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GLOBAL WARMING MITIGATION
POTENTIAL OF THREE
TREE PLANTATION SCENARIOS

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GLOBAL WARMING MITIGATION POTENTIAL OF THREE TREE PLANTATION SCENARIOS

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ABSTRACT

The report gives results of an analysis of three alternative uses of forests in the U.S. to reduce atmospheric carbon dioxide (CO_2) concentrations: (1) planting trees with no harvesting, (2) traditional forestry, and (3) short-rotation intensive culture of trees for biomass. Increasing concentrations of CO_2 and other radiatively important trace gases (RITGs) are of concern due to their potential to alter the Earth's climate. Some scientists, after reviewing the results of general circulation models, predict rising average temperatures and alterations in the Earth's hydrologic cycle. While the debate continues over the actual magnitude of global warming, most scientists agree that some change will occur over the next century. This places a burden on policymakers to address global warming and to develop mitigation measures. Since forests provide a sink for carbon by fixing CO_2 to produce biomass, halting deforestation and creating new forests have been proposed as ways to slow the buildup of carbon in the Earth's atmosphere.

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SECTION 1
INTRODUCTION

Increasing concentrations of carbon dioxide (CO_2) and other radiatively-important trace gases (RITGs) are of concern due to their potential to alter the earth's climate. Some scientists, after reviewing the results of general circulation models, predict rising average temperatures and alterations in the earth's hydrologic cycle. While the debate continues over the actual magnitude of global warming, most scientists agree that some change will occur over the next century. This places a burden on policymakers to address global warming, and to develop mitigation measures. To support the decision-making process, the U.S. EPA's Air and Energy Engineering Research Laboratory is providing technical analyses of a variety of global warming mitigation measures. This report describes the results of an analysis of some alternate uses of forests in the United States to reduce atmospheric CO_2 concentrations.

Since forests provide a sink for carbon by fixing carbon dioxide (CO_2) to produce biomass, halting deforestation and creating new forests have been proposed as means of slowing the buildup of carbon (Flavin, 1990). In addition to acting as a carbon sink, trees planted around buildings provide shade and can reduce energy required for cooling in the summer. However, using trees to scrub CO_2 from the atmosphere is a near-term solution. During the early, high-growth phase of life, a forest serves as a carbon sink. Eventually, the rate of growth slows, and the death and decay of branches and leaves begins to offset the carbon sink effect. Finally, as trees die and decompose, much of the sequestered carbon returns to the atmosphere.

An alternative is to harvest the trees periodically and replant. This maintains the forest in its active growth phase, maximizing the carbon uptake. In order for this to be effective, the harvested wood must be used in a way that conserves RITGs. If the wood is used for fuel, replacing fossil fuels, then although carbon dioxide is released, no "new" carbon dioxide is added to the atmosphere. On the other hand, if it is used to make disposable paper products, the carbon will again be released into the atmosphere without offsetting other carbon dioxide sources. If the wood is used in a form that delays its eventual decay and release to the atmosphere, then some mitigative effect will be realized.

The purpose of the work described in this report was to analyze three reforestation scenarios that are potential global warming mitigation methods: (1) planting trees with no harvesting, (2) traditional forestry, and (3) short-rotation intensive culture (SRIC) of trees for biomass. In addition to the cycling of CO_2 through the trees, all other sources of CO_2 and other RITGs associated with site preparation, tree planting, harvesting, and other activities specific to each scenario also were estimated. The costs associated with each scenario were estimated, and the cost of using wood biomass as an alternative to fossil fuel was evaluated.

An overview of the approach used in this study along with a discussion of the results is given in Section 2. The details of the analyses are described in Sections 3 and 4, and Appendices A, B, and C. Section 5 presents a brief discussion of some of the key assumptions and limitations of this study.

SECTION 2
OVERVIEW AND RESULTS

The choices of tree species, land base, and end-use of the wood will dramatically affect the results of an analysis such as this one. In this study, a common land base was used to evaluate three very different planting and end-use scenarios: No Harvest (NH), Traditional Forestry (TF), and Short-Rotation Intensive Culture (SRIC). In both the NH and TF scenarios, trees are planted in plantations at densities that average 1,000 trees/ha. The SRIC scenario assumes an average density of 2100 trees/ha. The NH scenario assumes the tree plantations are never harvested, but are left to follow a natural successional pattern. Trees are harvested every 6-8 years under the SRIC scenario, as compared to 35-80 year rotations under the TF scenario.

Existing forest land was not included in the land base. Since mature forests store large amounts of carbon, replacing these forests with plantations may actually increase atmospheric carbon dioxide concentrations (Harmon et al., 1990). This issue was avoided in this study by creating new forests on unforested land: crop and pasture land in the United States. Land that is in need of erosion control was used as the land base for all three scenarios. A total of 40.4 million hectares in ten geographical regions was used for this study (Figure 1).

In the NH scenario, mitigation of global warming is achieved by the sequestering of carbon in growing trees. In an actively growing forest, carbon (as CO_2) is removed from the atmosphere at a much higher rate than it is released (as CO_2 or methane) by decomposition. After some period of time, the growth rate slows, dead biomass accumulates, and decomposition processes become more predominant. For this study, it was assumed that a steady-state carbon balance (i.e., no net flux) is reached at maturity. In fact, it is not known whether mature forests continue to sequester carbon, become a source of carbon, or reach a steady-state. Also, the exact length of time that a young forest acts as a net sink is unknown. In this analysis, the length of one rotation in traditional forestry was assumed to represent the period of active growth. Therefore, in the NH scenario, carbon is sequestered for a period of time equal to the length of one TF rotation for the region.

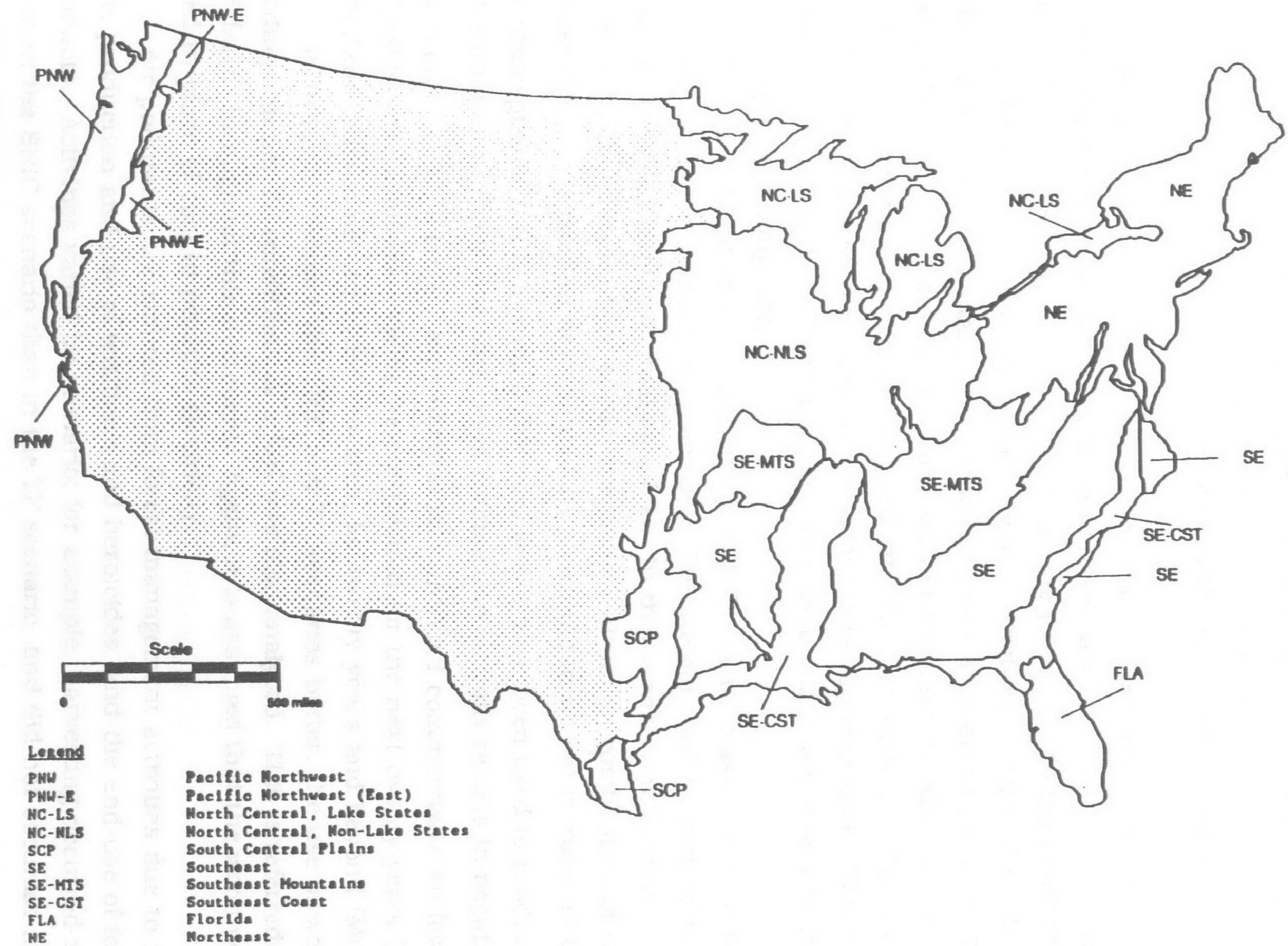

FIGURE 1. MAP OF REGIONS USED FOR ESTABLISHMENT OF TREE PLANTATIONS

It should be noted, however, that traditional forestry rotation lengths are based on the period of time it takes to maximize mean annual growth increment. Active growth periods may be twice as long, although growth rates decline over time.

The TF scenario, in effect, extends the carbon sink indefinitely by maintaining the forest in the active growth phase. It is assumed that the wood is used in such a way that carbon is not immediately returned to the atmosphere. This may be by using the wood to build houses, furniture, or other durable items, or by storing it in some manner which would prevent its decomposition. The practicality and cost of storing the wood are not considered. Also, the economic effect on the wood market are not factored into the cost analysis. Yields were derived from published data and were assumed constant over time. These same yields were used for the NH scenario, but were assumed to apply only to the young, rapidly growing forest.

The Short Rotation Intensive Culture (SRIC) scenario assumes that trees are grown solely for the production of biomass. The biomass will be burned to produce electricity, replacing coal as a fuel. In this scenario, mitigation is achieved by the displacement of coal emissions. Although combustion of wood releases CO_2, it is fixed in new plantations, resulting in no net increase of CO_2 in the atmosphere. If it is assumed that coal would have been used to produce the same amount of electricity, then wood combustion actually results in negative CO_2 emissions. SRIC is largely experimental and untested commercially, so few data on yields were available. Yields were estimated for the next twenty years (Near-term) and, assuming continued research, for twenty years and beyond (Mid-term).

In order to compare the SRIC and TF scenarios better, the use of wood produced under TF conditions as a fuel was also analyzed. This is referred to as "TF burn" throughout this document. Again, it is assumed that the wood would be used in place of coal to produce electricity.

Air pollutants are emitted from forest management activities due to machine use, production and use of fertilizers and herbicides, and the end-use of forest products. Activities varied by scenario; for example, harvesting occurred more often in the SRIC scenario than in the TF scenario, and did not occurred at all in the NH scenario.

Table 1 lists the forest management activities included in this analysis, and the pollutants emitted from these activities that were included in the analysis. A

Table 1 lists the forest management activities included in this analysis, and the pollutants emitted from these activities that were included in the analysis. A few emissions were not included because the data were inadequate to calculate a reliable emission factor.

Emissions Analysis Results

The annual emissions for each scenario are shown in Table 2. The cumulative emissions are also shown for the years 2050 and 2100. The cumulative numbers were derived as follows:

- for SRIC, the near-term yields were assumed for the first 20 years, the mid-term yields thereafter;
- for TF and TF (burn), yields were assumed constant over time; and,
- for NH, TF yields were assumed through 2050, when carbon cycling was assumed to reach a steady-state. VOCs continue to be produced, however.

In Table 2, a negative number indicates a sink, a positive number indicates a source. Choosing the best mitigation scenario depends on the criteria used. If CO_2 reduction alone is considered, the SRIC scenario is clearly the most effective. This result is driven entirely by the high yields assumed for SRIC. Using the TF-produced wood for combustion is not nearly as effective, but only because yields are lower.

The TF scenario does appear to be a good long-term solution if only CO_2 reduction is considered. However, the periodic harvesting and planting emissions result in greater emissions of CO, CH_4, NO_x, N_2O, and SO_2 for the TF scenario than for the NH. Since the first four are greenhouse gases with radiative forcing values higher than CO_2, the relative contribution of these emissions should not be ignored. Furthermore, SO_2 is a contributor to acid precipitation. Overall, the NH scenario may be a better choice for RITG reduction than the TF.

TABLE 1. FOREST MANAGEMENT ACTIVITIES AND POLLUTANTS EMITTED[a]

Activity	CO_2	CO	VOC	NO_x	CH_4	SO_x	N_2O
Planting	X	X	X	X		X	
Fertilizer Production	X			X			
Pesticide Production	X	X		X		X	
Fertilizer Use							X
Hydrocarbons Emitted from Trees			X				
Prescribed Burning	X	X	X	X	X		
Harvesting	X	X	X	X		X	
Wood Transportation	X	X	X	X			
Wood Combustion	X	X		X			
Coal Mining (Displacement)					X		
Coal Transportation (Displacement)	X	X	X	X			
Coal Combustion (Displacement)	X	X		X		X	

[a]Only those pollutants and activities quantified in this study are shown.

TABLE 2. SUMMARY OF REFORESTATION SCENARIOS: EMISSIONS

Scenario	CO_2	CO	VOC	CH_4	NO_x	N_2O	SO_2
Total Annual Emissions (1000 Mg/Yr)							
SRIC							
Near-term	-980000	2006	8037	-2867	-1004	0.7	-4865
Mid-term	-1700000	3045	8005	-5038	-1720	0.7	-8275
TF	-210000	2376	7884	104	63	0.3	1.4
TF (burn)	-90000	2597	7873	-240	-81	0.3	-566
NH	-260000	0	7740	--	1.5	0.3	1.0
Total Emissions by Year 2050 (1000 Mg)							
SRIC	-8.8E+07	176400	490000	-258900	-8894	42	-428300
TF	-1.3E+07	142600	473100	6240	3786	18	84
TF (burn)	-5400000	155900	472400	-14440	-4872	18	-34010
NH	-1.6E+07	12	464400	0	90	18	60
Total Emissions by Year 2100 (1000 Mg)							
SRIC	-1.7E+08	346600	881300	-510800	-174900	77	-842100
TF	-2.3E+07	271500	867300	11440	6941	33	154
TF (burn)	-9900000	285800	866100	-26470	-8932	33	-62360
NH	-1.6E+07	12	851400	0	90	18	60

The SRIC and TF (burn) scenarios result in decreased CH_4, NO_x, and SO_2 emissions. The latter two are reduced because wood combustion releases somewhat less NO_x and significantly less SO_2 than coal combustion. The CH_4 reduction occurs because less coal has to be mined (methane is released when coal is mined).

All scenarios result in increased CO, VOC and N_2O. The increase in VOC comes almost entirely from the trees in the form of terpenes and isoprenes. The increase in CO is partly due to the combustion of diesel fuel in the machinery used for planting and harvesting, but is mostly attributable to wood combustion. In the two cases where wood replaces coal, a net increase in CO occurs because wood combustion produces relatively high amounts of CO. Also, prescribed burning in the TF scenario contributes some CO.

To put these results in perspective, Table 3 shows the anthropogenic emissions of four of the pollutants expressed as a percentage of the 1985 NAPAP annual anthropogenic emissions. VOC emitted from trees were not included since biogenic sources are not included in the NAPAP inventory. Also, CO_2, N_2O, and CH_4 are not in the inventory. All scenarios result in a small increase in CO emissions, but significant reductions in SO_2 are achieved in the SRIC scenario.

Cost Analysis Results

Costs of Biomass Production

To adjust for differences in the rotation length and annual yields between the investment scenarios, present net costs for each investment scenario were found and annualized over the investment's length. The method used to annualize the investments converted cash streams, which were variable over time, into even flow cash streams. The annualized values were then divided by the annual biomass yields to give the annualized cost of producing a Mg. of biomass. These costs are reported in Table 4.

TABLE 3. ANTHROPOGENIC EMISSIONS FROM TREE PLANTATION SCENARIOS EXPRESSED AS PERCENTAGE OF 1985 NAPAP ANTHROPOGENIC EMISSIONS

Scenario	CO	NO_x	SO_2	VOC
SRIC				
Near-term	3.62	-5.38	-23.21	-.23
Mid-term	6.14	-9.21	-39.47	-.39
TF	4.29	0.34	0.01	.72
TF (burn)	4.68	-0.43	-2.70	.67
NH	0.00	0.01	0.00	0
1985 NAPAP Annual Anthropogenic Emissions (1000 Mg/year)[a]	55,460	18,670	20,960	20,080

[a]Derived from: U.S. Environmental Protection Agency, 1989.

TABLE 4. DISCOUNTED COSTS OF BIOMASS PRODUCTION
(per Mg)

Region	Near-term Mid-term SRIC	Traditional SRIC[a]	Forestry
South Florida	$51.45	$38.17	$51.48
Southeast Coast	53.15	39.91	51.48
Southeast	57.65	42.41	33.48
Southeast Mountains	60.66	44.16	35.12
Northeast	57.30	45.94	63.13
North Central Lake States	54.44	43.95	36.08
North Central Non-Lake States	49.16	41.08	50.57
South Central Plains	64.34	49.32	___[b]
Pacific Northwest-West	49.28	39.11	12.46
Pacific Northwest-East	59.25	49.28	87.13

[a]Yields projected to be obtainable in 20 years.

[b]Traditional forestry not practical in this region.

Market values of the products from each scenario were not included. It was assumed that a unit of biomass was equally valuable toward mitigating CO2 concentrations in the atmosphere regardless of its value as a forest product. Experts estimate large increases in the productivity of SRIC forestry. Separate cost analyses were conducted for the SRIC scenario using the higher mid-term yields. No increases in productivity were assumed for traditional forestry.

Management costs, including planting and harvest costs, for traditional forestry and no harvest scenarios were lower than for the SRIC scenario. This is countered by higher yields and shorter rotations for the SRIC scenario. Biomass can be grown more cheaply under the traditional forestry option in the following regions: All Southeast regions, the North Central Lake States, and the Pacific Northwest. These regions have been important historically for producing forest products. The results for these regions were consistent for both the current and mid-term SRIC yields.

Growing biomass using SRIC technologies is competitive in other regions. This is the case for the Pacific Northwest-East, the Northeast, and North Central Non-lake States. In these regions the difference in yields per acre between the SRIC and traditional forestry are great enough to counter the lower management costs for traditional forestry.

In the South Florida region, high land costs also favor SRIC forestry (although high land costs could lead to the elimination of forestry altogether). Higher annual expenditures in general tend to favor shorter rotations. Using the current SRIC yields, there is virtually no difference between the costs of producing biomass with SRIC and traditional forestry in South Florida. The mid-term SRIC yields significantly reduce the costs of producing biomass below what can be accomplished with traditional forestry methods for the region.

The Costs of Using Biomass as Fuel

Additional CO_2 emissions savings can be obtained by using biomass instead of fossil fuels. Both electricity and ethanol can be produced using wood as the feedstock. These fuel costs are reported as a function of feedstock price. Given the unit costs of producing biomass under the scenarios, the viability of producing electricity and ethanol from wood was determined.

The costs of producing electricity from wood biomass are reported in Table 5. In order for biomass to be competitive with coal for producing electricity, the biomass must be available for less than $25.78/Mg. This occurs only in the Pacific Northwest. However, as the technology of wood fired power plants improves, the economics of producing electricity from wood biomass are likely to improve as well. If credits are given to utilities for using wood instead of coal, the economics could improve further.

Two methods of producing ethanol from wood biomass were examined. The costs of these methods were compared to the costs for producing ethanol from corn. For both of the wood based systems, the capital costs and non-feedstock operating costs were too high to make these technologies competitive with ethanol produced from corn. Ethanol from corn can be produced for $.41 a liter. The capital and non-fuel operating costs for producing ethanol using the acid hydrolysis and enzymatic hydrolysis are $.52 and $.62 per liter respectively (Williams, 1988).

General Conclusions

On a per acre basis, growing biomass using traditional forestry methods appears to be cheaper than SRIC methods. However, the total potential productivity of the land is much higher for SRIC. Because of this high productivity, SRIC appears to best choice for mitigating emissions of greenhouse gases. However, if a variety of other factors are considered (including some discussed here and in Section 5), the "best" mitigation method is likely to be a composite scenario with different methods implemented in different regions.

TABLE 5. COST OF ELECTRICITY PRODUCTION FROM WOOD BIOMASS[a] (per MWH)

Region Forestry	Near-term SRIC	Mid-term SRIC[b]	Traditional Forestry
South Florida	$73.69	$61.45	$73.71
Southeast Coast	75.25	63.06	57.78
Southeast Piedmont	79.40	65.37	57.14
Southeast Mountains	82.18	66.97	58.65
Northeast	79.08	68.62	84.45
North Central Lake States	76.44	66.78	59.53
North Central Non-Lake States	71.58	64.14	72.88
South Central Plains	85.57	71.73	--.--
Pacific Northwest-West	71.70	62.32	37.77
Pacific Northwest-East	80.87	71.70	106.56

[a]Using the feedstock costs per Mg given in Table 3.

[b]Yields projected to be obtainable in 20 years.

SECTION 3
YIELDS AND EMISSIONS METHODOLOGY

This section discusses the activities that produce pollutants, the methods and assumptions used to quantify these emissions, and the methods and assumptions used to estimate land availability and yields. For ease of comparison, all of the emission estimates presented in this report are annualized. This was necessary because rotation length, treatment frequencies, and yields vary by scenario and by region.

Land Availability and Yields

Data from 1982 National Resources Inventory were used to develop a land base for this study.[1] Crop and pasture land classified as needing erosion control was determined for each Major Land Resource Area (MLRA). MLRAs (rather than state groupings) were used because they are defined partly on the basis of climate and soils (United States Department of Agriculture 1981), both important determinants of tree growth. Some MLRAs were eliminated as being unsuitable for forestry, either due to climate or unsuitable terrain. The remaining MLRAs were grouped into regions wherein biomass yields could be assumed to be reasonably homogeneous. Total hectares available in each region are shown in Table 6.

Yields and rotation lengths for the TF scenario were derived primarily from United States Department of Agriculture (1982). More recent data for the Southeast was obtained from McClure and Knight (1984). These yields assume the use of currently available cultivars and the use of fertilizers and weed suppression. Yields, rotation lengths, and species planted in each region are shown in Table 7.

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[1]Personal communication from Jeff Goebel, Soil Conservation Service, U.S. Department of Agriculture, to Rebecca Peer, Radian Corporation, October 13, 1989.

TABLE 6. HECTARES OF LAND

Region	Hectares (000s)
Florida (FLA)	87
North Central, Lake States (NC-LS)	3,415
North Central, Non-Lakes States (NC-NLS)	21,924
Northeast (NE)	3,265
Pacific Northwest (PNW)	125
Pacific Northwest, East (PNW-E)	14
Southeast, Coast (SE-CST)	2,305
Southeast, Mountains (SE-MTS)	2,450
Southeast (SE)	5,115
South Central Plains (SCP)	1,719
TOTAL	40,419

TABLE 7. TRADITIONAL FORESTRY YIELDS, SPECIES, AND ROTATION LENGTHS

Region[a] (Years)	Annual Yield (dry Mg/ha)	Species	Rotation Length
SE-CST	4.1	Loblolly Pine, Longleaf Pine, Slash Pine	30
SE	3.9	Loblolly Pine	35
SE-MTS	3.5	Shortleaf Pine	45
FLA	4.1	Slash Pine	30
SCP	0		
NE	2.2	Red Pine, White Pine	60
NC-LS	3.8	Red Pine, Jack Pine	60
NC-NLS	2.6	Red Pine, Jack Pine	80
PNW	10.6	Douglas Fir	85
PNW-E	1.4	Ponderosa Pine, Lodge Pole Pine	120

[a]See Table 6 for complete region names.

The SRIC yields were estimated from field trials and expert judgments.[2] Two sets of yield estimates were developed (Table 8). The near-term yields are probable yields achievable in the next 5 to 10 years. The mid-term yields are target yields that should be achievable in 20 years, assuming additional research.[2] The rotation lengths used are estimates based on field trials.

The SRIC yields assume two coppice rotations per planting with harvesting done in the winter in all regions except the Pacific Northwest. In the Pacific Northwest, winters are too wet and harvesting must take place in the summer. Since photosynthesis occurs mostly in the summer, and a large proportion of the tree's energy is stored in the leaves rather than in the roots, summer harvesting stresses the roots and reduces subsequent yields. Therefore, plantations must be replanted after every harvest (every 8 years). In all other regions, a cycle of plant-coppice-coppice is assumed.

The yield estimates used in this study are within the range of other recently published data. Eucalyptus grandis yields in experimental studies in Florida ranged from 17.6 to 71.2 Mg/ha after two years (Rockwood and Rippon, 1989). Yields of 14.2 Mg/ha for Robinia pseudoacacia (black locust) in Kansas trials have been reported (Geyer, 1989). Other recent yield data (Wright et al., 1989) were considered in the development of the yields used in this study.

Carbon Dioxide Uptake

The percent of carbon in biomass varies from species to species; the percent carbon content of wood has been estimated to be between 47% and 52% of the dry mass (summarized in Marland, 1988). Following Marland's example, in this study, the amount of carbon sequestered in the wood was assumed to be 50% of the dry weight.

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[2]Personal communication from Lynn Wright, Oak Ridge National Laboratory, to Rebecca Peer, Radian Corporation, February 12, 1990.

TABLE 8. SRIC YIELDS, SPECIES, AND ROTATION LENGTHS

Region[a]	Annual Yield (dry Mg/ha) Near-term	Mid-term	Species	Rotation Length Years
SE-CST	10	18	Sweet gum, black locust	6
SE	10	18	Sweet gum, black locust	6
SE-MTS	10	18	Sweet gum, black locust	6
FLA	15	3	Eucalyptus	6
SCP	6	9	Mesquite	6
NE	10	15	Poplars, silver maple	8
NC-LS	10	17	Poplars, silver maple	8
NC-NLS	12	20	Poplars, silver maple	8
PNW	15	30	Poplars	8
PNW-E	10	15	Poplars, red alder	8

[a]See Table 6 for complete region names.

Yield estimates used for the TF scenario include only the bole (stem) of the tree. Leaves, branches, and roots are not included. In the SRIC scenario, yield estimates include all above-ground biomass. Carbon sequestering calculations were based on these yields alone. Carbon dioxide uptake in the soil was not counted in any scenario due to the difficulty of quantifying it for the TF and SRIC scenarios. For the NH scenario, the carbon stored in branches and roots was included by assuming that roots and branches are 22% and 10% of the above-ground biomass, respectively. The exact ratio of total tree biomass to bole varies with species, age and site. The ratio used here is a median value derived from various sources (Hyde and Wells, 1979; Harmon et al., 1990).

This approach underestimates carbon sequestering, particularly in the two harvesting scenarios. For SRIC, some carbon storage in the roots occurs but root systems are not as well-developed as in natural forests or traditional plantations. This is partly due to the short rotation length, and partly due to the stress of coppicing on root systems. In this study, replanting was assumed after every second coppice, so no root system could ever have more than 24 years to develop. No estimates of the whole-tree to root ratio for SRIC trees were available. In the TF scenario, some soil disturbance occurs when trees are harvested and replanted. However, some root material is likely to remain undisturbed in the soil. Since the amount is unknown, no attempt was made to quantify it for this study.

In addition to their role in the CO_2 cycle, forests may serve as CH_4 sinks; however, the application of nitrogenous fertilizers may reduce the amount of CH_4 consumed by solid microorganisms (Steudler et al. 1989). The addition of fertilizer may also increase aerobic decomposition of organic matter in the forest floor, thereby reducing the carbon storage of the soil. None of these potential effects could be quantified for this analysis.

Plantation Establishment and Maintenance Emissions

SRIC Scenario--

Plantation establishment and maintenance emissions for the SRIC scenario are calculated by multiplying total machine hours per hectare planted by pollutant emission factors (kg/hr) and by the total number of hectares to be treated. The equation is as shown:

hrs/ha	x	kg/hr	x	ha	=	Pollutant emissions, kg/yr (annualized)
(Total annualized number of hours)		(Pollutant emission factor)		(Hectares to be treated)		

Planting machine hours, fertilizer application machine hours, and weed and pest control machine hours are shown in Table 9, along with the application frequencies per rotation.

Pollutant emission factors for carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO_x), and sulfur oxides (SO_x) were based on estimates for diesel farm tractors (70 horsepower) Table 10. Emissions for CO_2 were calculated using the ratio of CO_2/CO estimated for transportation emissions (see Table 14).

Traditional Forestry and No Harvest Scenarios--

Plantation establishment and maintenance emission estimates for these two scenarios were based on the assumption that machine planting (1.85 hrs/ha) Blankenhorn et al., 1983) and one fertilization treatment occurred in the life of every stand. Herbicide treatment for the TF and NH stands will be done manually. To annualize the machine hours for the TF scenario, it was necessary to calculate an average weighted rotation length by region. The average weighted rotation length was 65.32 years.

The diesel farm tractor emission estimates used are also shown in Table 10. For the NH scenario, the plantation establishment emissions (planting and fertilizing once) are annualized in the same way that the TF scenario is annualized.

TABLE 9. MACHINE HOURS AND APPLICATION FREQUENCIES FOR SRIC SCENARIO

Type of Machine Hours	No. Hours/ha	Reference
PLANTING	2.51	Blankenhorn et al., 1985
Frequency: Varies by Region		
WEED CONTROL	0.31	Blankenhorn et al., 1985
Frequency: Once per rotation		
FERTILIZATION	0.66	Blankenhorn et al., 1985
Frequency: Twice per rotation		Perlack and Ranney, 1987
PEST CONTROL	0.31	Blankenhorn et al., 1985
Frequency: Twice per rotation		Perlack and Ranney, 1987

TABLE 10. DIESEL FARM TRACTOR EMISSION FACTORS

Pollutant	Emission Factor (kg/hr)
Carbon Monoxide	0.161
Volatile Organic Compounds	0.079
Nitrogen Oxides (as NO_2)	0.452
Sulfur Oxides (as SO_2)	0.422

Source: U.S. Environmental Protection Agency, 1985.

Fertilizer Production Emissions

Fertilizer used on forest stands is typically urea and/or triple superphosphate (TSP). For the short rotation plantations, the fertilizer application rate (urea only) per hectare is assumed to be 65 kg/ha (derived from Perlack and Ranney (1987) and Wright et al. (1989)).

Emission factors for fertilizer production are based on energy required (assumed to be from fossil fuels) to produce a Mg of TSP or urea (U.S. Environmental Protection Agency, 1977, 1985). The emission factors for CO_2 and NO_x from fertilizer production are shown in Table 11.

These emissions factors are then multiplied by the fertilizer application rate and the number of hectares treated, as shown in the equation below to yield total emission estimates:

kg/ha (Annualized application rate)	x	kg/Mg (Emission factor for fertilizer production)	x	ha (Area treated)	=	Emissions from fertilizer treatment

The use of fertilizer for forest plantation establishment or intermediate stand treatments is more common for the short rotation plantations than it is for TF plantations. Currently, traditional commercial forests only use fertilizers on a small scale, but yields have been shown to increase significantly with their use (40 percent in the southeast and 20 percent in the northwest) (North Carolina State University Forest Cooperative, 1988). Urea and TSP are commonly used fertilizers, and the assumption was made that 359 kg of urea and 196 kg of TSP are applied per hectare treated in the southern states, and 487 kg/ha of urea are applied to the rest of the country.

Pesticide Production

Pesticide use frequencies for the SRIC scenario are given in Table 9. Herbicides for weed control are used once per rotation on the TF and NH scenarios. Pesticide production emission estimates are based on the average amount of energy required (49,020 Kcal/kg active ingredient) for production of herbicide or insecticide (Pimentel, 1980). Table 12 presents the emission factors used to calculate emissions associated with energy use in pesticide production.

TABLE 11. FERTILIZER PRODUCTION EMISSION FACTORS

Pollutant	Emission Factor (kg/Mg produced) Urea	TSP
CO_2	861.0	851.1
NO_x	1.5	0.6

Source: U.S. Environmental Protection Agency, 1977, 1985.

TABLE 12. EMISSIONS FROM FOSSIL FUEL ENERGY PRODUCTION (kg/MW-hr)

Pollutant	Natural Gas[a]	Oil[b]	Coal[c]
CO_2	539	752	909
CO	0.18	0.14	0.14
NO_x	1.22	2.04	2.68
SO_x	----	11.07	3.99

[a]38% of fuel used for pesticide production (Pimentel, 1980).
[b]42% of fuel used for pesticide production (Pimentel, 1980).
[c]20% of fuel used for pesticide production (Pimentel, 1980).

Source: Bechtel Group Inc., 1988; Electric Power Research Institute, 1986; U.S. Environmental Protection Agency, 1982, 1985; 40 CFR60, 1989.

According to Blankenhorn et al. (1985), about 3 kg/ha of herbicide active ingredients are applied. Thus, 0.17 MW-hr/ha of energy are required. The total emissions associated with pesticide production and application were calculated as shown:

MW-hr/ha	x	kg/MW-hr	x	ha	=	Total pollutant emissions
(Energy required/ha)		(Pollutant emission factor by fuel usage)		(Area treated)		

These emissions are annualized estimates based on the treatment regime discussed previously.

Emissions From Fertilizer Usage

Field studies following the application of nitrogen fertilizers have shown that nitrous oxide is produced due to nitrification (Breitenbeck et al.,1980). The application of urea is estimated to release approximately 0.13% of the nitrogen applied as nitrous oxide (Breitenbeck et al., 1980). Nitrous oxide emissions are thus calculated as:

kg/ha	x	ha	x	0.0013	x	0.46	x	44/28	=	N_2O Emissions
(Fertilizer application rate)		(Area treated)		(Proportion of applied nitrogen emitted as N_2O)		(Proportion of nitrogen in urea)		(1 kg.mol N_2O/2 kg.mol N)		

Emissions from Prescribed Burning

Prescribed burning is used for stand establishment and intermediate control of competing vegetation. This treatment is used only in the TF scenario. It is assumed that burning is used twice in the life of a stand, and emissions are estimated by combining pollutant emission factors per amountof fuel consumed with an estimate of the litter or logging debris consumed. Table 13 presents the emissions factors for prescribed burning (U.S. Department of Agriculture, 1976; U.S. Environmental Protection Agency, 1985).

The amount of fuel consumed during prescribed burning operations will vary by type of burn (control of competing vegetation or logging debris removal). Estimates of fuel consumed are derived from the U.S. Department of Agriculture (1976) estimates for southern pine fuel. Other regions will vary and will probably be lower, but the southern pine estimate was used in all regions.

For intermediate burning operations, 17 Mg/ha of fuel will be consumed. For combustion of logging debris, the fuel consumed is based on the yield harvested--0.19 Mg/green Mg harvested. The emission factors presented in Table 13 were then combined with area burned and yields to prepare total emissions associated with prescribed burning treatments.

Hydrocarbons Emitted From Trees

Several researchers have estimated VOC emissions from growing trees. Lamb et al. (1987) estimated that coniferous and deciduous trees will emit 204.22 kg/ha/yr and 108.27 kg/ha/yr VOC, respectively. The difference in total hydrocarbons emissions between coniferous and deciduous trees is due primarily to higher density of coniferous stands. Because densities of short rotation stands are higher than typical hardwood stand densities, the VOC emission estimate for coniferous stands is used. For the traditional forestry and NH scenarios, conifers are planted, so the 204.22 kg/ha/yr emission factor is also used for these scenarios. Total VOC emissions are estimated by combining the VOC emission estimate with the number of hectares planted. The VOC emissions from this land previous to tree planting are assumed to be negligible.

Harvesting Emissions

Emissions associated with the harvesting of SRIC stands are related to the number of machine hours required. The pollutant emission factors are the same as those used to calculate planting emissions. Harvesting rates will vary by stand density, slope, method of harvesting, and other factors, but an average harvesting rate of 13.6 green Mg/hr has been reported (Blankenhorn et al., 1985). The annualized emissions are based on this harvesting rate (converted to 6.8 dry Mg/hr) and the emission factors presented in Table 9.

The amount of time it takes to harvest forest stands in the TF scenario is estimated by assuming skidding and loading hours will be the same across the country. These estimates actually will vary by region and stand. It is assumed that felling will be done manually and that TF harvesting can be accomplished twice as fast as SRIC harvesting.[3] Thus, an average harvesting rate estimate of 27 green Mg/hr is assumed. This estimate is combined with total yield and hectares harvested to estimate harvesting emissions.

Transportation Emissions

For all scenarios except the NH scenario, emissions associated with transporting the wood to a mill or power plant must be estimated. It is assumed that a 161 km round trip[4] is required whether the wood is taken to a mill for processing or to a power plant. Emission factors for CO_2, CO, VOC, and NO_x are shown in Table 14 (U.S. Environmental Protection Agency, 1985). These emission estimates are based on the assumptions that vehicle mileage averages 2.12 km/liter, average green weight of wood transported is 29.94 Mg.

Displacement of Coal Mining Emissions

If the wood grown in the SRIC or traditional forestry scenarios is used for power generation, some other form of fuel will be required in lesser amounts. If it is assumed that coal use is displaced by wood, then emissions associated with coal production, transportation, and combustion will be reduced. Coal mining is a source of atmospheric methane (CH_4), but there is large variation in the emission estimates. Emissions are affected by type of coal, depth of the vein, and type of

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[3]Personal communication from Nels Christofferson, U.S. Forest Service, Houghton, MI, to Darcy Campbell, Radian Corporation, January 11, 1990.

[4]Personal communication from Earl Deal, North Carolina Extension Service, Raleigh, NC, to Darcy Campbell, radian Corporation, May 31, 1989.

TABLE 13. PRESCRIBED BURNING POLLUTANT EMISSION FACTORS

Pollutant	Emission Rate (kg/kg fuel)
CO_2	1.375
CO	0.135
Methane	0.00575
Other VOC	0.0083
NO_x	0.0025

Source: U.S. Department of Agriculture, 1976; U.S. Environmental Protection Agency, 1985.

TABLE 14. EXHAUST EMISSION RATES FOR HEAVY DUTY POWERED VEHICLES

Pollutant	Average Emission Factor (kg/Mg green wood)
CO2	6.65[a]
CO	0.3
VOC	0.006
NO_x	0.07

[a]Calculated by mass balance based on density of diesel fuel of 0.84 kg/liter.

Source: U.S. Environmental Protection Agency, 1985.

mining (surface or underground). Using an estimate of 8.4 m^3/Mg coal mined for methane (Robertson and Rightmine, 1986), approximately 5.5 kg CH_4 are emitted with every Mg of coal mined. Wood burned to generate electricity will substitute for coal at a ratio of

$$\frac{0.4915 \text{ Mg coal}^{5}}{1 \text{ Mg wood}}$$

This information was then incorporated with the annual yields of the SRIC (near- and-mid terms) and traditional forestry scenarios for an estimate of CH_4 not emitted.

Displacement of Coal Transportation Emissions

If wood displaces the need for coal for energy production, then emissions will also be saved from the transport of coal. Assuming that coal is typically transported by locomotive, it is estimated that nationwide, the average length of a coal haul by major freight railroads was 1619 km roundtrip.[6] Fuel usage is calculated to be 106,458 km-kg per liter of fuel.[7] Average locomotive emission factors are provided in Table 15. These estimates were then used to estimates emissions displaced by replacing coal with wood as shown in the equation:

$$\text{kg}/10^3 \text{ liter} \times 1619 \text{ km} \div \frac{106{,}458 \text{ km-kg}}{\text{liter}} \times \frac{0.4915 \text{ Mg coal}}{\text{Mg coal}}$$

kg/10³ liter	1619 km	106,458 km-kg/liter	0.4915 Mg coal/Mg coal
(Average pollutant emission factors)	(Round-trip distance)	(Fuel usage)	(Ratio of wood/coal energy production)

$$\times \text{ yield} = \text{Displaced coal transportation emissions}$$

(Mg dry wood)

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[5]See Appendix A for calculation.

[6]Personal Communication from Carol Perkins, Association of American Railroads, Washington, DC, to Ed Moretti, Radian Corporation, June 9, 1989.

[7]Personal communication from Dick Cataldi, Association of American Railroads, Washington, DC, to Ed Moretti, Radian Corporation, June 9, 1989.

Displacement of Coal Combustion Emissions

As presented in Table 12, air pollutant emissions are generated from coal usage for energy production. Carbon dioxide, CO, NO_x, and SO_2 emissions will be reduced if less coal is burned because wood is used to generate this energy. The calculation shown in Appendix A for coal displacement by wood for energy generated is used to estimate the magnitude of coal combustion emissions displaced by wood combustion as shown in the equation:

$$\text{kg/MW-hr out as coal} \times \frac{0.3493 \text{ MW-hr out}}{\text{MW-hr in}} \times \frac{6.4 \text{ MW-hr in}}{\text{Mg coal}} \times$$

(Pollutant emission factors) (Coal plant efficiency) (Heat value of coal)

$$\frac{0.4915 \text{ Mg coal}}{\text{Mg wood}} \times \text{Yield} = \text{Displaced coal combustion emissions}$$

VOC and N_2O are also emitted, but the emission factors are of doubtful quality. Since VOC and N_2O emission factors for wood combustion in a power plant are also of poor quality, these two gases were not quantified for either fuel type.

Emissions From Wood Combustion

Air pollutant emissions will occur due to energy production from a wood-fired boiler. Table 16 shows the emissions factors used to quantify these emissions. These factors take into account the efficiency of the facility.

Emissions from industrial wood boilers are estimated as shown in the equation:

$$\text{kg/MW-hr out as wood} \times \frac{0.204 \text{ MW-hr out}}{\text{MW-hr in}} \times \frac{5.4 \text{ MW-hr in}}{\text{Mg wood}} \times$$

(Pollutant emission factors) (Wood plant efficiency) (Heat value of wood)

$$\text{Yield} = \text{Pollutants emitted from wood plant}$$

(Mg dry wood)

TABLE 15. AVERAGE LOCOMOTIVE EMISSION FACTORS

Pollutant	Average Emissions ($kg/10^3$ liter)
CO_2	2636
CO	16.0
VOC	11.0
NO_x (as NO_2)	44.0
SO_x (as SO_2)	6.8

Source: U.S. Environmental Protection Agency, 1985.

TABLE 16. EMISSIONS FROM WOOD COMBUSTION FACILITIES

Pollutant	Emission Factor (kg/MW-hr out)
CO_2[a]	1758
CO	2.68
NO_x	1.90
SO_2	--.--

[a]Calculated by mass balance of carbon, assuming VOC is emitted as pentane (72g/g.mol) and particulate matter is 95% naphthalene (128g/g.mol).

Source: Electric Power Research Institute, 1986; U.S. Environmental Protection Agency, 1985, 1982; North Carolina Department of Environmental Management, 1982.

SECTION 4
COST ANALYSIS METHODOLOGY

This section discusses the cost of growing biomass under the three scenarios discussed in Sections 2 and 3. Costs were calculated for the three scenarios using existing published data sources and information obtained from contacts with experts in the field. The cost of using wood biomass as an input to producing electricity was included as part of the analysis. The cost of converting wood biomass to ethanol was examined as an ancillary to the primary research. While the value of the biomass product is not included in the cost analysis, the breakeven costs of producing electricity and ethanol using the wood biomass feedstock were calculated and give a proxy of market biomass value for producing these goods.

The value of the products produced for SRIC and TF were not included in this study. Large differences exist between values of products from these two methods. Currently, little or no market value exists for woody biomass fuels. Wood used for fuel in the United States is a residual forest product, and is primarily waste wood from other production processes or surplus growing stock.

Costs were analyzed for the average treatment of cost on the average hectare in each region. The present net cost (PNC) of each scenario was calculated. However, the use of PNC alone is not an adequate investment analysis criterion. This is because PNC cannot be used to compare costs of investments having different lengths. Furthermore, the PNC calculation on a per hectare basis does not account for the greater yields per hectare associated with SRIC forestry.

To account for the differences in rotation age, yields, and timing of costs between the scenarios, the PNC was used to calculate the annual equivalent cost (AEC) of producing a metric ton of biomass on an average hectare for each region. The AEC is a discounted measure of the investment cost annualized over the life of the investment. This annualized cost is divided by the annual yield to determine the cost per unit of biomass produced.

Also calculated was the total cost per acre of continuing with the investment into perpetuity. This measure accounts for the differences in rotation length, but does not account for the differences in yield per acre.

The TF scenario had lower yields and took longer to mature than SRIC investments. Because the value of the product was not included in the analysis, the comparison of AEC for SRIC and traditional forestry is misleading from an investor's standpoint. Harvesting the biomass occurs later for the traditional forestry scenario than for the SRIC scenario. The investor realizes the value of the product produced at harvest. Because the harvests occur at different times, the discounted value per ton harvested is different for the two scenarios. Because global mitigation occurs when the biomass is produced, not when it is harvested, this does not impact the biomass value for global climate change mitigation. It is important to note however that AEC reported in this document represents only the costs and not the financial returns from growing biomass.

Costs were converted to 1988 dollars using the producer price index for lumber and wood products (CEA, 1989). The following sections report the assumptions and data used to calculate the costs of producing biomass for the three scenarios. In addition, the methods for deriving the costs of producing electricity and ethanol using wood feedstocks are described for the SRIC and traditional forestry scenarios.

SRIC Cost Analysis Methods and Assumptions

Two sets of cost were derived for the SRIC scenario. The first is the cost of producing a ton of biomass given yields which are currently obtainable. The second set is the costs associated with the mid-term yields. The costs for the SRIC scenarios were initially derived from Perlack (1986). SRIC schedules were divided into planting sequences with each planting sequence consisting of one planted rotation and two coppice rotations except in the PNW-East and West. Conditions in the PNW are not favorable to coppicing. As a result, each successive rotation will need to be planted after harvest. Scheduled costs include: administration, land, planting, herbicide, pesticide, fertilizer, road, and harvest costs. Table 17 lists SRIC costs and schedules by region.

TABLE 17. SHORT ROTATION INTENSIVE CULTURE COST AND SCHEDULE DATA

Region[a] Names	Hectares Avail (x1000)	Land Rent[b] & Admin Costs ($/ha)	Site Prep. & Plant Costs ($/ha)	Weed Control[c] Cost ($/ha)	Fertilize Costs ($/ha)	Pest Control[d] Cost ($/ha)	Harvest[e] Cost ($/dry Mg)	Road Cost ($/ha)	Near-Term Yields (Mg/ha/yr)	Mid-Term Yields (Mg/ha/yr)	Rotation Length
NC-LS	3,415.7	89.0	763.5	128.2	212.0	50.2	29.5	83.8	10.0	17.0	8
NC-NLS	21,923.8	89.0	612.8	128.2	212.0	50.2	29.5	83.8	12.0	20.0	8
NE	3,264.7	89.0	763.5	128.2	212.0	50.2	29.5	83.8	9.0	15.0	8
PNW	124.6	77.8	763.5	128.2	212.0	50.2	29.5	83.8	15.0	30.0	8
PNW-E	13.8	77.8	763.5	128.2	212.0	50.2	29.5	83.8	10.0	15.0	8
SCP	1,718.8	66.7	763.5	128.2	212.0	50.2	29.5	83.8	8.0	12.0	6
SE-CST	2,305.6	66.7	763.5	128.2	212.0	50.2	29.5	83.8	12.0	22.0	6
SE-MTS	2,449.6	66.7	763.5	128.2	212.0	50.2	29.5	83.8	9.0	16.0	6
SE	5,115.4	66.7	763.5	128.2	212.0	50.2	29.5	83.8	10.0	18.0	6
FLA	87.0	138.4	612.8	0.0	212.0	50.2	29.5	83.8	15.0	30.0	6

[a]See Table 6 for complete region names.

Schedule:
[b]Annual costs.
[c]Incurred in year 2 of each rotation.
[d]Incurred in year 2 and 4 of each rotation.
[e]Incurred each harvest.

Detailed Costs of Traditional Forestry

The schedule of treatments for the traditional forestry scenarios varied greatly between regions. Rotation ages varied from 30 years in the Southeast Coast and Florida regions, to 120 years in the Pacific Northwest (East) Region. Land and administration costs were assumed to be the same as in the SRIC scenario. Table 18 presents the cost and schedules associated with this scenario.

Traditional forestry planting cost are lower than those for the SRIC scenarios because less intensive site preparation is needed and fewer stems per hectare are planted. Data on harvest costs were derived from Deal.[8] Harvest costs are roughly a third lower per Mg than the SRIC harvest costs. This is a function of the volume of biomass per hectare at harvest, and the size of the stems being harvested. Delaying harvest far into the future substantially lowers the discounted cost of harvesting.

Detailed Costs of No Harvest Scenario

The costs of the NH scenario are the same as the traditional forestry option until the point of harvest. No harvest costs and harvest road costs are included in this scenario and no further rotations are assumed. The land rent costs are assumed to continue into perpetuity. Schedule and cost information is reported in Table 18.

Because no product is produced at the end of the NH scenario, no value can be obtained from selling woody biomass. This is an additional cost incurred by the investor. Since the values of the product being produced is not included in any of the analyses, the opportunity cost of the foregone harvest is also not included.

[8]Personal communication from Earl Deal, North Carolina Extension Service, to Darcy Campbell, Radian Corporation, May 31, 1989.

TABLE 18. TRADITIONAL FORESTRY AND NO HARVEST COST AND SCHEDULE DATA

Region Names[a]	Hectares Avail (x1000)	Land Rent &[b] Adminis Costs ($/ha)	Site Prep. &[c] Plant Costs ($/ha)	Weed Control[d] Cost ($/ha)	Fertilize[e] Costs ($/ha)	Harvest Cost ($/dry Mg)	Yields (Mg/ha/yr)	Rotation
NC-LS	3,415.7	89.0	227.3	128.0	211.8	19.7	3.8	60
NC-NLS	21,923.8	89.0	227.3	128.8	211.8	19.7	2.6	80
NE	3,264.7	89.0	227.3	128.8	211.8	19.7	2.2	60
PNW	124.6	77.8	363.2	128.0	211.8	19.7	10.6	85
PNW-E	13.8	77.8	303.9	128.0	211.8	19.7	1.4	120
SCP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SE-CST	2,305.6	66.7	288.3	128.8	211.8	19.7	4.1	30
SE-MTS	2,449.6	66.7	349.0	128.0	211.8	19.7	3.5	45
SE	5,115.4	66.7	288.3	128.0	211.8	19.7	3.9	35
FLA	87.0	138.4	288.3	128.0	211.8	19.7	4.1	30

[a]See Table 6 for complete region name.

Traditional Forestry Schedule:

[b]Annual costs
[c]Incurred in year 0.
[d]Incurred in year 2.
[e]Incurred at end of rotation.

No Harvest Schedule:

[b]Annual cost.
[c]Incurred in year 0.
[d]Incurred in year 2.

Electricity Generation

The cost of producing electricity using woody biomass as the feedstock was compared to the cost of generating electricity using coal. Costs and plant efficiencies were obtained from EPRI (1986). A model coal plant and wood burning plant were selected for the cost analysis. The two plants had significant differences: the coal plant was much bigger than the wood burning power plant (500 versus 24 MW capacity); and, the wood burning plant was assumed to have co-generation capabilities. While these differences impact the economics of producing electricity, they do represent typical coal and wood burning units in the United States. Size of woodburning plants will vary with local criteria.

The total cost (including fuel and non-fuel costs) for producing electricity from a 500 MW subcritical bituminous coal power plant with a flue gas desulfurization unit was calculated to be $50.04 dollars per MWh. The non-fuel costs associated with producing electricity from a wood burning co-generation power plant were calculated to be $26.29 per MWh. Fuel costs were calculated as a function of feedstock price: in this case,

$$\text{Fuel Cost (\$/Mg)} = .9213 \text{ Mg/MWH} * \text{Cost (\$ /Mg Biomass)}$$

This assumes 15.4×10^6 Btus/Mg and 16.74×10^6 Btus/MWH. The breakeven cost for biomass fuel is the cost which results in the same final cost per MWh as can be obtained using coal as the feedstock. Using this calculation, the breakeven biomass cost for producing electricity is $25.78 per Mg. Since no viable CO_2 controls currently exist, none are assumed in this analysis.

Ethanol Production

The cost of producing ethanol from wood biomass was calculated from published cost algorithms (Williams, 1988). The cost algorithms were converted to 1988 dollars and the annualized capital costs were recalculated using a 6% interest rate. Two options for producing ethanol were analyzed: acid hydrolysis, and enzymatic hydrolysis. Ethanol can be produced from corn for $1.60 a gallon ($.42 per liter). The non-fuel costs of producing ethanol from wood using either wood biomass technology are higher than the cost of producing ethanol from corn. In order for these technologies to be competitive with ethanol from corn, the wood feedstock value must be negative.

SECTION 5
KEY ASSUMPTIONS AND LIMITATIONS OF THIS STUDY

This study is the first in-depth evaluation of alternative biomass-based mitigation possibilities. Although other estimates of the carbon sequestering potential of trees have been published (e.g., Flavin 1990; Marland, 1988; Harmon, et. al., 1990), none have included the other emissions associated with planting and harvesting. While the results of this study may be the most comprehensive to date, many factors need to be weighed in evaluating them. In this section, the major assumptions and limitations not addressed previously in this report are discussed.

Implications of Some Key Assumptions

Since this study included establishment of the plantations in some areas not generally considered forest land (such as the Midwest) and evaluation of commercially untried methods (SRIC), many assumptions had to be made that affect productivity calculations. For both harvesting scenarios (TF and SRIC), no decline in productivity of the land over time was assumed. How this might be achieved is not addressed. Fertilizer applications rates do not increase over time in this study, so if declining soil fertility is corrected with fertilizers, an increase in fertilizer effectiveness must also be assumed.

While an increase in productivity of SRIC is assumed, no increases in TF yields are allowed to occur. In fact, silviculturalists continue to improve yields of traditional timber species (Farnum et al. 1983). If the target yields (as high as 25-30 Mg/ha) can be achieved, the yields from traditional forestry methods become comparable to those of SRIC. Experimental trials have achieved yields of 50% of the target (Farnum et al. 1983) in more productive regions. However, these increased yields do not necessarily mean more carbon is being fixed; many of the improvements in yield are due to changes in the partitioning of carbon. If more carbon is being stored in stem wood and less in rapidly-decomposing tissues such as fine roots and leaves, then the net CO_2 sink may be increased.

The SRIC yields also assume that researchers can overcome the potential threat of pests. As agricultural research has sometimes shown, the development of high-yielding clones is sometimes difficult to achieve without loss of disease resistance. Methods for discouraging the evolution of pest biotypes (selection for insect populations which can tolerate a given pest resistance property of a plant) in SRIC plantations include alternating resistant genotypes and mixing clonal varieties as well as the use of biological, cultural, and chemical controls (Raffa, 1989).

Limitations of This Study

The accuracy of the emissions and costs estimates are limited by the data. This is particularly true for estimating yields and costs for the commercially untried SRIC scenario. Also, emission factors for many sources and pollutants had to be developed for this study, often from scanty data. The emissions of hydrocarbons from trees, for example, is by no means well-quantified. Whenever possible, emissions estimates were checked by using alternative methods of calculation (see Appendix B for an example).

Other environmental impacts were also not considered. The land base used in this study represents roughly 4% of the total U.S. land area. Although this is not a very large percentage of the total, some regions would have significant increases in forested land. The effect of these large forest areas on microclimate and the hydrologic cycle are unknown. Also, the additional chemical burden from pesticides and fertilizers may cause increased contamination of the groundwater. However, since most of this land is already used as cropland, changing to silviculture may actually reduce chemical inputs to ground water. In choosing the "best" scenario, only air pollution mitigation was considered. If other criteria are included, the NH scenario may be preferable. For example, the value of forest as wildlife habitat or for recreation was not included. In addition, either of the harvesting scenarios may require building more roads. However, since the land is currently agricultural, the amount of new roads needed is probably very small. Finally, the terrain will affect the choice of scenario. The steeper slopes in mountainous regions may be unsuitable for SRIC. Although the southeastern mountains have been included in this study, in reality, SRIC may be impractical here.

As shown in the regional breakdown of costs (Appendix C), some regions are economically more attractive than others. However, given the current costs of producing biomass and the value of biomass for producing electricity and ethanol, landowners cannot be expected to undertake these investments without additional incentives.

As has been noted above, SRIC is still experimental. The costs used in this study are based on field trials and are likely to be reduced as SRIC becomes commercialized. In fact, given the trend towards more intensive culture in traditional forestry, the distinctions between TF and SRIC are likely to become blurred in the future.

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APPENDIX A

COAL DISPLACEMENT BY WOOD BURNED FOR ENERGY

Wood grown in the SRIC or TF scenario can be burned in a wood-fired boiler for energy. It is assumed that the energy supplied can replace the same amount of energy supplied by a coal-fired power plant. To estimate the amount of coal displaced by wood, the different heat values of the two fuels must be taken into account, as well as the different efficiencies of the power plants. Table A-1 shows the factors used to compare the two fuels.

To compare the energy supply of coal and wood (MW-hr out), the following equation is used:

$$\frac{18{,}739{,}100\ \text{Btu}}{\text{Tonne wood}} \times \frac{\text{MW-hr wood}}{3{,}472{,}191.6\ \text{Btu}} \times \frac{0.204\ \text{MW-hr out as wood}}{\text{MW-hr in as wood}} \times$$

$$\frac{\text{MW-hr in as coal}}{0.3493\ \text{MW-hr out as coal}} \times \frac{3{,}472{,}191.6\ \text{Btu}}{\text{MW-hr coal}} \times \frac{\text{Tonne coal}}{22{,}266{,}460\ \text{Btu}}$$

$$= 0.4915\ \frac{\text{Tonne coal}}{\text{Tonne wood}}$$

(To supply the same amount of energy)

TABLE A-1. HEAT VALUES AND POWER PLANT EFFICIENCY FOR COAL AND WOOD FUELS

Fuel	Heat Value (Btu/tonne)	Plant Efficiency (MW-hr in/MW-hr out)
Coal	22,266,460	0.3493
Wood	18,739,100	0.204

APPENDIX B

ANNUAL EMISSIONS BY SOURCE

The following spreadsheets show the annual emissions of each gas by source and scenario. Note that some inconsistencies occur. For example, the total amount of carbon released when wood is burned in slightly greater than the amount of carbon sequestered. This reflects the uncertainty in either or both sets of assumptions used to calculate the emission factors (see Section 3). Since the two values are within 5% of each other, and neither set of assumptions could be shown to be obviously wrong, these two numbers were not altered.

Clearly, some uncertainty exists for all these emissions factors. Comparisons such as the one discussed above give some magnitude of the uncertainty.

Pollutants by source

		TOTAL EMISSIONS (Mg/year)				
		SRIC				
Source	Pollutant	(Near-term)	(Mid-Term)	TF	TF (Burn)	NH
Wood Trans.	CO_2	14615000	24800000	1700000	1700000	
	CO	76900	131000	8940	8940	
	VOC	33000	56000	3830	3830	
	NO_x	143000	243000	16600	16600	
Respiration	VOC	8080000	8080000	7740000	7740000	7740000
Fert. Prod. SRIC	CO_2	606000	606000			
	NO_x	1060	1060			
Fert. Prod. TF,NH	CO_2			269000	269000	269000
	NO_x			438	438	438
Fert. Use SRIC	N_2O	662	662			
Fert. Use TF,NH	N_2O			261	261	261
Coal Mining Displacement	CH_4	-2970000	-5040000		-345000	
Coal Trans. Displacement	CO_2	-2.2E+07	-3.7E+07		-2550000	
	CO	-127000	-216000		-14800	
	VOC	-92300	-216000		-10700	
	NO_x	-363000	-616000		-370000	
	SO_x	-56000	-95200		-6510	
Coal Comb. Displacement	CO	-169000	-284000		-19700	
	NO_x	-3190000	-5410000		-370000	
	SO_2	-4840000	-8210000		-562000	
	CO_2	-1.1E+09	-1.9E+09		-1.3E+08	
Wood Comb.	NO_x	2310000	3920000		268000	
	CO	2180000	3730000		255000	
	SO_2	0	0		0	
	CO_2	2.1E+09	3.6E+09		2.5E+08	

Source	Pollutant	SRIC (Near-term)	SRIC (Mid-term)	TF	TF(Burn)	NH
		TOTAL EMISSIONS (Mg/year)				
Post-Harvest and Prescribed Burning TF & NH Pine Only	TSI					
	CO_2			14100000	14100000	
	CO			13600000	13600000	
	CH_4			58000	58000	
	VOC			82900	82900	
	NO_x			23700	23700	
	Slash Burning					
	CO_2			10200000	10200000	
	CO			1000000	1000000	
	CH_4			46000	46000	
	VOC			56900	56900	
	NO_x			17100	17100	
Harvesting Machine Hours TF & NH	CO			1530	1530	
	VOC			727	727	
	NO_x			4210	4210	
	SO_x			395	395	
	CO_2			255000	255000	
SRIC	CO	26400	26400			
	VOC	12600	21500			
	NO_x	73000	124000			
	SO_x	6813	11600			
	CO_2	4400000	7470000			
Planting Machine Hours SRIC	CO	750	750			
	VOC	362	362			
	NO_x	2100	2100			
	SO_x	1970	1970			
	CO_2	125000	125000			
TF & NH	CO			177	177	177
	VOC			59.2	59.2	59.2
	NO_x			473	473	473
	SO_x			473	473	473
	CO_2			29600	29600	29600

TOTAL EMISSIONS (Mg/year)

Source	Pollutant	SRIC (Near-term)	SRIC (Mid-term)	TF	TF(Burn)	NH
Weed Control Machine Hours SRIC	CO	276	276			
	VOC	133	133			
	NO_x	776	776			
	SO_x	724	724			
	CO_2	46000	46000			
Pest Control Machine Hours SRIC	CO	522.9	522			
	VOC	267.2	267			
	NO_x	1550	1550			
	SO_x	1450	1450			
	CO_2	87200	87200			
Herb Prod. SRIC	CO_2	1960000	1960000			
	CO	441	441			
	NO_x	16300	16300			
	SO_x	14700	14700			
TF,NH	CO_2			71100	71100	71100
	CO			15.9	15.9	15.9
	NO_x			592	592	592
	SO_x			533	533	533
C Sequestering						
NH	CO_2					-2.6E+08
SRIC	CO_2	-2.0E+09	-3.4E+09			
TF	CO_2			-2.3E+08	-2.3E+08	

APPENDIX C
REGIONAL COSTS SPREADSHEETS

SHORT ROTATION INTENSIVE CULTURE

Region: Pacific Northwest
Acres available: 308000 ac
Admin/land: 31.5 $/ac/yr
Site prep/plant: 309 $/ac
Weed control: 51.9 $/ac
Fertilization: 85.8 $/ac
Pest Control: 20.3 $/ac
Harvest Cost: 32.5 $/ton
Road: 33.9 $/harvest
Yield 1: 6.69 Ton/ac/yr
Yield 2: 13.39 Ton/ac/yr
Rotation Age: 8 Years

TRADITIONAL FORESTRY

Region: Pacific Northwest
Acres available: 308000 ac
Admin/land: 31.5 $/ac/yr
Site prep/plant: 147 $/ac
Weed control: 51.8 $/ac
Fertilization: 85.7 $/ac
Pest Control: 0 $/ac
Harvest Cost: 21.7 $/ton
Road : 0 $/harvest
Yield: 4.725 Dry tons/ac/yr
Rotation Age: 85 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Pacific Northwest

Hectares in Region: 125,000

	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Costs and Yields per Hectare				
Present Net Cost:	$9,272.39	$14,728.43	$2,182.80	$2,046.93 per Hectare
Cost per Tonne (AEC):	$49.28	$39.11	$12.46	per Tonne
Cost into Perpetuity:	$12,313.59	$19,559.11	$2,198.33	$2,056.09 per Hectare
Annual Yield:	15	30	10.59	10.59 Dry tonnes/Ha/yr (THROUGH 85 YEARS)
Costs and Yields for Region				
Present Net Cost:	$1,159,000,000.00	$1,841,000,000.00	$273,000,000.00	$256,000,000.00
Cost into Perpetuity:	$1,539,000,000.00	$2,445,000,000.00	$275,000,000.00	$257,000,000.00
Annual Yield:	1,874,000	3,751,000	1,323,000	1,323,000 Tonnes (THROUGH 85 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.77	$0.72	$0.59 per liter	
Region Cost	$284,000,000.00	$531,000,000.00	$152,000,000.00	
Potential Production	367,000,000	735,000,000	259,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.87	$0.83	$0.73 per liter	
Region Cost	$427,000,000.00	$817,000,000.00	$253,000,000.00	
Potential Production	493,000,000	987,000,000	348,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$71.70	$62.32	$37.77 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	Pacific Northwest Eastside
Acres available:	34000 ac
Admin/land:	31.5 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	4.49 Ton/ac/yr
Yield 2	6.69 Ton/ac/yr
Rotation Age:	8 Years

TRADITIONAL FORESTRY

Region:	Pacific Northwest Eastside
Acres available:	34000 ac
Admin/land:	31.5 $/ac/yr
Site prep/plant:	123 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	0.61 Dry tons/ac/yr
Rotation Age:	120 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Pacific Northwest Eastside

Hectares in Region: 14,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$7,480.86	$9,272.39	$1,983.04	$1,995.61 per Hectare
Cost per Tonne (AEC):	$59.25	$49.28	$87.13	per Tonne
Cost into Perpetuity:	$9,934.46	$12,313.59	$1,984.87	$1,996.81 per Hectare
Annual Yield:	10	15	1.37	1.37 Dry tonnes/Ha/yr (THROUGH 120 YEARS)
Costs and Yields for Region				
Present Net Cost:	$105,000,000.00	$130,000,000.00	$28,000,000.00	$28,000,000.00
Cost into Perpetuity:	$139,000,000.00	$172,000,000.00	$28,000,000.00	$28,000,000.00
Annual Yield:	141,000	210,000	19,000	19,000 Tonnes (THROUGH 120 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.83	$0.77	$0.97 per liter	
Region Cost	$23,000,000.00	$32,000,000.00	$4,000,000.00	
Potential Production	28,000,000	41,000,000	4,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.90	$0.87	$1.01 per liter	
Region Cost	$33,000,000.00	$48,000,000.00	$5,000,000.00	
Potential Production	37,000,000	55,000,000	5,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$80.87	$71.70	$106.56 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	Northeast
Acres available:	8067000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	4.01 Ton/ac/yr
Yield 2	6.69 Ton/ac/yr
Rotation Age:	8 Years

TRADITIONAL FORESTRY

Region:	Northeast
Acres available:	8067000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	110.5 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	0.96 Dry tons/ac/yr
Rotation Age:	60 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Northeast

Hectares in Region: 3,265,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$6,461.29	$8,643.70	$2,194.78	$2,119.68 per Hectare
Cost per Tonne (AEC):	$57.30	$45.94	$63.13	per Tonne
Cost into Perpetuity:	$8,580.49	$11,478.70	$2,263.40	$2,164.61 per Hectare
Annual Yield:	9	15	2.15	2.15 Dry tonnes/Ha/yr (THROUGH 60 YEARS)
Costs and Yields for Region				
Present Net Cost:	$21,096,000,000.00	$28,222,000,000.00	$7,166,000,000.00	$6,921,000,000.00
Cost into Perpetuity:	$28,015,000,000.00	$37,478,000,000.00	$7,390,000,000.00	$7,067,000,000.00
Annual Yield:	29,338,000	48,945,000	7,024,000	7,024,000 Tonnes (THROUGH 60 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.82	$0.76	$0.84 per liter	
Region Cost	$4,689,000,000.00	$7,268,000,000.00	$1,164,000,000.00	
Potential Production	5,752,000,000	9,597,000,000	1,377,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.90	$0.85	$0.92 per liter	
Region Cost	$6,924,000,000.00	$10,994,000,000.00	$1,698,000,000.00	
Potential Production	7,721,000,000	12,880,000,000	1,848,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$79.08	$68.62	$84.45 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	North Central Lake States
Acres available:	8440000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	4.46 Ton/ac/yr
Yield 2	7.58 Ton/ac/yr
Rotation Age:	8 Years

TRADITIONAL FORESTRY

Region:	North Central Lake States
Acres available:	8440000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	92 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.7 Dry tons/ac/yr
Rotation Age:	60 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: North Central Lake States

Hectares in Region: 3,416,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST	
Present Net Cost:	$6,827.74	$9,368.46	$2,221.23	$2,073.99	per Hectare
Cost per Tonne (AEC):	$54.44	$43.95	$36.08		per Tonne
Cost into Perpetuity:	$9,067.13	$12,441.16	$2,290.67	$2,118.91	per Hectare
Annual Yield:	10	17	3.81	3.81	Dry tonnes/Ha/yr (THROUGH 60 YEARS)
Costs and Yields for Region					
Present Net Cost:	$23,324,000,000.00	$32,003,000,000.00	$7,588,000,000.00	$7,085,000,000.00	
Cost into Perpetuity:	$30,973,000,000.00	$42,499,000,000.00	$7,825,000,000.00	$7,238,000,000.00	
Annual Yield:	34,139,000	58,021,000	13,013,000	13,013,000	Tonnes (THROUGH 60 YEARS)
Annual Ethanol Production					
Via Acid Hydrolysis					
Unit Cost	$0.80	$0.75	$0.71		per liter
Region Cost	$5,359,000,000.00	$8,499,000,000.00	$1,804,000,000.00		
Potential Production	6,694,000,000	11,376,000,000	2,551,000,000		liters per year
Via Enzymatic Hydrolysis					
Unit Cost	$0.89	$0.85	$0.82		per liter
Region Cost	$7,959,000,000.00	$12,918,000,000.00	$2,795,000,000.00		
Potential Production	8,984,000,000	15,269,000,000	3,425,000,000		liters per year
24 MW Wood Power Plant					
Cost per MW	$76.44	$66.78	$59.53		per MW

SHORT ROTATION INTENSIVE CULTURE

Region:	South Central Plains
Acres available:	4247000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	3.57 Ton/ac/yr
Yield 2	5.36 Ton/ac/yr
Rotation Age:	6 Years

TRADITIONAL FORESTRY

Region:	South Central Plains	
Acres available:	N/A	ac
Admin/land:	N/A	$/ac/yr
Site prep/plant:	N/A	$/ac
Weed control:	N/A	$/ac
Fertilization:	N/A	$/ac
Pest Control:	N/A	$/ac
Harvest Cost:	N/A	$/ton
Road :	N/A	$/harvest
Yield:	N/A	Dry tons/ac/yr
Rotation Age:	N/A	Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: South Central Plains

Hectares in Region: 1,719,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST	
Present Net Cost:	$5,572.99	$6,911.28			per Hectare
Cost per Tonne (AEC):	$64.34	$53.15			per Tonne
Cost into Perpetuity:	$8,578.36	$10,638.37			per Hectare
Annual Yield:	8	12			Dry tonnes/Ha/yr
					N/A YEARS)
Costs and Yields for Region					
Present Net Cost:	$9,580,000,000.00	$11,880,000,000.00			
Cost into Perpetuity:	$14,746,000,000.00	$18,287,000,000.00			
Annual Yield:	13,751,000	20,646,000			Tonnes
					N/A YEARS)
Annual Ethanol Production					
Via Acid Hydrolysis					
Unit Cost	$0.85	$0.79	per liter		
Region Cost	$2,295,000,000.00	$3,214,000,000.00			
Potential Production	2,696,000,000	4,048,000,000	liters per year		
Via Enzymatic Hydrolysis					
Unit Cost	$0.92	$0.88	per liter		
Region Cost	$3,342,000,000.00	$4,786,000,000.00			
Potential Production	3,619,000,000	5,433,000,000	liters per year		
24 MW Wood Power Plant					
Cost per MW	$85.57	$75.25	per MW		

SHORT ROTATION INTENSIVE CULTURE

Region:	North Central Non-Lake States
Acres available:	54173000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	248 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	5.36 Ton/ac/yr
Yield 2	8.93 Ton/ac/yr
Rotation Age:	8 Years

TRADITIONAL FORESTRY

Region:	North Central Non-Lake States
Acres available:	54173000 ac
Admin/land:	36 $/ac/yr
Site prep/plant:	92 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.14 Dry tons/ac/yr
Rotation Age:	80 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: North Central Non-Lake States

Hectares in Region: 21,924,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$7,409.97	$10,317.14	$2,132.62	$2,104.90 per Hectare
Cost per Tonne (AEC):	$49.16	$41.08	$50.57	per Tonne
Cost into Perpetuity:	$9,840.32	$13,700.99	$2,152.97	$2,118.91 per Hectare
Annual Yield:	12	20	2.55	2.55 Dry tonnes/Ha/yr (THROUGH 80 YEARS)
Costs and Yields for Region				
Present Net Cost:	$162,456,000,000.00	$226,193,000,000.00	$46,756,000,000.00	$46,148,000,000.00
Cost into Perpetuity:	$215,739,000,000.00	$300,381,000,000.00	$47,202,000,000.00	$46,455,000,000.00
Annual Yield:	263,320,000	438,704,000	56,005,000	56,005,000 Tonnes (THROUGH 80 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.77	$0.73	$0.78 per liter	
Region Cost	$39,946,000,000.00	$63,009,000,000.00	$8,575,000,000.00	
Potential Production	51,629,000,000	86,017,000,000	10,981,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.87	$0.84	$0.87 per liter	
Region Cost	$59,996,000,000.00	$96,413,000,000.00	$12,839,000,000.00	
Potential Production	69,295,000,000	115,449,000,000	14,738,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$71.58	$64.14	$72.88 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	Southeast Piedmont
Acres available:	12640000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	4.46 Ton/ac/yr
Yield 2	8.04 Ton/ac/yr
Rotation Age:	6 Years

TRADITIONAL FORESTRY

Region:	Southeast Piedmont
Acres available:	12640000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	116.66 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.75 Dry tons/ac/yr
Rotation Age:	35 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Southeast Piedmont

Hectares in Region: 5,115,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$6,238.40	$8,914.99	$2,051.12	$1,637.86 per Hectare
Cost per Tonne (AEC):	$57.65	$45.70	$36.08	per Tonne
Cost into Perpetuity:	$9,602.61	$13,722.63	$2,357.90	$1,782.47 per Hectare
Annual Yield:	10	18	3.92	3.92 Dry tonnes/Ha/yr (THROUGH 35 YEARS)
Costs and Yields for Region				
Present Net Cost:	$31,909,000,000.00	$45,600,000,000.00	$10,491,000,000.00	$8,378,000,000.00
Cost into Perpetuity:	$49,117,000,000.00	$70,191,000,000.00	$12,061,000,000.00	$9,117,000,000.00
Annual Yield:	51,119,000	92,151,000	20,058,000	20,058,000 Tonnes (THROUGH 35 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.82	$0.76	$0.71 per liter	
Region Cost	$8,189,000,000.00	$13,661,000,000.00	$2,781,000,000.00	
Potential Production	10,023,000,000	18,068,000,000	3,933,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.90	$0.85	$0.82 per liter	
Region Cost	$12,081,000,000.00	$20,677,000,000.00	$4,307,000,000.00	
Potential Production	13,452,000,000	24,250,000,000	5,278,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$79.40	$68.39	$59.53 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	Southeast Mountains
Acres available:	6053000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	4.01 Ton/ac/yr
Yield 2	7.14 Ton/ac/yr
Rotation Age:	6 Years

TRADITIONAL FORESTRY

Region:	Southeast Mountains
Acres available:	6053000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	141.22 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.54 Dry tons/ac/yr
Rotation Age:	45 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Southeast Mountains

Hectares in Region: 2,450,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$5,901.95	$8,242.11	$2,018.37	$1,762.38 per Hectare
Cost per Tonne (AEC):	$60.66	$47.58	$37.84	per Tonne
Cost into Perpetuity:	$9,084.73	$12,686.87	$2,176.49	$1,843.13 per Hectare
Annual Yield:	9	16	3.45	3.45 Dry tonnes/Ha/yr (THROUGH 45 YEARS)
Costs and Yields for Region				
Present Net Cost:	$14,460,000,000.00	$20,193,000,000.00	$4,945,000,000.00	$4,318,000,000.00
Cost into Perpetuity:	$22,258,000,000.00	$31,083,000,000.00	$5,332,000,000.00	$4,516,000,000.00
Annual Yield:	22,015,000	39,198,000	8,454,000	8,454,000 Tonnes (THROUGH 45 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.83	$0.77	$0.72 per liter	
Region Cost	$3,593,000,000.00	$5,885,000,000.00	$1,187,000,000.00	
Potential Production	4,316,000,000	7,686,000,000	1,658,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.91	$0.86	$0.82 per liter	
Region Cost	$5,269,000,000.00	$8,869,000,000.00	$1,831,000,000.00	
Potential Production	5,793,000,000	10,315,000,000	2,225,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$82.18	$70.12	$61.15 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	South Florida
Acres available:	215000 ac
Admin/land:	56 $/ac/yr
Site prep/plant:	248 $/ac
Weed control:	0 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	6.69 Ton/ac/yr
Yield 2	13.39 Ton/ac/yr
Rotation Age:	6 Years

TRADITIONAL FORESTRY

Region:	South Florida
Acres available:	215000 ac
Admin/land:	56 $/ac/yr
Site prep/plant:	118.66 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.84 Dry tons/ac/yr
Rotation Age:	30 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: South Florida

Hectares in Region: 87,000

Costs and Yields per Hectare	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST
Present Net Cost:	$8,350.98	$13,360.25	$3,147.82	$2,661.44 per Hectare
Cost per Tonne (AEC):	$51.45	$41.12	$55.47	per Tonne
Cost into Perpetuity:	$12,854.46	$20,565.12	$3,811.43	$3,062.83 per Hectare
Annual Yield:	15	30	4.12	4.12 Dry tonnes/Ha/yr (THROUGH 30 YEARS)
Costs and Yields for Region				
Present Net Cost:	$727,000,000.00	$1,162,000,000.00	$274,000,000.00	$232,000,000.00
Cost into Perpetuity:	$1,118,000,000.00	$1,789,000,000.00	$332,000,000.00	$266,000,000.00
Annual Yield:	1,304,000	2,610,000	359,000	359,000 Tonnes (THROUGH 30 YEARS)
Annual Ethanol Production				
Via Acid Hydrolysis				
Unit Cost	$0.79	$0.73	$0.81 per liter	
Region Cost	$201,000,000.00	$375,000,000.00	$56,000,000.00	
Potential Production	256,000,000	512,000,000	70,000,000 liters per year	
Via Enzymatic Hydrolysis				
Unit Cost	$0.87	$0.84	$0.89 per liter	
Region Cost	$300,000,000.00	$574,000,000.00	$84,000,000.00	
Potential Production	343,000,000	687,000,000	94,000,000 liters per year	
24 MW Wood Power Plant				
Cost per MW	$73.69	$64.18	$77.39 per MW	

SHORT ROTATION INTENSIVE CULTURE

Region:	Southeast Coast
Acres available:	5697000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	309 $/ac
Weed control:	51.9 $/ac
Fertilization:	85.8 $/ac
Pest Control:	20.3 $/ac
Harvest Cost:	32.5 $/ton
Road:	33.9 $/harvest
Yield 1	5.36 Ton/ac/yr
Yield 2	9.82 Ton/ac/yr
Rotation Age:	6 Years

TRADITIONAL FORESTRY

Region:	Southeast Coast
Acres available:	5697000 ac
Admin/land:	27 $/ac/yr
Site prep/plant:	116.66 $/ac
Weed control:	51.8 $/ac
Fertilization:	85.7 $/ac
Pest Control:	0 $/ac
Harvest Cost:	21.7 $/ton
Road :	0 $/harvest
Yield:	1.84 Dry tons/ac/yr
Rotation Age:	30 Years

FORESTRY PROGRAM COSTS AND PRODUCTIVITY

Region: Southeast Coast

Hectares in Region: 2,306,000

Costs and Yields per Hectare

	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST	
Present Net Cost:	$6,911.28	$10,245.81	$2,090.22	$1,588.95	per Hectare
Cost per Tonne (AEC):	$53.15	$43.00	$36.83		per Tonne
Cost into Perpetuity:	$10,638.37	$15,771.13	$2,530.86	$1,782.47	per Hectare
Annual Yield:	12	22	4.12	4.12	Dry tonnes/Ha/yr
				(THROUGH 30 YEARS)	

Costs and Yields for Region

	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	NO HARVEST	
Present Net Cost:	$15,937,000,000.00	$23,627,000,000.00	$4,820,000,000.00	$3,664,000,000.00	
Cost into Perpetuity:	$24,532,000,000.00	$36,368,000,000.00	$5,836,000,000.00	$4,110,000,000.00	
Annual Yield:	27,696,000	50,742,000	9,508,000	9,508,000	Tonnes
				(THROUGH 30 YEARS)	

Annual Ethanol Production

	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	
Via Acid Hydrolysis				
Unit Cost	$0.79	$0.74	$0.71	per liter
Region Cost	$4,312,000,000.00	$7,385,000,000.00	$1,325,000,000.00	
Potential Production	5,430,000,000	9,949,000,000	1,864,000,000	liters per year
Via Enzymatic Hydrolysis				
Unit Cost	$0.88	$0.84	$0.82	per liter
Region Cost	$6,420,000,000.00	$11,249,000,000.00	$2,049,000,000.00	
Potential Production	7,288,000,000	13,353,000,000	2,502,000,000	liters per year

24 MW Wood Power Plant

	SRIC NEAR TERM	SRIC MID TERM	TRADITIONAL FORESTRY	
Cost per MW	$75.25	$65.91	$60.22	per MW

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-91-003		

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9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation, P.O. Box 13000, Research Triangle Park, North Carolina 27709	**10. PROGRAM ELEMENT NO.** **11. CONTRACT/GRANT NO.** 68-02-4286, Tasks 97 and 112
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15. SUPPLEMENTARY NOTES AEERL project officer is Christopher D. Geron, Mail Drop 63, 919/541-4639.

16. ABSTRACT The report gives results of an analysis of three alternative uses of forests in the U.S. to reduce atmospheric carbon dioxide (CO2) concentrations: (1) planting trees with no harvesting, (2) traditional forestry, and (3) short-rotation intensive culture of trees for biomass. Increasing concentrations of CO2 and other radiatively important trace gases (RITGs) are of concern due to their potential to alter the Earth's climate. Some scientists, after reviewing the results of general circulation models, predict rising average temperatures and alterations in the Earth's hydrologic cycle. While the debate continues over the actual magnitude of global warming, most scientists agree that some change will occur over the next century. This places a burden on policymakers to address global warming and to develop mitigation measures. Since forests provide a sink for carbon by fixing CO2 to produce biomass, halting deforestation and creating new forests have been proposed as ways to slow the buildup of carbon in the Earth's atmosphere.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Climatic Changes	Pollution Control	13B 04B
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Carbon		Global Climate	
Reforestation			02F
Wood			11L
Biomass			08A, 06C

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