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Costs of Producing Biomass from Riparian Buffer Strips

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Energy Division

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CONTENTS

FIGURES

TABLES

ABSTRACT

Nutrient runoff from poultry litter applied to agricultural fields in the Delmarva Peninsula contributes to high nutrient loadings in Chesapeake Bay. One potential means of ameliorating this problem is the use of riparian buffer strips. Riparian buffer strips intercept overland flows of water, sediments, nutrients, and pollutants; and ground water flows of nutrients and pollutants. Costs are estimated for three biomass systems grown on buffer strips: willow planted at a density of 15,300 trees/ha (6200 trees/acre); poplar planted at a density of 1345 trees/ha (545 trees/acre); and switchgrass. These costs are estimated for five different scenarios: (1) total economic costs, where everything is costed [cash costs, noncash costs (e.g., depreciation), land rent, labor]; (2) costs with Conservation Reserve Program (CRP) payments (which pays 50% of establishment costs and an annual land rent); (3) costs with enhanced CRP payments (which pays 95% of establishment costs and an annual payment of approximately 170% of land rent for trees and 150% of land rent for grasses); (4) costs when buffer strips are required, but harvest of biomass is not required [costs borne by biomass are for yield enhancing activities (e.g., fertilization), harvest, and transport]; and (5) costs when buffer strips are required. and harvest of biomass is required to remove nutrients (costs borne by biomass are for yield enhancing activities and transport). CRP regulations would have to change to allow harvest. Delivered costs of willow, poplar, and switchgrass [including transportation costs of $0.38/GJ ($0.40/million Btu) for switchgrass and $0.57/GJ ($0.60/million Btu) for willow and poplar] at 11.2 dry Mg/ha-year (5 dry tons/acre-year) for the five cost scenarios listed above are [$/GJ ($million Btu)]:

1) 3.30–5.45 (3.45–5.75)
2) 2.30–3.80 (2.45–4.00)
3) 1.70–2.45 (1.80–2.60)
4) 1.85–3.80 (1.95–4.05)
5) 0.80–1.50 (0.85–1.60).

At yields of 15.7 to 17.9 GJ/ha-year (7 to 8 dry tons/acre-year), lower willow and poplar establishment costs, transportation costs of $0.30 to $0.45/GJ ($0.30–$0.50/million Btu), and lower willow and poplar harvest costs, total economic costs for willow (19-year stand life), poplar, and switchgrass are $2.35 to $2.60/GJ ($2.50 to $2.75/million Btu). The potential production of biomass from riparian buffer strips in the Delmarva Peninsula ranges from 190,000 to 380,000 Mg (210,000 to 420,000 dry tons) per year.

INTRODUCTION

In the Delmarva Peninsula[1] large quantities of poultry (primarily chicken as broilers) are produced and litter from this poultry production is spread over agricultural fields. Because poultry litter is often applied to fields at a rate to meet crop nitrogen needs, phosphorus is applied in excess of crop nutrient needs. Runoff from application of poultry litter and other activities; such as fertilization, pesticide applications, urban wastes, and urban runoff; contribute to high levels of nutrient loading in Chesapeake Bay. One proposed means of reducing nutrient runoff from fields where poultry litter is applied, is to establish biomass crops as riparian buffer strips to intercept both overland and ground water flows. However, over time, nutrients may build up in buffer strips to the point where the capacity to absorb nutrients is saturated, at which point in time the buffer strips lose their effectiveness. This is especially true of phosphorus. (Nitrogen may be an exception, because under appropriate conditions, denitrification can occur and nitrogen is given off to the atmosphere as a gas.) One means of removing some nutrients from the buffer strips would be to periodically harvest biomass from the strips.

Agriculture in the Delmarva Peninsula is primarily chickens for broiler production and raising of cash grain crops and vegetables. There are 0.52 million ha (1.3 million acres) of harvested cropland. About 8% of cropland is irrigated. Double cropping is practiced on 97,200 ha (240,000 acres). Of harvested acreage, about 85% is in soybeans, corn, and wheat. Forage crop production is relatively small (about 4% of cropland), 14,000 ha (35,000 acres) of hay and 8,500 ha (21,000 acres) of silage. Pasture is an additional 28,000 ha (69,000 acres) (Table 1) (USDOC/BEA 1993–1994). (Table 1 in its equivalent English units is Table A.1 in Appendix A.)

In the counties of Sussex in Delaware; Caroline, Dorchester, Somerset, Talbot, Wicomico, and Worcester in Maryland; and Accomack in Virginia; an estimated 600,000 Mg (660,000 tons) of poultry litter, containing 2.7% nitrogen and 3.8% phosphorous (as P_2O_5), are produced annually (Antares Group Inc. et al 1999). These counties account for 92% of total broiler production in the Delmarva Peninsula. Over the entire Delmarva Peninsula and accounting for the additional broiler production in counties other than those listed above, if poultry litter is spread over all cropland, then annual nitrogen and phosphorous applications (as P_2O_5) would average 31 kg/ha (28 lb/acre) and 45 kg/ha (40 lb/acre), respectively.

There are a number of federal and state programs which help pay for establishing and maintaining riparian buffer strips (see Appendix B). One means of addressing issues relating to sedimentation and water quality has been the Conservation Reserve Program (CRP). It was initiated by Congress in 1985 and initially was directed toward reducing soil erosion on highly erodible cropland. The 1990 Farm Act changed the goals of the CRP toward addressing water quality and other environmental concerns. Under the CRP, participants (land owners or farm operators) voluntarily remove land from crop production for 10 to 15 years and establish a permanent cover (usually grasses or trees) in exchange for an annual rental payment and half the cost of establishing the permanent cover (USDA/ERS 1997). Land in the CRP is not allowed to be harvested except under emergency circumstances. If harvest of grasses and trees during the tenure of a CRP contract is desired, then the provisions of the CRP would have to be changed. However, in southern Iowa, switchgrass is presently being harvested from CRP land to be used

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[1]The Delmarva Peninsula is east of Chesapeake Bay and west of the Atlantic Ocean and consists of Delaware, Maryland east of Chesapeake Bay, and a small portion of Virginia. Table 1 lists the counties in the Delmarva Peninsula.

Table 1. Broilers and cropland in the Delmarva Peninsula

	Delaware			Maryland									Virginia	
	Kent	Newcastle	Sussex	Caroline	Cecil	Dor-chester	Kent	Queen Anne's	Somerset	Talbot	Wico-mico	Worces-ter	Acco-mack	Total
Broilers sold (1000)	29143	-[a]	194186	35549	0	19672	2157	8599	48523	8015	76498	57408	17406	497156
							1000 ha							
Land in farms	79909	35277	123352	51409	32486	50106	53151	66943	22533	44173	36945	43530	37072	676887
Cropland	67278	29731	103459	43162	24362	40589	45834	57618	16233	37913	28994	32766	29321	557261
Harvested	63547	27470	99406	41260	20075	38328	42081	52647	15082	35759	27166	31253	28105	522181
Irrigated	8212	823	15975	5996	288	4339	1931	3166	609	803	1861	942	3194	48139
Corn	17486	12975	31984	9458	7532	7622	22174	22604	4581	12610	8011	15442	2799	175279
Wheat	10870	3904	10227	9268	2534	8082	4831	10907	2675	7500	3949	2107	8117	84973
Sorghum	387		3455	788		1941		245	110	432	988	40		8386
Barley	8105	600	6515	4655	1039	3896	902	1962	380	1002	382	299		29736
Oats	194		103	20	37		40	8		21	4		22	449
Rye	63	28	209	43	12	15	96	43		28	71		51	657
Soybeans	33057	10361	50458	24782	5845	25104	14414	23845	8714	19100	15503	15394	19774	266349
Canola				187			152	83						422
Potatoes	1671	429	1	2								409		2513
Sweet potatoes						2					15		181	198
Cotton													218	218
Hay	1913	1329	1595	1283	3359	327	1331	1179	449	502	449	287	73	14076
Corn silage	1666	389	1770	845	1111		1107	720	155	272	87	102		8223
Sorghum silage	22		294	28			7							350
Vegetables	6779	433	9946	2544	76	2363	416	1006	441	395	1134	140		25672
Orchards													50	50
Nursery and greenhouse	199	138	283	139		30		341	52	170	251	13	127	1743
All crops	82412	30586	116839	54041	21545	49381	45470	62942	17558	42033	30843	34232	31412	619294
Double crop	18864	3116	17433	12781	1470	11053	3390	10294	2476	6274	3677	2978	3306	97114
Pasture	4257	1418	2747	1751	5428	1144	1770	2517	682	783	1318	2810	1135	27761
Woodland pasture	1009	259	1016	417	387	500	222	624	213	210	662	969	164	6651
Woodland on farms	9021	3039	14748	6503	4665	6970	5068	7496	4667	4768	5964	7761	6134	86803

[a]Broiler data in Delaware for Kent and New Castle counties is not disaggregated, but most broilers are likely in Kent County.

Source: USDOC/BOC (1993–1994)

in a test to cofire switchgrass and coal in an electric power generating station. Where one is trying to prevent nutrients from reaching water bodies, not permitting harvest may be counter productive. Because part of the purpose of the CRP is to enhance wildlife habitat and concerns during the nesting period, no harvest is allowed from April 15 to August 15.

In Maryland an enhanced CRP program, known as the Conservation Reserve Enhancement Program, was instituted in 1998. In this program, the federal CRP and Maryland state programs, in cooperation with the Chesapeake Bay Foundation and Ducks Unlimited, pay up to 95% of establishment costs for riparian vegetative buffers (or filter strips), make rental payments of 170% of prevailing rental rates for land planted to trees and 150% of prevailing rental rates for land planted to grasses, and pay a $12.35/ha ($5/acre) annual payment for buffer strip maintenance. (If a planted area qualifies as a riparian forest buffer strip, then up to 100% of establishment costs are reimbursed. In this report, the buffer strips considered are assumed to qualify as riparian vegetative buffers for costing purposes.) Up to $1420/ha ($575/acre) and $988/ha ($400/acre) of establishment costs are reimbursed for hardwood trees and warm season grasses, respectively. [For a vegetative buffer 95% of these maximum establishment costs can be reimbursed for trees, up to $1420/ha*0.95=$1349/ha ($575/acre*0.95 = $546/acre).] There is a goal of enrolling 40,400 ha (100,000 acres) in Maryland (Maryland Department of Agriculture, c. 1998).

One potential means of encouraging riparian buffer strips to be created along waterways would be to allow landowners to produces crops from these strips that, when harvested, would still allow the buffer strip to function to intercept nutrients, soil particles, and pesticides. Perennial biomass crops, such as perennial grasses and short rotation woody crops (SRWC), could possibly meet this requirement. The harvested biomass could be used for energy in a number of ways. At present, the most likely uses would be for cofiring with coal in an electric power generating facility, for heating buildings, or for cogenerating steam and electricity at small scales. In the future, biomass could be converted to gaseous or liquid fuels (e.g., ethanol). [See Antares Group Inc. et al (1999) for examples of potential biomass use in the Delmarva Peninsula.]

It is possible that regulations could be promulgated that require riparian buffer strips to be established if poultry litter is to be spread on agricultural fields or for other reasons, such as soil erosion control, streambank erosion control, or to improve water quality in general. This would change the economics of biomass production from riparian buffer strips because the cost of establishing and maintaining the crops in the buffer strips would be borne by activities that contribute to nutrient and pollutant runoff. Only the costs of enhancing yields (e.g., fertilization if advantageous and it does not degrade the functioning of the buffer strip), harvest, and transportation would be borne by biomass produced from buffer strips. If periodic harvest is required by regulation to remove nutrient buildup from the buffer strip, then only the costs of enhancing yields and transportation would be borne by the biomass.

In this report, costs are estimated for producing biomass from riparian buffer strips in the Delmarva Peninsula. There are five levels of costs estimated. First, total economic costs (referred to as total costs) are estimated. Second, costs after payments from the standard CRP program are estimated. Third, costs after payments from the enhanced CRP program are estimated. For the enhanced CRP program it is assumed that buffer strips created with biomass crops would be reimbursed for establishment costs at the rate for vegetative buffers, up to $1349/ha ($546/acre) for SRWC and up to $988/ha ($400/acre) for switchgrass. In the second and third cases it is assumed that biomass crops can be planted in a program that receives payments the same as land enrolled in the CRP or enhanced CRP, and that the biomass crops can be harvested and used for energy purposes. In the fourth and fifth cases, buffer strips are assumed to be required (e.g., by regulation) if poultry litter is to be applied to agricultural fields. The fourth case is where buffer strips are required, but harvest of the biomass to remove nutrients is not required. In the fifth case buffer strips are required and harvest is required to remove nutrients from the buffer strip. Therefore, in the fourth and fifth cases, a significant fraction of the costs is associated with the application of poultry litter to agricultural fields (i.e., establishing the buffer strip and in the fifth case also harvesting the biomass) and does not affect the decision whether to harvest and/or transport the biomass for use as a fuel. Costs for the fourth and fifth cases are reported in the section entitled "Costs for biomass when buffer strips are required." Costs are estimated for willow and poplar as wood chips and switchgrass as bales of hay. Costs are calculated using 19.8 GJ/dry Mg (17 million Btu/dry ton) for willows and poplars and 16.4 GJ/dry Mg (15 million Btu/dry ton) for switchgrass.

The width of buffer strips depends upon the circumstances at a site. In this report, it is assumed that strips are 30 m (100') wide. For a 40.5 ha (100 acre) square field with a buffer strip on one side, the buffer strip is 2100' long by 30 m (100') wide, or contain 1.9 ha (4.8 acres). If the 4.6 m (15') closest to the water body is not harvested, then only 1.7 ha (4.1 acres) are available for harvest. This is less than the minimum size tract one would ideally want to harvest with trees.

One of the concerns about costs is the small size of the potentially harvestable area in a buffer strip. The costs in the main body of the report are for large tracts. The effects of small tracts are relatively minor and are reported in the Summary and Conclusions.

BACKGROUND AND ASSUMPTIONS

RIPARIAN BUFFER AND FILTER STRIPS

A riparian buffer strip is an area of trees and/or shrubs and/or grasses adjacent to and upslope from water bodies. A filter strip is a strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater. Its purpose is: "to remove sediment and other pollutants from runoff by filtration, infiltration, absorption, adsorption, decomposition, and volatilization, resulting in improved water quality and protecting the environment" (USDA/NRCS 1997a). Note that filter strips and buffer strips are defined differently. The Natural Resources Conservation Service (NRCS) and some states have promulgated standards for riparian forest buffer and filter strips. [For NRCS Standards see Conservation Practice Standard, Riparian Forest Buffer (Acre), Code 391A and Conservation Practice Standard, Filter Strip (acre) Code 393A (USDA/NRCS 1997a,b).] In some cases states have their own standards or they may use national NRCS standards. Delaware has a standard for filter strips but uses the NRCS standard for riparian forest buffers (personal communication, Paul M. Petrichenko, National Resources Conservation Service, Dover, DE, January 11, 1999). Maryland uses NRCS standards for riparian forest buffer and filter strips (personal communication, Mark Wagener, National Resources Conservation Service, Annapolis, MD, June 4, 1999).

The purposes of riparian forest buffers are:

- Create shade to reduce water temperatures to improve habitat for aquatic organisms;
- Provide a source of detritus and large woody debris for aquatic organisms and provide habitat for wildlife;
- Reduce amounts of sediment, organic material, nutrients and pesticides in surface runoff and reduce nutrients, and other chemicals in shallow ground water flow (USDA/NRCS 1997a).

Under NRCS standards, riparian forest buffers consist of three zones (Fig. 1). Zone 1 begins at the normal water line or top of the bank and extends a minimum of 4.6 m (15') away from the water. Dominant vegetation consists of trees and shrubs. Occasional removal of some tree and shrub products is permitted as long as the intended purposes are not compromised by the loss of vegetation or disturbance.

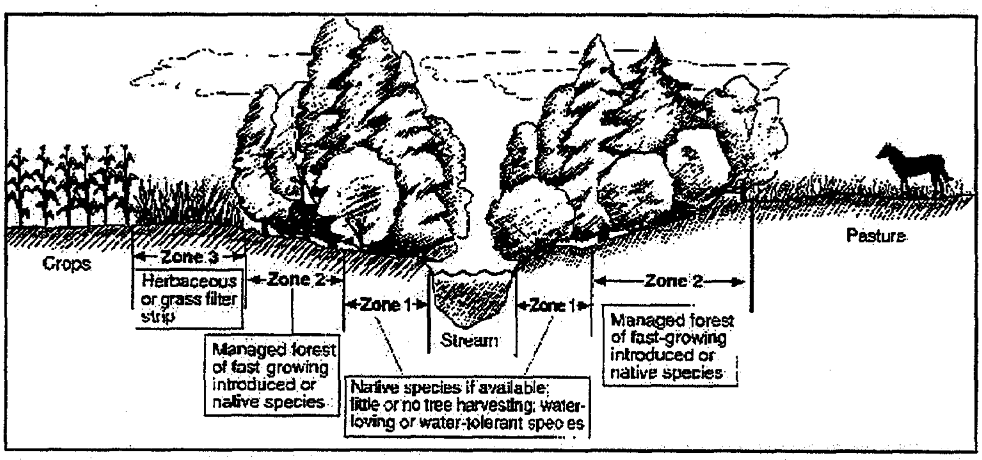

Fig. 1. The three zones of a riparian forest buffer (Source: USDA/NRCS).

Zone 2 begins at the edge of zone 1 and extends a minimum of 6.1 m (20') away from the water. The minimum combined widths of zones 1 and 2 are 30 m (100') or 30% of the flood plain, whichever is less, but not less than 10.7 m (35'). Dominant vegetation in zone 2 also consists of trees and shrubs. Removal of trees and shrubs on a periodic and regular basis is permitted.

Zone 3 is up gradient of zone 2 and its purpose is to control concentrated flow erosion or mass soil movement (USDA/NRCS 1997b). Zone 3 is designed in accordance with criteria in filter strip standards (393A) (USDA/NRCS 1997a).

In Delaware, filter strips are designed with trees with a dense ground cover and/or a thick sod of grass with a minimum width of 7.3 m (24') if the slope is less than 6%. If the slope is greater than 6%, then the width of the filter strip in meters (ft) is determined using the formula 1.22*%slope (4*%slope) {e.g., if the slope is 8% then the width of the filter strip is 9.76 m (32') [1.22*8 = 9.76 m (4*8=32')]}. Grass species that are approved for planting are: tall fescue (Ky 31) at 67.2 kg/ha (60 lb/acre), reed canarygrass at 22.4 kg/ha (20 lb/acre), and a mixture of reed canarygrass at 11.2 kg/ha (10 lb/acre) and tall fescue (Ky 31) at 33.6 kg/ha (30 lb/acre). Fertilization is done according to soil tests. Harvest is permitted (USDA/SCS, Delaware 1984).

In zones 2 and 3 of a riparian forest buffer and in filter strips, harvest of biomass is allowed. Assuming that in zones 2 and 3 of forest buffers and in filter strips; willow, poplar, and switchgrass can serve the required functions described previously and are allowed to be harvested on a periodic basis; then costs are estimated for producing biomass from these areas.

PARTICIPATION IN CONSERVATION PROGRAMS

Landowners'/farm operators' decisions to participate in conservation programs such as the CRP are affected by their knowledge of the program and program characteristics. Esseks and Kraft (1986, 1988, 1989); Force and Bills (1989); Hatley et al. (1989); and Mortensen et al. (1989) discuss factors that affect participation and nonparticipation in the CRP. One should note that some of the problems these authors discuss have been addressed by changes to the CRP process, as discussed below.

Esseks and Kraft (1986) found that after the first three CRP sign-ups in 1986, 41% of nonbidders believed their land was ineligible for the CRP. However, in most cases this was a mistaken belief. This percent decreased over time as landowners became more familiar with the CRP. Economic considerations, such as perceived inadequate annual rental payments and the belief that more could be earned by cropping than enrolling in the CRP, discouraged some nonbidders. Another obstacle to some was the 10-year enrollment requirement. Five years would have been more acceptable to many.

In the original formulation of the CRP, landowners bid for an annual rental payment, and if the payment bid was above the regional ceiling (not differentiated by land quality), then the bid was rejected. A substantial fraction of the nonbidders did not accurately know the maximum rate. Rates were only published after each sign-up. Some bidders were discouraged if they assumed annual rental payments would be too low. Because there was a maximum regional rental rate, owners of highly productive cropland that may have been desirable to have enrolled in the CRP did not bid that land because the annual rental payment was perceived as being too low. Higher annual rental payment would have encouraged some additional bidding. However, Esseks and Kraft found that a $25/ha ($10/acre) increase in annual rental payment would have only increased bids by 11 to 24% across four corn belt sites. Farmers with off-farm income and those who perceived their land as being erosive were more likely to participate in the CRP. Another possible incentive to encourage CRP participation is to allow grazing or haying of CRP land. However, this option is strongly opposed by cattle groups (Esseks and Kraft 1986). With changes in the CRP procedure, land rental rates requested by bidders are just one of seven factors considered in whether to accept a bid, and land productivity based rental rates are now published during the bidding process.

Getting CRP participants to plant trees has been difficult. The CRP had a goal of 12.5% of enrolled acres planted in trees. But of 36.4 million acres enrolled in sign-ups 1 to 12 (1986 to 1992), only 1 million ha (2.5 million acres) or 6.8% was planted to trees. In the Southeast (Alabama, Florida, Georgia, and South Carolina) and Delta States (Arkansas, Louisiana, and Mississippi) 77% and 60% of enrolled acreages were planted to trees, respectively. The only other region with a high percentage of tree planting was the Northeast with 47%, but total enrolled area was only 10,000 ha (25,000 acres) (USDA/ERS 1994). Even with more recent sign-ups this has not changed significantly. In sign-up 15 in 1997, 6.6% of the enrolled area was planted to trees (Osborn 1997)

The southern states where significant tree planting on CRP land has taken place have existing markets for timber and some state and federal agency offices within these states have made concrete efforts to encourage and assist tree planting (Mixon and Thompson 1989, Morse 1987). In a study in southern Illinois, which is 30% covered by commercial forest land, those who planted trees on CRP land tended to be: 1) younger than nontree planting CRP participants, 2) have off-farm incomes, 3) have farms of less than 40 ha (100 acres), and 4) have owned land less than 10 years. The most frequently cited purposes for tree planting were conservation and wildlife habitat. Only 24% reported timber production as the motivation for tree planting. The three most important reasons for not planting trees under the CRP were length of timber rotation, lack of information on tree planting, and the annual rental payment was not high enough (Olmstead and McCurdy 1989). In a North Dakota study where only 5.3% of CRP land was planted to trees, 30% of CRP participants indicated a willingness to consider planting trees if the cost share percentage were higher (Mortensen et al. 1989).

West (1988) cites problems associated with tree plantings on CRP lands as: producers cannot effectively manage tree plantings that are small and fragmented and a reluctance to break off parts of fields to plant to trees. West notes that of lands from the Soil Bank Program of the 1950s planted to trees, 90% are still in trees.

Starting in 1988, filter strips 20 to 30 m (65' to 100') wide became eligible for inclusion in the CRP and 1.6 to 2 million ha (4 to 5 million acres) of cropland were eligible for enrollment under this criterion. In 1994 only 21,000 ha (52,000 acres) of filter strips were included in the CRP (Lant et al. 1995). [The 1996 Farm Act expanded eligibility significantly for filter strips, to 8.5 million ha (21 million acres).] Esseks and Kraft (1989) found that about half of potential CRP participants were unaware of the filter strip option. Reasons cited for not enrolling in CRP filter strips were economic, such as: (1) a higher return could be earned farming the land, (2) the length of commitment reduces flexibility to respond to changing economic circumstances, and (3) the reduced acreage farmed interferes with efficient machinery utilization. Other reasons cited were simply a desire not to deal with government programs and an aversion to government control of farming operations.

Planting trees reduces cropping flexibility even more than planting grasses and at the midwestern sites surveyed there is concern for plugging of drain tiles by tree roots. (Drain tiles may decrease the effectiveness of filter strips to remove nitrogen from groundwater because they may allow water to bypass the filter strips.) Only 26% of respondents felt they could not market timber profitably. Lands eligible for filter strips tend to be more productive lands, so the maximum rental rates discouraged enrollment of this land in the CRP (Lant et al. 1995).

Lant et al. (1995) presented landowners and/or farm operators with land eligible for enrollment as CRP filter strips with the options for: (1) enrollment of filter strips in the CRP for 10 years with annual payments and (2) enrollment of filter strips with a 30-year easement with provisions as in the Wetland Reserve Program (e.g., no crop production) with a lump sum payment. Landowners/operators preferred the annual rental payments over the lump sum easement payment. Even when the lump sum was greater than the market price of the land, a majority of landowners/operators preferred to farm the potential filter strip instead of accepting the easement. [Easement payments as high as $1600/ha ($4000/acre) were offered.] Increases in annual rental rates above $395/ha ($160/acre) brought little additional participation. Nonfinancial reasons for not participating were important.

Purvis et al. (1989) mention a pilot program in the Black Creek watershed in northeastern Indiana in which farmers were offered a one-time lump sum payment to establish filter strips along streams. Farmers were allowed to hay these filter strips. Nine years after the filter strips were installed, 92% of participating farmers still maintained their filter strips.

Over time the CRP has been modified, partly in response to some of the above observations. Since 1991, a national environmental benefits index (EBI) has been used to rank offers of land to enroll in the CRP. The EBI is the sum of six environmental factors: (1) wildlife habitat; (2) water quality benefits; (3) soil erosion; (4) long-term retention of trees, shrubs, and wetlands; (5) air quality; and (6) conservation priority area; and a seventh factor, cost. Weightings of these factors has changed over time. Offered rental rates are now screened against productivity based soil rental rates that are announced *during* the sign-up period (Feather et al. 1998, Osborn 1997, Smith 1999).

Under authority of the 1996 Farm Act, there is now a continuous sign-up for land to be devoted to specific purposes, including: filter strips, riparian buffers, grassed waterways, field windbreaks, shelterbelts, living snow fences, salt-tolerant vegetation, shallow water areas for wildlife, and wellhead protection. Land for these purposes is accepted for the CRP as long as the land owner is willing to accept a rental payment limited to a maximum productivity-adjusted payment rate that is calculated by the Farm Services Agency of the U.S. Department of Agriculture. As of March 1999, 340,000 ha (841,000 acres) has been enrolled under the continuous sign-up.

While financial considerations and incentives are important to landowner/farm operator participation in programs such as the CRP, merely increasing the financial incentives will not increase participation to its fullest. Landowners/farm operators must be knowledgeable about program eligibility and options and the financial incentives. If maximum participation in conservation programs is desired, then federal and state agencies must make a concerted effort to inform potential participants of the programs and their characteristics and make participation in the programs as easy as is reasonable. It appears that once trees or filter strips are established, most are maintained by land owners and farm operators.

BIOMASS CROPPING SYSTEMS

Short-rotation woody crop (SRWC) systems can be designed to produce wood for energy and/or pulp and energy. In Europe, especially Sweden, willows (*Salix* spp.) are being planted at dense spacings of 15,300 trees/ha (6200 trees/acre), harvested after three years with a diameter breast height (DBH) of less than 7.62 cm (3"), and allowed to coppice. The biomass is being used for energy. In the United States poplars (*Populus* spp.) are being planted at much wider spacings [e.g., 2.44 m x 2.44 m (8' x 8'), 2.44 m x 3.05 m (8' x 10')] so only 1680 or 1345 trees are planted per ha (680 or 545 trees are planted per acre), are harvested at 6 to 10 years of age depending upon climatic and soil conditions and crop management, and not allowed to regrow by coppice (Culshaw and Stokes 1995). This biomass is being used primarily for pulp (65–75% of the harvested biomass) and the remainder (25–35%), the bark and limbs, for energy.

In this report two SRWC systems are costed for use in riparian buffer strips. The first system is willow planted mechanically at a density of 15,300 trees/ha (6200 trees/acre), mowed at the end of the first growing season, harvested using modified agricultural equipment at the end of the fourth growing season and every three years thereafter. Because coppicing is desired, harvest takes place during the winter months. The trees are chipped as they are harvested, blown into a forage wagon, which in turn is dumped into a chip van which is taken to the place where the biomass is used. Willow stand life is varied from 9 to 22 years. The second system is poplars planted by hand at a density of 1345 trees/ha (545 trees/acre) that are assumed to be harvested after 10 years with conventional forestry equipment. Note that harvest at the end of 10 years would be consistent with a 10-year CRP contract. Because no coppicing is desired, harvest can be any time during the year. However, because of concerns for wildlife, the harvest window would exclude the period April 15 to August 15.

A third system that is costed is switchgrass (*Panicum virgatum*). Harvest is with conventional haying equipment. A single annual late summer/fall harvest is assumed and, because of wildlife concerns, would take place after August 15.

Note that under the CRP most plantings are of mixed species, the species to be planted have to be approved, and harvest is not generally allowed. The two systems that are costed in this report with CRP and with enhanced CRP payments, are two scenarios in which it is assumed that biomass is allowed to be planted as willow, poplar, or switchgrass and harvested for use as energy, and these plantings are eligible to receive payments that are equivalent to those received from the CRP and enhanced CRP programs.

COSTING METHODOLOGY

Costing of biomass systems requires many assumptions. The methodology and most of the assumptions used are from the BIOCOST Model (Walsh and Becker 1996). These are supplemented when necessary from Turhollow et al. (1998) and an unpublished report by Turhollow on SRWC transportation costs, which is included in Appendix C.

Costs are calculated using a spreadsheet model based on inputs used in the BIOCOST Model. The BIOCOST Model itself is not used. Costs are calculated using a total economic cost accounting approach, as is used in the BIOCOST Model (Walsh and Becker 1996). Under this approach cash and noncash, variable and fixed costs are included. This methodology is used by the U.S. Department of Agriculture for estimating costs of traditional agricultural crops such as corn, wheat, soybeans, and cotton. The total economic cost accounting approach takes a long run perspective, in that over a long period of time all costs must be covered by revenue from products sold (i.e., all costs in the long run are variable).

While costs are calculated using a total economic cost accounting approach, this is merely an accounting method, and some farmers may be willing to produce crops for less than the costs calculated from total economic cost accounting. In the short run farmers need only cover their variable costs, because they are better off financially producing something as long as their variable costs are covered and they are contributing something toward their fixed costs. While rent is charged for land, some farmers may own the land so the concept of rent to them is merely an opportunity cost and not an out-of-pocket expense. Under the total economic cost accounting approach, land is a large fraction of total costs, 18% to 26%. If the land is owned outright by a farmer, the farmer may not require a rate of return equal to the $141/ha ($57/acre) land rent charged for cropland. Land-owning farmers may not calculate the full rental value in calculating the price at which they are willing to sell.

There are two types of custom operators, those who perform custom operations as a full-time occupation (e.g., harvesting SRWC) and those who are farmers who do custom operations (e.g., tillage) as a side occupation when they have time. The full time custom operator is likely to charge rates in line with a total economic cost accounting approach. The part-time custom operator may only charge slightly higher than his variable costs plus a labor charge.

Costs are divided into three general categories: variable cash costs (VC), fixed cash costs (FC), and economic costs (EC) (costs of owned resources). Subcategories within each are shown in Table 2.

Table 2. Costs by category

Variable cash costs (VC)	Fixed cash costs (FC)	Economic (owned resources) costs (EC)
Cuttings	Farm overhead	Labor
Seed	Interest on real estate	Land (excluding interest)
Fertilizers	Taxes and insurance	Nonland capital (interest on machinery)
Nitrogen	Interest on operating	Capital replacement (depreciation)
Phosphorus	Loans	
Potassium		
Lime		
Herbicides		
Insecticides		
Fuel, lube, oil		
Machinery repairs		
Twine		
Soil testing		
Hired services		
custom harvesting		
custom planting		

These costs are calculated for each year of stand life and then discounted using the real discount rate back to time 0. The same is done with crop yields. Discounted costs $\{\sum[(VC_j + FC_j + EC_j)/(1+i)^n]\}$ are divided by discounted yields $\{\sum[(yield_j/(1+i)^n]\}$ to get average crop price. (See Appendix D for a derivation of price. Discounted yields are an artifact of the mathematical process of setting discounted yields equal to discounted costs and solving for price, which is assumed to be constant.) Mathematically this is:

$$price = \frac{\sum_{j=1}^{n} [(VC_j + FC_j + EC_j)/(1+i)^j]}{\sum_{j=1}^{n} [yield_j/(1+i)^j]}$$

where: price = average crop price,
VC_j = variable cash costs in year j,
FC_j = fixed cash costs in year j,
EC_j = economic costs in year j,
i = real interest (discount) rate.

Cost data from different years are adjusted to 1995 dollars for use in the spreadsheet models and to 1999 dollars for use in this report. The adjustments are made using the Gross Domestic Product chain-type price deflator (Table 3).

Table 3. Gross Domestic Product chain-type price deflator, 1990–1999

Year	GNP price deflator	Ratio (GNP price deflator in year to 1995)
1999		1.0600[a]
1998	112.7	1.0483[b]
1997	111.57	1.03776392894
1996	109.54	1.01888196447
1995	107.51	1
1994	105.09	0.977490466
1993	102.64	0.9547018882
1992	100	0.93014603293
1991	97.32	0.90521811924
1990	93.64	0.87098874523

[a]Estimated
[b]Preliminary
Source: USDOC/BEA (1998)

ACCOUNTING FOR SMALL TRACT SIZE

Riparian buffer strips are likely to be small in size, 0.8 to 2.0 ha (2 to 5 acres). For fields ranging in size from 10.1 to 40.5 ha (25 to 100 acres), square in shape, with a 30-m (100') wide buffer strip on one side, and 4.6 m (15') of the strip nearest the water body unharvested, harvestable area ranges from 0.8 to 1.7 ha (2.0 to 4.1 acres). Most crop budgets are designed for tracts much larger than 0.8 to 1.7 ha (2.0 to 4.1 acre). Therefore, to try to account for the small field size some adjustments are made and the results reported in the Summary and Conclusions. Otherwise costs reported are for larger tracts.

Not all time is spent with equipment operating at its theoretical rate. According to Hunt (1995), there are 10 time elements that need to be considered that involve labor associated with field operations:

1. Machine preparation time at the farm (e.g., removal from storage, attaching and unattaching implements from a tractor);
2. Travel time to and from field;
3. Machine preparation in the field;
4. Theoretical field time (i.e, time machine operating at optimum forward speed);
5. Turning time;
6. Loading and unloading;
7. Machine adjustment time (e.g., unplugging);
8. Maintenance time in field (e.g., refueling, lubrication, chain adjustment);
9. Repair time in field; and
10. Operator's personal time.

Elements 4 to 9 are included in the calculation of field efficiency. Field efficiency is the ratio of the time spent for elements 4 to the time spent for elements 4 to 9. To account for time spent in elements 1 to 3 and 10, a factor of 1.2 of labor hours per machine hours is assumed. However, for small tracts the 1.2 factor will significantly underestimate time required for 1 to 3 and 10. It is assumed that elements 1 to 3 and 10 require a minimum of 0.5 hours per hour of machine operation. For farmer operations (as opposed to custom operations) the labor hours to machine hours ratio is recalculated as:

$$\text{maximum } [(\text{machine hours} + 0.5)/\text{machine hours}, 1.2].$$

For example, to spray herbicide with a boom sprayer requires 0.22 hours/ha (0.09 hours/acre). For a 0.81 ha (2 acre) tract calculate the labor hours to machine hours ratio as:

$$\text{maximum } [(0.81*0.22 + 0.5)/(0.81*0.22), 1.2] = 3.78$$
$$\{\text{maximum } [(2*0.09 + 0.5)/(2*0.9), 1.2] = 3.78\}.$$

For a 2.02 ha (5 acre) tract the ratio is 2.31.

The calculation of the labor hours to machine hours ratio in this manner assumes there is no coordination between machine operations in the riparian buffer strip and adjacent fields. It could be, for example, that disking is done at the same time in buffer strip as in an adjacent field.

For custom harvest operations by full time custom operators, the calculation is done differently. In the field there is a labor hours to machine hours ratio of 1.2, as for farmer operations. In addition it is assumed that each move from one tract to the next requires 1 hour. The labor hours to machine hours ratio is calculated as:

$$(\text{machine hours per tract} * 1.2 + 1)/(\text{machine hours per tract}).$$

For harvesting willows, machine hours are based on the harvester [3.93 hours/ha (1.59 hours/acre) at 33.6 dry Mg/ha (15 dry tons/acre) (the base case)] and for poplars machine hours are based on the chipper [11.2 hours/ha (4.55 hours/acre) at 112 dry Mg/ha (50 dry tons/acre), 1345 trees/ha (545 trees/acre) (the base case)]. For a 0.81-ha (2-acre) tract, for willows the ratio is {(3.93*0.81*1.2+1)/(3.93*0.81 = 1.51 [(1.59*2*1.2+1)/(1.59*2) = 1.51]} and for poplars is {(11.2*0.81*1.2+1)/(11.2*0.81) = 1.31 [(4.55*2*1.2+1)/(4.55*2) = 1.31]}. For a 2.02-ha (5-acre) tract the ratios are 1.32 and 1.24 for willows and poplars, respectively.

INPUT PRICES

In 1998, cropland rental rates were \$143.30/ha (\$58.00/acre) in Delaware and \$135.80/ha (\$55.00/acre) in Maryland (USDA/NASS 1998a). Rents for 1994 to 1998 are in Table 4. Pasture rent for 1994 to 1998 is only reported for Maryland in 1994, \$82.70/ha (\$33.50/acre). Johnson and West (c. 1994) list data on land rents by region of Maryland for 1988 to 1992 and Jones (1997) lists rents for the whole state (Table 5). Of the five regions, the Upper Eastern Shore has the highest cash rents and the Lower Eastern Shore the second highest. From this data, average cropland rental rates are higher in the Delmarva Peninsula portion of Maryland than the rest of the state. In the Delmarva Peninsula it is assumed that cropland

Table 4. Cropland rental rates in Delaware and Maryland, 1994–1998

Year	Delaware	Maryland	Delaware	Maryland
	\$/ha		\$/acre	
1994	135.60	102.30	54.90	41.40
1995	150.90	110.40	61.10	44.70
1996	158.80	118.60	64.30	48.00
1997	148.20	126.70	60.00	51.30
1998	143.30	135.80	58.00	55.00

Source: USDA/NASS (1998a)

Table 5. Cropland rental rates for Maryland by region, 1988–1992

Year	Maryland	Lower Eastern Shore	Upper Eastern Shore	Southern Maryland	Piedmont	Western Maryland
				$/ha		
1988	124.75	124	143	62	111	64
1989	136.10	119	131	72	106	69
1990	121.75	109	121	67	109	74
1991	131.65	111	121	67	114	74
1992	NA[a]	111	126	72	116	74
1988–1991 average	128.55	115.45	129.05	66.70	109.90	70.40
				$/acre		
1988	50.50	50	58	25	45	26
1989	55.10	48	53	29	43	28
1990	49.30	44	49	27	44	30
1991	53.30	45	49	27	46	30
1992	NA[a]	45	51	29	47	30
1988–1991 average	52.05	46.75	52.25	27.00	44.50	28.50

[a]NA = not available.
Sources: Johnson and West (c. 1994), Jones (1997).

rents for $149.87/ha ($60.67/acre) (1999$) or $141.38/ha ($57.24/acre) (1995$) and pasture rents for $99.91/ha ($40.45/acre) (1999$) or $94.26/ha ($38.16/acre) (1995$).

Input prices used are in Table 6 and machinery prices and parameters are in Table 7. (Table 7 in its equivalent English units is Table A.2 in Appendix A.) Machinery prices and parameters for poplar harvest equipment are in Table 8. Some operations such as tree planting and harvest are custom operations and are costed using total economic cost accounting.

Table 6. Input prices (in 1995$)

Chemicals	Units	Price($/unit)	Units	Price($/unit)
Potassium	kg	0.362	lb	0.164
Phosphorus	kg	1.444	lb	0.655
Nitrogen	kg	0.679	lb	0.308
Lime (spread)	Mg	29.32	ton	26.60
Glyphosate	kg	29.82	lb	13.53
Simazine	kg	10.03	lb	4.55
2,4-D-amine	kg	7.83	lb	3.55
Atrazine	kg	7.94	lb	3.60
Linuron	kg	48.06	lb	21.80
Insecticides	kg	22.49	lb	10.20
Planting materials				
Poplar cuttings	cutting	0.16	cutting	0.16
Willow cuttings	cutting	0.10	cutting	0.10
Switchgrass seed	kg	4.41	lb	2.00
Other inputs				
Diesel fuel	L	0.244	gal	0.925
Diesel fuel - over-the-road	L	0.346	gal	1.311
Oil	L	1.31	gal	4.97
Soil testing	ha	0.62	acre	0.25
Fixed cash inputs				
Average farm overhead	ha	19.27	acre	7.80
Average real estate interest	ha	18.60	acre	7.53
Average taxes and insurance	ha	41.94	acre	16.98
Economic costs				
Labor				
Hired agricultural	hr	7.74	hr	7.74
Truck, harvest	hr	14.40	hr	14.40
Mechanic, supervisor	hr	18.00	hr	18.00
Land rent				
Cropland-nonirrigated	ha	141.38	acre	57.24
Pasture	ha	94.26	acre	38.16
Interest rates		Fraction		Fraction
Real machinery rate		0.065		0.065
6 month treasury rate		0.035		0.035
Real discount rate		0.065		0.065

Table 7. Machinery prices and parameters (costs in 1995$)

Machine type	Purchase price	Lifetime (hr)	Annual use (hr)	Repair rates	Speed (km/hr)	Width (m)	Field efficiency	Hours/ ha	Lifetime (years)	Fuel use (L/hr)	Oil use (L/hr)
Moldboard plow, 6-41cm	10700	2000	200	100	7.24	2.44	0.85	0.67	10		
Moldboard plow, 7-41cm	13800	2000	200	100	7.24	2.84	0.85	0.57	10		
Chisel plow, 4.57m	6321	2000	200	75	8.05	4.57	0.85	0.32	10		
Offset disk, 4.27m	8200	2000	200	60	9.66	4.27	0.8	0.3	10		
Offset disk, 5.49m	10200	2000	200	60	9.66	5.49	0.8	0.25	10		
Offset disk 6.40m	16900	2000	200	60	9.66	6.4	0.8	0.2	10		
Fertilizer & lime spreader, 3.6Mg, 12.2m	8000	1200	120	80	11.27	12.2	0.7	0.1	10		
Grain drill, 7.62m	24900	1500	150	75	8.05	7.62	0.7	0.22	10		
No-till drill (fertilizer attach), 4.57m	20500	1500	150	75	8.05	4.57	0.6	0.44	10		
4-row planter	45000	1500	150	75				1.65	10		
Boom sprayer, 15.2m	4700	1500	150	70	4.83	15.24	0.6	0.22	10		
Row cultivator, 2-91cm	2100	600	60	75	9.66	1.83	0.8	0.72	10		
Mower, 2.13m, bushhog	3500	2000	200	175	8.05	2.13	0.8	0.72	10		
Mower-conditioner, 2.13m	7700	2500	250	80	7.24	2.13	0.8	0.82	10		
Mower-conditioner, 3.66m	11700	2500	250	80	7.24	3.66	0.8	0.47	10		
Side-delivery rake, 2.74m	3300	2500	250	60	9.66	2.74	0.8	0.47	10		
Round baler, pto, 1.83m diam, 1.22m wide	15480	1500	150	90	8.05	1.22	0.67	1.53	10		
Round baler, pto, <1.52m diam, 1.22m wide	11300	1500	150	90	8.05	1.22	0.65	1.56	10		
Bale carrier, forklift	2700	1000	100	40					10		
Claas Jaguar harvester	300000	6400	800	40			0.7		8	66.16	0.08
High dump forage wagon (31.2 m^3)	17739	2000	400	60					5		
Tractor, 30 kW	16900	10000	833.33333	100					12	7.48	0.053
Tractor, 45 kW	21400	10000	833.33333	100					12	11.21	0.069
Tractor, 60 kW	27500	10000	833.33333	100					12	14.95	0.085
Tractor, 75 kW (cab, air)	40100	10000	833.33333	100					12	18.69	0.1
Tractor, 90 kW (cab, air)	55200	10000	833.33333	100					12	22.43	0.12
Tractor, 168 kW, (cab, air)	80500	10000	833.33333	100					12	42.06	0.2
Truck, 1.81Mg, (hoist)	45000	5000	500	60					10	14.19	0.13
Tandem truck (hay)	52200	5000	500						10	4.7	0.035
Fork lift	15300	5000	500						10	1.98	
Pickup	18400	5000	500	60					10	2.25	0.028
Truck tractor (wood)	81500	10000	1000						10		
Chip van	29000	6000	300						20		

Table 8. Machinery prices and parameters for poplar harvest equipment

Equipment	Purchase price (1995$)	Lifetime (hrs)	Lifetime (yrs)	Annual use (hrs)	Repair rates	Fuel use		Oil use	
						L/hr	gal/hr	L/hr	gal/hr
Feller-buncher head	35000	2000	4	500	80				
CAT 518 skidder-120 HP	130000	10000	5	2000	70	13.2	3.5004	0.11	0.029
Chipper-400 HP	175000	10000	5	2000	80	34.7	9.168	0.193	0.051

BIOMASS CROP YIELDS

Costs are very sensitive to yields because a large fraction of costs do not change as yields change (e.g., establishment, land costs). Average hay yields (other than alfalfa and alfalfa mixtures) have averaged between 5.2 and 9.0 Mg/ha-year (2.3 and 4.0 tons/acre-year) in Delaware from 1995 to 1997 (USDA/NASS 1998b). (The moisture content of this hay is probably about 15%). When grown and managed specifically for biomass as opposed to forage quality, higher yields can be expected. Willows in the United States are still an experimental crop. In Sweden willows are grown as a commercial crop and yields average about 11.2 dry Mg/ha-year (5 dry tons/acre-year). In New York state yields are expected to range from 9.0 to 17.9 dry Mg/ha-year (4 to 8 dry tons/acre-year) (Kopp et al. 1997). Poplars as SRWC are being grown in the Pacific Northwest, Minnesota, and Mississippi. Minnesota is a better example for the Delmarva Peninsula than the Pacific Northwest. Expected poplar yields are in Minnesota on an 2.44 m x 2.44 m (8' x 8') spacing 1680 trees/ha (680 trees/acre) are 10.1 to 12.3 dry Mg/ha-year (4.5 to 5.5 dry tons/acre-year) (personal communication, Mark Downing, Oak Ridge National Laboratory, Oak Ridge, TN, February 1, 1999).

In this study, 11.2 dry Mg/ha-year (5 dry tons/acre-year) is used as the baseline yield. Costs with yields of 9.0 and 13.4 dry Mg/ha-year (4 and 6 dry tons/acre-year) are also estimated. The range of 9.0 to 13.4 dry Mg/ha-year (4 to 6 dry tons/acre-year) represents a reasonable range of yields that can be expected for switchgrass, willow, and poplars. In examining some least cost scenarios in the conclusions, costs for higher yields are estimated.

For willow, yield at the first harvest (year 4) is 60% of mature yield. In the baseline only 20.1 dry Mg/ha (9 dry tons/acre) is harvested in year 4 versus 33.6 dry Mg/ha (15 dry tons/acre) in all subsequent harvests. For switchgrass yield in year 1 is 30% and in year 2 is two-thirds of mature yield. In the baseline in year 1, 3.36 dry Mg/ha (1.5 dry tons/acre) and in year 2, 7.46 dry Mg/ha (3.33 dry tons/acre) are harvested versus 11.2 dry Mg/ha (5 dry tons/acre) in all succeeding years.

COSTS OF BIOMASS

WILLOW AT 15,300 TREES PER HA (6200 TREES PER ACRE)

Site preparation takes place in the summer and fall preceding planting, if the site was previously in pasture, and in the spring of planting (Table 9). Willow cuttings cost $0.10/cutting and mechanical planting costs $0.02/cutting (Walsh and Becker 1996). Kopp et al. (1997) report willow cuttings cost $0.07/cutting. A cost of $0.10/cutting is used as the base case and costs are also determined for $0.07/cutting. Mechanical tillage is assumed to be two diskings for land that was previously in cropland and moldboard plowing plus two diskings if the land was formerly in pasture. It may be that moldboard plowing is not an acceptable practice to establishment buffer strips, so a chisel plow could be substituted for a moldboard plow at a slightly lower cost.

Table 9. Establishment practices for willow

Cropland	Pasture
Summer and/or fall (prior to planting)	
No activities	Herbicide [glyphosate 2.24 kg active ingredient (a.i.)/ha (2 lb a.i./acre)] moldboard plow
Spring	
Herbicide [glyphosate 2.24 kg active a.i./ha (2 lb a.i./acre)] Disk (2 times) Apply lime [1.12 Mg/ha (1 ton/acre)] Mechanical planting [15,300 cuttings/ha (6200 cuttings/acre)] Herbicide [simazine 2.24 kg active a.i./ha (2 lb a.i./acre)]	

For herbicide use, glyphosate and simazine are assumed to be used for purposes of estimating costs. Simazine may not be the best herbicide to use after planting. While Goal [also at 2.24 kg active ingredient (a.i.)/ha (2 lb a.i./acre)] is a possibility, based on experience with poplars in Minnesota a combination of Oust [70 g a.i./ha (1 oz a.i./acre)] and glyphosate [70 g a.i./ha (1 oz a.i./acre)] may be better (personal communication, Mark Downing, Oak Ridge National Laboratory, Oak Ridge, TN, February 1, 1999). The cost differential among these choices should be less than $25/ha ($10/acre).

No replanting is assumed. At the end of the first growing season, after leaf fall but before bud swell in the spring, a mower is used to cut down the willows to encourage coppicing. This promotes multiple stems growing from each cutting and should result in quick canopy closure during the second growing season (Kopp et al. 1997). After the establishment year, neither herbicide treatments nor mechanical weed control is assumed to be necessary.

Because of high soil nutrient levels after chicken litter has been applied to nearby fields over time, no applications of phosphorus and potassium are assumed. Lime to adjust pH is applied at 2.24 Mg/ha (1 ton/acre) at establishment. Assumed is a single application of nitrogen in the second growing season at 112 kg/ha (100 lb/acre). This may or may not be necessary. Application of nitrogen subsequent to harvest may or may not be necessary. None is assumed in the cost calculations other than in year 2.

Total establishment costs (1999$) are $2210/ha ($895/acre) for cropland and $2315/ha ($935/acre) for pasture. If a chisel plow is substituted for a moldboard plow on former pasture land, then establishment costs decrease slightly to $2300/ha ($930/acre).

Harvesting is critical to the success of willows for energy. In the harvested material 50% moisture on a wet weight basis is assumed. Some commercial harvesting is presently being done in Sweden. However, the reliability and effectiveness of harvesting equipment is somewhat tenuous. Because each stem is relatively small, modified forage or sugar cane harvesting equipment can be used. Similar to forage harvesting, equipment can be self propelled or operate off a tractor. For descriptions of harvesting equipment and experience with harvesting of short rotation woody crops (SRWC) stands see Hartsough and Yomogida (1996), and Kofman and Spinelli (1997), and Mitchell (1997).

There are many potential willow harvesters, many of which are experimental. Three of the more promising ones are: a Claas Jaguar forage harvester with a SRWC head; an Austoft sugar cane harvester with a SRWC head; and the Bender II from Salix Maskiner, a SRWC head mounted on a tractor (Table 10). All three are cut and chip harvesters.

Table 10. Willow harvesters

Harvester	Purchase price[a]		Engine size[a]		Cost per hour[b]	
	ECU	$	kW	hp	Dkr	$
Claas	234,000	262,000	260	349	1186 2004	179 302
Austoft	195,000	218,000	176	236	945 1949	143 294
Bender II	107,000[c]	120,000	–[d]	–	937	141

[a]*Source*: Mitchell (1997), converted at $1.12/ECU (ECU is unit of currency used in the European Community)
[b]*Source*: Kofman and Spinelli (1997), converted at 6.63 Danish krone (Dkr)/$, first cost is harvester only, second cost is harvester plus wagons.
[c]No cost listed for Bender II. Cost listed is for Bender III with Case Magnum 7120 tractor. Mitchell lists tractor as 150kW (201 hp), but is 112kW (150 hp) in literature.
[d]Listed in Mitchell with a 125/140kW (168/188hp) tractor. A 150kW (201 hp) tractor is probably better.

The Claas Jaguar and Austoft harvesters are self propelled. The Claas Jaguar harvester [260 kW (349 hp)] is a wheeled forage harvester with a sugar cane head modified for SRWC. It can have problems in wet conditions (i.e., gets stuck in mud) and requires specific row spacing of trees for optimum harvest. The Austoft harvester [176 kW (236 hp)] is a modified sugar cane harvester with tracks instead of wheels. This allows it to operate under very wet conditions, but it cannot operate over public roads. However, if wagons are used to move chips from the harvester to chip van, they would also need to be tracked to avoid getting stuck in wet conditions. There are indications that the Austoft could use a larger engine (Mitchell 1997). The third is a head from Salix Maskiner (called the Bender) designed to attach to the front of a tractor [minimum of 101 kW (135 hp), better at 149 kW (200 hp)] to harvest SRWC. The Bender is of interest because a relatively low cost head (probably $30,000–$50,000) can be used on an existing relatively high powered tractor. The Austoft and Claas harvesters are expensive and would only be used by custom harvest operators. The Salix Maskiner head could potentially be used by individual farmers.

Improvements are needed in willow harvesting equipment. These include improving the mechanical reliability of the harvesting head and the quality of the chips.

Walsh and Becker (1996) have cost information on the Claas Jaguar harvester (Table 7). The Jaguar is a standard 260 kW (349 hp) forage harvester with a head modified for use with SRWC and augmented hydraulic capacity. It is an expensive machine, costing $300,000 (1995$). However it is also possible to use the base forage harvester with different heads to harvest forage crops. It is designed to harvest two rows at a time that are spaced 0.75 m (2.5') apart. Time required to harvest a ha (acre) varies with yield harvested. At 33.6 dry Mg/ha (15 dry tons/acre), the harvester requires 3.93 hours/ha (1.59 hours/acre), or it harvests 8.55 dry Mg/hour (9.43 dry tons/hour). Often it is assumed that a harvester will use two wagons and one or two tractors to forward chips to a chip van, with one wagon being filled while the other travels to and from the chip van and unloads. However, in this report, only a single wagon attached to the harvester is modeled and no tractor shuttle is assumed. The harvester pulls a 31.1 m^3 (1100 ft^3) high dump forage wagon [capacity of 4.49 dry Mg at 144 dry kg/m^3 (4.95 dry tons at 9.0 dry lb/ft^3)]. The wagon has a scale and a dumping time of 1 minute. [For more information on high dump forage wagons see Turhollow et al. (1998).] A truck tractor with a chip van, capacity of 22.7 Mg (11.3 dry Mg) [25 tons (12.5 dry tons)], is used to transport the wood chips. It is assumed that the chip van is located at the edge of the tract being harvested. Three forage wagon loads of 7.56 Mg (3.78 dry Mg) [8.33 tons (4.17 dry tons)] fills a chip van. So it is assumed that a forage wagon is filled to only 7.56 Mg (8.33 tons) or 84% of capacity. Only 2.26 loads are required per hour of harvest. When the forage wagon reaches 7.56 Mg (8.33 tons), the forage harvester takes it to the chip van and dumps its load into the chip van. As long as the distance that the forage harvester has to travel is not too long, this system works well. The system modeled minimizes equipment and labor required. Cost (1999$) for this harvest system is $24/dry Mg ($22/dry ton). If the physical configuration of the area harvested is favorable, when the harvester reaches the end of the rows it is harvesting near the chip van and has reached a load of approximately 7.56 Mg (8.33 tons), then travel distance is minimal. If the travel distance is long, then a shuttle system using two wagons is less costly.

The truck tractor is assumed to be in motion most of the day, driving between harvesting sites and where the wood chips are utilized. Because the time required to load a chip van is about 1.5 hours, it is assumed that the truck tractor unhitches the empty van and then hitches a full van at that site or goes to another site and hitches and takes the full van to the site where the chips are used. An average round trip length is assumed to be 80 km (50 miles), an average round trip takes 1.8 hours for the truck tractor, and each truck tractor services three chip vans. The use of three chip vans per truck tractor is reflected in the number of hours of annual use of chip vans. Some of the truck costing parameters are in Table 7. Average transportation cost (1999$) is $12/dry Mg ($11/dry ton).

Stump removal costs at the end of the stand's life are included in costs. These are estimated to be $146/ha ($59/acre). Amortized over all willow production, these costs range from only $0.36/dry Mg ($0.33/dry ton) (22-year stand life) to $1.43/dry Mg ($1.30/dry ton) (10-year stand life).

Costs are for delivered biomass [i.e., they include the $12/dry Mg ($11/dry ton) transportation cost]. Costs are determined for stands that last 10, 13, 16, 19, and 22 years. For willow on cropland put into riparian buffer strips, with an average mature yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year), costs (total costs, costs if payments to landowners are made as in the CRP program, and costs if payments are made as in the enhanced CRP program) are shown in Fig. 2. Total costs (1999$) at equal yields are only slightly lower for pasture than cropland, by about $4/dry Mg ($4/dry ton), because of lower land costs. However, land that has been in pasture is probably lower yielding than cropland. With willow grown on land formerly in pasture, with a yield 90% of yield on cropland, willow on former pastureland is more expensive, by $2 to $4/dry Mg ($2 to $4/dry ton). Looking at total costs, costs per dry ton are fairly high, between $84 and $108/dry Mg ($76 and $98/dry ton). Receiving payments as from the CRP program reduces costs substantially, to $60 to $75/dry Mg ($54 to $68/dry ton). The enhanced CRP program payments reduce costs to $40 to $49/dry Mg ($37 to $44/dry ton). Extending the stand life from 10 years has a significant impact on total costs per dry ton of willow, but has only a minor impact under the enhanced CRP (Fig.1). This is because extending stand life amortizes establishment costs over a longer

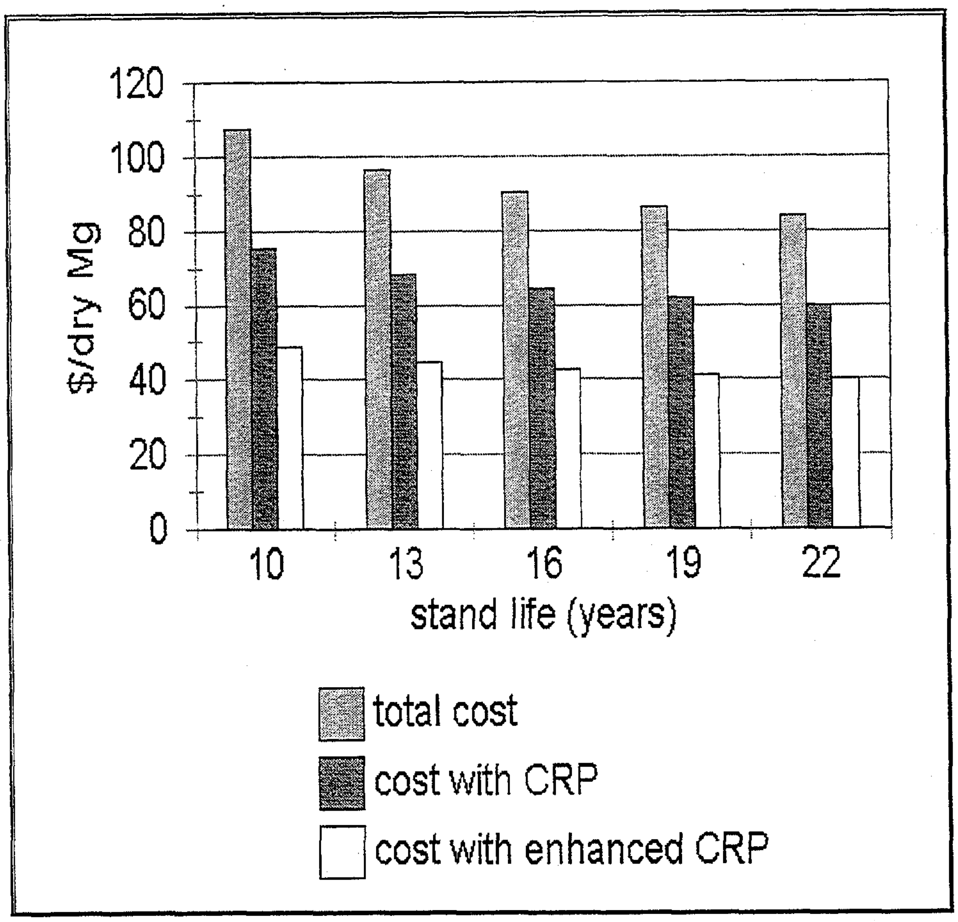

Fig. 2. Delivered costs (1999$) of willow chips with no payments (total costs), CRP payments, and enhanced CRP payments [mature yield = 11.2 dry Mg/ha-year (5 dry tons/acre-year)].

period. However, under the enhanced CRP, only 5% of establishment costs are borne by the farmer. Note that the largest portions of total economic costs (about 75%) are for cuttings, harvest and land (Fig. 3).

Yields impact costs (Fig. 4). For a 19-year stand life, total costs for willow delivered to the place of use decrease from $103/dry Mg ($94/dry ton) to $76/dry Mg ($69/dry ton) as mature yield increases from 9.0 to 13.4 dry Mg/ha-year (4 to 6 dry tons/acre-year). As payments increase, the impact of yield on costs decrease. Under the enhanced CRP delivered costs are in the $38 to $46/dry Mg ($34 to $42/dry ton) range.

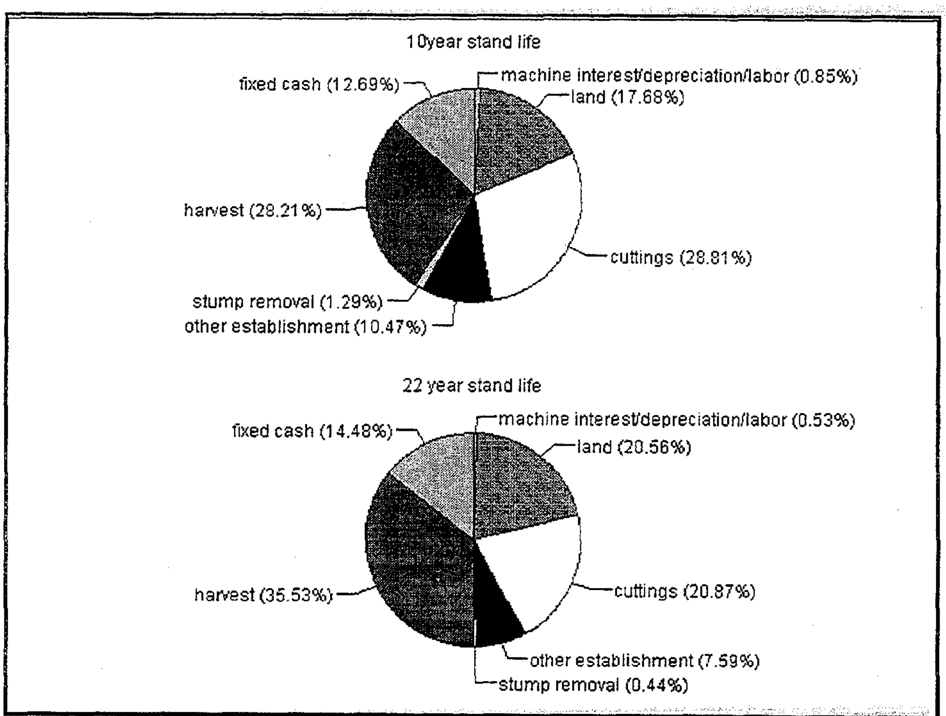

Fig. 3. Percent of farm gate willow costs by activity for 10 and 22 year stand lives [mature yield = 11.2 dry Mg/ha-year (5 dry tons/acre-year)].

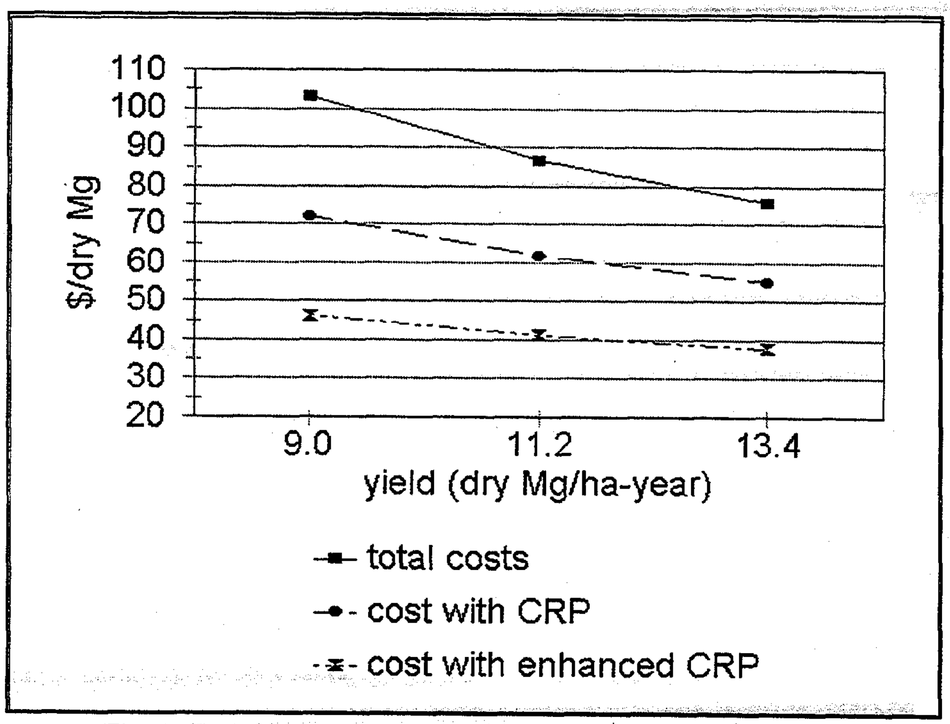

Fig. 4.. Impact of yields on delivered willow cost (1999$), based on 19 year stand life.

If cuttings cost only $0.07/cutting instead of $0.10/cutting, then for a 19-year stand life and a yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year), total costs (costs for $0.10/cutting in parentheses) are $82 ($87)/dry Mg [$74 ($79)/dry ton], with CRP payments costs are $57 ($62))/dry Mg [$51 ($56)/dry ton], and for enhanced CRP payments costs are $36 ($41)/dry Mg [$33 ($37)/dry ton].

POPLARS

Poplars are being planted at wider spacings than willows, 2.44 m x 3.05 m (8' x 10') or 2.44 m x 2.44 m (8' x 8') [1345 or 1680 trees/ha (545 or 680 trees/acre). They are harvested at about 6 to 10 years, because this spacing and maturity results in a higher wood-to-bark ratio and better quality wood chips. In this analysis, harvest is assumed to occur at 10 years of age and there is no coppice regrowth. Such spacing results in significantly lower establishment costs than willows but, because of tree size at harvest due to both spacing and tree age, requires the use of conventional forestry equipment for harvesting.

Poplar establishment practices are listed in Table 11. Field preparation is similar to willows. Planting is done by hand. Poplar cuttings cost more than willow cuttings ($0.16 versus $0.10) and hand planting (as is done for poplar cuttings) is more expensive than machine planting (as is done for willow cuttings) ($0.08/cutting versus $0.02/cutting). Because of the wider spacings, weed control must be practiced into the third year. Glyphosate and linuron are not necessarily the best combination of herbicides to use, but are used to estimate the costs of using herbicides for poplar.

Table 11. Poplar establishment practices

Cropland	Pasture
Establishment year	
Disk (2 times) Herbicide in fall [glyphosate 4.48 kg a.i./ha (2 lb a.i./acre)] Apply lime [1.12 Mg/ha (1 ton/acre)] Hand plant [1345 cuttings/ha (545 cuttings/acre)] Herbicide [linuron 1.68 kg a.i./ha (1.5 lb a.i./acre)] Mechanical cultivation (3 times)	Herbicide in fall [glyphosate 4.48 kg a.i./ha (2 lb a.i./acre)] Moldboard plow Disk (2 times) Apply lime [1.12 Mg/ha (1 ton/acre)] Hand plant [1345 cuttings/ha (545 cuttings/acre)] Herbicide [linuron 1.68 kg a.i./ha (1.5 lb a.i./acre)] Mechanical cultivation (3 times)
Year 2	
Mechanical cultivation (2 times)	
Year 3	
Mechanical cultivation (1 time)	

Harvest uses a feller-buncher head on a 75-kW (100-hp) tractor to sever trees, gather a multiple number of trees together, then drop them on the ground; two skidders to move the trees from the field to the chipper; and a chipper to make chips from trees and blow the chips into a chip van. The feller-buncher and skidders are oversized and more rugged than required to harvest short-rotation poplar. At a 45 dry Mg/ha (50 dry tons/acre) harvest at 10 years, two skidders [20.8 hours/ha (8.44 hours/acre) each] approximately equal the productivity of the chipper [11.24 hours/ha (4.55 hours/acre)]. The feller-buncher requires only 1.98 hours/ha (0.80 hours/acre). A flatbed truck is used to transport the harvest equipment and costs $45,000. This complement is expensive, with a purchase price of $550,000. Such a complement is suitable only for a custom operator.

Presently poplars planted at a density of 1345 or 1680 trees/ha (545 or 680 trees/acre) are not being allowed to regrow by coppice after harvest, in part because multiple stems from coppice regrowth would result in a higher bark-to-wood ratio. This is not a concern for energy, so it may be desirable to allow coppice regrowth.

For this analysis, a density of 1345 trees/ha (545 trees/acre) is assumed. Total establishment costs are $745/ha ($300/acre) on former cropland and $770/ha ($310/acre) on former pasture. Use of a chisel plow instead of a moldboard plow on former pasture reduces establishment costs by $15/ha ($6/acre). Establishment costs for poplars are significantly less than for willows. At a 11.2 dry Mg/ha-year (5 dry tons/acre-year) yield for a 10-year stand life with no coppice regrowth, total delivered costs are $76/dry Mg ($69/dry ton) [$3.80/GJ ($4.05/million Btu)]. The included transportation cost is the same as for willows, $12/dry Mg ($11/dry ton). With CRP payments, costs are $52/dry Mg ($47/dry ton) and with enhanced CRP payments, costs are $33/dry Mg ($30/dry ton) (Fig. 5).

The largest portions of costs are for harvest (37%) and land 25% (Fig. 6). Yield impacts on total delivered costs are in Fig. 7. Total delivered costs decrease from $88/dry Mg ($80/dry ton) at 9.0 dry Mg/ha-year (4 dry tons/acre-year) to $67/dry Mg ($61/dry ton) at 13.4 dry Mg/ha-year (6 dry tons/acre-year). With enhanced CRP payments costs range from $32 to $36/dry Mg ($29 to $32/dry ton). The yield impact is relatively minor with enhanced CRP payments.

If the cost of cuttings decreases from $0.16 to $0.10 and planting costs from $0.08 to $0.05/cutting, total costs decrease by $2/dry Mg ($2/dry ton). If poplar is planted on pastureland with its associated lower land rent (two-thirds of cropland) and yield is 90% of that on cropland, then total costs are nearly identical to poplar on cropland.

SWITCHGRASS

Two sizes of machinery complements to produce switchgrass are costed, large scale and small scale. Costs differ little between these two complements. Site preparation for switchgrass can start in the fall preceding planting or in the spring of planting. Establishment activities for cropland are shown in Table 12.

Table 12. Establishment activities for switchgrass on cropland

Disk or disk harrow (1 time)
Herbicide [2, 4-D 1.12 kg a.i./ha (1 lb a.i./acre)]
Herbicide [Atrazine 2.24 kg a.i./ha (2 lb a.i./acre)]
Apply lime [4.48 Mg/ha (2 tons/acre)]
Plant seed with grain drill (15% replant rate)

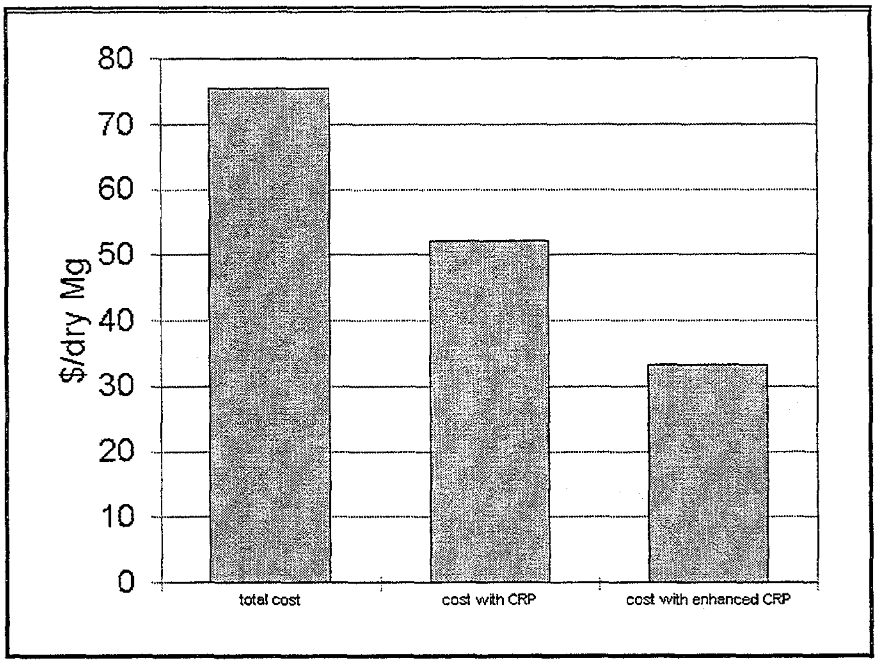

Fig. 5. Costs (1999$) of poplar chips with no payments (total costs), CRP payments, and enhanced CRP payments [mature yield = 11.2 dry Mg/ha-year (5 dry tons/acre-year)].

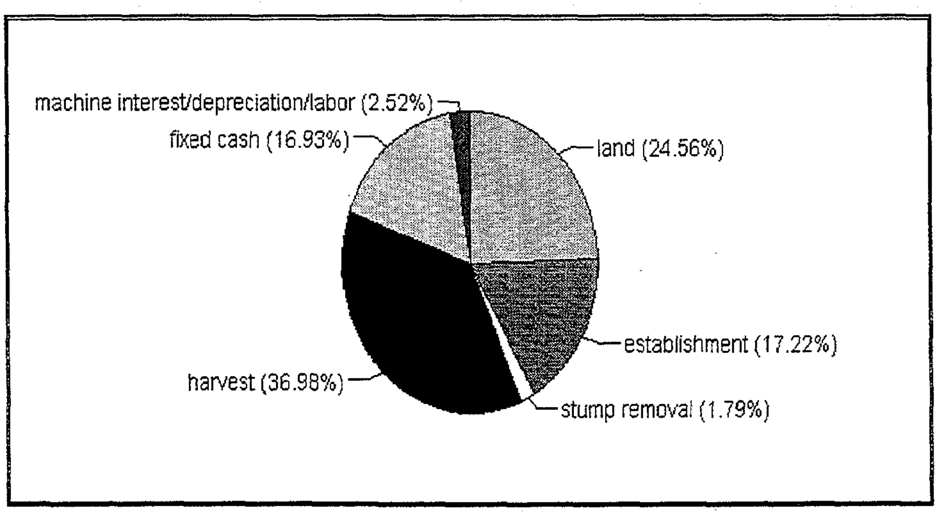

Fig. 6. Percent of farm gate poplar costs by type [mature yield = 11.2 dry Mg/ha-year (5 dry tons/acre-year)].

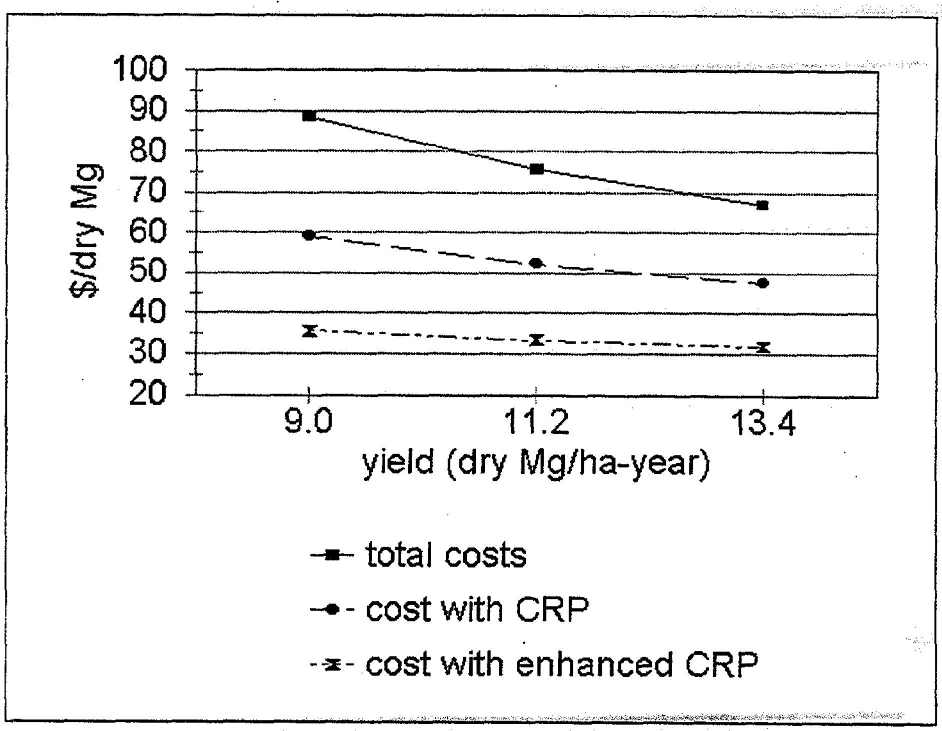

Fig. 7. Impact of yields on delivered poplar cost (1995&).

Establishment costs for large and small scale machinery complements differ by less than $1/ha ($1/acre). Total establishment costs (1999$) are about $240/ha ($100/acre), only 11% of those for willow. Stands are assumed to exist for 10 years.

Because of high soil nutrient levels, no potassium or phosphorus is assumed to be applied and no nitrogen is applied in the establishment year. Nitrogen is applied in subsequent years at 101 kg/ha (90 lb/acre). This nitrogen application may or may not be necessary. Lime is applied at 4.5 Mg/ha (2 tons/acre) at establishment.

Harvesting of switchgrass is done with conventional hay balers. The large scale equipment complement uses a large round baler that makes 1.22 m (4') wide bales 1.83 m (6') in diameter, weighing 510 kg (1125 lb) on a wet basis. The small-scale equipment complement uses a large round baler that makes 1.22 m (4') wide bales 1.52 m (5') in diameter weighing 354 kg (781 lb) on a wet basis. Dry matter content is assumed to be 88%. Bales are moved to the field edge by a tractor with bale carriers on each end. A tractor thus equipped can move 10 bales/hour. Harvesting costs (1999$) are around $17/dry Mg ($16/dry ton).

Bales are moved from the field edge to the facility where they are utilized, by a tandem truck with a 14.6-m (48') trailer which carries a fork lift to load bales on the truck. The truck driver is assumed to operate the fork lift. The truck makes three round trips per eight-hour day. Transportation costs (1999$) for 1.82 m (6') diameter bales are $6.50/dry Mg ($5.90/dry ton) and for 1.52 m (5') diameter bales are $8.30/dry Mg ($7.55/dry ton).

Delivered costs (1999$) for switchgrass in 1.83 m (6') diameter bales; total costs, costs with CRP payments, and costs with enhanced CRP payments, for a mature yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year) are shown in Fig. 8. Total delivered costs are $57/dry Mg ($52/dry ton) and decrease to $40/dry Mg ($37/dry ton) with CRP payments and $30/dry Mg ($27/dry ton) with enhanced CRP payments. Yield affects the cost of switchgrass as shown in Fig. 9. While yield significantly impacts total costs with no program payments, yield only has a minor impact on delivered costs when switchgrass receives enhanced CRP payments.

The distribution of costs for switchgrass (Fig. 10) is quite different than for willow (Fig. 3).

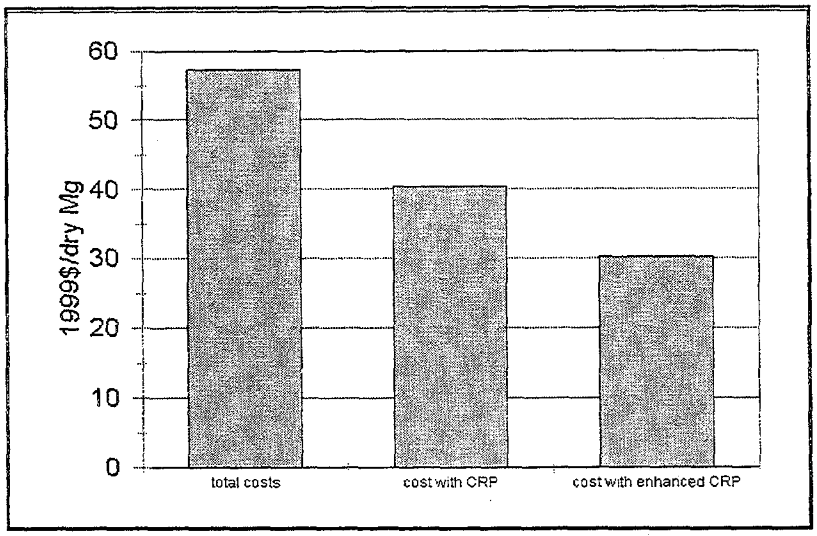

Fig. 8. Costs (1999$) of switchgrass bales with no payments (total costs), CRP payments, and enhanced CRP payments [mature yield = 11.2 dry Mg/ha-year (5 dry tons/acre-year)].

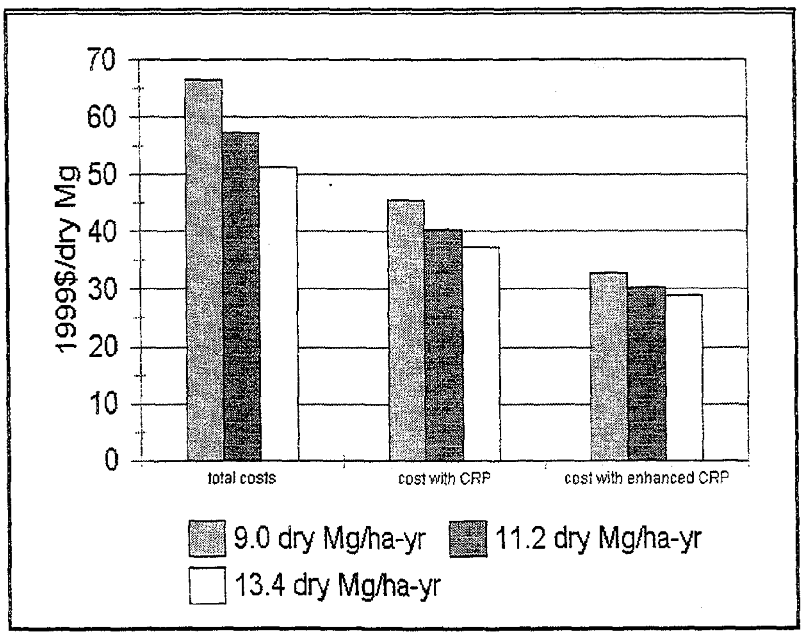

Fig. 9. Impact of yield on delivered switchgrass costs (1999$).

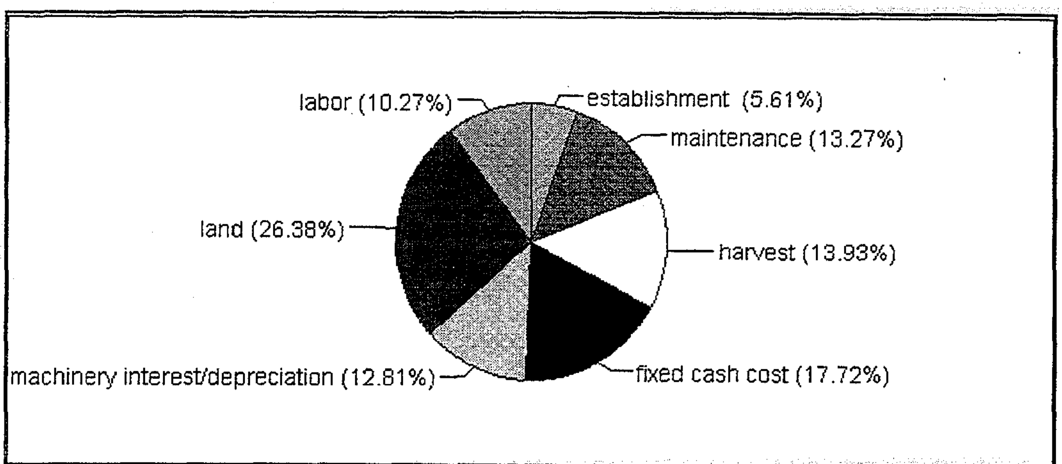

Fig. 10. Distribution of switchgrass costs by activity

COSTS FOR BIOMASS WHEN BUFFER STRIPS ARE REQUIRED

Consider the case where if chicken litter is to be applied to a field, a buffer strip is required and harvesting biomass to remove nutrients is not required (but harvesting is allowed). In the section of the buffer strip where harvesting is allowed, switchgrass which is the least costly to establish among willow, poplar, and switchgrass, is an acceptable choice of crop. In considering the decision as to what crop to plant and whether to harvest the biomass, the fixed cash costs of farm overhead, interest on real estate, and taxes and insurance; the economic (owned resource) costs of land (land rent) (excluding interest); and any costs associated with establishment of switchgrass [e.g., seed, lime, herbicides, soil testing, labor, nonland capital (interest on machinery), capital replacement (depreciation)]; are costs are that are incurred regardless of whether the biomass crop is harvested or not. These costs are incurred because a buffer strip is required if chicken litter is to be applied to the field. Therefore the costs associated with the decision to utilize the biomass crop for energy are for establishment costs above those of the least cost choice, switchgrass, and any yield enhancing activities such as fertilization, harvest costs, and transport costs. Under these circumstances, at a mature yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year), delivered costs of switchgrass are $32/dry Mg ($1.85/GJ) [$29/dry ton ($1.95/million Btu)].

Consider the case where in addition to buffer strips being required, harvest is required to remove nutrients. In addition to the costs that are not allocated to the harvested biomass in the previous case, harvest costs are excluded from the biomass cost because harvest is required. At a mature yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year) delivered costs of switchgrass are only $14/dry Mg ($0.80/GJ) [$13/dry ton ($0.85/million Btu)]. (These costs are for any applied fertilizer, which in the case of switchgrass is assumed to be nitrogen, and the cost of transporting the biomass from the field to the facility where it is used.)

For poplar at a yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year), in the case where a buffer strip is required but harvesting is not required, delivered costs are $46/dry Mg ($2.30/GJ) [$42/dry ton ($2.45/million Btu)] and in the case where harvesting is required delivered costs are $16/dry Mg ($0.80/GJ) [$15/dry ton ($0.85/million Btu)]. These costs are calculated in comparison to what if the farmer had chosen the least cost switchgrass option.

For willow with a 19-year stand life at a yield of 11.2 dry Mg/ha-year (5 dry tons/acre-year), in the case where a buffer strip is required but harvest is not required, delivered costs are $59/dry Mg ($3.00/GJ) [$54/dry ton ($3.15/million Btu)] and in the case where harvest is required costs are $29/dry Mg ($1.50/GJ) [$27/dry ton ($1.55/million Btu)]. These costs are calculated in comparison to what if the farmer had chosen the least cost switchgrass option.

These costs are compared to total costs in Fig. 11. Note that the reduction in cost between total costs and the costs for these two cases where buffer strips are required do not just disappear, but they are not borne by the biomass because regardless of whether the biomass is used or not, the costs are incurred.

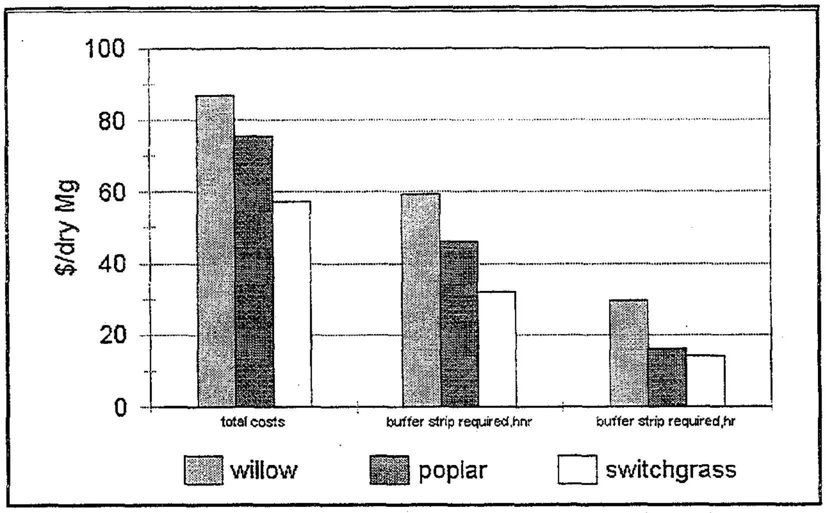

Fig. 11. Costs for delivered biomass (1999$) when buffer strips are required [yield = 11.2 dry Mg/ha-year (5 dry tons/ac-year)].

ESTIMATES OF BIOMASS PRODUCED FROM BUFFER STRIPS

To estimate how much biomass can be produced from buffer strips, one needs to know how much land will potentially be in buffer strips in the Delmarva Peninsula, what fraction of this land is harvested, and what is the yield of the harvested land. Assuming a buffer strip is on average 30 m (100') wide and the 4.6 m (15') closest to a water body is not harvested, then 85% of aggregate buffer strip area is harvested. Using baseline yield assumptions, yield averages about 11.2 dry Mg/ha (5 dry tons/acre-year).

The issue of how much land will potentially be in buffer strips is more complex. Poultry litter is not applied to all crops. However, because of crop rotations, it is assumed that poultry litter is applied to all cropland at some point in time and therefore all cropland may potentially need a buffer strip. Two methods are used to estimate buffer strip area.

The first method is based on data on stream length and riparian buffer width. Palone and Todd (1997) show data for riparian buffer width and stream length for watersheds in the Chesapeake Bay drainage in Maryland and Virginia, but not in Delaware. For Delaware and areas in Maryland and Virginia outside the Chesapeake Bay drainage, an extrapolation is made from the data for Maryland and Virginia in the Chesapeake Bay drainage, assuming the same length of streams per unit area both inside and outside of the Chesapeake Bay drainage.

Poultry production and hence chicken litter field application is concentrated in the following counties: Kent and Sussex in Delaware; Caroline, Dorchester, Somerset, Talbot, Wicomico, and Worcester in Maryland; and Accomack in Virginia.

Riparian buffer width is classified in Palone and Todd as follows: both sides 91+ m (300'+), both sides 30-91 m (100-300'), one side 91+ m (300'+), one side 30-91 m (100-300'), and both sides < 30 m (100'). The data for one side 30-91 m (100-300') and both sides < 30 m (100') add up to 100%. One side 30-91 m (100-300') is interpreted to mean at least one side with a buffer > 30 m (100') in width and also both sides 30-91 m (100-300') to mean both sides have a buffer > 30 m (100') in width. If it is assumed that the concern is to establish buffers where present buffers are less than 30 m (100') in width, then the length of buffers needed along streams is two times both sides < 30 m (100') plus one side 30-91 m (100-300') minus both sides 30-91 m (100-300'). This length is given in km (miles). Assuming a 30 m (100') buffer is desired and ignoring any existing buffer less than 30 m (100') in width, then length in km (miles) can be converted buffer area in ha (acres) by multiplying by 1000 m/km (5280'/mile) and dividing by 10,000 m^2/ha (43,560 ft^2/acre). Total buffer area needed to have a 30 m (100') wide buffer on all streams is 43,000 ha (106,000 acres) in the parts of Maryland and Virginia in the Chesapeake Bay drainage (Table 13). (Table 13 in its equivalent English units is Table A.3 in Appendix A.)

The 1992 National Resources Inventory (NRI), available from the NRCS of the U.S. Department of Agriculture, is used to determine which fractions of Worcester County in Maryland and Accomack County in Virginia are in the Chesapeake Bay drainage. All other counties of interest in Maryland lie completely within the Chesapeake Bay drainage. In Table 14, the estimation of needed buffer area is shown. Areas for which data are available for riparian buffer size and stream length are indicated as "data available." Areas for which data are not available, both within the Chesapeake Bay drainage (parts of Kent and Sussex counties in Delaware) and areas outside the Chesapeake Bay drainage (parts of Kent and Sussex counties in Delaware, Worcester County in Maryland, and Accomack County in Virginia) are indicated as "no data available." There are 42,900 ha (106,000 acres) needed in buffers in the 5993 km^2 (2314 mi^2) with data. Assuming the same density of buffers is needed in the 5346 km^2 (2064 mi^2) without data, then 81,500 ha (201,000 acres) are required in the whole area (Table 14).

This is an overestimate because not all stream lengths are affected by poultry litter runoff, and some area of buffers exist, although less than 30 m (100') in width. According to the 1992 Census of Agriculture (USDOC 1993–1994) 400,000 ha (987,000 acres) are in cropland, which is 35.2% of total land area. Taking 35.2% of 81,400 ha (201,000 acres) in the total area results in 28,700 ha (70,900 acres) of buffer required in farming areas.

The second method involves some assumptions about field geometry and buffer strip returned. For a square 40 (10) ha [100 (25) ac] field with a 30-m (100') buffer strip on one side, the buffer strip occupies approximately 5% (10%) of the field. If every field requires a buffer strip on one side, then between 5% and 10% of cropland would be in buffer strips. Thus between 20,000 and 40,000 ha (49,400 and 98,700 acres) would need to be in buffer strips.

Table 13. Length of streams and buffer width by watershed in the Delmarva Peninsula in the Chesapeake Bay drainage

Watershed	Stream length	Length of stream with buffers of stated widths: Both sides 30.5-91.5 m	1 side 30.5-91.5 m	Both sides < 30.5 m	1 side < 30.5 m	Total length < 30.5 m	Buffer area needed
Maryland			km				ha
Pocomoke Sound	242.7	48.6	60.8	181.9	12.2	375.9	1146
Lower Pokomoke River	324.8	203.1	223.2	101.5	20.1	223.2	681
Upper Pokomoke River	202.5	117.2	121.5	81.0	4.3	166.2	507
Dividing Creek	92.4	80.3	82.6	9.8	2.3	21.9	67
Nassawango Creek	96.9	71.5	74.4	22.5	2.9	48.0	146
Tangier Sound	346.2	4.5	6.8	339.4	2.3	681.1	2077
Big Annemessex River	186.2	28.0	35.9	150.3	7.9	308.5	941
Manokin River	328.9	80.5	95.1	233.8	14.6	482.3	1471
Lower Wicomico River	333.0	77.1	89.6	243.3	12.6	499.2	1522
Monie Bay	117.8	9.7	10.9	106.9	1.3	215.0	656
Wicomico Creek	71.5	23.0	26.9	44.6	3.9	93.0	284
Wicomico River Head	100.7	51.8	58.1	42.6	6.3	91.6	279
Nanticoke River	650.8	162.5	188.9	461.9	26.4	950.2	2897
Maryshope Creek	469.4	219.4	249.1	220.3	29.8	470.4	1434
Fishing Bay	803.2	46.0	59.7	743.5	13.7	1500.7	4576
Transquaking River	396.9	94.5	117.2	279.7	22.7	582.1	1775
Honga River	341.5	14.2	18.2	323.3	4.0	650.7	1984
Little Choptank	358.4	17.7	23.5	334.9	5.8	675.6	2060
Lower Choptank	970.4	126.0	164.0	806.4	38.0	1650.9	5034
Upper Choptank	868.6	395.6	448.5	420.0	52.9	893.0	2723
Tackahoe creek	566.7	200.5	237.4	329.3	36.9	695.4	2120
Eastern Bay	168.7	6.3	9.3	159.3	3.1	321.7	981
Miles River	215.0	29.5	38.1	176.9	8.7	362.4	1105
Wye River	282.0	71.9	88.8	193.1	16.9	403.1	1229
Total Maryland						12362.2	37696
Virginia							
Pokomoke River/Pitts Creek	72.3	32.0	37.2	35.1	5.1	75.3	230
Chesapeake Bay/Holdens Creek	672.9	78.4	93.2	579.7	14.8	1174.2	3580
Chesapeake Bay/Onancock Creek	217.7	10.1	13.5	204.2	3.4	411.8	1256
Pungoteague Creek	63.1	13.0	15.0	48.1	1.9	98.2	299
Total Virginia						1759.5	5365
Total						14121.7	43061

Source: Palone and Todd (1997)

Table 14. Area with stream length and buffer width data and buffer area needed

County, state	Data available	No data available	Land area		Data available		No data available		Buffer area needed	
	Fraction		km²	mi²	km²	mi²	km²	mi²	ha	Acres
Kent, DE	0.000	1.000	1541	595	0	0	1541	595		
Sussex, DE	0.000	1.000	2440	942	0	0	2440	942		
Caroline, MD	1	0	831	321	831	321	0	0		
Dorchester, MD	1	0	1536	593	1536	593	0	0		
Somerset, MD	1	0	875	338	875	338	0	0		
Talbot, MD	1	0	671	259	671	259	0	0		
Wicomico, MD	1	0	982	379	982	379	0	0		
Worcester, MD	0.480	0.520	1230	475	590	228	640	247		
Accomack, VA	0.412	0.588	1233	476	508	196	725	280		
Total					5993	2314	5346	2064	81480	201250

SUMMARY AND CONCLUSIONS

Total (economic) costs of delivered biomass ($1999), at 11.2 dry Mg/ha-year (5 dry tons/acre-year), of willow are $84 to $108/dry Mg ($76 to $98/dry ton) [$4.25 to $5.45/GJ ($4.50 to $5.75/million Btu)], poplar are $76/dry Mg ($69/dry ton) [$3.80/GJ ($4.05/million Btu)], and switchgrass are $57/dry Mg ($52/dry ton) [$3.30/GJ ($3.45/million Btu)]. With CRP payments, delivered costs decrease significantly to $40 to $75/dry Mg ($37 to $68/dry ton) [$2.30 to $3.80/GJ ($2.45 to $4.00/million Btu)] and with enhanced CRP payments, delivered costs are $30 to $49/dry Mg ($27 to $44/dry ton) [$1.70 to $2.45/GJ ($1.80 to $2.60/million Btu)] (Fig. 12). Willow costs are significantly higher than switchgrass costs because establishment costs are nine times greater, and harvest costs are about $6/dry Mg ($5/dry ton) higher.

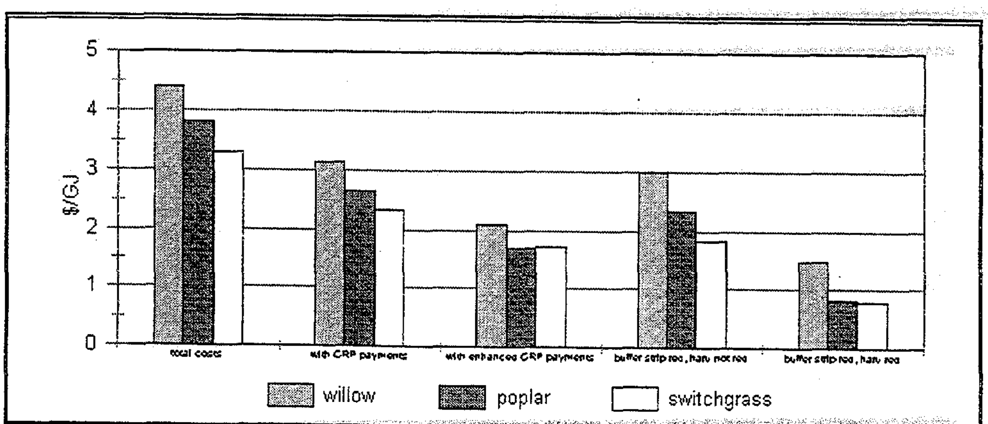

Fig. 12. Costs of willow, poplar, and switchgrass at 11.2 dry Mg/ha-year (5 dry tons/ac-year).

If buffer strips are required to prevent nutrient runoff into water bodies, but harvesting is not required to remove nutrients from the buffer strips, delivered biomass costs are significantly less than total costs. Delivered costs range from $32 to $76/dry Mg ($29 to $68/dry ton) [$1.85 to $3.80/GJ ($1.95 to $4.05/million Btu)], similar to costs with CRP payments. These costs are primarily for establishment costs above those of establishing the least cost buffer with switchgrass, some fertilizers assumed required for optimal yields, harvest, and transportation. If in addition harvest is required to remove nutrients, then delivered biomass costs are low and range from $14 to $43/dry Mg ($13 to $39/dry ton) [$0.80 to $2.20/GJ ($0.85 to $2.30/million Btu)]. These costs are primarily for establishment costs above those of establishing the least cost buffer with switchgrass, some fertilizers assumed required for optimal yields, and transportation. The higher end of these ranges is for willow with shorter stand lives. Costs are low because significant costs are required to be borne by the chicken litter disposal activity regardless of whether the biomass is harvested and delivered.

One of the concerns with regards to costs is that of small tract size being planted and harvested. The costs reported assume no additional costs because of small tract size. For willow, a 0.8-ha (2-acre) tract increases total costs by $3.30/dry Mg ($3.00/dry ton) and a 2-ha (5-acre) tract by $1.20/dry Mg ($1.10/dry ton). For poplar, a 0.8-ha (2-acre) tract increases costs by $2.00/dry Mg ($1.80/dry ton) and a 2-ha (5-acre) tract by $0.65/dry Mg ($0.60/dry ton). For switchgrass, a 0.8-ha (2-acre) tract increases costs by $2.20/dry Mg ($2.00/dry ton) and a 2-ha (5-acre) tract by $0.65/dry Mg ($0.60/dry ton).

There are a number of means to reduce costs. For any of the three crops, one method is to increase average annual yield. An increase in average annual yield from 11.2 to 13.4 dry Mg/ha-year (5 to 6 dry tons/acre-year) decreases costs by 10% to 13%. At higher yields, fixed costs (e.g., establishment, land) are spread over more units of production and harvest equipment is more productive. Another possibility is to decrease the average transportation distance through the locations of buffer strips and conversion facilities. For example, for switchgrass each truck is assumed to make three trips per eight hour day. With four trips per eight hour day, costs are reduced $1.65/dry Mg ($1.50/dry ton) for 1.83 m (6') diameter bales and $2.10/dry Mg ($1.90/dry ton) for 1.52 m (5') diameter bales. For willow and poplar, if trips increase by 33% per day, as in the switchgrass example [each trip takes 1.35 hours and distance is 60 km (37.5 miles)], then costs decrease by $2.85/dry Mg ($2.60/dry ton). The reduced transportation costs for switchgrass are approximately $0.30/GJ ($0.30 million Btu) and for willow and poplar are approximately $0.45/GJ ($).50/GJ).

It may be possible to reduce willow harvest costs by using smaller scale equipment. Establishment costs may be reduced though the propagation of lower cost cuttings. Also the possibility of using wider spacings should be investigated as a means to reduce establishment costs. For willow, where establishment costs are 30% to 40% of total costs, reducing either the cost of cuttings or density of trees can have an impact. If cuttings cost $0.07 instead of $0.10, then total costs for a 19-year stand life are reduced by $5/dry Mg ($4/dry ton). If stand density is reduced to 12,350 trees/ha (5000 trees/acre) from 15,300 trees/ha (6200 trees/acre), then for a 19-year stand life costs are reduced by $4/dry Mg ($4/dry ton). Combining the lower cost per cutting plus lower density reduces costs by $8/dry Mg ($7/dry ton), and delivered costs to $79/dry Mg ($71/dry ton). Harvest uses an expensive machine, the Claas Jaguar harvester. If similar productivity can be achieved using a less expensive tractor-mounted harvest head, then it may be possible to reduce harvest costs by $6 to $11/dry Mg ($5 to $10/dry ton). With a tractor-mounted harvest head with a one man harvest crew which results in a $6/dry Mg ($5/dry ton) reduction in harvest cost, a round trip transport distance of

60 km (37.5 miles) and time of 1.35 hours, cuttings at $0.07 each, 12,350 cuttings/ha (5000 cuttings/acre), and a yield of 18 dry Mg/ha-year (8 dry tons/acre-year), then total delivered costs decrease to $49/dry Mg ($44/dry ton) [$2.45/GJ ($2.60/million Btu)]. This is probably as low a total economic cost (without any payments such as from the CRP) as biomass can be produced from willow.

For poplar, a yield of 13.4 dry Mg/ha-year (6 dry tons/acre-year) reduces total costs to $67/dry Mg ($61/dry ton) [$3.40/GJ ($3.60/million Btu)]. Reducing the cost of cuttings plus planting from $0.24/cutting to $0.15/cutting reduces costs by $2/dry Mg ($2/dry ton). With the use of more appropriately sized harvest equipment which results in a $6/dry Mg ($5/dry ton) reduction in harvest cost, a round trip transport distance of 60 km (37.5 miles) and time of 1.35 hours, cuttings at $0.10 each, planting costs of $0.05/cutting, and a yield of 17.9 dry Mg/ha-year (8 dry tons/acre-year), then total delivered costs decrease to $47/dry Mg ($42/dry ton) [$2.35/GJ ($2.50/million Btu)].

For switchgrass, because hay production systems are much more mature, possible decreases in cost are much less than for willow. Costs can be reduced by producing 1.52 m (5') wide bales instead of 1.22 m (4') wide bales. For a yield of 15.7 dry Mg/ha-year (7 dry tons/acre-year) and transportation costs based on four round trips per eight hour day, total delivered costs are $46/dry Mg ($41/dry ton) [$2.60/GJ ($2.75/million Btu)].

With the most optimistic possible improvements in SRWC and switchgrass growing, harvest, and transport conditions, one can envision total delivered costs as low as $46 to $49/dry Mg ($41 to $44/dry ton) [$2.35 to $2.60/GJ ($2.50 to $2.75/million Btu)] and with enhanced CRP payments as low as $22 to $28/dry Mg ($20 to $25/dry ton) [$1.15 to $1.60/GJ ($1.20 to $1.70/million Btu)].

High yields are required for low total costs, but yields do not greatly affect the producer cost of biomass when enhanced CRP payments are received. The lowest CRP payments per unit of biomass produced is for switchgrass. However switchgrass may not produce the same environmental benefits as with SRWC, because of differences in rooting depths and their possible impacts on treating groundwater contaminants, abilities to cause sediment deposition from surface water runoff, and wildlife habitat impacts.

If buffer strips are a required practice, then biomass costs are significantly lower than total costs, with costs ranging from $32 to $76/dry Mg ($29 to $68/dry ton) [$1.85 to $3.80/GJ ($1.95 to $4.05/million Btu)] if no harvest is required and $14 to $43/dry Mg ($13 to $39/dry ton) [$0.80 to $2.20/GJ ($0.85 to $2.30/million Btu)] if harvest is required to remove nutrients. The cost differentials from total economic costs do not just disappear, but these costs are not borne by the harvested biomass. The cost differentials are borne by activities that contribute to nutrient runoff into the waterways of the Delmarva Peninsula.

The potential production of biomass from riparian buffer strips in the Delmarva Peninsula ranges from 190,000 to 380,000 Mg (210,000 to 420,000 dry tons) per year.

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APPENDIX A

TABLES 1, 7, AND 13 IN ENGLISH UNITS

Table A1. Boilers and cropland in the Delmarva Peninsula

	Delaware			Maryland								Virginia	
	Kent	New-castle	Sussex	Caroline	Cecil	Dorches-ter	Kent	Queen Anne's	Somerset	Talbot	Wico-mico	Worces-ter	Acco-mack	Total
Broilers sold (1000)	29143	-[a]	194186	35549	0	19672	2157	8599	48523	8015	76498	57408	17406	497156
							1000 acres							
Land in farms	197375	87134	304680	126981	80241	123762	131283	165349	55657	109108	91254	107519	91568	1671911
Cropland	166177	73436	255543	106610	60174	100255	113211	142316	40096	93646	71616	80931	72423	1376434
Harvested	156962	67852	245534	101911	49585	94671	103939	130039	37253	88324	67100	77196	69420	1289786
Irrigated	20283	2033	39458	14809	711	10718	4770	7821	1504	1983	4597	2327	7889	118903
Corn	43191	32048	79001	23361	18605	18827	54771	55831	11316	31147	19786	38141	6913	432938
Wheat	26850	9643	25261	22893	6260	19962	11933	26940	6608	18526	9754	5205	20048	209883
Sorghum	955		8534	1947		4794		605	272	1068	2440	98		20713
Barley	20020	1481	16091	11498	2566	9622	2227	4847	938	2476	943	739		73448
Oats	480		255	49	91		99	19		52	10		55	1110
Rye	155	70	516	105	30	36	236	105		70	176		125	1624
Soybeans	81650	25591	124631	61211	14436	62006	35602	58897	21524	47176	38292	38022	48843	657881
Canola				461			376	206						1043
Potatoes	4128	1060	2	6								1011		6207
Sweet potatoes						6					36		446	488
Cotton													538	538
Hay	4724	3283	3940	3169	8296	808	3288	2911	1110	1239	1110	708	181	34767
Corn silage	4114	961	4371	2087	2744		2735	1779	384	672	214	251		20312
Sorghum silage	54		725	68			17							864
Vegetables	16744	1069	24566	6283	188	5837	1028	2484	1089	975	2802	346		63411
Orchards													124	124
Nursery and greenhouse	492	342	700	343		74		842	128	420	620	31	314	4306
All crops	203557	75548	288593	133481	53216	121972	112312	155466	43369	103821	76183	84552	77587	1529657
Double crop	46595	7696	43059	31570	3631	27301	8373	25427	6116	15497	9083	7356	8167	239871
Pasture	10515	3502	6784	4325	13407	2826	4373	6218	1685	1934	3255	6941	2804	68569
Woodland pasture	2491	640	2510	1029	955	1236	549	1541	525	518	1634	2394	405	16427
Woodland on farms	22282	7507	36428	16062	11522	17216	12518	18514	11528	11778	14730	19169	15150	214404

[a]Broiler data in Delaware for Kent and New Castle counties are not disaggregated, but most broilers are likely in Kent County
Source: USDOC/BOC (1993-1994)

Table A2. Machinery prices and parameters (costs in 1995$)

Machine type	Purchase price	Lifetime (hrs)	Annual use (hrs)	Repair rates	Speed (mph)	Width (ft)	Field efficiency	Hours/ Acre	Lifetime (yrs)	Fuel use (gal/hr)	Oil use (gal/hr)
Moldboard plow, 6-16"	10700	2000	200	100	4.50	8.00	0.85	0.27	10.0		
Moldboard plow, 7-16"	13800	2000	200	100	4.50	9.33	0.85	0.23	10.0		
Chisel plow, 15'	6321	2000	200	75	5.00	15.00	0.85	0.13	10.0		
Offset disk, 14 ft.	8200	2000	200	60	6.00	14.00	0.80	0.12	10.0		
Offset disk, 18 ft.	10200	2000	200	60	6.00	18.00	0.80	0.10	10.0		
Offset disk 21 ft.	16900	2000	200	60	6.00	21.00	0.80	0.082	10.0		
Fertilizer & lime spreader, 4t, 40'	8000	1200	120	80	7.00	40.00	0.70	0.04	10.0		
Grain drill, 25'	24900	1500	150	75	5.00	25.00	0.70	0.09	10.0		
No-till drill (fertilizer attach), 15 ft.	20500	1500	150	75	5.00	15.00	0.60	0.18	10.0		
4-row planter	45000	1500	150	75				0.67	10.0		
Boom sprayer, 50'	4700	1500	150	70	3.00	50.00	0.60	0.09	10.0		
Row cultivator, 2-36"	2100	600	60	75	6.00	6.00	0.80	0.29	10.0		
Mower, 7', bushhog	3500	2000	200	175	5.00	7.00	0.80	0.29	10.0		
Mower-conditioner, 7'	7700	2500	250	80	4.50	7.00	0.80	0.33	10.0		
Mower-conditioner, 12'	11700	2500	250	80	4.50	12.00	0.80	0.19	10.0		
Side-delivery rake, 9'	3300	2500	250	60	6.00	9.00	0.80	0.19	10.0		
Round baler, pto, 6'diam, 4'wide	15480	1500	150	90	5.00	4.00	0.67	0.62	10.0		
Round baler, pto, <5'diam, 4'wide	11300	1500	150	90	5.00	4.00	0.65	0.63	10.0		
Bale carrier, forklift	2700	1000	100	40					10.0		
Claas Jaguar harvester	300000	6400	800	40			0.70		8.0	17.48	0.080
High dump forage wagon (1100 ft^3)	17739	2000	400	60					5.0		
Tractor, 40 hp	16900	10000	833	100					12.0	1.98	0.014
Tractor, 60 hp	21400	10000	833	100					12.0	2.96	0.018
Tractor, 80 hp	27500	10000	833	100					12.0	3.95	0.023
Tractor, 100 hp (cab, air)	40100	10000	833	100					12.0	4.94	0.027
Tractor, 120 hp (cab, air)	55200	10000	833	100					12.0	5.93	0.031
Tractor, 225 hp, (cab, air)	80500	10000	833	100					12.0	11.11	0.053
Truck, 2 ton, (hoist)	45000	5000	500	60					10.0	3.75	0.035
Tandem truck (hay)	52200	5000	500						10.0	4.70	0.035
Fork lift	15300	5000	500						10.0	1.98	
Pickup	18400	5000	500	60					10.0	2.25	0.028
Truck tractor (wood)	81500	10000	1000						10.0		
Chip van	29000	6000	300						20.0		

Table A3. Length of streams and buffer width by watershed in the Delmarva Peninsula in the Chesapeake Bay drainage

Watershed	Stream length	Length of stream with buffers of stated widths: Both sides 100-300'	1 side 100-300'	Both sides < 100'	1 side < 100'	Total length < 100'	Buffer area needed
	miles						acres
Maryland							
Pocomoke Sound	150.8	30.2	37.8	113.0	7.6	233.6	2832
Lower Pokomoke River	201.8	126.2	138.7	63.1	12.5	138.7	1681
Upper Pokomoke River	125.8	72.8	75.5	50.3	2.7	103.3	1252
Dividing Creek	57.4	49.9	51.3	6.1	1.4	13.6	165
Nassawango Creek	60.2	44.4	46.2	14.0	1.8	29.8	361
Tangier Sound	215.1	2.8	4.2	210.9	1.4	423.2	5130
Big Annemessex River	115.7	17.4	22.3	93.4	4.9	191.7	2324
Manokin River	204.4	50.0	59.1	145.3	9.1	299.7	3633
Lower Wicomico River	206.9	47.9	55.7	151.2	7.8	310.2	3760
Monie Bay	73.2	6.0	6.8	66.4	0.8	133.6	1619
Wicomico Creek	44.4	14.3	16.7	27.7	2.4	57.8	701
Wicomico River Head	62.6	32.2	36.1	26.5	3.9	56.9	690
Nanticoke River	404.4	101.0	117.4	287.0	16.4	590.4	7156
Maryshope Creek	291.7	136.3	154.8	136.9	18.5	292.3	3543
Fishing Bay	499.1	28.6	37.1	462.0	8.5	932.5	11303
Transquaking River	246.6	58.7	72.8	173.8	14.1	361.7	4384
Honga River	212.2	8.8	11.3	200.9	2.5	404.3	4901
Little Choptank	222.7	11.0	14.6	208.1	3.6	419.8	5088
Lower Choptank	603.0	78.3	101.9	501.1	23.6	1025.8	12434
Upper Choptank	539.7	245.8	278.7	261.0	32.9	554.9	6726
Tackahoe creek	352.1	124.6	147.5	204.6	22.9	432.1	5238
Eastern Bay	104.8	3.9	5.8	99.0	1.9	199.9	2423
Miles River	133.6	18.3	23.7	109.9	5.4	225.2	2730
Wye River	175.2	44.7	55.2	120.0	10.5	250.5	3036
Total Maryland						7681.5	93109
Virginia							
Pokomoke River/Pitts Creek	44.9	19.9	23.1	21.8	3.2	46.8	567
Chesapeake Bay/Holdens Creek	418.1	48.7	57.9	360.2	9.2	729.6	8844
Chesapeake Bay/Onancock Creek	135.3	6.3	8.4	126.9	2.1	255.9	3102
Pungoteague Creek	39.2	8.1	9.3	29.9	1.2	61.0	739
Total Virginia						1093.3	13252
Total						8774.8	106361

Source: Palone and Todd (1997)

APPENDIX B

FEDERAL, STATE AND NONGOVERNMENTAL PROGRAMS TO ENCOURAGE RIPARIAN BUFFER STRIPS

There are a number of federal, state, and nongovernmental programs that help pay for best management practices, including establishment of riparian buffer strips. The Conservation Reserve Program (CRP), a federal program, pays 50% of establishment costs and an annual rental payment in return for removing land from agricultural production and establishing ground cover. Contracts covering CRP lands are for 10 to 15 years. No harvest is allowed during the contract period.

The Wetlands Reserve Program, a federal program, is designed to restore wetlands that have been drained or tilled. Payments from lands entered into this program range from a 75% cost share for a 10-year contract to a 100% cost share and a lump sum payment based on agricultural value for a permanent program easement.

The Wildlife Habitat Incentive Program, a federal program, is designed to improve or increase wildlife habitat and other environmental benefits. Up to a 75% cost share is allowed for land in this program.

The Environmental Quality Incentives Program, a federal program, provides assistance to farmers to conserve soil, water, air, and other natural resources. Up to a 75% cost share is provided to establish riparian forest buffers and related practices under five- to 10-year contracts.

The Stewardship Incentive Program, a federal program, is designed to improve management of nonindustrial private forest land [0.4 to 405 ha (1 to 1000 acres)]. Eligible lands are forested or other rural lands suitable for conversion to program practices. Up to a 65% cost share for program practices is allowed, and the practices must be maintained for at least 10 years. Riparian and wetland improvement and protection are included.

The Forestry Incentives Program, a federal program, provides up to a 65% cost share for tree planting and site preparation.

The Maryland Agricultural Cost Share Program is designed to encourage farmers on farms with existing agriculturally related water quality problems to institute best management practices (BMPs) to control or reduce these problems. Up to 37.5% of eligible costs are reimbursed (in addition to federal reimbursement).

The Maryland Buffer Incentive Program provides a $741/ha ($300/acre) one time grant to land owners who plant and maintain forested buffers for a minimum of 10 years.

Maryland also has a Woodland Incentive Program and Virginia has a Woodland Buffer Filter Area program.

Only one federal program may be utilized on a parcel of land, but state programs may be piggybacked onto federal programs.

The Maryland Conservation Reserve Enhancement Program (referred to as the enhanced Conservation Reserve Program) combines the CRP with the Maryland Agricultural Water Quality Cost Share program, and Ducks Unlimited/Chesapeake Bay Foundation funds to provide 100% cost sharing for establishing riparian forest buffers and 95% for vegetative buffers on lands near streams. In addition the annual rental payment is increased by 70% for riparian forest buffers and 50% for other practices. As with the CRP, contracts are for 10 to 15 years and no harvest is allowed during the contract. Costs are reimbursed up to 95% to 100% of a maximum amount based on the type of cover established:

Cool season grass seeding	$741/ha ($300/acre)
Warm season grass seeding	$988/ha ($400/acre)

Softwood tree planting	$1050/ha ($425/acre)
Hardwood tree planting	$1420/ha ($575/acre)
Shrub planting	$1976 ($800/acre)
Weed control	$124/ha ($50/acre)

A $12.35/ha ($5/acre) maintenance fee is also paid for land in the enhanced CRP. If riparian forest buffers are established, Zone 1 must contain at least two native species plus less than 10% nonnative, noninvasive species. There is more flexibility in the choice of species in Zone 2. (Zones are defined on p. 4.)

APPENDIX C

Chesapeake Bay Drainage

Chesapeake Bay Drainage

There are two systems to load wood chips into chip vans: "hot" loading where the tractor stays attached to the van and "cold" loading where vans are delivered to a staging area by over-the-road tractors and older tractors deliver trailers to and remove trailers from the chipper. Both systems are used for harvesting short rotation woody crops (SRWC) by the forest products industry. Boise Cascade in eastern Washington uses a staging area (personal communication, Chuck Wierman, Boise Cascade , 9 June 1998) while Fort James Paper along the Columbia River in northwestern Oregon uses hot loading because of physical constraints (personal communication, Don Rice, Fort James Paper, 6 July 1998). The hot loading system is easier to model and I do not believe costs vary significantly between the two systems. I model the hot loading system.

The length of time required to fill a chip van depends on the size of the chipper and the size of the chip van. Johnson and Folk (1995) list three sizes of chippers (Table 1). Walsh and Becker (1996) use a 298 kW (400 hp) chipper with a 25 Mg/hr (27.5 ton/hr) capacity in BIOCOST. Most states have an 36,300 kg (80,000 pound) truck weight limit which allows for a 22,700 kg (50,000 pound) [22.7 Mg (25 ton)] load. I assume a 14.6 m (48 ft) chip van with a 50,000 pound [22.7 Mg (25 ton)] load. The amount of time to fill the chip van as a function of chipper size is in Table 1. Rice says that typically it takes 30 to 35 minutes to fill a chip van, but can range from 20 minutes to 1 hour (personal communication from Don Rice, Fort James Paper, 6 July 1998). Stokes also states that a chip van can be filled in as little as 20 to 25 minutes (personal communication from Bryce Stokes, USFS, 3 June 1998). Note that these times are less than the times listed in Table 1 and the 0.73 hours (44 minutes) assumed by Walsh and Becker (1996) to load an 18.2 Mg (20 ton) capacity chip van. Based on a chipper capacity of 25 Mg/hr (27.5 ton/hr), a 22.7 Mg (25 ton) load requires 55 minutes (0.91 hr) to fill. I assume that it takes 55 minutes to fill a chip van. An alternative assumption is that it takes 35 minutes to fill a chip van, which implies a chipper capacity of 38.9 Mg/hr (42.9 ton/hr).

Table C.1. Chipper costs and capacities from Johnson and Folk (1995)

	Chipper size		Capital cost	Capital, operating, labor cost	Capacity		Time to load a 22.7 Mg (25 ton load	
	hp	kW	1000$	$/hr	Tons/hr	Mg/hr	Hours	Minutes
Small	250	186	146.4	65	20.0	18.1	1.25	75
Medium	450	336	193.0	80	27.8	25.2	0.90	54
Large	600	448	244.6	96	39.4	35.7	0.63	38

Johnson and Folk (1995) list a tractor-chip van as costing $110,500. A 14.6 m (48 ft) double axle tandem chip van lists for $31,000 which is approximately $29,000 in 1995 dollars (personal communication from Don Nicely, Western Trailer, Boise, ID, 24 June 1998). This would mean that the tractor costs $81,500, which is considerably more than the $52,000 that Noon (1996) assumes for a tractor hauling switchgrass.

The most efficient way to unload wood chips at a conversion facility is to use a whole-truck dumper, where the tractor is not detached from the chip van. The next most efficient way is to use a trailer dumper, where the tractor is detached from the chip van. At Burlington Electric Company's McNeil Power Plant a trailer dumper is used. It takes a tractor-trailer 15 minutes from the time it goes in the plant gate, dumps its load, and exits the plant gate. The trailer dumper can handle up to 10 trucks/hr, but averages 3 trucks/hr (68 Mg/hr (75 tons/hr)] from 7 a.m. to 9 p.m., Monday through Saturday. A replacement trailer dumper is budgeted at $200,000 (personal communication from John Irving, Burlington Electric Company, 8 June 1998). A whole-truck dumper would be even faster. I assume that a whole-truck dumper would only require a truck to use 10 minutes from the time it enters the plant gate to the time it exits the plant gate.

A 227 million L/year (60 million gallon/year) ethanol facility would require approximately 1.36 million Mg/year (1.5 million tons/year), or based on 300 delivery days/year for 14 hr/day, 324 Mg/hr (357 tons/hr) must be delivered. This is approximately 14 trucks/hr. A 50 MW_e power plant uses 1/3 the requirements of a 227 million L/year (60 million gallon/year) ethanol facility. Some large pulp mills process 9070 Mg/day (10,000 tons/day). At some pulp mills trucks may require up to 2 hours to dump their loads because of congestion at the dumpers (personal communication, Bryce Stokes, USFS, 3 June 1998). For cost purposes, I assume adequate dumping capacity and that a truck requires 15 minutes from the time it enters the plant gate, dumps its load, and exits the plant gate.

Loading, transport, and unloading times for wood chips can vary considerably. Timelines for wood chip transportation by truck could be as follows:

55 min 15 min
Typical |----------------------|----------------------|------|----------------------|----------|
(70 min + load travel to unload return to slack
travel time + conversion chipping site time
slack time) facility

25 min 10 min
Minimum |----------|----------------------|----|----------------------|----------|
(35 min + load travel to unload return to slack
travel time + conversion chipping site time
slack time) facility

60 min 120 min
Maximum |------------------------|----------------------|-----------------------------------|------------------
---|----------|
(180 min + load travel to unload return to
slack
travel time + conversion chipping site time
slack time) facility

I currently model slack time (i.e., unproductive time) as 0.

The number of hours that a tractor and trailer operate in a year affects their costs. The Burlington Electric Company's McNeil Power Plant receives wood chips 14 hr/day, 6 days/wk (personal communication, John Irving, Burlington Electric Company, 8 June 1998). Fort James Paper along the Columbia River in northwestern Oregon harvests 8 to 12 hr/day (personal communication from Don Rice, Fort James Paper, 6 July 1998). Trucks may be operating over 4000 hr/yr.

In Noon (1996) hours of tractor operation are 2000 hr/yr, which is the time the truck engine is running (over-the-road travel time plus unloading time). In Walsh and Becker (1996) hours of operation are assumed to be 500 hr/yr, which appears to be over-the-road travel time, plus when the truck engine is on in at the chipper. Depending on how tractor time is allocated among loading, travel, unloading, and slack time; over-the-road travel time can vary between approximately 25 and 65% of total working time. Based on working 4000 hr/yr, I assume that the tractor engine operates 2000 hr/yr as does Noon (1996). Fixed tractor costs (depreciation, interest, insurance, and fees) are allocated over these 2000 hr/yr. Note that for switchgrass Noon (1996) assumed 1.5 trailers per tractor, a life of 10,000 hours for the tractor, and a trailer life of 5 years. This implies a trailer life of 6,667 hours. Because the trailer always stays attached to the tractor, it is used 2000 hr/yr and has a life of 3.33 years.

Tractor and trailer salvage value are discounted and calculated as:

$$\frac{0.18 * \text{purchase price}}{(1 + \text{real interest rate})^{\text{life}}}$$

Noon does not use this formula but Walsh and Becker do.

Depreciation (called capital replacement in Walsh and Becker) per year is calculated as:

$$\frac{(\text{purchase price - discounted salvage value})}{\text{life}}$$

Interest (called non-land capital costs in Walsh and Becker) per year is calculated as:

$$(\text{purchase price + discounted salvage value}) * \text{real interest rate}$$

Note that this formula is different than what Noon (1996) uses for switchgrass, but the same as Walsh and Becker use. The real interest rate is assumed to be 6.5%.

I assume tractor and trailer purchase costs of $81,500 and $29,000, respectively. For variable (tractor repair, lube, maintenance, and tire; trailer repair and tire) costs I use Noon's numbers.

Fuel and labor costs and tractor and trailer fees vary by region (Table 2). The Bureau of Labor Statistics (1998) lists average hourly earnings for tractor-trailer drivers of $14.07 in 1995 and states that drivers in the west and northeast have higher and drivers in the southeast have lower than average earnings, but give no number data. I could find no regional wage data so I assume that wages in the northeast and Pacific northwest are $2/hr higher than average, in the midwest (lake states and corn belt) are average, and in the southeast (southeast, Appalachia, and southern plains) and northern plains are $2/hr less than average. I assume that benefits are 30% of the wage rate. Note that Walsh and Becker assume $12/hr for wages plus 20% for benefits, for a total labor cost of $14.40/hr, which does not vary by region.

For fuel I assume that the trucks use diesel. Diesel prices excluding taxes are from Walsh and Becker (1996). In 1997 federal road use tax was $0.0644/L ($0.244/gal) and all states also charge diesel road use taxes. In addition some states charge sales tax and some states have additional per gallon and percent taxes for trucks. Data by state for taxes and fees are in the appendix, Table C7. In addition to the state fees there is a federal fee, $550 in 1997 ($518 in 1995 dollars) for a 34,020 kg (75,000 pound) gross vehicle weight. All taxes and fees are adjusted to 1995 dollars assuming an average 3% inflation rate.

Table C2. Regionalized data for fuel, labor, and fees (1995 dollars)

Region number	Region	Diesel $/L	Diesel $/gal	Tractor fee ($)	Trailer fee ($)	Labor rate ($/hr)	Labor rate including benefits ($/hr)
1	Northeast	0.343	1.30	1652	75	16	20.80
2	Lake States	0.336	1.27	2227	31	14	18.20
3	Corn Belt	0.330	1.25	2246	16	14	18.20
4	Southeast	0.306	1.16	1183	15	12	15.60
5	Appalachia	0.312	1.18	1677	22	12	15.60
6	Delta States	0.288	1.09	2148	18	12	15.60
7	Northern Plains	0.309	1.17	1864	19	12	15.60
8	Southern Plains	0.288	1.09	1449	31	12	15.60
9	Pacific Northwest	0.333	1.26	1463	20	16	20.80

Parameter values used in the model for costs that vary by distance and time are in Table 3. Variables used to determine FIXED_COST_PER_LOAD are unload time, which is costed at the VARIABLE_COST_PER_LOADHOUR and loading time which is charged at the labor rate. VARIABLE_COST_PER_LOADKM is the sum of tractor repair, lube, maintenance, and fuel costs; and trailer repair and tire costs. Fuel cost per km is based on the per gallon price of diesel divided by 7 km per gallon, as per Noon (1996). VARIABLE_COST_PER_LOADHOUR is the sum of tractor annual depreciation, interest, insurance, and fees; and trailer depreciation, interest, insurance, and fees; divided by hours of annual use. To get K_F, FIXED_COST_PER_LOAD is divided by dry Mg per load. And to get K_D and K_T, VARIABLE_COST_PER_LOADKM and VARIABLE_COST_PER_LOADHOUR, respectively, are divided by dry Mg per load and multiplied by 2 (because K_D and K_T are defined for one-way distance and time).

Table C3. Tractor and trailer cost variables used by Noon (1996) and in this study

Tractor variable name	Noon value	Value this study	Trailer variable name	Noon value	Value this study
TRACTOR_REPAIR_COST_PER_KM	0.07	0.07	TRAILER_REPAIR_COST_PER_KM	0.02	0.02
TRACTOR_LUBE_COST_PER_KM	0.01	0.01	TRAILER_LUBE_COST_PER_KM	0	0
TRACTOR_MAINT_COST_PER_KM	0.02	0.02	TRAILER_MAINT_COST_PER_KM	0	0
TRACTOR_TIRE_COST_PER_KM	0.02	0.02	TRAILER_TIRE_COST_PER_KM	0.02	0.02
TRACTOR_FUEL_COST_PER_KM	0.164	-[a]			
COST_PER_GALLON_FUEL	1.15	-[a]			
KM_PER_GALLON_FUEL	7	7			
			NUM_TRAILERS_PER_TRACTOR	1.5	1
TRACTOR_DEPRECIATION_PER_YEAR	4000	7369	TRAILER_DEPRECIATION_PER_YEAR	1200	7557
TRACTOR_INTEREST_PER_YEAR	2040	2903	TRAILER_INTEREST_PER_YEAR	276	1312
TRACTOR_INSURANCE_PER_YEAR	7000	10971	TRAILER_INSURANCE_PER_YEAR	250	1036
TRACTOR_FEES_PER_YEAR	2400	-[a]	TRAILER_FEES_PER_YEAR	70	-[a]
TRACTOR_PURCHASE_COST	52000	81500	TRAILER_PURCHASE_COST	7000	29000
TRACTOR_SALVAGE_VALUE	12000	7815	TRAILER_SALVAGE_VALUE	1000	3810
TRACTOR_LIFE_YEARS	10	10	TRAILER_LIFE_YEARS	5	3.33

[a]Varies by region (see Table 2)

One of the objectives of this study is to develop transportation costs from the point where Walsh and Becker (1996) end their calculations. Walsh and Becker (1996) and Noon (1996) use different assumptions and methodologies to determine transportation related costs. I try to reconcile some of these differences. For example, the assumed real interest rate is 6.5%, and capital costs (depreciation and interest) are calculated the same. Walsh and Becker (1996) assume that tractors for chip vans operates 0.25 hr/acre while loading chips. While this works out to be only 2 to 3 minutes per load, so costs are quite small, these costs must be subtracted from K_D and K_T. The major cost is the labor charge while the chip van is filled. This must be subtracted from the calculated K_F value. Adjusting K_F is straight forward.

First all transportation costs are calculated. Then the costs Walsh and Becker (1996) include in BIOCOST are subtracted from all transportation costs. Walsh's and Becker's data for chip vans are in Table 4. I take the Walsh and Becker data as is, except for labor costs which I price at my assumed labor rates. Note that the assumptions are not consistent between the Walsh and Becker data and how costs are calculated in Noon's spreadsheet (e.g. initial cost for a chip van and thus interest and depreciation, diesel price and use, taxes and insurance). (While this may be intellectually troubling, in terms of the effect on costs, it is quite small.) Repairs, fuel/lube, and tax/ins are grouped and modify K_D and cap/rep and non-land are grouped and modify K_T. Noon's numbers are on a per load basis. To get Walsh's and Becker's data on a per load basis, repairs, fuel/lube, and tax/ins are added together, multiplied by 0.25 hr/acre (loadkm column in Table 5), and divided by loads per acre; and cap/rep and non-land are added together, multiplied by 0.25 hr/acre, and divided by loads per acre (loadhr column in Table 5).

$$\text{loadkm column value in Table 5} = \frac{(\text{repairs} + \text{fuel/lube} + \text{tax/ins})*(0.25\ \text{hr/acre})}{\text{loads/acre}}$$

$$\text{loadhr column value in Table 5} = \frac{(\text{cap/rep and non-land})*(0.25\ \text{hr/acre})}{\text{loads/acre}}$$

Note that loads/acre vary by region (Table 5) and that I have assumed 11.34 dry Mg/load in these calculations instead of the 9.1 dry Mg/load in Walsh and Becker. To get the adjusted K_D:

$$K\_D_{adjusted} = \frac{\$/\text{load-km(one-way)} - \$/\text{load(loadkm column value in Table 5)}*2}{\text{distance(one way)}}$$

$$K\_T_{adjusted} = \frac{\$/\text{load-hr(one-way)} - \$/\text{load(loadhr column value in Table 5)}*2}{\text{time(one way)}}$$

The loadhr and loadkm column values in Table 5 are multiplied by 2 because K_D and K_T are based on one-way distance and time, respectively. Unadjusted K_F, K_D, and K_T values are found in cells B5, C5, and D5 (total transportation costs) and adjusted K_F, K_D, and K_T values are found in cells B5, C5, and D5 (total transportation costs minus Walsh and Becker costs for chip vans).

Table C4. Walsh's and Becker's data for chip vans

	Units	Chip van
Rate	hr/ha (hr/acre)	0.62 (0.25)
Purchase price ($)	$	45000
Salvage value ($)	$	8100
Lifetime (yrs)	years	10
Annual use (hrs)	hr	500
Repair rates	lifetime, % of list price	60
Fuel use	L/hr (gal/hr)	14.2 (3.75)
Oil use	L/hr (gal/hr)	0.15 (0.04)
Repairs	$/hr	6.00
Cap rep (depreciation)	$/hr	7.38
Non-land (interest)	$/hr	3.45
Fuel/lube	$/hr	3.41
Labor	$/hr	14.40
Tax/insurance	$/hr	0.36

Table C5. Data from Walsh and Becker used to adjust K_D and K_T

Region	Yield (dt/acre)	Loads/acre	Adjustment for load-hr (per load) loadhr	Adjustment for load-km(per load) loadkm
Northeast	70	5.60	0.484	0.436
Lake States	70	5.60	0.484	0.436
Corn Belt	70	5.60	0.484	0.436
Southeast	63	5.04	0.537	0.485
Appalachia	70	5.60	0.484	0.436
Delta States	70	5.60	0.484	0.436
Northern Plains	70	5.60	0.484	0.436
Southern Plains	63	5.04	0.537	0.485
Pacific Northwest	63	5.04	0.537	0.485

There is only one sheet in the spreadsheet. Each region is given a number (see Table 2 or cells A63:B72) and this region number is entered in cell B2. A sample of the spreadsheet output is in table 6. Note that K_D and K_T change little. I compared the total transportation costs based on large (38.9 Mg/hr) and medium (25.0 Mg/hr) chippers. In the southeast, costs were $8.45 for the medium chipper and $8.00/dry Mg for the large chipper.

Table C6. Sample of spreadsheet output (based on distance of 40 km and time of 0.75 hr).

Units	Fixed cost K_F ($/DRYTON)	Variable distance K_D ($/DRYTON-KM)	Variable time K_T ($/DRYTON-HOUR)	Total ($/DRYTON)
Noon methodology	1.948	0.0573	5.604	8.446
	K_F adjusted	K_D adjusted	K_T adjusted	TOTAL adjusted
Adjusted for Walsh and Becker	0.700	0.0552	5.477	7.018
	($/LOAD)	($/LOAD-KM) (1 way)	($/LOAD-HOUR) (1 way)	($/LOAD)
Total-Noon methodology	22.10	0.651	63.55	95.78
Total adjusted for Walsh and Becker	7.94	0.626	62.11	79.58

Table C7. State data for taxes and fees

Region	Price exclud-ing taxes	Federal tax-1997	State tax-1996	Sales tax-1996 Exclud-ing taxes	Sales tax-1996 Excluding state taxes	Additional taxes-1996 Per gal	Additional taxes-1996	Total diesel price	Fees Tractor-trailer	Fees Trailer only
	$/gal			%		$/gal	%	1995$/gal	1993$	
Northeast	0.85	0.244	0.215					1.271	1117	71
Connecticut	0.85	0.244	0.18					1.224	1555	35
Delaware	0.85	0.244	0.22					1.259	880	368
Maine	0.85	0.244	0.20					1.241	848	16
Maryland	0.85	0.244	0.2425					1.279	1308	20
Massachusetts	0.85	0.244	0.21					1.250	1450	250
New Hampshire	0.85	0.244	0.187					1.230	712	0
New Jersey	0.85	0.244	0.135					1.184	859	18
New York	0.85	0.244	0.2174		0.04	0.089		1.384	989	23
Pennsylvania	0.85	0.244	0.2235			0.06		1.319	1152	27
Rhode Island	0.85	0.244	0.29					1.321	875	5
Vermont	0.85	0.244	0.26					1.294	1659	20
Lake States	0.83	0.244	0.196					1.239	1659	30
Michigan	0.83	0.244	0.15		0.06			1.241	1316	39
Minnesota	0.83	0.244	0.20					1.221	1760	0
Wisconsin	0.83	0.244	0.237					1.254	1900	50
Corn Belt	0.78	0.244	0.194					1.221	1676	15
Iowa	0.78	0.244	0.225					1.193	1705	10
Illinois	0.78	0.244	0.215	0.0625		0.06		1.290	2200	0
Indiana	0.78	0.244	0.16	0.05		0.11		1.278	1382	31
Missouri	0.78	0.244	0.15					1.127	1727	10
Ohio	0.78	0.244	0.22			0.03		1.217	1368	26

Table C7 (continued)

Region	Price excluding taxes	Federal tax-1997	State tax-1996	Sales tax-1996: Exclud-ing taxes	Sales tax-1996: Excluding state taxes	Additional taxes-1996: Per gal	Additional taxes-1996: %	Total diesel price	Fees: Tractor-trailer	Fees: Trailer only
	$/gal			%		$/gal	%	1995$/gal	1993$	
Southeast	0.78	0.244	0.142					1.133	675	14
Alabama	0.78	0.244	0.19					1.163	802	21
Georgia	0.78	0.244	0.075		0.04			1.102	412	12
South Carolina	0.78	0.244	0.16					1.136	810	10
Appalachia	0.77	0.244	0.180					1.157	1140	21
Kentucky	0.77	0.244	0.134			0.02	0.047	1.158	1280	20
North Carolina	0.77	0.244	0.22					1.179	933	10
Tennessee	0.77	0.244	0.17					1.135	1352	50
Virginia	0.77	0.244	0.195					1.157	1003	24
West Virginia	0.77	0.244	0.2535					1.209	1133	0
Delta States	0.67	0.244	0.190					1.063	1584	17
Arkansas	0.67	0.244	0.186	0.045				1.079	1370	20
Louisiana	0.67	0.244	0.20					1.061	490	10
Mississippi	0.67	0.244	0.184					1.047	2892	20
Northern Plains	0.74	0.244	0.209					1.139	1317	18
Kansas	0.74	0.244	0.20					1.131	1764	37
Nebraska	0.74	0.244	0.255					1.180	986	3
North Dakota	0.74	0.244	0.20					1.131	1056	20
South Dakota	0.74	0.244	0.18					1.114	1460	10
Southern Plains	0.70	0.244	0.17					1.065	925	29
Oklahoma.	0.70	0.244	0.14					1.039	994	43
Texas	0.70	0.244	0.20					1.091	856	15
Pacific Northwest	0.81	0.244	0.235					1.232	938	19
Oregon	0.81	0.244	0.24					1.237	320	0
Washington	0.81	0.244	0.23					1.228	1556	38

Sources: FHWA (1993, 1998a,b), USDA/NASS (1996)

APPENDIX D

Derivation of price from net present value

In calculating an average price for biomass over time, one sets:

discounted revenues = discounts costs or

$$\sum_{j=1}^{n} \frac{P_j Y_j}{(1+i)^j} = \sum_{j=1}^{n} \frac{C_j}{(1+i)^j}$$

$P_j = P$ for all j

$$P\sum_{j=1}^{n} \frac{Y_j}{(1+i)^j} = \sum_{j=1}^{n} \frac{C_j}{(1+i)^j}$$

$$P = \frac{\sum_{j=1}^{n} [(C_j)/(1+i)^j]}{\sum_{j=1}^{n} [Y_j/(1+i)^j]}$$

where P = price
P_j = price in year j
Y_j = harvested yield in year j
C_j = costs in year j
i = discount rate.

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