table 15).

3.1.2 Agricultural Chemical and Soil Emissions

Estimation of chemical emission rates were based on numerous literature sources (Table 16). Table 16 shows these emission rates (non-point) as a percentage of the applied agricultural chemical. For example, for every unit of phosphorous applied 5% is assumed to leach into groundwater, 5% leaves the site as runoff, 10% is lost to erosion, and the remainder (80%) is plant uptake. The same emission rate estimates are used for all locations and species even though site- and species-specific differences would be expected. Insufficient information was available to estimate site- and species-specific emission rates. In addition, volatization rates from chemicals are poorly understood. The product of these rates and the average annual chemical inputs (Table 3) provides an estimate of annual emissions from the application of agricultural chemicals. The fate of these fertilizer and pesticide emissions to air, surface water, and groundwater are summarized in Tables 18 through 22.

Soil erosion is specific to regions and crops. Estimates of annual erosion rates in Table 17 (tons/acre) are based on present erosion rates of similar crops in the 1982 NRI data and projected reductions based on USDA expectations (USDA, 1989). These expectations are associated with implemented measures of the Food Security Act, which are specific by region.

In the Rochester area, present erosion rates for corn, hayland, forest, and closecrops are 4.3, 0.9, 0.2, and 3.1, tons/acre respectively. For trees plantations, the first year establishment erosion rate was estimated at 4.3 tons/acre (same as corn). This was reduced to 3.0 tons/acre the second year. Thereafter, erosion was assumed at 0.2 tons/acre-year (same as forest and pasture). After each harvest (every 6 years) the erosion rate may increase slightly, but it is assumed that the intact root systems prevent most erosion. Perennial energy crop erosion rates were set at 3.1 tons/acre the first year and 0.9 tons/acre (same as hayland) for each of the remaining 9 years in the rotation. The erosion rates of land in perennial grass crops (including energy cane) are low since live root systems remain in place after each harvest.

Erosion rates are very low in the Tifton area. Hayland and pasture erosion rates are 0.1 and 0.2 tons/acre, respectively. For perennial energy crops other than energy cane, the first year erosion rate of 5.2 tons was averaged into a remaining rotation annual rate of 0.2 tons to average 0.7 tons. For the woody crops, a higher erosion rate at establishment and a lower rate throughout the remaining rotation years resulted in the same erosion average. Energy cane erosion was assumed identical to that of closecrops in the region.

Table 16. Estimated agricultural chemical emission rates

Agricultural Chemical	Percent of Applied Chemical				
	Groundwater	Runoff	Air	Plant uptake	Erosion
N-fertilizer					
Sorghum	15	10	15	50	10
Perennials	5	5	10	75	5
Trees	5	5	10	75	5
P-fertilizer	5	5	-	80	10
K-fertilizer	5	5	-	85	5
Herbicides	8	10	75	2	5
Insecticides/ fungicides	8	10	75	2	5

Notes: Emission rates are derived from a number of sources: Ahuja (1986), Alberts et al. (1978), Haith (1986), Hon et al. (1986), Isensee et al. (1990), McLaughlin et al. (1985), Ranney and Mann (1991), and Vaughan et al. (1989). Estimates are non-point emissions as a percent of chemicals applied to fields. These estimates do not include handling, transport, and storage of biomass, chemical spills and drift, container cleanup wastes, or fuel emissions. Pesticides include herbicides, fungicides, and insecticides.

Table 17. Present and future erosion rates by region and crop

Location/ species	Erosion rates (tons/acre)			Crop life (years)	Future erosion reduction (%)	Average erosion rate
	1st year	2nd year	Other years			
Rochester						
Trees	4.3	3.0	0.2	18	0.50	0.38
Perennials	3.1	0.9	0.9	10	0.26	1.04
Tifton						
Trees	7.0	4.0	0.1	18	0.50	0.39
Perennials	5.2	0.2	0.2	10	0.39	0.50
Energy cane	5.6	0.2	0.2	10	0.39	0.52
Peoria						
Trees	10.0	6.8	1.2	18	0.50	1.53
Perennials	9.1	1.1	1.1	10	0.21	1.71
Sorghum	8.6	8.6	8.6	1	0.21	6.79
Lincoln						
Perennials	8.6	1.6	1.6	10	0.30	2.04
Portland						
Trees	2.0	1.0	0.2	18	0.50	0.26

Allocation of soil erosion

Location	Percent into		
	Dissolved solution	Wind (air)	Runoff
Rochester	10	10	80
Tifton	10	10	80
Peoria	10	20	70
Lincoln	10	40	50
Portland	10	10	80

Notes: Average erosion rate is the sum of the erosion in the first and second year (tree crops) times the future erosion reduction (%) plus the other year erosion rate times the remaining crop life (16 years for trees, 9 years for perennial grasses) all divided by the total crop life (18 years for trees and 10 years for perennial grasses).

Table 18. Annualized N emissions by location and crop type

Location	Ground water	Surface water	Air	Soil
	tons/year (lbs/MMBtu)			
Tree crops				
Rochester	51 (0.0208)	51 (0.0208)	102 (0.0417)	51 (0.0208)
Tifton	61 (0.0179)	61 (0.0179)	122 (0.0359)	61 (0.0179)
Peoria	36 (0.0154)	36 (0.0154)	73 (0.0309)	36 (0.0154)
Lincoln	--	--		--
Portland	132 (0.0180)	132 (0.0180)	265 (0.0360)	132 (0.0180)
Perennial grasses				
Rochester	289 (0.0630)	289 (0.0630)	578 (0.1261)	289 (0.0630)
Tifton	110 (0.0377)	110 (0.0377)	220 (0.0754)	110 (0.0377)
Peoria	127 (0.0372)	127 (0.0372)	255 (0.0744)	127 (0.0372)
Lincoln	298 (0.0401)	298 (0.0401)	596 (0.0802)	298 (0.0802)
Portland	--	--	--	--
Energy cane and sorghum				
Tifton	27 (0.0433)	27 (0.0433)	55 (0.0866)	27 (0.0433)
Peoria	104 (0.1002)	69 (0.0668)	104 (0.1002)	69 (0.0688)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

Table 19. Annualized P emissions by location and crop type

Location	Ground water	Surface water	Air	Soil
	tons/year (lbs/MMBtu)			
Tree crops				
Rochester	15 (0.0062)	15 (0.0062)	0 (0.0000)	30 (0.0124)
Tifton	18 (0.0053)	18 (0.0053)	0 (0.0000)	36 (0.0106)
Peoria	11 (0.0043)	11 (0.0046)	0 (0.0000)	22 (0.0091)
Lincoln	--	--		--
Portland	39 (0.0053)	39 (0.0053)	0 (0.0000)	78 (0.0107)
Perennial grasses				
Rochester	167 (0.0365)	167 (0.0365)	0 (0.0000)	335 (0.0731)
Tifton	81 (0.0279)	81 (0.0279)	0 (0.0000)	163 (0.0559)
Peoria	83 (0.0242)	83 (0.0242)	0 (0.0000)	166 (0.0484)
Lincoln	221 (0.0297)	221 (0.0297)	0 (0.0000)	442 (0.0594)
Portland	--	--	--	--
Energy cane and sorghum				
Tifton	10 (0.0155)	10 (0.0155)	0 (0.0000)	20 (0.0310)
Peoria	19 (0.0180)	19 (0.0180)	0 (0.0000)	37 (0.0360)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

Table 20. Annualized K emissions by location and crop type

Location	Ground water	Surface water	Air	Soil
	tons/year (lbs/MMBtu)			
Tree crops				
Rochester	15 (0.0062)	15 (0.0062)	0 (0.0000)	15 (0.0062)
Tifton	18 (0.0053)	18 (0.0053)	0 (0.0000)	18 (0.0053)
Peoria	11 (0.0046)	11 (0.0046)	0 (0.0000)	11 (0.0046)
Lincoln	--	--		--
Portland	39 (0.0053)	39 (0.0053)	0 (0.0000)	39 (0.0053)
Perennial grasses				
Rochester	251 (0.0548)	251 (0.0548)	0 (0.0000)	251 (0.0548)
Tifton	122 (0.0419)	122 (0.0419)	0 (0.0000)	122 (0.0419)
Peoria	124 (0.0363)	124 (0.0363)	0 (0.0000)	142 (0.0363)
Lincoln	331 (0.0446)	331 (0.0446)	0 (0.0000)	331 (0.0446)
Portland	--	--	--	--
Energy cane and sorghum				
Tifton	16 (0.0248)	16 (0.0248)	0 (0.0000)	16 (0.0248)
Peoria	24 (0.0231)	24 (0.0231)	0 (0.0000)	24 (0.0231)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

Table 21. Annualized herbicide emissions by location and crop type

Location	Ground water	Surface water	Air	Soil
	tons/year (lbs/MMBtu)			
Tree crops				
Rochester	0.40 (0.0016)	0.50 (0.00020)	3.75 (0.00153)	0.25 (0.00010)
Tifton	0.48 (0.00014)	0.59 (0.00018)	4.46. (0.00132)	0.30 (0.00009)
Peoria	0.28 (0.00012)	0.36 (0.00015)	2.67 (0.00113)	0.18 (0.00008)
Lincoln	--	--		--
Portland	1.04 (0.00014)	1.30 (0.00018)	9.72 (0.00132)	0.65 (0.00009)
Perennial grasses				
Rochester	0.54 (0.00012)	0.67 (0.00015)	5.02 (0.00110)	0.33 (0.00007)
Tifton	0.30 (0.00010)	0.38 (0.00013)	2.85 (0.00098)	0.19 (0.00007)
Peoria	0.29 (0.00008)	0.36 (0.00010)	2.69 (0.00079)	0.18 (0.00005)
Lincoln	0.82 (0.00011)	1.03 (0.00014)	7.73 (0.00104)	0.52 (0.00007)
Portland	--	--	--	--
Energy cane and sorghum				
Tifton	0.05 (0.00008)	0.06 (0.00010)	0.47 (0.00074)	0.03 (0.00005)
Peoria	0.68 (0.00066)	0.85 (0.00082)	6.38 (0.00617)	0.43 (0.00041)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

Table 22. Annualized insecticide emissions by location and crop type

Location	Ground water	Surface water	Air	Soil
	tons/year (lbs/MMBtu)			
Tree crops				
Rochester	0.02 (0.00001)	0.02 (0.00001)	0.17 (0.00007)	0.01 (0.00000)
Tifton	0.02 (0.00001)	0.03 (0.00001)	0.20 (0.00006)	0.01 (0.00000)
Peoria	0.01 (0.00000)	0.02 (0.00001)	0.12 (0.00005)	0.01 (0.00000)
Lincoln	--	--		--
Portland	0.05 (0.00001)	0.06 (0.00001)	0.44 (0.00006)	0.03 (0.00000)
Perennial grasses				
Rochester	0.13 (0.00003)	0.17 (0.00004)	1.26 (0.00027)	0.08 (0.00002)
Tifton	0.07 (0.00002)	0.08 (0.00003)	0.61 (0.00021)	0.04 (0.00001)
Peoria	0.07 (0.00002)	0.08 (0.00002)	0.62 (0.00018)	0.04 (0.00001)
Lincoln	0.18 0.00002)	0.22 (0.00003)	1.66 (0.00022)	0.11 (0.00001)
Portland	--	--	--	--
Energy cane and sorghum				
Tifton	0.01 (0.00002)	0.02 (0.00002)	0.12 (0.00019)	0.01 (0.00001)
Peoria	0.17 (0.00016)	0.21 (0.00021)	1.59 (0.00154)	0.11 (0.00010)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

In the Peoria area, comparable erosion rates from the 1982 NRI database for pasture, hayland, forest, and corn are 1.2, 1.1, 0.7, and 8.6 tons/acre, respectively. For trees crops, the first year's erosion was estimated at 10 tons/acre, the second 6.8 tons/acre, and the 16 succeeding years of the full rotation at 1.2 tons/acre for a rotation average of 2.0 tons/acre. For perennial crops, the first year's erosion during crop establishment was 9.1 tons/acre (similar to closecrop of 8.9) and 1.1 tons/acre for the 9 remaining years of this established multiyear crop for an average of 1.9 tons/acre. Sorghum was assumed equivalent to corn in erosion rate.

For the Lincoln area where only perennial energy crops will be grown, hayland and pasture have erosion rates of 1.6 and 1.3 tons/acre, respectively. An establishment year erosion rate for the energy crop of 8.6 tons/acre (not too different from closecrop rates) was combined with 9 years of erosion at 1.6 tons/year to average 2.3 tons/acre-year.

Erosion rates for agricultural practices in the Portland supply area vary between 0.1 and 1.6 tons/acre-year. Since the rate is about 0.2 tons/acre for hayland and pasture, energy crop erosion rates were assumed to be only slightly higher. In specific terms, erosion during plantation establishment was estimated at 2.0 tons/acre (erosion for corn is about 1.4 tons/acre) and 1.0 tons/acre the second year. Thereafter, erosion is assumed to be 0.2 tons per acre.

It will be possible to significantly reduce erosion rates at the time of energy crop establishment if no-till and crop residue management methods are used. However considerations given to needs for herbicides and tilling to compensate for 10 to 18 years of field traffic compaction make assumptions of the future difficult. Many considerations are involved and need careful documentation.

Future erosion rates from perennial energy crops were estimated from USDA projections of agricultural erosion on nonfederal land (USDA 1989). Conservation practices primarily reduced sheet erosion. Wind erosion reduction (e.g., shelter belts) is especially important for parts of the Lincoln site. The percent reduction just for the establishment phase was 21% (combination of Corn Belt and Lade States statistics), 30% (Northern Plains and Corn Belt statistics), 39% (Southeast statistics), and 26% (Northeast statistics) for Peoria, Lincoln, Tifton, and Rochester, respectively. No reduction in erosion was assumed during the production phases after crop establishment. For future erosion rates of short-rotation plantations, no-till practices, the establishment of cover crops during the establishment phase, and strip spraying (rather than total site herbicide applications) were assumed. These assumptions should reduce establishment phase erosion by at least 50%.

The allocation of soil erosion to wind (dust), water erosion, and dissolved solution are not known for energy crops. Table 17 shows the allocation of soil erosion. This allocation was arbitrary but an attempt was made to recognize some regional differences. The division of erosion losses were the same for Tifton, Rochester, and the Portland area where 80% was lost to water and 10% to wind. At all sites, 10% was assumed lost in dissolved solution. Lincoln suffers from greater wind erosion so 40% of soil loss was allocated to this source rather than water erosion. In Peoria, 20% was assumed lost to wind erosion at the expense of water erosion.

Total annualized erosion rates are the product of planted acreage (Table 10) for each region and crop, the average future erosion rate (Table 17), and the allocation as emissions to air and water (Table 17). These estimates are summarized in Table 23.

Table 23. Annualized soil emissions by location and crop type

Location	Dissolved solution	Wind (air)	Runoff
	tons/year (lbs/MMBtu)		
Tree crops			
Rochester	2158 (0.88)	2158 (0.88)	17,264 (7.04)
Tifton	2344 (0.69)	2344 (0.69)	18,750 (5.53)
Peoria	6180 (2.62)	12,361 (5.24)	43,263 (18.36)
Lincoln	--	--	--
Portland	2553 (0.35)	2553 (0.35)	20,422 (2.78)
Perennial grasses			
Rochester	11,608 (2.53)	11,608 (2.53)	92,868 (20.27)
Tifton	2713 (0.93)	2713 (0.93)	21,705 (7.45)
Peoria	9453 (2.76)	18,906 (5.51)	66,171 (19.30)
Lincoln	30,030 (4.04)	120,122 (16.16)	150,152 (20.20)
Portland	--	--	--
Energy cane and sorghum			
Tifton	408 (0.65)	408 (0.65)	3260 (5.17)
Peoria	7218 (6.98)	14,437 (13.96)	50,529 (48.86)

Notes: Emissions rates that are expressed in lbs/MMBtu reflect total harvested biomass production before handling and storage losses (Table 12).

3.2 EMISSIONS FROM ENERGY CROPS

Known emissions from energy crops would include the CO_2 that results from decomposition of biomass during storage and from that left on the ground after harvest. It is possible that methane could be emitted in small quantities if some of the decompositions occurs under anaerobic conditions, but for this study it was assumed that all decomposition occurs under aerobic conditions. Actively growing energy crops also emit hydrocarbons. The calculation approach and the resultant emissions are discussed in separate subsections below.

3.2.1 Volatile Organic Carbon Emissions

The growing of energy crops will contribute hydrocarbons to the atmosphere. These are mostly non-methane aromatic hydrocarbons, primarily isoprenes and terpenes. Other compounds may be present (e.g., ethene) but data on their rates of evolution are virtually nonexistent. Thus, emissions of isoprene and terpene are the only biogenic hydrocarbons that are estimated for energy crops. These estimates are based on the foliage of woody plants and the above ground biomass of herbaceous crops. Data are essentially unavailable for emissions from bark, forest floor, and soil surfaces. Although it would seem likely that the steps involved in the operation of a biomass plantation (e.g., site preparation, growth, harvest, and storage) might lead to different rates of biogenic hydrocarbon emissions per unit land area over time, the data are insufficient to allow this detail to be resolved.

Table 24 summarizes emission rates for isoprene and terpene. Isoprene emissions are assumed to take place only during daylight hours of the growing season. Whereas, terpenes emission rates are assumed to take place as a function of temperature throughout the frost-free period of a particular location, and are not subjected to the diurnal patterns of evolution that appear to function in the case of isoprene. Rates of isoprene and monoterpene emissions from plant foliage are species-specific with *Populus* having the greatest and sorghum the least amount of biogenic hydrocarbon emissions. Greater annual emission rates in Georgia are primarily a function of the length of the growing season and a higher average temperature (emissions increase with temperature). Except for the high rates of isoprene emissions from *Populus* (Sharkey et al. 1991; Monson and Fall 1989), emission rates for biomass plantings should not exceed those of surrounding forested areas. For comparison, emission from pines and oaks are included in Table 24. Total annual biogenic emissions were calculated by dividing the isoprene and terpene emissions rate by the weighted average biomass productivity rate in Btus. Table 25 displays these emissions.

3.2.2 CO_2 Emissions from Aboveground Biomass

Carbon dioxide is taken up by plants in the growth process and emitted by plants as they decompose or are converted to other forms of energy. Once CO_2 is absorbed by the plants, the carbon is incorporated into plant tissues and the oxygen is released through respiration. A total carbon flow analysis would track all the carbon incorporated by the plant into leaves, stems and roots. This would require tracking the leaf carbon through the leaf litter processes and determining how much decomposes or goes into the soil. It would also require determining the carbon captured by fine roots and how much decomposes or adds to the soil carbon pool. And it would also require calculating how much carbon is allocated to large roots which are a significant source of carbon inventory until the plants die. Accounting for all of these various

Table 24. Mean annual estimated isoprene and/or terpene emissions

Species	Site	Annual rates of emission	
		Isoprene (lbs/acre)	Monoterpenes (lbs/acre)
Sweetgum	GA	82	13
Sycamore	GA	125	nd
Hybrid poplar	PNW	272	nd
	NB	438	nd
	NY	438	nd
	IL	550	nd
	GA	169-1428	nd
Willow	IL	72	nd
	NB	58	nd
Sorghum	NB	nd	0.7
	IL	nd	0.9
	GA	nd	1.5
Pine	GA	nd	10-17
Oak	NY	90	nd
	IL	112	nd
	GA	66-299	nd

Notes: "nd" denotes no data or no detectable emissions. Emission rates derived from a report by Hanson (1991) references to Allwine et al. (1985), Arey et al. (1991), Arnts et al. (1982), Evans et al. (1982), Monson and Fall (1989), and Sharkey et al. (1991).

Table 25. Total annual biogenic hydrocarbon emissions from energy crop production by region

Location	Total hydrocarbon emissions: Isoprene	Total hydrocarbon emissions: Monoterpene
	tons (lbs/MMBtu)	
Tree crops		
Rochester	7771 (3.17)	nd nd
Tifton	3359 (0.99)	254 (0.075)
Peoria	5962 (2.53)	nd nd
Lincoln	0	0
Portland	8876 (1.21)	nd nd
Perennial grasses		
Rochester	nd	nd
Tifton	nd	nd
Peoria	nd	nd
Lincoln	nd	nd
Portland	0	0
Energy cane and sorghum		
Tifton	nd nd	5.87 (0.0093)
Peoria	nd nd	4.76 (0.0046)

Notes: "nd" denotes not detectable emission or no data. Emissions are expressed in MMBtu of total harvested crop production before handling and storage losses (Table 10). The energy content of wood and herbaceous crops is assumed to be 17 and 15 MMBtu/dry ton, respectively.

carbon flows would be complicated and was felt to be beyond the scope of this report. The carbon captured in the aboveground biomass is easiest to track and was used as the basis of CO_2 emissions reported in Table 26. Of the carbon going to the leaves and roots, most of it is recycled to the atmosphere through decomposition but some of it is bound to soil molecules and becomes a pool of "sequestered" carbon which offers a benefit to the entire fuel cycle.

Basically all of the carbon (or CO_2) annually captured in aboveground biomass should be (or can be considered to be) emitted in the same year through decomposition or combustion. Decomposition is the source of CO_2 emission from: (1) the biomass left on the field during harvest, (2) the biomass stored in the field after harvest, and (3) the biomass stored and lost at the facility. The amounts of CO_2 contained in biomass carried through the production system and the CO_2 emitted by decomposing biomass are summarized in Table 26 for all locations and crops. These numbers come directly from converting the annual biomass feedstock flows and losses in Table 12 to CO_2 values. Once the biomass is processed through the conversion facility, additional CO_2 losses will occur as some of the lignin and other excess biomass components are converted to electricity. Finally all of the remaining CO_2 embodied in the original biomass will be emitted by vehicles using the biofuel.

3.2.3 CO_2 Benefits from Carbon Sequestered in the Soil

The carbon allocated to roots and to leaves (in the case of trees) eventually becomes part of the pool of sequestered carbon which builds up in the soil as organic matter. The proportion of carbon going to roots and leaves varies as a function of age of the plant in the case of trees. However, much of the carbon allocated to roots and leaves is relatively quickly released back to the atmosphere through decomposition processes. Rather than attempt to track all the carbon going to roots and leaves and determining what proportions are sequestered in the soil versus that amount released through decomposition, it is simpler to consider the amount which remains in the soil carbon pool. The value of this soil carbon pool as a carbon "benefit" to the biofuels system depends on the period of time over which it is evaluated. It is anticipated that the net changes in soil which will occur as a function of land use change will reach an equilibrium condition in about 30 years.

Data on soil organic carbon inventories at equilibrium for energy crops are largely unknown. Each general crop type will have a different equilibrium condition since there will be differing levels of disturbance as a function of crop type and management systems. Estimating net changes in soil carbon inventories is therefore subject to some speculation. Here, net changes in soil carbon are from Ranney, Wright, and Mitchell (1991), who made estimates and extrapolations on the basis of existing agricultural and forestry studies. For example, they assume that the displacement of corn with trees will result in a net accumulation of soil carbon (8 tons/acre at equilibrium), while the displacement of fully stocked forests with tree plantations will result in a net loss of soil carbon (11 tons/acre at equilibrium). These and other assumed net changes in soil carbon inventories from the conversion of current land uses to energy crops are found in Table 27. Estimating the total change in carbon inventory is simply the product of the net change per acre at equilibrium and the total number of acres involved. These results are summarized in Table 27. For all regions and current land use to energy crop displacements, there is a positive net change in soil biomass inventory (at equilibrium) except in situations involving conversion of "other" land uses to sorghum. The "other" landuse category includes closecrop, pasture, and a very small amount of poorly stocked forest land.

Table 26. Annual CO_2 flows

Location	Total annual CO_2 flows (tons CO_2/year)					
	Standing Yield	Pre-haul losses	Haul	Post-haul losses	Conversion hopper	lbs CO_2/MMBtu
Tree crops						
Rochester	576,742	76,995	499,747	23,070	476,677	11.41
Tifton	782,763	104,499	678,265	31,311	646,954	11.18
Peoria	551,374	73,608	477,766	22,055	455,711	11.34
Lincoln	--	--	--	--	--	--
Portland	1,702,004	227,217	1,474,786	68,080	1,406,706	11.21
Perennial grasses						
Rochester	1,086,629	195,593	891,036	42,379	848,657	11.87
Tifton	696,189	111,390	584,798	24,019	560,780	10.26
Peoria	816,100	130,576	685,524	28,155	657,368	10.26
Lincoln	1,768,125	420,637	1,347,488	70,725	1,276,763	13.22
Portland	--	--	--	--	--	--
Energy cane and sorghum						
Tifton	145,857	14,586	131,271	5,470	125,802	10.06
Peoria	242,501	25,463	217,038	9,094	207,945	10.27

Notes: The assumed carbon contents are: Hybrid Poplar - 54.3%, Black Locust - 53.9%, Silver Maple - 54.5%, Sweetgum - 53.3%, Sycamore - 53.7%, Willow - 56.1%, Red Alder - 54.3%, Hybrid Cottonwood - 53.5%, Switchgrass - 48.9%, Reed Canarygrass - 48.2%, Wheatgrass - 48.4%, Sorghum - 48.0%, and Energy Cane - 47.3%. CO_2 equivalence based on the ratio of molecular weight of CO_2 to the atomic weight of C (3.664).

Table 27. Estimated soil organic carbon changes for energy crops

Location/ Initial land use	Estimated acreage	Change in carbon inventory		
		C tons/acre	Total tons C	Total tons CO_2
Tree crops				
Rochester				
Rowcrop	8,420	+8	67,360	
Other	48,369	+6	290,214	
Total	56,789		357,574	1,310,151
Tifton				
Rowcrop	28,521	+8	288,168	
Other	28,521	+6	171,126	
Total	57,042		459,294	1,682,853
Peoria				
Rowcrop	20,000	+8	160,000	
Other	20,395	+6	122,273	
Total	40,395		282,273	1,034,248
Lincoln	--	--	--	--
Portland				
Rowcrop	1,963	+8	15,704	
Other	94,228	+6	565,368	
Total	98,154		559,479	2,049,931
Perennial grasses				
Rochester				
Rowcrop	8,420	+2	16,840	
Other	103,200	0	0	
Total	111,620		16,840	61,702
Tifton				
Rowcrop	25,603	+2	51,206	
Other	25,604	0	0	
Total	51,207		51,206	187,619
Peoria				
Rowcrop	25,281	+2	50,562	
Other	30,000	0	0	
Total	55,281		50,562	185,259
Lincoln				
Rowcrop	58,883	+2	117,766	
Other	88,325	0	0	
Total	147,208		117,766	431,495

Portland	--	--	--	--
Energy cane and sorghum				
Tifton				
Rowcrop	7,823	0	0	
Other	0	-2	0	
Total	7,823		0	0.0000
Peoria				
Rowcrop	10,431	0	0	
Other	200	-2	-400	
Total	10,631		-400	-1,466
Notes: Row crops, especially corn, can be well managed with respect to residues. However, it is assumed that most corn is grown for silage (residues are minimum) and that energy grasses will provide a year-round below ground root mass. Other refers to CRP land, closecrop, hayland, fallow, pasture, range, and nonrow crops. Change in carbon for trees includes that in soil organics, roots, and litter layer. Carbon change estimates are from Ranney, Wright, and Mitchell (1991). CO_2 sequestration is based on harvested biomass before handling and storage losses. CO_2 equivalence based on the ratio of moleculr weight of CO_2 to the atomic weight of C (3.664).				

Assumptions for each region about the particular crops displaced and the energy crops displacing them are explained in the following paragraphs.

Rochester. Rochester feedstocks are comprised of trees and perennial grasses. Much acreage is involved because productivity rates are lower than at other sites. Of existing crops, rowcrops occupy only 30% of the filtered land base. Except for a small percentage in forest (with less than 55% forest cover), the rest of the land base is in closecrop agriculture, pasture, hayland, and fallow. CRP acreage falls roughly two thirds short of supplying necessary acreage if all were used. Because of the small amount of existing land in rowcrops, energy crops will displace only a small percentage of this land use. It is assumed that 10% of the needed land comes out of rowcrops and is evenly divided between wood and herbaceous energy crops. The remainder of energy crop acreage (80%) displaces non-rowcrop uses, proportionately split between herbaceous and wood crops.

Tifton. The Tifton filtered land base is comprised of 64% rowcrops; 22% in a mixture of pasture, closecrop, fallow, and hayland; and the rest (14%) in forest. Total use of CRP signup land within a 50 mile radius would fall about 10% short of the needed land base. It is assumed that 30% of the land base would come from the CRP, 20% from non-rowcrops, 45% from rowcrops, and 5% from poorly stocked forest lands. The energy crops are trees, perennials, and energy cane. Energy cane would be placed on rowcrop land because of site requirements. Trees and perennials are assumed to be evenly split among the remaining land uses.

Peoria. Corn and soybeans make up over 85% of the filtered land base in the region. CRP land alone would be sufficient to provide the land base for energy crops, if nearly all of it were used within the 32 mile hauling distance. Instead, it is assumed that 50% of the energy crops are placed on corn and soybean land, about 40% is placed on CRP land (using about 35 to 40% of the CRP signup land) and the rest comes from other non-row crop uses such as pasture and hayland.

Lincoln. The Lincoln site's filtered land base is about 70% rowcrops, 11% closecrop agriculture, and 15% pasture, hayland, and fallow. The CRP signup is quite sufficient to provide almost enough land to feed the conversion facility within the calculated haul distance. However, experience indicates that much of the CRP land will be of inadequate quality, thus it is assumed that 40% of the needed land will come out of CRP signup, 40% from rowcrop land, and the rest from non-rowcrop use. The only energy crop produced is perennial grass.

Portland. The particular growing conditions of the valley between the Coastal Range and the Cascade Range favor trees over other crops. The valley also holds the primary land resource. Rowcrops comprise only about 5% of the suitable landbase and poorly stocked forest 8%. The remainder is in non-rowcrop uses dominated by closecrop, pasture and hayland in that order. It is assumed that 4% of energy crop land will come evenly split between rowcrop and forested land. The remaining 96% will come principally from closecrop, pasture, and hayland.

3.2.4 Carbon Sequestered in Aboveground Inventory

The standing biomass that supplies the conversion facility, particularly the carbon in the trunks and stems of the average inventory of trees and in the leaf litter is generally thought of as a repository of sequestered carbon. However, it may only be a temporary repository of carbon. The extent to which the carbon in growing stock inventory can be considered a benefit the biofuels systems depends on the assumptions made about the phasing out of a particular conversion facility. If it is assumed that the facility will be replaced or updated and thus that the trees will continue to be grown indefinitely, then counting the carbon inventory in the trees as a benefit is valid. However, one could just as logically assume that at some point in time, the energy crop trees and leaf litter will be removed and their embodied carbon will be recycled back to the atmosphere. Since the current total energy cycle analysis does not clearly establish close-out assumptions, the calculations on standing inventory carbon will be presented so that they may be available for future analysis.

It would be erroneous to attempt to calculate the average standing inventory as a carbon benefit to be compared with the fossil carbon inputs required in single year. If considered as a benefit, it must be compared against the lifetime of the conversion facility. The longer the period of useful lifetime considered, clearly the smaller the benefit of the average standing carbon inventory.

Only the carbon in the standing inventory of trees and leaf litter will be considered. It may be contended that herbaceous crops do have a standing inventory of captured biomass for short periods of time. That is true, but most of the biomass (and carbon) is removed each year at harvest. All carbon removed by harvest is tracked in the analysis of carbon flows and thus it would be double counted if also considered here. The average standing inventory of tree carbon is different because it is equal to the inventory of tree carbon that is built up prior to the first harvest and prior to the first year of operation of the facility.

Estimating the aboveground biomass inventory in tree trunks and stems is based on the assumption of a six year rotation plus two coppice cycles and the equivalent of linear growth. In addition, it is assumed that the first harvest is 10% less than the second harvest and that the third harvest is 10% less than the second (for an average productivity of some number P). The equation for annualized tree biomass inventory, B, is:

$$B = [(0.9\ P)6/2 + P(6/2) + (0.9\ P)6/2]/3 = 2.8\ P$$

To this equation must be added leaves and litter. It is assumed that the first year in six contains on average 0.5 tons/acre of leaves and litter over a four month period. Since this is only for one third of a year, only 0.5/3 tons/acre need to be added to the biomass inventory for that year. The second year is assumed at 1.5 tons for a third of the year. During the last four years leaves and litter are assumed to be equal to $B = (2 + P/5)/3$, which says that the leaf mass will be 2 tons plus 20% of the average annual wood mass over a four month period. To annualize the leaf mass inventory, it is divided by 3.

The mean annual aboveground biomass for trees is:

$$B = [(0.9\ P)6/2 + P(6/2) + (0.9\ P)6/2]/3 + [0.5/3 + 1.5/3 + 4(2 + P/5)/3]/6$$

$$B = 2.8\ P + 0.556 + 0.044\ P = 2.844\ P + 0.556$$

Substituting regional productivity rates into these equations will yield the average inventory of the standing or aboveground biomass for each major species. The biomass inventories are then converted to carbon inventories by assuming the appropriate carbon contents. These average carbon inventories are shown in Table 28. The product of the average inventory per acre, as calculated from the preceding equations, and the total acreage planted in a given crop will give the total aboveground biomass inventory (Table 28). The estimates in Table 28 show that the locations with large proportions of tree crops, do provide a large (temporary) pool of sequestered carbon.

3.3 EMISSIONS FROM ENERGY FEEDSTOCK TRANSPORTATION

Table 29 summarizes the haul tonnage (field tons) and mode of transport for each region. Average truck haul distance ranges from a low of about 26 miles for the Peoria site to a high of 48 miles for the Rochester site. The haul distance for the barge mode in the Rochester area is 90 miles plus an additional 24 miles of truck haul distance. For the rail mode in the Portland area 140.5 miles are assumed with an additional 25 miles of truck haul distance. The haul tonnage shown in Table 29 reflects a 25% moisture content on a dry weight basis for tree crops and perennial grasses. The haul tonnage for energy cane and sorghum, which is in forage form, reflects a 233% dry weight basis moisture content. Total haul tonnage is about 940,000 field tons except at the Tifton site and Peoria site where transport amounts are higher because of the high moisture (weight) of energy cane and sorghum.

Table 28. Average annual growing stock inventories of standing biomass

Location/ productivity rate (dry tons/acre)	Total acres	Average C inventory (tons/acre)	Total inventory (of C tons)	Total CO_2 (tons)
Rochester				
5	52,336	14.78	773,526	2,834,200
6	4,453	17.62	78,462	287,484
Total	56,789		851,988	3,121,684
Tifton				
5	19,294	14.78	285,165	1,044,846
6	2,683	17.62	47,274	173,214
7	25,342	20.46	518,497	1,899,774
8	5,793	23.31	135,035	494,768
9	6,985	26.15	182,658	669,258
Total	54,304		1,168,629	4,281,860
Peoria				
5	14,457	14.78	213,674	782,903
6	1,276	17.62	22,483	82,378
8	24,662	23.31	574,871	2,106,328
Total	40,395		811,028	2,971,609
Lincoln	--	--		--
Portland				
5	17,736	14.78	262,138	960,474
8	13,743	23.31	320,349	1,173,760
10	67,675	29.00	1,962,575	7,190,875
Total	98,154		2,545,062	9,325,109

Notes: A 30-year facility operation and plantation scenario is used for estimating average growing stock inventory of tree biomass. CO_2 equivalence based on the ratio of molecular weight of CO_2 to the atomic weight of C (3.664).

Table 29. Average transport distances and tonnage

Location	Haul Tonnage (Field tons)	Transport mode (miles)		
		Truck	Rail	Barge
Rochester	563,097 375,398	48.0 24.0	-- --	0 90.0
Tifton	1,016,830	43.1	--	--
Peoria	1,067,830	25.7	--	--
Lincoln	943,953	29.4	--	--
Portland	309,419 628,214	46.0 25.0	0 140.5	-- --

Notes: Haul tonnage for wood and perennial grasses reflects a 125% moisture content on a dry weight basis. Tonnage for sorghum and energy cane reflects a 233% moisture content on a dry weight basis.

High speed diesel engines used in truck transport give off hydrocarbons, CO, NO_x, particulates, CO_2, and SO_2. Emissions of VOCs and aldehydes are negligible. Emissions of hydrocarbons, CO, NO_x, and particulates from diesel trucks were computed as the product of annual load-miles and an emission factor. Total annual load miles are a function of the haul tonnage (Table 29), the round trip distance, and an assumed 20 ton load for trucks. Baseline emission factors for hydrocarbons, CO, NO_x, and particulates are 0.5, 2.0, 2.0, and 0.08 grams/bhp-hr, respectively. (These factors were converted to lbs/mile by an assumption of 2.69 bhp-hr/mile and 454 grams/lb.) Table 30 provides estimates of these emissions in terms of the energy content of delivered feedstocks (Table 12). Emissions of CO_2 and SO_2 were calculated as the product of total annual load miles and factors of 1708.0 and 0.536 grams/mile, respectively.

Emissions from barge and rail modes were based on the product of annual ton-miles, an energy transport efficiency, and an emission factor for hydrocarbons, CO, NO_x, particulates, CO_2, and SO_2. The estimate of ton-miles is the product of the haul tonnage (Table 29) and the round trip distance. An energy transport efficiency of 400 and 430 Btu/ton-mile was assumed for barge and rail, respectively. The transport efficiency factor was converted to bhp-hr/ton-mile by assuming 128,700 Btu/gal of diesel fuel, 7.08 lbs of fuel/gal, and 0.37 lbs of fuel/bhp-hr. Emissions factors for hydrocarbons, CO, NO_x, and particulates are 0.001, 0.002, 0.011, and 0.0002 lbs/bhp-hr (0.3, 1.0, 5.0, and 0.1 grams/bhp-hr), respectively (EPA 1991). The emissions factor for SO_2 was assumed to be 0.0004 lbs/bhp-hr. (This emission factor is based on a baseline rate of 0.536 grams/vehicle mile and a conversion of 2.69 bhp-hr/vehicle mile.) For CO_2, Btus/ton-mile were converted to lbs CO_2/ton-mile by assuming 128,700 Btus/gal of diesel fuel and 0.87% C/lb of fuel or 22.57 lbs CO_2/gal of fuel. For all emissions, total emissions were expressed in lbs/MMBtu by dividing by the energy contained in the delivered feedstocks (Table 12). Barge and rail transport emissions are shown in Table 30.

3.4 QUALITATIVE ENVIRONMENTAL ISSUES

The environmental effects of using irrigation in the production of energy crops needs to be addressed. The issue has been avoided in this analysis by our initial assumption that only land suitable for growing energy crops without irrigation will be utilized. We feel relatively safe in this assumption since irrigation is a high cost management input that is unlikely to pay off in energy crop production in most cases. This does not rule out the possibility that individual landowners with previous access to irrigation equipment may choose to use it if conditions are than anticipated.

One aspect of production that this report fails to address is the environmental effects associated with the production of tree seedlings or cuttings and grass seed. The impact on a regional scale is likely to be very minor because of the relatively small amount of acreage needed and the short time period over which it is needed. The addition of tree propagation and seed production acreage to our evaluation of emissions would not make a significant difference in the results. There could be concerns at the local level, however. Since, in nursery or seed production areas there is likely to be greater use of chemicals and a greater potential for using irrigation than would occur in the biomass production fields.

Table 30. Feedstock transport emissions

Location/ transport mode	lbs/MMBtu					
	Hydro-carbons	CO	NO_x	Particu-lates	CO_2	SO_2
Rochester						
Truck	0.00095	0.00381	0.00381	0.00015	1.21050	0.00038
Barge	0.00024	0.00079	0.00395	0.00008	0.42288	0.00016
Tifton						
Truck	0.00114	0.00456	0.00456	0.00018	1.44830	0.00045
Peoria						
Truck	0.00073	0.00291	0.00291	0.00012	0.92311	0.00029
Lincoln						
Truck	0.00077	0.00307	0.00307	0.00012	0.97346	0.00031
Portland						
Truck	0.00073	0.00292	0.00292	0.00012	0.92667	0.00029
Rail	0.00061	0.00204	0.01022	0.00020	1.09437	0.00041

Notes: Truck emission factors for hydrocarbons, CO, NO_x, and particulates are 0.5, 2.0, 2.0, and 0.08 grams/bhp-hr, respectively. (These factors were converted to lbs/mile by an assumption of 2.69 bhp-hr/mile and 454 grams/lb.) Emissions of CO_2 and SO_2 are based on total annual load miles and factors of 1708.0 and 0.536 grams/mile, respectively. An energy transport efficiency of 400 and 430 Btu/ton-mile was assumed for barge and rail, respectively. The transport efficiency factor was converted to bhp-hr/ton-mile by assuming 128,700 Btu/gal of diesel fuel, 7.08 lbs of fuel/gal, and 0.37 lbs of fuel/bhp-hr. Barge and rail emissions factors for hydrocarbons, CO, NO_x, and particulates are 0.001, 0.002, 0.011, and 0.0002 lbs/bhp-hr (0.3, 1.0, 5.0, and 0.1 grams/bhp-hr), respectively. The emissions factor for SO_2 is 0.0004 lbs/bhp-hr (0.536 grams/vehicle mile, 2.69 bhp-hr/vehicle mile). For CO_2, emissions are 22.57 lbs CO_2/gal of fuel. Unit emission rates are based delivered biomass quantities after accounting for all losses (Table 12). The energy content of wood and herbaceous crops is 17 and 15 MMBtu/dry ton, respectively.

One acre dedicated to switchgrass seed production can produce about 500 lb of seed annually (Ken Vogel, personal communication). Depending on planting techniques this could be adequate for planting about 125 acres of field crops (planting rates vary from 3 to 6 lb/acre). Thus to produce enough seed to plant all the perennial grasses (switchgrass, wheatgrass, reed canarygrass) included in this analysis, about 3000 acres would be the maximum required. However, seed can be stored over a few years and thus it is probable that sufficient seed could be produced on 1000 acres or less. Furthermore this acreage might only be required prior to the first establishment since future seed could be harvested from some of the biomass production fields prior to cutting for biomass. Seed production would not necessarily occur near the facility supply locations, it could occur anywhere in the country.

Most of the tree cuttings or seedlings can probably be produced by nurseries already in place. Even if we assumed that all seedlings were produced on ground newly converted to nursery production, it would only require about 170 acres total to supply all seedlings for silver maple, sweetgum, sycamore, black locust and red alder. Hybrid poplar or willow cutting can be produced at a rate of about 100,000 to 150,000 per acre each year (Miles Fry, personal communication). Assuming a planting rate of about 1000 trees per acre, it should only require about 250 acres for a six year period to supply all the cuttings needed for planting hybrid poplars and willows.

3.4.1 Biodiversity and Habitat Change

Biodiversity is defined as genetic variability within species or populations, and species diversity within biomass. Large number of common genetically variable species would represent greater biodiversity than just a few uncommon species.

Biodiversity and habitat change have three important variables to consider in their evaluation. They are time, space (scale), and some definition of background genetic or species diversity. Different forces are at work at the microsite scale compared to the landscape-regional-global ones. Energy crops, likewise, may have measurable influence at larger scales if they occupy more than a few percent of energy supplies or land use at that given scale. If energy crops are disposed to utilize uncommon, unusually productive, or relatively undisturbed habitats, the effect on biodiversity may be disproportionately worsened since these sites would be associated with higher background biodiversity. Conversely, if energy crops displace agricultural monocultures, improvements in biodiversity and habitats may be possible.

In order to determine the effects of energy crops on biodiversity and habitat, several variables need definition. The first is the characterization of energy crops themselves as to the species which occupy them and the kinds of habitats they may offer. The second is some definition of the kinds of habitat (land use or vegetative cover) energy crops would displace and the characterization of biodiversity and habitat qualities within those displaced land uses. The third is the scale of change anticipated within the context of regional land use characterizations and patterns. The fourth and final variable is the regional condition and need with respect to biodiversity and habitat in the context of both larger and smaller scale known and reasonably anticipated biodiversity issues and principles. The questions exceed the data and principles needed to answer them since these new energy crops have not yet reached field applications on a significant scale. Fortunately, however, the questions are being addressed for a series of new crops before they reach the field in contrast to any known previous crops.

3.4.1.1 Biodiversity and Habitat Characterization of Energy Crops

Field investigations are necessary to collect adequate systematic data on biodiversity in energy crops. In the few existing studies within biomes characterized by hardwood woodlands, perennial thin-stemmed grasses contain an avian diversity associated with hayland and pasture, about five different nesting bird species. In contrast, small monocultural stands of short-rotation woody species eventually contain around 16 avian species many of which are closely associated with woodland species. This transition begins occurring around the third year of tree plantation

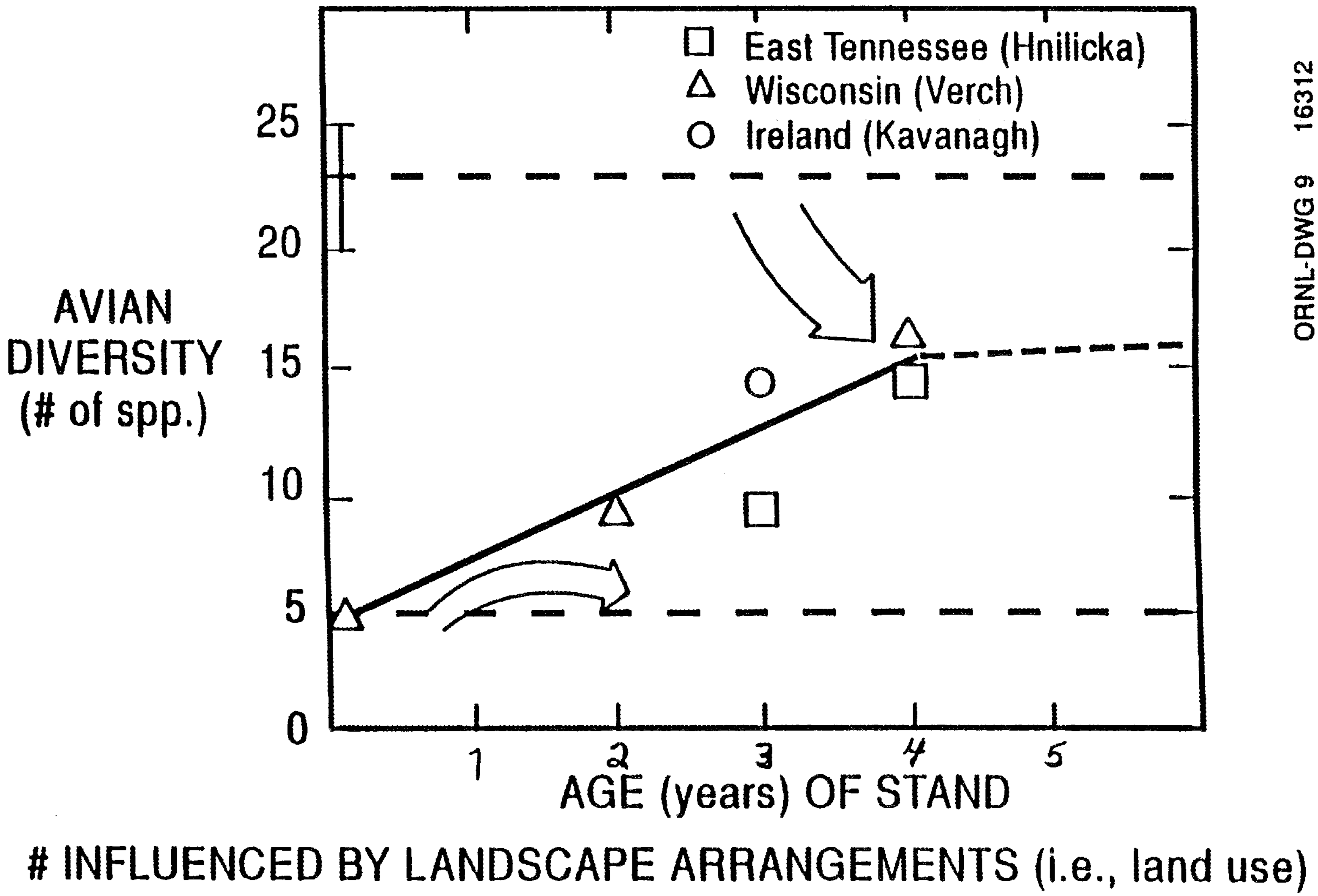

Fig. 4. Avifauna diversity changes with age of wood energy crops and in species groups

growth. Insect and soil macrofauna show similar trends but at a slightly slower pace. Figure 4 was developed for several studies and includes some rather anecdotal observations.

Researchers are now suggesting that short-rotation plantings in the tall grass prairies may play a more pronounced role for animal diversity than their woodland biome counterparts. The type of habitat plantings would provide may be quite unusual and consequently of high value to some unusual prairie species.

One should be cautioned that characterization of energy crop biodiversity based on these few studies has some short comings. Environmental considerations and cultural modifications are likely to lead to changes in energy crop habitat qualities. Even-aged monocultures over vast land tracts and devoid of habitat considerations are probably not a good characterization on which to base biodiversity impacts. Also, data collected on energy crop species occurrence is predominantly from research plots of 0.1 to 10 acres. These plots are too small and too isolated to suggest that study results are completely accurate or that genetic diversity within a species would be influenced at all. No data exist on the later. Biodiversity within concepts of island biogeography (invasion, extinction, etc.) are influenced by the size of "islands" and the habitat diversity within those islands. How well these principles may be applied to islands of energy crop polycultures containing habitat accommodations such as corridors and buffer areas has not been investigated.

Energy crops may also contain genetic additions and deletions unnatural to wild populations as a result of breeding, selection, and biotechnology. The extent of these modifications for growth, morphology, stress tolerance, pest resistance, reproduction, nutrient use, chemical qualities, and harvest index offers potential to affect both habitat qualities and risks for genetic escape into natural genetic pools. The presence of new crops at any scale may present modified disease and pest vectors to existing ecosystems not common in the background environment. They may also affect populations of existing species more indirectly through modified ecological balances and interactions. One example of this is the decline in a raptor population in a portion of Ireland resulting from tree planting and improved (or destroyed) habitat for small mammals, the main food source of the affected raptor.

Information on the biodiversity and habitat qualities of energy crops is lacking. This diversity in row crops and perennial herbaceous energy crops may be analogous to food row crops, hayland, and pasture but the assumption needs verification. Short-rotation woody crops do not have a clear analogy for species diversity and habitat qualities. Limited information suggests they have greater diversity than pine plantations, old fields, and pastures but less diversity than hardwood woodlands.

3.4.1.2 Anticipated Habitats and Biodiversity Displaced By Energy Crops

A general evaluation of the five study sites with each delivering 2,000 dry tons a day to a bioenergy conversion process suggests that the following land use and acreage would be displaced by the mixture of energy crops shown in Tables 31, 32, 33, and 34.

What Tables 31, 32, 33, and 34 cannot reveal are what energy crops are displacing which agricultural crops. The implicit assumption in this study is that energy crops will displace other crops according to their relative occurrence in the landscape. Although this is probably not an accurate assumption, an alternative was more difficult to justify. In general, rowcrops, pasture, and hayland will be displaced by perennial grasses and trees. Forests are listed as being displaced but the quality of these forests is defined as less than 55% canopy coverage rather than closed canopy habitats. Given the qualitative statements about energy crop species diversity, it appears that they will generally improve the species diversity of the crops they displace. This needs careful evaluation.

Of greater concern, however, is the conversion of selected land uses and soil capability classes. These involve bottomlands or soil capability classes with a "W" or wetness limitations. Table 35 was developed from the same data base used to generate Tables 31 and 33.

From this analysis, 213,083 acres with wetness limitations would be affected. This amounts to 33.2% of the total land area needed at all five sites together. Much of this will occur on capability class 2 in the Pacific Northwest which would be converted from agriculture (generally closecrop and pasture) to trees which should be a positive habitat change. Also, capability class 3 with wetness limitations in the Rochester (Northeast) site is significant. Here, agricultural pasture would be displaced by perennial grasses with minimum negative habitat change anticipated. Other considerations beyond the scope of this evaluation are small sites, refugia, buffer zones, and special corridors on other capability classes. And finally, displacement of forests, although generally assumed not to occur or to occur at very low levels, may be a risk worth considering. More commonly displaced agricultural crops yield much less of a habitat loss risk because energy crops appear to offer either no change in critical habitat or improved habitat for species of concern. This must be weighed against the point that energy crops would displace about 5 to 6% of agricultural land uses. It is not known whether this amount is crucial or not. Sorghum and energy cane, although considered relatively poor habitat crops, will generally displace annual rowcrops and not pasture, hayland, or forest conditions due to the crops requirements for high quality sites already in rowcrop use. In the five sites together, sorghum and energy cane account for only 3.6% of the total acreage dedicated to energy crops.

3.4.1.3 Scale of Change Anticipated by Region and Associated Patterns

It is unlikely that large industrial land holdings in any region will be involved in energy crop deployment to a significant degree. This assumption places the bulk of production on farmers and private land owners. The effect on landscape patterns and extent of plantings can be inferred from these assumptions. It is likely that energy crops will be grown in the same tract sizes as agricultural commodity crops and that energy crops will occupy no more than perhaps 5 to 10% of the landscape.

Excluding the Great Plains site, an average of 50% of the energy crops (2.5 to 5% of the landscape) will be planted as trees. This is about eight times the amount of open-canopy forest estimated to be displaced by energy crops for all five sites. Individual planted tracts may vary from 5 to 40 acres. On the average, one out of every 15 to 20 fields would be planted in energy crops. Most of the change would be the conversion of rowcrops, pasture, closecrop, and hayland to perennial grasses and woody crops. The most dramatic habitat changes should involve about one field in 50 being converted from pasture, rowcrop, or hayland to woody crops in the Midwest, South, and Northeast. About one field in 20 would be affected in this way in the Pacific Northwest. Little change would be noticed in the Great Plains except that about one field in 30 would be converted from rowcrops to perennial grasses.

Table 31. Regional agricultural crops displaced by energy crops

Crop	Total Acres by Location				
	Rochester	Tifton	Peoria	Lincoln	Portland
Corn	46,818	30,060	60,267	56,381	3,534
Pasture	36,208	12,220	5,209	11,335	28,759
Soybeans	674	29,083	30,297	29,589	-
Closecrop	12,462	8,187	4,359	16,193	41,322
Hayland	41,260	1,100	2,020	5,447	10,601
Row (other)	3,199	18,940	213	18,990	1,767
Fallow	23,409	5,254	3,614	5,447	3,926
Forest	4,379	17,352	319	294	7,852
Range	-	-	-	3,533	393

Table 32. Total agricultural acreage displaced by energy crops and percentages by crop

Crop	Acreage	Percent of total
Corn	197,068	30.7
Pasture	93,731	14.6
Soybeans	89,643	14.0
Closecrop	82,523	12.8
Hayland	60,428	9.4
Row (other)	43,109	6.7
Fallow	41,650	6.5
Forest	30,196	4.7
Range	3,926	0.6

Table 33. Energy crop acreages by species and region

Species	Total acres by Location				
	Rochester	Tifton	Peoria	Lincoln	Portland
Poplar spp.	32,335	-	20,199	-	78,523
S. Maple	-	-	12,119	-	-
Sweetgum	-	28,105	-	-	-
Sycamore	-	22,484	-	-	-
B. Locust	10,778	5,621	8,079	-	-
R. Alder	-	-	-	-	19,631
Willow spp.	10,778	-	-	-	-
Switchgrass	57,259	43,013	41,459	88,325	-
Wheatgrass	-	-	-	58,883	-
Canarygrass	57,259	10,753	13,820	-	-
Sorghum	-	-	10,631	-	-
E. Cane	-	12,220	-	-	-

Table 34. Total acreage in various energy crops and percentages of total acreages for all five regional site evaluations

Species	Total acreage	Percentage
Poplar spp.	131,057	20.4
S. Maple	12,119	1.9
Sweetgum	28,105	4.4
Sycamore	22,484	3.5
B. Locust	24,478	3.8
R. Alder	19,631	3.0
Willow spp.	10,778	1.7
Switchgrass	230,056	35.8
Wheatgrass	58,883	9.2
Reed Canarygrass	81,832	12.7
Sorghum	10,631	1.7
Energy Cane	12,220	1.9

Table 35. The inventory of agricultural sites with some degree of wetness limitations and the types of energy crops grown

Location/ crop	Capability Class (ares)			Total Acres	Percent
	2	3	4		
Rochester					
Trees	8,064	-	-	8,064	
Grasses	15,850	29,133	2,902	47,885	33.2
Portland					
Trees	44,010	19,443	13,743	77,196	78.6
Lincoln					
Grasses	19,873	5,888	442	26,203	17.8
Peoria					
Trees	14,457	1,063	213	15,733	
Grasses	17,077	1,242	248	18,567	32.3
Tifton					
Trees	5,793	2,683	1,193	9,669	
Grasses	5,873	2,705	1,188	9,766	11.5
Total	130,997	62,157	19,929	213,083	

The effect of these changes on biodiversity is difficult to predict except that climax, endangered, and threatened species will probably be little affected. Perennial crops will favor field species while woody crops will favor a variety of woodland species to a limited extent. Common woodland and hayland species may be the most favored species if any change can be detected at all.

The use of fertilizer, herbicide, pesticide, and fungicide on a landscape basis is not likely to be substantially reduced. Qualitative changes may be significant but implications on wildlife and its diversity has not been examined.

3.4.1.4 Major Regional Issues Concerning Biodiversity

The one site where island biogeography studies might show a significant change in species dynamics is in the Midwest. At this site, perhaps one field in 50 may be converted from rowcrops to trees. In a landscape limited in forested tracts and formerly partially forested, such additions may enhance wildlife movement and low populations of woodland species. This will be limited by the young age of woody crops. Such additions in the Northeast, Southeast, and Pacific Northwest would not present significantly altered patterns in forested tracts.

Regardless of these speculations, it will be important to conserve and protect wildlife corridors and refugia in all regions. The amount of land with wetness limitations in this evaluation translates to about one field in 60 over the landscape. Most of these fields are not considered candidate wetland sites. With roughly a third of the energy crop sites having some kind of wetness limitation, opportunities for wetland habitat improvement and corridor connections should be investigated.

The exclusion of agricultural sites with wetness limitations would have biomass supply ramifications that are regionally specific. It would eliminate the feasibility of energy crops in the Pacific Northwest and the concomitant reforestation of one field in 20 in that region. The Great Plains and Southeast would be little affected. The Northeast could not provide enough feedstock within a reasonable haul distance. And the Midwest would be significantly affected but still could generate needed biomass supplies. An alternative to categorical exclusions of land with wetness limitations is the search for buffer habitat opportunities on these sites.

The status of biological diversity, its trends, and the time needed to detect any changes as a result of energy crop deployment needs to be addressed. Data on particular species may not provide adequate information on the ecosystem as a whole so ecosystem functions may better provide indicators on this topic. This needs discussion and review among national and regional experts.

Obviously, economics will determine farmer decisions on land use. Prices of commodity crops, land productivity, and energy crop valuation weigh heavily but are difficult to predict. As demonstrated with the CRP, land of particular qualities can be moved in and out of agricultural production. These dynamics will have significant ramifications on the way biodiversity may be affected since both land quality and energy crop type are affected. An economic evaluation as a basis for land use conversion to energy crops is needed for better assessments on biodiversity.

The interactions between energy crop deployment and climate change have not been considered. In a time of rapid environmental change, species mobility (or avoidance of isolation) becomes increasingly important. In this respect, the woody crops as polycultures with rotation ages adjusted to their maximum, inclusion of buffer habitats, vegetation structural and species diversity, and improvement of wooded habitat connectivity are the dominant landscape improvements energy crops could provide.

The effects energy crops would have on reducing acid deposition and greenhouse gas emissions from fossil fuels was not translated to biodiversity effects. Such an effort would be difficult and highly speculative. However, these positive far ranging effects on biodiversity need to be evaluated and compared, in some form, as part of a total effect of energy crops compared to fossil fuel alternatives.

This five-site study assumed that no more than 7% of qualifying agricultural land uses would be converted to energy crops. The basis for this assumption is a crude attempt to maximize acreage for energy crops without significantly impacting agricultural commodity markets. The extent of the land converted to energy crops may have profound effects on biodiversity if this percentage were doubled or quadrupled. Such a comparative evaluation would assist in defining an ecologically acceptable and sustainable level. However, it would be worthwhile to first quantify the habitat and biodiversity qualities of the energy crops themselves.

It appears that harvest procedures and timing may be very important to selected species for all energy crops involved. This needs evaluation as a logical extension of energy crop habitat definition.

3.5 SOCIOECONOMIC ISSUES

3.5.1 Health and Safety

In the production of energy crops long-term storage of biomass will be required, although storage can be minimized by growing a variety of crops with different harvest windows. As noted by Egeneus and Wallin (1985), a breakdown of plant material occurs during storage because many types of microorganisms, which are present in the biomass, can use the lignocellulosic component as a substrate for growth. The resultant growth of spores and microorganisms can be a serious health hazard in handling biomass. Some of the potential health risks associated with spore and microorganism growth from biomass storage are presented in Table 36.

Standard forestry and farming operations have always been high risk occupations, and the production of energy crops is not likely to be much different from those situations. According to the National Safety Council about 4000 deaths and 200,000 disabling injuries occur each year from work-related accidents in farming and ranching (Hunt, 1983). About a quarter of these injuries are associated with tractors and farm machinery. Another 16% are associated with farm vehicles and trucks. However, nearly half of these injuries occur when the machinery is stopped or in-transit with the major cause being negligence on the part of the operator. Only 14% of farm-related injuries are from harvesting operations. Harvesting of short-rotation woody crops may not be as dangerous as standard forestry operations in that smaller equipment and smaller trees are being dealt with. Regulations or guidelines which address safety issues, particularly for harvesting practices, may be needed to reduce the risks involved. Such regulations are difficult to implement when many individual farmers are actually doing the work, such as would be the case with most herbaceous crops. In the case of short rotation woody crops, where much of the harvesting may be done by contract groups which specialize in harvesting, it would be easier to require that specific standards of safety be implemented.

3.5.2 Aesthetics and Employment

To supply an ethanol facility with 2000 dry tons of feedstocks each day will require the planting of 168,000 acres in the Northeast to 98,000 acres in the Pacific Northwest. The conversion of such large quantities of land may have numerous effects on the local economy and may create a number of externalities. For example, supplying 2000 dry tons/day (or about 2500 wet tons/day) will require that, on average, approximately 125 trucks enter and leave the facility each day. Somewhat more will be needed when energy cane and sorghum are being delivered. This means that five to seven trucks loads will be delivered per hour on a 24 hour schedule or up to 15 to 21 per hour if delivered only during eight hours of the day. The latter level of truck traffic would likely meet strong objections by the public living near the facility. If delivery is made over a 24 hour period, the objections might not be as strong unless the noise of the nighttime truck traffic becomes a problem.

Table 36. Health and safety risks from microorganism and spore growth on biomass in storage

Health risk	Type of biomass	Etiologic agent
Farmer's lung	Grain, straw	Micropolyspora faeni, Thermoactinomyces vulgare, Aspergillus fumigatus and others
Chip boiler's complaint	Mouldy chips	Rhizopus spp., Mucor spp., Aspergillus fumigatus and others
Brewer's lung	Grain	Aspergillus clavatus and others
Sauna bather's disease	Mouldy wood	Pullaria pullulans, Paecilomyces spp., and others
Notes: Reproduced from Egeneus and Wallin (1985)		

There may also be impacts resulting from changes in land use and ownership patterns. However, at the outset it was decided that energy crops would be viewed as a secondary crop occupying only 7% of the suitable land base. This low level of penetration should avoid competition with major agricultural crops yet make energy production a significant part of the local economy. Of course, specific impacts will depend on the relative economics of energy crops as compared with traditional crops and the influence of governmental policy on energy and agriculture. The nature of any impact depends on whether energy crops displace some existing crop or whether energy crops are grown in addition to current agricultural production. Total employment could be increased in an area if energy crops do not displace agriculture. If agriculture is displaced then the number and type of jobs may not change significantly but may change in composition.

The total labor hours required for supplying 715,400 dry tons of biomass feedstocks per year to a conversion facility are shown in Table 37. Total hours are highest at the Lincoln site (441,624 hours) and lowest at the Tifton site (351,050 hours). The number of hours required are function of the type of crop grown in the area and the assumed productivity. Transportation labor hours are also reported in Table 37. These hours are based on a 20 ton truck delivery load and an assumption of the number of hours required to deliver a load at each location. For the Rochester and Portland sites four labor hours per load were assumed, 3.5 hours per load at the Tifton site, and three hours per load at the Peoria and Lincoln sites. Total transport labor hours range from a low of 141,600 hours at Lincoln to 187,500 hours at Rochester and Portland.

Table 37. Total labor hours for energy crop production and harvesting

Location	Production and harvesting labor hours		
	Hours/acre	Total acres	Total labor hours
Tree crops			
Rochester	2.4	56,789	136,294
Tifton	2.6	60,097	156,252
Peoria	3.2	40,395	129,264
Lincoln	--	--	--
Portland	4.1	98,154	402,431
Perennial grasses			
Rochester	2.4	111,620	267,888
Tifton	3.2	54,262	173,638
Peoria	3.6	55,281	199,012
Lincoln	3.0	147,208	441,624
Portland	--	--	
Energy cane and sorghum			
Tifton	2.7	7,837	21,160
Peoria	4.3	10,307	44,320
Location	Transportation labor hours		
	Haul tonnage	Loads	Total labor hours
Rochester	938,495	46,865	187,460
Tifton	1,016,830	50,842	177,947
Peoria	1,067,830	53,392	160,176
Lincoln	943,953	47,198	141,594
Portland	937,309	46,865	187,460

Notes: Production and harvesting labor hours are based on average annual equipment operating hours (derived from Table 14). Transportation hours are based on a 20 ton delivery load and an assumption of 4 hours per load at the Rochester and Portland sites, 3.5 hours per load at the Tifton site, and 3 hours per load at the Peoria and Lincoln sites.

4. SUMMARY AND CONCLUSIONS

Land, fuel, and chemicals are all used in the production, harvesting, handling and transport of energy crops. The operations involved create soil erosion and compaction, particulate releases, air emissions from fuel use and chemical applications, (eg. CO_2 CO, NO_x, etc.), and runoff or leachate containing nitrogen (N), phosphorus (P) and potassium (K). Emissions from energy crop production and harvesting operations are calculated based on assumptions about equipment use (i.e., diesel fuel), soil losses, and agricultural chemical inputs. Emissions from feedstock transportation are based on assumptions about the consumption of low-sulphur diesel fuel. CO_2 recycled to the atmosphere from biomass decomposition are based on assumptions about the amount of biomass that is "lost" between the production fields and the conversion facility hopper. Emissions of VOCs from the growing biomass were deduced from literature reports of VOC emissions in controlled laboratory experiments.

Our analysis only summarized the direct emissions resulting from energy crop production, harvesting, handling and transportation. It did not attempt to evaluate the impact of those emissions by comparisons with agricultural food production operations since that would have required projections about future land use. The analysis of emissions from important supporting operations (such as the production of fertilizers) was performed separately from the direct emissions associated with energy crop production and is reported in another appendix. Emissions expressed as tons/acre and lbs/MMBtu are summarized in Tables 38 through 52 for each major crop type and location. Comparisons among the crop types and locations show the following.

Differences in emissions from woody and herbaceous crops were apparent and the best comparison can be made at Tifton were the amounts and type of land allocated to each are relatively similar. Herbaceous crop production produced larger nutrient emissions than woody crops because of the larger input levels. Woody crops resulted in larger herbicide emissions because of larger input levels. Emissions resulting from equipment use were relatively similar between woody and herbaceous crops. With respect to VOCs, the trees produced isoprenes and sorghum produced monoterpenes. No data were available to determine whether perennial grasses produced any emissions. Both the tree and sorghum levels of VOC production were within levels that might be expected from natural vegetation in the area.

Comparison of the Portland location and the Lincoln location shows some of the differences occurring between locations. Woody crops in Portland require almost one-third fewer acres than perennial grasses in Lincoln to produce the same amount of delivered feedstock. This results primarily from the higher yield capacity of the Portland location rather than inherent differences between trees and grasses. The use of less land and factor inputs in Portland results in considerably lower emissions to air and water resulting from fertilizer additions. Soil erosion is considerably lower in the Portland region because less land is used, and erosion is assumed to be lower.

A very large emission of CO_2 is shown in the final summary tables as a release from the decomposition of crops. Decomposition is a natural process that breaks down the crops left in the field during harvest and the crops held in storage. This CO_2 emission is not considered to be a "real emission", since it and all of the CO_2 emitted from the use of the feedstock in the conversion process is assumed to be recycled each year back into the growing feedstocks. This is true as long as energy crops continue to be produced to supply the energy facilities. The loss of this carbon to the atmosphere is negative only in the sense that it is carbon that is not converted to ethanol. However all the biomass carbon converted to ethanol also eventually ends up in the atmosphere. The output of decomposition derived CO_2 was calculated and shown for the purpose of providing input to a model which accounts for carbon throughout the entire biofuels system.

Of the emissions or outputs associated with crop production and harvesting which may not be recycled, the largest (expressed as tons of output) for all crops and locations is soil erosion. Sorghum production resulted in highest losses of soil both per acre and per unit of energy produced. However, sorghum did not strongly affect total soil loss since it was incorporated into the energy crop mix at only one site and is only planted on a total of about 10,000 acres of land. The biggest differences in soil loss were a function of the region of the country. The highest absolute soil loss was at the Lincoln location while the lowest soil loss was at the Portland location. The relationship of these estimated losses to "allowable soil loss rates" was not determined. However, in both locations the average soil loss per acre was estimated to be less than is presently occurring on cropland in those same general regions (based on the 1982 NRI). Future agricultural procedures would also likely result in less soil erosion. Thus the net effect of growing energy crops is likely to be only slightly, if any different from producing other agricultural commodities.

Fossil-fuel CO_2 was the second largest emission in terms of tons of material released from the production system. Total emissions of CO_2 and other compounds resulting from fossil-fuel use and fertilizer application are relatively similar for all locations even though crop types, inputs and operations varied. The specific crops with the lowest fossil-fuel emissions per unit of energy produced were sorghum and sugar cane. This was probably a function of the higher yields obtained while equipment use was similar to that assumed for other crops. The fossil-fuel emissions resulting from handling and transportation were considerably lower at the two locations with relative short average transportation distances, Peoria and Lincoln. The barge mode of transportation resulted in lower CO_2 emissions than either truck or rail per unit of material hauled, however the opportunity for barge transportation was limited in these locations. Although not obvious from the final summary tables (Tables 38-52), the net emissions of fossil-fuel CO_2 would likely be zero for many years due sequestration of carbon in the soil.

Carbon sequestration in the soil is a major benefit likely to accrue from energy crop production. Available information suggests that woody crops will have the greatest potential for sequestering carbon in the soil while perennial crops will have some potential provided the original land use was for some type of rowcrop (Table 27). Annual crops such as sorghum actually result in release of soil carbon to the atmosphere. A summary of soil carbon accumulation by location indicates that the estimated soil carbon accumulation that would occur in a 30 year time frame would offset all feedstock related fossil-fuel emissions for 45 to 65 years except at the Lincoln location where the offset would only last for 17 years. The Lincoln location is the only site not including trees and it also assumed that more than half of the land available was originally pasture thus the potential for soil carbon increases was limited. The value of soil carbon sequestration is maximized at the time when the soil carbon content first reaches equilibrium conditions. Literature suggests that equilibrium conditions would normally occurring in 20 to 50 years depending on initial site conditions. If an energy crop site were to be converted back to rowcrop use, the carbon sequestration benefits would eventually be lost.

The carbon sequestered in the aboveground biomass can only be considered a benefit to the biofuel system if the average standing biomass on the site exceeds the average standing biomass on the land prior to conversion to energy crops, and if biomass remains on the land after the conversion facility is shut down. If the latter assumptions are made, then the carbon sequestered in the standing biomass does add considerably to the CO_2 mitigation benefit that can be obtained from substituting biomass derived energy for fossil-fuel derived energy. Like the soil carbon benefit however, the benefit diminishes after some amount of time since the amount of carbon sequestered in the average standing biomass has a finite limit.

The vision of large scale production of energy crops is already raising many questions related to biodiversity and sustainability. Of course, evaluation of effects on biodiversity and sustainability would best be approached by determining the possible future use of the land. Without a crystal ball, we were only able to analyze how such factors might be affected given current land use. With the assumptions made for our study, it was determined that large amounts of rowcrops, pasture, closecrops, and hayland would be converted to perennial grasses and woody crops. Use of fertilizer, herbicide, pesticide and fungicide on a landscape basis is not likely to be substantially reduced in amount. However, it is believed that the changes in vegetation may provide more favorable habitat for common woodland and hayland species. Climax, endangered and threatened species are not likely to be affected either positively or negatively. Land with wetness limitations included in our selected energy crop landbase was primarily capability class II land. Since this is currently mostly in rowcrops and was generally assumed to be converted to tree crops, it would appear to be a positive habitat change.

The environmental risks and benefits of energy crop production, harvest, storage and transport emissions cannot be evaluated until a similar analysis is performed for other possible land use scenarios that could occur in 2010. One supposition is that much of the land would still be producing excess food crops. In that case, conversion to energy crop production and biofuel systems would have multiple societal benefits with very little risk. If, however, the excess cropland were to be permanently removed from crop production and allowed to revert to a natural state, then the benefits are not quite as clear cut. The risks of energy crop production would have to be weighed against the risks of continued fossil fuel use.

Follow-up studies are needed to develop future economic and policy based landuse scenarios both with and without energy crops. These studies will not be easy and will likely require the use of sophisticated models as well as the expertise of several people intimately familiar with farm policy effects and landowner decision making processes. It must include expertise that is available within the U.S. Department of Agriculture. It is only then that, perhaps, the environmental risks and benefits of energy crop production on a large scale in the U.S. can be predicted.

Much can be done to minimize the possible risks that can be associated with growing energy crops. It would be a worthwhile effort to evaluate a number of different possible energy crop production scenarios to determine which can best minimize risk and maximize benefits. The analysis can also point to needed areas of research for minimizing environmental, health and safety risks.

Table 38. Rochester tree feedstock production and harvesting summary

Main input: None
Main Output: 288,398 dry tons (4,902,766 MMBtu)
Planted acreage: 56,789

Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	574,219 gals	0.1171 gal
CO_2 (captured in feedstock)	576,742 tons	235.27 lbs
N-fertilizer	1022 tons	0.4170 lbs
P_2O_5-fertilizer	302.8 tons	0.1235 lbs
K_2O-fertilizer	302.8 tons	0.1235 lbs
Herbicides	4.99 tons	0.0020 lbs
Insecticides	0.23 tons	0.0001 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	11.20	0.0046
CO	48.89	0.0199
NO_x	48.89	0.0199
PM	5.09	0.0021
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	6479	2.64
SO_2	2.03	0.00083
N-fertilizer	102.2	0.0417
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	3.75	0.00153
Insecticides	0.17	0.00007
Soil (wind erosion)	2158	0.8803
Isoprene	7771	3.17
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	51.11	0.0208
P_2O_5-fertilizer	15.14	0.0062
K_2O-fertilizer	15.14	0.0062
Herbicides	0.50	0.00020
Insecticides	0.02	0.00001
Soil (dissolved solution)	2158	0.8803
Ground water		
N-fertilizer	51.11	0.0208
P_2O_5-fertilizer	15.14	0.0062
K_2O-fertilizer	15.14	0.0062
Herbicides	0.40	0.00016
Insecticides	0.02	0.00001
Land Erosion		
N-fertilizer	51.11	0.0208
P_2O_5-fertilizer	30.28	0.0124
K_2O-fertilizer	15.14	0.0062
Herbicides	0.25	0.00010
Insecticides	0.01	0.00000
Soil (Runoff)	17264	7.04

Table 39. Rochester perennial grass feedstock production and harvesting summary

Main input: None Main Output: 610,853 dry tons (9,162,795 MMBtu)		Planted acreage: 111,620
Inputs	**Units of Inputs**	**Inputs/MMBtu**
Diesel fuel	1,128,896 gals	0.1232 gals
CO_2 (captured in feedstock)	1,086,629 tons	237.18 lbs
N-fertilizer	5776.34 tons	1.2608 lbs
P_2O_5-fertilizer	3349 tons	0.7309 lbs
K_2O-fertilizer	5023 tons	1.0964 lbs
Herbicides	6.70 tons	0.0015 lbs
Insecticides	1.67 tons	0.0004 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	22.03	0.0048
CO	96.11	0.0210
NO_x	96.11	0.0210
PM	10.11	0.0022
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	12,734	2.78
SO_2	4.00	0.00087
N-fertilizer	577.6	0.1261
P_2O_5-fertilizer	0.0	0.0000
K_2O-fertilizer	0.0	0.0000
Herbicides	5.02	0.00110
Insecticides	1.26	0.00027
Soil (wind erosion)	11608	2.53
Isoprene	nd	nd
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	288.8	0.0630
P_2O_5-fertilizer	167.43	0.0365
K_2O-fertilizer	251.15	0.0548
Herbicides	0.67	0.00015
Insecticides	0.17	0.00004
Soil (dissolved solution)	11608	2.53
Ground water		
N-fertilizer	288.8	0.0630
P_2O_5-fertilizer	167.4	0.0365
K_2O-fertilizer	251.2	0.0548
Herbicides	0.54	0.00012
Insecticides	0.13	0.00003
Land Erosion		
N-fertilizer	288.8	0.0630
P_2O_5-fertilizer	334.9	0.0731
K_2O-fertilizer	251.15	0.0548
Herbicides	0.33	0.00007
Insecticides	0.08	0.00002
Soil (Runoff)	92868	20.27

Table 40. Tifton tree feedstock production and harvesting summary

Main input: None	Planted acreage: 60,097	
Main Output: 399,171 dry tons (6,785,907 MMBtu)		
Inputs	**Units of Inputs**	**Inputs/MMBtu**
Diesel fuel	653,144 gals	0.0963 gals
CO_2 (captured in feedstock)	782,763 tons	230.70 lbs
N-fertilizer	1217 tons	0.3587 lbs
P_2O_5-fertilizer	360.5 tons	0.1062 lbs
K_2O-fertilizer	360.5 tons	0.1062 lbs
Herbicides	5.95 tons	0.0018 lbs
Insecticides	0.27 tons	0.0001 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	12.74	0.0038
CO	55.61	0.0164
NO_x	55.61	0.0164
PM	5.79	0.0017
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	7372	2.17
SO_2	2.31	0.00068
N-fertilizer	121.7	0.0359
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	4.46	0.00132
Insecticides	0.20	0.00021
Soil (wind erosion)	2344	0.6908
Isoprene	3359	0.99
Monoterpene	254.47	0.075
Water Releases		
Surface water		
N-fertilizer	61	0.0179
P_2O_5-fertilizer	18.02	0.0053
K_2O-fertilizer	18.02	0.0053
Herbicides	0.59	0.00018
Insecticides	0.03	0.00001
Soil (dissolved solution)	2344	0.6908
Ground water		
N-fertilizer	60.85	0.0179
P_2O_5-fertilizer	18.02	0.0053
K_2O-fertilizer	18.02	0.0053
Herbicides	0.48	0.00004
Insecticides	0.02	0.00001
Land Erosion		
N-fertilizer	60.85	0.0179
P_2O_5-fertilizer	36.05	0.0106
K_2O-fertilizer	18.02	0.0053
Herbicides	0.30	0.00009
Insecticides	0.01	0.00000
Soil (Runoff)	18750	5.53

Table 41. Tifton perennial grass feedstock production and harvesting summary

Main input: None — Planted acreage: 54,262
Main Output: 388,564 dry tons (5,828,460 MMBtu)

Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	710,047 gals	0.1218 gals
CO_2 (captured in feedstock)	696,189 tons	238.89 lbs
N-fertilizer	2198 tons	0.7541 lbs
P_2O_5-fertilizer	1628 tons	0.5586 lbs
K_2O-fertilizer	2442 tons	0.8379 lbs
Herbicides	3.80 tons	0.0013 lbs
Insecticides	0.81 tons	0.0003 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	13.85	0.0048
CO	60.45	0.0207
NO_x	60.45	0.0207
PM	6.30	0.0022
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	8015	2.75
SO_2	2.52	0.00086
N-fertilizer	219.8	0.0754
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	2.85	0.00098
Insecticides	0.61	0.00021
Soil (wind erosion)	2713	0.9310
Isoprene	nd	nd
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	109.9	0.0377
P_2O_5-fertilizer	81.39	0.0279
K_2O-fertilizer	122.09	0.0419
Herbicides	0.38	0.00013
Insecticides	0.08	0.00003
Soil (dissolved solution)	2713	0.9310
Ground water		
N-fertilizer	109.9	0.0377
P_2O_5-fertilizer	81.39	0.0279
K_2O-fertilizer	122.1	0.0419
Herbicides	0.30	0.00010
Insecticides	0.07	0.00002
Land Erosion		
N-fertilizer	109.9	0.0377
P_2O_5-fertilizer	162.8	0.0559
K_2O-fertilizer	122.1	0.0419
Herbicides	0.19	0.00007
Insecticides	0.04	0.00001
Soil (Runoff)	21704	7.45

Table 42. Tifton energy cane feedstock production and harvesting summary

Main input: None	Planted acreage: 7,837	
Main Output: 84,161 dry tons (1,262,415 MMBtu)		
Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	89,096 gals	0.0706 gals
CO_2 (captured in feedstock)	145,847 tons	231.08 lbs
N-fertilizer	546.6 tons	0.8660 lbs
P_2O_5-fertilizer	195.9 tons	0.3104 lbs
K_2O-fertilizer	313.5 tons	0.4966 lbs
Herbicides	0.63 tons	0.0010 lbs
Insecticides	0.16 tons	0.0002 lbs
Outputs/Releases	Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	1.74	0.0028
CO	7.59	0.0120
NO_x	7.59	0.0120
PM	0.79	0.0013
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	1005	1.59
SO_2	0.32	0.00050
N-fertilizer	54.66	0.0866
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	0.47	0.00074
Insecticides	0.12	0.00019
Soil (wind erosion)	407.5	0.6456
Isoprene	nd	nd
Monoterpene	5.87	0.0093
Water Releases		
Surface water		
N-fertilizer	27.33	0.0433
P_2O_5-fertilizer	9.80	0.0155
K_2O-fertilizer	15.67	0.0248
Herbicides	0.06	0.00010
Insecticides	0.02	0.00002
Soil (dissolved solution)	407.5	0.6456
Ground water		
N-fertilizer	27.33	0.0433
P_2O_5-fertilizer	9.80	0.0155
K_2O-fertilizer	15.67	0.0248
Herbicides	0.05	0.00008
Insecticides	0.01	0.00002
Land Erosion		
N-fertilizer	27.33	0.0433
P_2O_5-fertilizer	19.59	0.0310
K_2O-fertilizer	15.67	0.0248
Herbicides	0.03	0.00005
Insecticides	0.01	0.00001
Soil (Runoff)	3260	5.16

Table 43. Peoria tree feedstock production and harvesting summary

Main input: None Main Output: 277,237 dry tons (4,713,029 MMBtu)	Planted acreage: 40,395	
Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	541,914 gals	0.1150 gals
CO_2 (captured in feedstock)	551,374 tons	233.98 lbs
N-fertilizer	727.1 tons	0.3086 lbs
P_2O_5-fertilizer	215.4 tons	0.0914 lbs
K_2O-fertilizer	215.4 tons	0.0914 lbs
Herbicides	3.56 tons	0.0015 lbs
Insecticides	0.16 tons	0.0001 lbs
Outputs/Releases	Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	10.57	0.0045
CO	46.14	0.0196
NO_x	46.14	0.0196
PM	4.81	0.0020
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	6117	2.60
SO_2	1.92	0.00082
N-fertilizer	72.71	0.0309
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	2.67	0.00113
Insecticides	0.12	0.00005
Soil (wind erosion)	12361	5.25
Isoprene	5962	2.53
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	36.36	0.0154
P_2O_5-fertilizer	10.77	0.0046
K_2O-fertilizer	10.77	0.0046
Herbicides	0.36	0.00015
Insecticides	0.02	0.00001
Soil (dissolved solution)	6180	2.62
Ground water		
N-fertilizer	36.36	0.0154
P_2O_5-fertilizer	10.77	0.0046
K_2O-fertilizer	10.77	0.0046
Herbicides	0.28	0.00012
Insecticides	0.01	0.00001
Land Erosion		
N-fertilizer	36.36	0.0154
P_2O_5-fertilizer	21.54	0.0091
K_2O-fertilizer	10.77	0.0046
Herbicides	0.18	0.00008
Insecticides	0.01	0.00000
Soil (Runoff)	43263	18.36

Table 44. Peoria perennial grass feedstock production and harvesting summary

Main input: None   Planted acreage: 55,281
Main Output: 457,126 dry tons (6,856,890 MMBtu)

Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	831,283 gals	0.1212 gals
CO_2 (captured in feedstock)	816,100 tons	238.04 lbs
N-fertilizer	2550 tons	0.7437 lbs
P_2O_5-fertilizer	1658 tons	0.4837 lbs
K_2O-fertilizer	2488 tons	0.7256 lbs
Herbicides	3.59 tons	0.0010 lbs
Insecticides	0.83 tons	0.0002 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	16.22	0.0047
CO	70.77	0.0206
NO_x	70.77	0.0206
PM	7.37	0.0022
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	9382	2.74
SO_2	2.95	0.00086
N-fertilizer	255.0	0.0744
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	2.69	0.00079
Insecticides	0.62	0.00018
Soil (wind erosion)	18906	5.51
Isoprene	nd	nd
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	127.49	0.0372
P_2O_5-fertilizer	82.92	0.0242
K_2O-fertilizer	124.38	0.0363
Herbicides	0.36	0.00010
Insecticides	0.08	0.00002
Soil (dissolved solution)	9453	2.76
Ground water		
N-fertilizer	127.49	0.0372
P_2O_5-fertilizer	82.92	0.0242
K_2O-fertilizer	124.38	0.0363
Herbicides	0.29	0.00008
Insecticides	0.07	0.00002
Land Erosion		
N-fertilizer	127.49	0.0372
P_2O_5-fertilizer	165.64	0.0484
K_2O-fertilizer	124.38	0.0363
Herbicides	0.18	0.00005
Insecticides	0.04	0.00001
Soil (Runoff)	66171	19.30

Table 45. Peoria sorghum feedstock production and harvesting summary

Main input: None Main Output: 137,885 dry tons (2,068,275 MMBtu)	Planted acreage: 10,631	
Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	188595 gals	0.0912 gals
CO_2 (captured in feedstock)	242,501 tons	234.50 lbs
N-fertilizer	691.0 tons	0.6682 lbs
P_2O_5-fertilizer	372.1 tons	0.3598 lbs
K_2O-fertilizer	478.4 tons	0.4626 lbs
Herbicides	8.51 tons	0.0082 lbs
Insecticides	2.13 tons	0.0021 lbs
Outputs/Releases	Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	3.68	0.0036
CO	16.06	0.0155
NO_x	16.06	0.0155
PM	1.67	0.0016
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	2128	2.06
SO_2	0.67	0.00065
N-fertilizer	103.6	0.1002
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	6.38	0.00617
Insecticides	1.59	0.00154
Soil (wind erosion)	14436	13.96
Isoprene	nd	nd
Monoterpene	4.76	0.0046
Water Releases		
Surface water		
N-fertilizer	69.10	0.0668
P_2O_5-fertilizer	18.60	0.0180
K_2O-fertilizer	23.92	0.0231
Herbicides	0.85	0.00082
Insecticides	0.21	0.00021
Soil (dissolved solution	7218	6.98
Ground water		
N-fertilizer	103.6	0.1002
P_2O_5-fertilizer	18.60	0.0180
K_2O-fertilizer	23.92	0.0231
Herbicides	0.68	0.00066
Insecticides	0.17	0.00016
Land Erosion		
N-fertilizer	69.10	0.0668
P_2O_5-fertilizer	37.21	0.0360
K_2O-fertilizer	23.92	0.0231
Herbicides	0.43	0.00041
Insecticides	0.11	0.00010
Soil (Runoff)	50529	48.86

Table 46. Lincoln perennial grass feedstock production and harvesting summary

Main input: None Planted acreage: 147,208
Main Output: 990,897 dry tons (14,863,455 MMBtu)

Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	1,825,339 gals	0.1228 gals
CO_2 (captured in feedstock)	1,768,125 tons	237.92 lbs
N-fertilizer	5962 tons	0.8022 lbs
P_2O_5-fertilizer	4416 tons	0.5942 lbs
K_2O-fertilizer	6624 tons	0.8914 lbs
Herbicides	10.30 tons	0.0014 lbs
Insecticides	2.21 tons	0.0003 lbs
Outputs/Releases	**Outputs (tons)**	**Outputs (lbs/MMBtu)**
Air Releases		
HC	35.61	0.0048
CO	155.40	0.0209
NO_x	155.40	0.0209
PM	16.19	0.0022
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	20,598	2.77
SO_2	6.47	0.00087
N-fertilizer	596.2	0.0802
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	7.73	0.00104
Insecticides	1.66	0.00022
Soil (wind erosion)	120121	16.16
Isoprene	nd	nd
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	298.1	0.0401
P_2O_5-fertilizer	220.8	0.0297
K_2O-fertilizer	331.2	0.0446
Herbicides	1.03	0.00014
Insecticides	0.22	0.00003
Soil (dissolved solution)	30030	4.0408
Ground water		
N-fertilizer	298.1	0.0401
P_2O_5-fertilizer	220.8	0.0297
K_2O-fertilizer	331.2	0.0446
Herbicides	0.82	0.00011
Insecticides	0.18	0.00002
Land Erosion		
N-fertilizer	298.1	0.0401
P_2O_5-fertilizer	441.6	0.0594
K_2O-fertilizer	331.22	0.0446
Herbicides	0.52	0.00007
Insecticides	0.11	0.00001
Soil (Runoff)	150152	20.20

Table 47. Portland tree feedstock production and harvesting summary

Main input: None Main Output: 865,374 dry tons (14,716,458 MMBtu)		Planted acreage: 98,184
Inputs	Units of Inputs	Inputs/MMBtu
Diesel fuel	1,674,373 gals	0.1138 gals
CO_2 (captured in feedstock)	1,702,004 tons	231.31 lbs
N-fertilizer	2649.74 tons	0.3601 lbs
P_2O_5-fertilizer	785.0 tons	0.1067 lbs
K_2O-fertilizer	785.0 tons	0.1067 lbs
Herbicides	12.95 tons	0.0018 lbs
Insecticides	0.59 tons	0.0001 lbs
Outputs/Releases	Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	32.67	0.0044
CO	142.6	0.0194
NO_x	142.6	0.0194
PM	14.85	0.0020
VOCs	nil	nil
Aldehydes	nil	nil
CO_2-fossil fuel	18,890	2.57
SO_2	5.93	0.00081
N-fertilizer	265.0	0.0360
P_2O_5-fertilizer	0.00	0.0000
K_2O-fertilizer	0.00	0.0000
Herbicides	9.72	0.00132
Insecticides	0.44	0.00006
Soil (wind erosion)	2553	0.3469
Isoprene	8876	1.21
Monoterpene	nd	nd
Water Releases		
Surface water		
N-fertilizer	132.5	0.0180
P_2O_5-fertilizer	39.25	0.0053
K_2O-fertilizer	39.25	0.0053
Herbicides	1.30	0.00018
Insecticides	0.06	0.00001
Soil (dissolved solution)	2553	0.3469
Ground water		
N-fertilizer	132.49	0.0180
P_2O_5-fertilizer	39.25	0.0053
K_2O-fertilizer	39.25	0.0053
Herbicides	1.04	0.00014
Insecticides	0.05	0.00001
Land Erosion		
N-fertilizer	132.5	0.0180
P_2O_5-fertilizer	78.49	0.0107
K_2O-fertilizer	39.25	0.0053
Herbicides	0.65	0.00009
Insecticides	0.03	0.00000
Soil (Runoff)	20,422	2.78

Table 48. Rochester biomass feedstock losses and transportation summary

Mode #1: Diesel truck	Mode #2: Diesel barge
Average distance (one-way): 48.0 miles	Average distance (one-way): 90.0 miles with 24.0 miles truck
Haul tonnage: 563,097 tons	Haul tonnage: 375,398 tons
Main input: 899,251 dry tons (14,065,561 MMBtu)	
Main output: 715,437 dry tons (11,208,279 MMBtu)	

Transport Mode #1: Diesel Truck		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	600,637	0.0322
Outputs/Releases	Units of Output (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	5.34	0.00095
CO	21.37	0.00381
NO_x	21.37	0.00381
PM	0.85	0.00015
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	6783	1.21
SO_2	2.13	0.00038
CO_2 - decomposition	172,639	30.81

Transport Mode #2: Diesel Barge		
Inputs	Units of Inputs (gals)	Inputs (lbs/MMBtu)
Diesel Fuel	210,013	0.0075
Outputs/Releases	Units of Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	1.33	0.00024
CO	4.43	0.00079
NO_x	22.13	0.00395
PM	0.44	0.00008
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	2370	0.42288
SO_2	0.88	0.00016
CO_2 - decomposition	115,092	20.54

Table 49. Tifton biomass feedstock losses and transportation summary

Mode: Diesel truck Average distance (one-way): 43.1 miles Haul tonnage: 1,016,830 tons Main input: 871,896 dry tons (13,876,782 MMBtu) Main output: 715,492 dry tons (11,392,210 MMBtu)		
Transport Mode: Diesel Truck		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	730,423	0.0641
Outputs/Releases	Units of Output (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	6.50	0.00114
CO	25.99	0.00456
NO_x	25.99	0.00456
PM	1.04	0.00018
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	8250	1.45
SO_2	2.59	0.00045
CO_2 - decomposition	254,601	44.70

Table 50. Peoria biomass feedstock losses and transportation summary

Mode: Diesel truck Average distance (one-way): 25.7 miles Haul tonnage: 1,067,830 tons Main input: 872,248 dry tons (13,638,194 MMBtu) Main output: 715,588 dry tons (11,192,089 MMBtu)		
Transport Mode: Diesel Truck		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	457,376	0.0409
Outputs/Releases	Units of Output (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	4.07	0.00073
CO	16.27	0.00291
NO_x	16.27	0.00291
PM	0.65	0.00012
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	5166	0.92311
SO_2	1.62	0.00029
CO_2 - decomposition	247,225	44.18

Table 51. Lincoln biomass feedstock losses and transportation summary

Mode: Diesel truck
Average distance (one-way): 29.4 miles
Haul tonnage; 943,953
Main input: 990,897 dry tons (14,863,455 MMBtu)
Main output: 715,527 dry tons (10,732,901 MMBtu)

Transport Mode: Diesel Truck		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	462,537	0.0431
Outputs/Releases	Units of Output (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	4.11	0.00077
CO	16.46	0.00307
NO_x	16.46	0.00307
PM	0.66	0.00012
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	5224	0.97346
SO_2	1.64	0.00031
CO_2 - decomposition	403,583	75.20

Table 52. Portland biomass feedstock losses and transportation summary

Mode #1: Diesel truck	Mode #2: Diesel locomotive
Average distance (one-way): 46.0 miles	Average distance (one-way): 140.5 miles with 25.0 miles truck
Haul tonnage: 309,419 tons	Haul tonnage: 628,215 tons
Main input: 865,674 dry tons (14,716,458 MMBtu)	
Main output: 715,480 dry tons (12,163,153 MMBtu)	

Transport Mode #1: Diesel Truck		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	498,977	0.0275
Outputs/Releases	Units of Output (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	4.44	0.00073
CO	17.75	0.00292
NO_x	17.75	0.00292
PM	0.71	0.00012
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	5635.62	0.92667
SO_2	1.77	0.00029
CO_2 - decomposition	90,802	14.93

Transport Mode #2: Diesel Locomotive (Rail)		
Inputs	Units of Inputs (gals)	Inputs (gals/MMBtu)
Diesel Fuel	589,799	0.0160
Outputs/Releases	Units of Outputs (tons)	Outputs (lbs/MMBtu)
Air Releases		
HC	3.73	0.00061
CO	12.43	0.00204
NO_x	62.15	0.01022
PM	1.24	0.00020
VOCs	nil	nil
Aldehydes	nil	nil
CO_2 - fuel	6656	1.09
SO_2	2.48	0.00041
CO_2 - decomposition	184,355	30.31

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