Economic Value of Poultry Litter Supplies In Alternative Uses

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Introduction

In response to outbreaks of the toxic dinoflagellate *Pfiesteria* in the Chesapeake Bay in 1997, Maryland enacted the Water Quality Improvement Act of 1998, which imposes new regulations aimed at reducing nutrient emissions into the Bay from animal production. These regulations impose new restrictions on the application of poultry litter to cropland as a fertilizer, the traditional use to which poultry litter has been put. The imposition of these restrictions has raised questions about the continued feasibility of land application on the Delmarva Peninsula and the extent to which long distance transport of litter off the Peninsula or other methods of poultry litter disposal might become necessary. The Act provided funding for innovative programs to develop ways of helping farmers improve nutrient management. It also provided funding for innovative programs to develop alternative uses of poultry litter that might be more profitable (or less costly). The Inter-Agency Nutrient Reduction Oversight Committee, created to carry out these provisions of the Act, has provided funds from the Animal Waste Technology Fund (AWTF) for pilot studies of a number of new ways of utilizing poultry litter, including pelletization, composting, energy production, and forest fertilization.

The availability of poultry litter for each of these uses depends on two factors. One is physical: the absolute amount of litter generated by the poultry industry, which sets an upper bound on the amount available. The second is economic: the amount of litter available to any given use depends on how much that user is willing to pay for litter relative to the price litter can command in alternative uses. Simply put, growers will tend to direct poultry litter to the use(s) that earn the highest return (or, in other words, poultry litter, like other resources, will tend to be put to its highest value use). It is quite possible, of course, that no single use will earn the highest return for the total quantity of poultry litter generated. For example, even if land application of fertilizer is the most valuable use on fields close to chicken houses, other uses may be more valuable for any litter that must be transported to more distant fields due to regulatory restrictions on land application.

This study investigates the availability of poultry litter for six alternative potential uses: land application as fertilizer, compost, pelletization, electric power generation, cogeneration of steam and electric power, and forest fertilization. The economic value of poultry litter (that is, the maximum a user would be willing and able to pay for poultry litter) is estimated for each of these uses. These estimates of value are then used to assess the extent to which poultry litter is likely to be directed toward each alternative use.

Physical Availability of Poultry Litter

Physical quantities of poultry litter produced annually were estimated at the county level by multiplying the average amount of litter generated per bird times the number of broilers produced annually in each county. The amount of litter generated annually by broilers was assumed to equal 1.2 tons per 1,000 birds (Carr 2002). The number of broilers produced annually was estimated using data from two sources: (1) the 1997 Census of Agriculture and (2) the Agricultural Statistics Annual Summaries for Maryland Delaware, and Virginia. The annual agricultural statistics reports published by each state provide figures on the number of broilers sold annually; data from the most recent year available (2000) were used. The Census of Agriculture provides county-level estimates of broiler production. The Census figures were used to estimate each county's share of total broiler production, which were then used to allocate the year 2000 production figures across counties. To simplify the analysis, broiler production in New Castle County, Delaware was included in the figure for Kent County, Delaware. This procedure generated an estimate of 589,205,105 broilers produced on the Delmarva Peninsula during 2000. The total amount of poultry litter generated annually on the Peninsula was thus estimated to be 706,399 tons (Table 1).

Feasibility of Land Application

At present, the most common use of poultry litter is application to cropland as fertilizer. Regulations promulgated for Maryland under the Water Quality Improvement Act of 1998 have imposed new restrictions on land application. Similar regulations have been promulgated for Delaware by that state's Nutrient Management Program. These regulations require that every crop producer have a nutrient management plan specifying the total amounts of nutrients that can be applied to each field. The amount of poultry litter that can be applied as fertilizer depends on the phosphorus status of the soil in the field, as indicated by a combination of the field's soil test phosphorus Fertility Index Value (FIV) and its Phosphorus Site Index (PSI). The imposition of these restrictions has raised questions about (1) the continued feasibility of land application on the Delmarva Peninsula and (2) the extent to which long distance transport of litter off the Delmarva Peninsula or diversion of litter into other uses may be necessary.

The feasibility of land application on the Delmarva Peninsula was investigated using information about the status of soil phosphorus levels, crop acreage, and permissible crop application rates for all Eastern Shore counties in Maryland, Kent and Sussex Counties in Delaware, and Accomack County in Virginia.

Soils were divided into four categories based on manure application restrictions due to phosphorus levels and runoff potential. Soils with a FIV in excess of 150 and a PSI greater than 100 are classified as having very high phosphorus runoff potential; poultry litter cannot legally be applied to these fields. Soils with a FIV in excess of 150 and a PSI between 75 and 100 are classified as having a high phosphorus runoff potential; poultry litter can be applied to these fields in accordance with a phosphorus-based nutrient management plan, which limits the amount of phosphorus applied to the crop removal rate. Soils with an FIV in excess of 150 and a PSI between 50 and 75 are classified as having medium phosphorus runoff potential; poultry litter can be applied to these fields in accordance with a nitrogen-based nutrient management plan but cannot be planted to corn continuously. Soils with a FIV less than 150 or PSI less than 50 are classified as having a low phosphorus runoff potential; poultry litter can be applied to these soils in accordance with a nitrogen-based nutrient management plan.

FIV and PSI values calculated from data from soil tests conducted by the University of Maryland were used to estimate the shares of corn acreage with very high, high, medium, and low runoff potential. These estimates were made on a regional basis: All counties on the Lower Eastern Shore were assumed to have the same distribution of soil phosphorus runoff potential, as were all counties on the Upper Eastern Shore (Table 2). Data from individual counties were used to extrapolate the Maryland data to Delaware and Virginia. Sussex and Kent Counties in Delaware were assumed to have the same distribution of phosphorus runoff potential as Caroline and Wicomico Counties combined. Accomack County, Virginia, was assumed to have the same distribution of phosphorus runoff potential as Somerset and Worcester Counties combined.

It was assumed that poultry litter would be applied only to corn acreage at rates determined by soil phosphorus status and the phosphorus index level. Application rates were adjusted to take into account likely crop rotations, as discussed below. Planted corn acreage was assumed to equal the year 2000 level, the most recent figures reported in each state's agricultural statistics (see Table 1). Corn acreage in Cecil County, Maryland was not included in the analysis. Corn acreage in New Castle County, Delaware was not included in the total for Kent County, Delaware, even though broiler production in New Castle County was included in the total for Kent County. This procedure underestimates the amount of corn land to which poultry litter could be applied as fertilizer.

The following legally permissible application rates were used in the analysis. As noted above, in accordance with current regulations, it was assumed that no poultry litter could be applied to fields with very high phosphorus runoff potential. Poultry litter can be applied to land with high phosphorus runoff potential at a rate equal to the crop removal rate, so that no additional phosphorus accumulates in the soil. It was assumed that the phosphorus removal rate for corn corresponded to a poultry litter application rate of 1 ton per acre. It was assumed that land with medium phosphorus runoff potential would be farmed using a two-year corn-wheat-soybean rotation with poultry litter applied at nitrogen-based nutrient management plan application rate of 3 tons per acre on corn, 1 ton per acre on wheat, and none on soybeans, giving an average annual application rate of 2 tons per acre. Poultry litter can be applied to land with low phosphorus runoff potential at a rate equal to the crop nitrogen removal rate, which was assumed to correspond to a poultry litter application rate of 3 tons per acre.

As Table 3 indicates, there is more than enough crop acreage to absorb poultry litter applied as fertilizer at legally permissible rates in all but three counties on the Delmarva Peninsula. As a result of having very large numbers of broilers relative to corn acreage, those three counties—Somerset and Wicomico Counties in Maryland and Sussex County, Delaware—generate an estimated total surplus of 127,605 tons of poultry litter that cannot legally be applied as fertilizer. However, other counties on the Peninsula have sufficient corn acreage to absorb an additional 411,504 tons of poultry litter, more than three times the excess generated in Somerset, Wicomico, and Sussex Counties. One can therefore conclude that it is physically feasible to utilize all poultry litter generated by the broiler industry on the Delmarva Peninsula as fertilizer applied to crop land at legally permissible rates that will not result in phosphorus runoff.

The preceding analysis does not take into account possible increases in the phosphorus runoff potential of corn acreage on which poultry litter is applied under nitrogen-based nutrient management plans. Such increases in phosphorus runoff potential could, of course, compromise the long run sustainability of applying poultry litter as fertilizer on cropland. To assess the long run sustainability of using poultry litter as fertilizer, the absorption capacity of cropland was estimated under the assumption that the phosphorus runoff potential of land currently classified as having low runoff potential increased to medium while the phosphorus runoff potential of all other cropland remained unchanged. This is a conservative assumption, since the soil phosphorus status of land currently classified as having high or very high runoff potential is likely to decrease over time. Under this set of assumptions, out-of-county transport would be required in Caroline, Somerset, Wicomico, and Worcester Counties in Maryland and Sussex County, Delaware. The total amount of poultry litter requiring out-of-county transport would increase to 221,289 tons per year. Cropland in the remaining counties on the Peninsula would be able to absorb 222,671 tons of poultry litter at legally permissible application rates, more than enough to absorb the surplus requiring out-of-county transport. This result suggests that the application of poultry litter to cropland as fertilizer at legally permissible application rates will remain feasible in the long run even if phosphorus accumulates in some soils.

Value of Poultry Litter Applied to Cropland as Fertilizer

While the preceding analysis indicates that using poultry litter as fertilizer on crop land is a feasible method of disposing all of the litter generated on the Delmarva Peninsula, it does not necessarily show that land application is the highest value use of that litter. The value of poultry litter in land application as fertilizer depends on several factors, including (1) the value of the nutrients provided, (2) application costs, and (3) transportation costs. The most straightforward approach to estimating the value of poultry litter as fertilizer is to assume that it is used in place of commercial fertilizer. This approach estimates the value of the nutrients provided, adjusted for any increments in application cost, e.g., due to the need to apply poultry litter separately. Estimates of nutrient value (less application cost) must also be adjusted for transportation cost to take into account the potential effects of regulatory restrictions on land application.

This approach ignores some factors that reduce the value of poultry litter in this use and other factors that increase it. It assumes that farmers credit the full amounts of nutrients available for crop uptake in poultry litter and reduce their commercial fertilizer purchases commensurately. It ignores transaction costs incurred by both buyers and sellers associated with arranging purchase and delivery of poultry litter. It also ignores the value of enhanced soil productivity due to additional organic matter and micronutrients provided by poultry litter.

Data from the Maryland Cooperative Extension manure testing program indicate that poultry litter averaged 3.522% nitrogen, 2.971% phosphorus, and 2.343% potassium during the period 1995-2001, the most recent period for which data are available. These estimates indicate that each ton of poultry litter contains 70.44 pounds of nitrogen, 59.42 pounds of phosphorus, and 46.86 pounds of potassium (Table 4). Not all of the nitrogen in poultry litter is available for crop uptake immediately, however. About half is mineralized (and is thus available for uptake) during the year in which the litter is applied. An additional 20 percent is mineralized and thus available during the year after application while 5 percent more is mineralized two years after application. The remainder is lost through volatilization, leaching, and runoff. All of the phosphorus and potassium is assumed to be available immediately and remain available in the soil indefinitely.

Nutrients provided to the crop vary according to application rate, crop rotation, and time (Table 4). Because poultry litter provides nitrogen for crop uptake in three years, all rotations were analyzed in terms of three-year periods. It was assumed that poultry litter would be applied in years when corn is planted. Thus, poultry litter was assumed to be applied prior to planting corn in all three years in a continuous corn rotation; prior to planting corn in years one and three in a corn-soybean rotation; and prior to planting corn (in the spring) and prior to planting winter wheat (in the fall) in years one in a corn-winter wheat-soybean rotation. Each crop was assumed to take up either its annual requirement of each nutrient or the amount of each nutrient available in poultry litter (including carryover from a previous year application), whichever was smaller (see Table 4 for details). Poultry litter applied to continuous corn was assumed to provide nitrogen in all three years but phosphorus and potassium only in year one (since poultry litter applied in subsequent years suffices to meet corn uptake needs in those years). Poultry litter applied to a corn-soybean rotation was assumed to provide nitrogen to corn in years one and three, phosphorus and potassium to corn in year one, and phosphorus and potassium to soybeans in year two. Two applications of poultry litter (one of 3 tons per acre, the second of 1 ton per acre) were assumed to be made to each corn-wheat-soybean rotation. Poultry litter applied to a corn-wheat-soybean rotation was assumed to provide nitrogen to corn in years one and three and nitrogen to wheat in year two plus phosphorus and potassium to corn in year one and to wheat and soybeans in year two. It was assumed that corn and wheat take up all of the nitrogen available in any given year while soybeans take up none. Nutrients were valued at current market prices and were time-discounted at a rate of 10 percent (Table 4).

The value of poultry litter nutrient content ranges from $19 to $34 per ton, depending on rotation and nutrient management plan (Table 5). This range is consistent with other recent estimates (see for example Pierson and Wyvill 2001). Less of the phosphorus and potassium contained in the litter applied are taken up by crops under nitrogen-based nutrient management plans than under phosphorus-based nutrient management plans, so that the average nutrient value per ton of litter is lower under the former than the latter. The per-ton value is highest under a corn-wheat-soybean rotation because it utilizes the largest share of the total nutrient content of the litter applied. A continuous corn rotation utilizes more nitrogen but less phosphorus and potassium than a corn-soybean rotation.

The cost of applying poultry litter was estimated using custom rates reported by the Maryland Agricultural Statistics Service and time and spreader capacity information provided by Tommy Bowles. According to Tommy Bowles, a farmer with a nitrogen-based nutrient management plan can spread poultry litter on 50 to 100 acres of cropland in a 12-hour day. Manure spreaders typically hold 2.5 tons, implying that farmers can apply between 20 and 40 loads a day. Under a nitrogen-based nutrient management plan, time is split equally between loading the spreader and applying litter, suggesting that each task takes 0.15 to 0.30 hours per load. The Maryland Agricultural Statistics Service reports custom rates for loading and applying manure of $29.80 and $30.70 per hour, respectively, implying an application cost between $9.08 and $18.15 per load or $3.63 to $7.26 per ton.

Under a phosphorus-based nutrient management plan, more time is needed to spread litter, since each load is applied over a larger area. It was assumed that the time required to apply litter was proportional to the area over which it was applied, which implies that it takes 0.45 to 0.90 hours to spread each load in addition to the 0.15 to 0.30 hours loading time for each load. The application cost under a phosphorus based nutrient management plan was thus estimated at $18.29 to $36.57 per load or $7.31 to $14.63 per ton.

A corn-wheat-soybean rotation was assumed to receive two applications of poultry litter, one of three tons per acre and a second of one ton per acre. The application cost under a nitrogen-based nutrient management plan was used for the first application. The application cost under a phosphorus-based nutrient management plan was used for the second application. For consistency with the treatment of nutrient value, the cost of the second application made to a corn-wheat-soybean rotation was discounted at a rate of 10 percent.

Assuming a cost of testing litter for nutrient content of $0.20 per ton (the figure used by the Maryland Department of Agriculture) and a cleanout cost of $4 per ton (the cost estimate reported by Perdue AgriRecycle and Litter Management), the value of poultry litter as a fertilizer substitute net of cleanout, testing, and application costs ranges from just under $4 per ton (corn-wheat-soybean rotation under a nitrogen-based nutrient management plan) to almost $23 per ton (corn-wheat-soybean rotation under a phosphorus-based nutrient management plan), as can be seen in Table 6.

In some situations, poultry litter will be worth less. For example, farmers whose cropland has high phosphorus (and by inference potassium) levels would not need to apply either phosphorus or potassium. Poultry litter affords such farmers no savings in expenditures on phosphorus or potassium fertilizers, so its value derives only from the nitrogen it provides, which is worth between $9.53 and $12.73 per ton by itself and thus between zero and $3.90 per ton net of cleanout, testing, and application costs. However, poultry litter will most likely be applied to land on which it is worth the most. As Table 3 indicates, there is more than enough cropland with low phosphorus levels on the Delmarva Peninsula to absorb all of poultry litter generated by the broiler industry. For this reason, the figures in Table 6 reflect the likely range of values of poultry litter when applied to cropland as a substitute for fertilizers.

Transportation Distance and Cost

The cost of transporting poultry litter to cropland was estimated using a spatial economic model. Detailed spatial information about the location of chicken houses and the phosphorus status of the soils in the fields surrounding them is not available. Assumptions about the spatial distribution of both were used instead. Specifically, it was assumed that:

1. Poultry litter would be applied only to fields on which corn is grown;
2. Corn fields were distributed uniformly in concentric circles around each chicken house in proportions equal to corn acreage as a share of total county land;
3. Phosphorus concentrations decreased with distance from each chicken house; and
4. The distribution of corn acreage was independent of the distribution of soil phosphorus status.

The spatial distribution of phosphorus status and corn fields implied by these assumptions is depicted in Figure 1 and is explained in detail below.

Formally, the spatial model used to estimate transportation requirements was as follows. Consider a county of total size A and planted corn acreage C. Let s = C/A denote corn acreage as a share of total county land area, p_k equal the share of the county's soils with phosphorus status k (k = V, H, M, L for very high, high, medium, and low runoff potential), and u_k be the legally permissible poultry litter application rate on soil with phosphorus status k. The total amount of corn acreage with very high phosphorus runoff potential is $p_V C$. The assumption that it is located closest to a poultry production facility implies that all of it lies within a distance of t_V miles such that

$$640\pi s t_V^2 = p_V C,$$

which can be solved to yield

$$t_V = \sqrt{p_V A \big/ 640\pi}\ .$$

(There are 640 acres in a square mile.) Under current regulations, no poultry litter can be applied legally to land with very high runoff potential, i.e., $u_V = 0$.

The total amount of corn acreage with high runoff potential is $p_H C$. The assumption that it is located second closest to a poultry production facility implies that all of it lies within a distance of t_H miles such that

$$640\pi s(t_H^2 - t_V^2) = p_H C,$$

which can be solved to yield

$$t_H = \sqrt{\frac{p_H A}{640\pi} + t_v^2} = \sqrt{\frac{(p_H + p_V)A}{640\pi}}\ .$$

The amount of poultry litter that can be applied to corn acreage with high runoff potential is $u_H 640\pi s(t_H^2 - t_V^2)$.

It is also possible that there is more than enough land with high phosphorus runoff potential to absorb the total amount of poultry litter generated, even when application is limited to the rate of crop phosphorus uptake. In this case, all corn acreage to which poultry litter is applied will lie within a distance of t_H miles such that

$$u_H 640\pi s(t_H^2 - t_V^2) = mN,$$

where m is the average amount of litter produced annually by each broiler and N is the total number of broilers produced. In this case,

$$t_H = \sqrt{\left(\frac{mN}{u_H C} + p_V\right)\frac{A}{640\pi}}\ .$$

Generally, then, the maximum distance poultry litter would be transported in this case is given by:

$$t_H = \sqrt{\frac{[\min(p_H, mN/u_H C) + p_V]A}{640\pi}}.$$

If the total amount of poultry litter produced exceeds the amount that can be applied to corn acreage with both high and medium phosphorus runoff potential, all corn acreage with medium phosphorus runoff potential to which poultry litter will be applied will lie within a distance equal to

$$t_M = \sqrt{\frac{(p_M + p_H + p_V)A}{640\pi}}.$$

If the total amount of poultry litter produced exceeds the amount that can be applied to corn acreage with high runoff potential but not medium runoff potential, then all corn acreage with medium phosphorus potential to which poultry litter will be applied will lie within a distance t_M defined by

$$u_M 640\pi s(t_M^2 - t_H^2) = mN - u_H 640\pi s(t_H^2 - t_V^2),$$

which can be solved to yield

$$t_M = \sqrt{\frac{A}{640\pi}\frac{1}{u_M}\left[\frac{mN}{C} - (u_H - u_M)t_H^2 + u_H t_V^2\right]}.$$

Thus, generally, all corn acreage with medium phosphorus runoff potential to which poultry litter will be applied will lie within a distance equal to

$$t_M = \sqrt{\frac{A}{640\pi}\min\left\{\frac{1}{u_M}\left[\frac{mN}{C} - (u_H - u_M)t_H^2 + u_H t_V^2\right], (p_M + p_H + p_V)\right\}}.$$

Finally, if the total amount of poultry litter produced exceeds that amount that can be applied to corn acreage with high and medium runoff potential, the same procedure can be used to show that all corn acreage to which poultry litter can be applied will lie within a distance equal to

$$t_L = \sqrt{\frac{A}{640\pi}\min\left\{\frac{1}{u_L}\left[\frac{mN}{C} - (u_L - u_M)t_M^2 + (u_H - u_M)t_H^2 + u_H t_V^2\right], (p_L + p_M + p_H + p_V)\right\}}.$$

If the total amount of corn acreage is insufficient to absorb the total amount of poultry litter produced, given legal restrictions on permissible application rates, the excess poultry litter that cannot be applied in-county is given by

$$mN - 640\pi s[u_H (t_H^2 - t_V^2) + u_M(t_M^2 - t_H^2)\ u_L(t_L^2 - t_M^2)].$$

If the total amount of acreage in the county is more than sufficient to absorb the total amount of poultry litter produced at legally permissible application rates, the additional amount of poultry litter that could be applied in the county was calculated using a procedure similar to those shown above.

Planted corn acreage C was assumed to equal the year 2000 level, the most recent figures reported in each state's agricultural statistics. Estimates of total county acreage S were taken from state planning documents. Both are shown in Table 1. As noted above, corn acreage in New Castle County, Delaware was not included in the total for Kent County, Delaware, even though broiler production in New Castle County was included in the total for Kent County, a procedure that underestimates the amount of corn land to which poultry litter could be applied as fertilizer. The share of total county land planted to corn was estimated as the ratio of planted corn acreage to total land area in each county.

FIV and PSI values calculated from data from soil tests conducted by the University of Maryland and PSI value were used to estimate the shares of corn acreage with very high, high, medium, and low runoff potential (p_V, p_H, p_M, and p_L, respectively). As noted above, these estimates were made on a regional basis: All counties on the Lower Eastern Shore were assumed to have the same distribution of soil phosphorus runoff potential, as were all counties on the Upper Eastern Shore (Table 2). Data from individual counties were used to extrapolate the Maryland data to Delaware and Virginia. Sussex and Kent Counties in Delaware were assumed to have the same distribution of phosphorus runoff potential as Caroline and Wicomico Counties combined. Accomack County, Virginia, was assumed to have the same distribution of phosphorus runoff potential as Somerset and Worcester Counties combined.

The following legally permissible application rates were used in the analysis. As noted above, in accordance with current regulations, it was assumed that poultry litter could not be applied at all to fields with very high phosphorus runoff potential ($u_V = 0$); that poultry litter can be applied to land with high phosphorus runoff potential at a rate equal to the crop removal rate, assumed to correspond to a poultry litter application rate of 1 ton per acre ($u_H = 1$); that land with medium phosphorus runoff potential would be farmed using a corn-wheat-soybean rotation with poultry litter applied at a nitrogen-based nutrient management plan application rate of 3 tons per acre on corn, 1 ton per acre on wheat, and none on soybeans, giving an average application rate of 2 tons per acre ($u_M = 2$), and that poultry litter can be applied to land with low phosphorus runoff at a rate equal to the crop nitrogen removal rate, corresponding to a poultry litter application rate of 3 tons per acre ($u_L = 3$).

In the base case analysis, chicken houses were assumed to be distributed randomly throughout each county. Each chicken house in a given county was assumed to produce the average number per farm as indicated by the 1997 Census of Agriculture. (The data used in this calculation are shown in Table 1.) The procedures described above were used to calculate the maximum distance poultry litter would need to be transported for land application in-county. It was assumed that chicken houses were located sufficiently far apart from one another that poultry litter from no two houses would be applied to the same corn acreage. The results of the analysis were then used to check the plausibility of this assumption.

The results of the base case analysis (Table 7) indicate that in-county transportation distances are likely to be quite short. In all but two counties, the model indicates maximum transportation distances ranging from two-thirds of a mile to a mile. The maximum transportation distances in the remaining two counties are not much longer: 1.24 miles in Dorchester County and 1.12 miles in Accomack County. These distances figures indicate that it is quite plausible to assume that poultry litter from no two houses would be applied to the same corn acreage. Furthermore, such short distances can easily be handled by a manure spreader, suggesting that in-county land application of poultry litter as fertilizer will likely entail no additional transportation cost.

It was noted previously that application of poultry litter to continuous corn under nitrogen-based nutrient management plans might increase the phosphorus runoff potential of cropland currently classified as having low phosphorus runoff potential. To assess the effects of such changes, transportation distances were also estimated under the assumption that soils with low phosphorus runoff potential increased to medium while the phosphorus runoff potential of other soils remained unchanged. Under this set of assumptions, the distances required for poultry litter would not increase appreciably, so that the transportation distances derived in the base case analysis (Table 7) would remain approximately the same over the long run.

A sensitivity analysis was also conducted under the assumption that all poultry production in every county was located at a single point in the center of the county. This assumption maximizes transportation distances with each county and thus generates a high-end estimate of in-county transportation cost. Even in this case, the transportation distances required are quite short: Under 5 miles in most of Maryland's Upper Eastern Shore counties; under 10 miles in Caroline County, Maryland and Accomack County, Virginia; 10-12 miles in Maryland's Lower Eastern Shore Counties and Kent County, Delaware; and roughly 17 miles in Sussex County, Delaware (Table 8). Perdue AgriRecycle estimates the average cost of transporting poultry litter within a 25-mile radius at $10.00 per ton, $1.50 per ton for loading plus $8.50 per ton for hauling. Assuming that chicken houses are distributed uniformly within an area of any given radius, these figures suggest that the cost of transporting poultry litter would be about $1.85 per ton within a 5-mile radius, $2.85 per ton within a 10-mile radius, and $4.55 per ton within a 15-mile radius. The figures in Table 3 suggest that out-of-county transportation of poultry litter will involve roughly the same distances and thus the same transportation costs.

Pelletization

At present, the second largest use of poultry litter on the Delmarva Peninsula is pelletization for export. Perdue AgriRecycle, a joint venture between Perdue Farms and AgriRecycle, owns and operates a plant in Seaford, Delaware that transforms raw litter into dry pellets. The product, MicroStart 60®, is marketed mainly as a source of organic matter and micronutrients in formulated fertilizers, especially those produced for precision agriculture. Everything the plant produces is currently exported by rail from the region, primarily to southern Ohio, Arkansas, southern Illinois, Maine, and Florida.

The Perdue AgriRecycle plant has the capacity to produce 150,000 tons of pellets. It is licensed to produce only 80,000 tons, a restriction imposed due to concerns about delivery truck traffic. It currently produces 50-60,000 tons annually. The drying involved in the pelletization process results in shrinkage of about 15 percent, suggesting that the plant utilizes roughly 60-70,000 tons of raw litter annually.

The plant was constructed at a cost of about $12 million. The state of Delaware is providing $2 million ($400,000 annually over a five year period beginning in fiscal year 2002) for assistance with transportation improvements. The Maryland Department of Agriculture has been providing subsidies for transporting litter from Maryland chicken houses to the plant through its Poultry Litter Pilot Transport Project.

The value of poultry litter in this use was estimated using information provided by Mike Ferguson of AgriRecycle. When the company acquires poultry litter from growers, it pays for cleanout and transportation but does not pay growers for the litter itself. The company pays $4 per ton of raw litter to clean out a chicken house. The cost of transportation averages about $10 per ton of raw litter, all of which is obtained within a radius of 25 miles. Perdue AgriRecycle currently sells its product for $65 per ton FOB. To build market share in the Midwest, the company believes it could profitably offer its product for sale at a promotional price of as little as $45 per ton, provided it could obtain backhaul cargo for its railcars at a rate of at least $10 per ton. These figures imply that the company could earn a normal rate of return selling its product for a price as low as $55 per ton and thus that it earns a premium of $10 per ton of pelletized product above and beyond a normal rate of return on investment. Adjusting for shrinkage of 15 percent, these figures suggest that the company could pay on average as much as $8.50 per ton of raw litter and still earn a normal rate of return on its investment in plant and equipment.

Composting

A modest amount of poultry litter (less than 10,000 tons) is being composted at present. There are plans to increase production to about 15,000 tons, but no further expansion has been proposed.

There are four general methods of producing compost: static pile, standard windrow, improved windrow, and in-vessel and agitation. Static pile, the simplest, involves mixing the poultry litter with a carbon source (most often sawdust) and putting it into a pile that is aerated from below. Windrow methods involve laying out the poultry litter/sawdust mixture in long piles that form tall rows. The rows are turned periodically to increase aeration and thus speed the composting process. Improved windrow is similar to standard windrow but involves greater capital expenditure on equipment and facilities that increase production efficiencies and reduce production time. In-vessel and agitation systems involve putting the input mixture into trough bays or large drums that mechanically agitate the product. This system has the shortest production cycle but involves the greatest expenditure on equipment, facilities, and operation.

The production systems analyzed here are standard windrow used on-farm and improved windrow used off-farm. Three scales of operation are considered for off-farm systems. Compost production on-farm system was assumed to employ a standard windrow production system with a capacity of 10,000 tons of input annually, producing 8,920 tons of compost that is all sold as bulk product. Off-farm production was assumed to employ improved windrow production systems with capacities of 10,000 tons, 40,000 tons and 80,000 tons of input annually. Sales of bulk product (Table 9) and of screened and bagged product (Table 10) were analyzed for each of the off-farm systems.

Estimates of cost and productivity were based upon a 1990 North Carolina State University study, modified to reflect current conditions in Maryland (Carr 2002, Carr and Brodie no date). For the small on-farm system annual capital costs included expenditures on land, facilities and capital equipment, annualized over the life of each item. The on-farm system requires little investment in structures and facilities, so that annualized capital costs are low. Variable costs include some short-lived equipment, labor, fuel, insurance, and other operating expenses. Input costs include the costs of sawdust as a carbon source, and the costs to clean out poultry houses to provide the poultry litter. These costs were converted to costs per ton finished compost using the input and output quantities for the system involved. The on-farm system was assumed to be located on or near a poultry production facility and thus involves no transportation of poultry litter. The total cost of production, excluding marketing costs, is $16.59 per ton of compost produced.

Off-farm systems are more expensive to operate. Costs for the bulk operation are given in Table 9, while costs for the screening and bagging operation are shown in Table 10. The cost of producing bulk compost was significantly higher at the off-farm facility than on-farm, due to higher capital expenditures on facilities and the cost of transporting poultry litter from the poultry grower to the composting facility. The cost of transporting poultry litter was assumed to be the same as that involved in pelletization and electric power generation, $10 per ton (including loading and hauling). The increased expenditures on facilities results from a need for better control of dust, odors and runoff at an off-farm facility. There appear to be significant economies of scale in the production of bulk compost up to a capacity of 40,000 tons (Table 9). The average cost of compost produced at an 80,000 ton facility was only 4 percent lower than the average cost at a 40,000 ton facility, suggesting that economies of scale are largely exhausted at a capacity of 40,000 tons.

Screening and bagging raise the cost of the product substantially (Table 10). Again, it appears that economies of scale are largely, albeit not completely, exhausted at a capacity of 40,000 tons.

The price of compost depends on the quality of the product. It is expected that the off-farm facility will be able to produce a somewhat higher quality bulk product than the on-farm facility, since the more capital intensive production process involved in the former results in a more uniform product with better texture than the latter. The screened and bagged product will be of a higher quality still as the screening will help remove unwanted impurities. The price of bulk manure compost purchased at the production facility in the Northeast ranges from $5 per ton to $20 per ton, with an average price of $18.10 per ton (Composting News 1998). Bagged product prices are more difficult to discern. Bagged compost product in the Northeast retails at the facility at an average price of $59.76 per ton (Composting News 1998). Data on the costs of running a retail operation and likely sales volumes were not available. However the majority of the bagged compost produced by a medium or large capacity facility would likely be sold wholesale in substantial volumes. While price figures for such wholesale transactions were not available, discounts for large purchases of bulk product can vary from 25% to 60%, depending upon the size of the sale (Pat Condon 2002). A relatively small wholesale discount of 25% of the retail sales price implies a wholesale FOB price of $44.82 per ton.

These figures suggest that on-farm operations producing bulk compost and medium- and large-sized off-farm operations producing bagged compost could afford to pay positive prices for poultry litter and still remain economically viable (Tables 9 and 10). The estimated implicit value of poultry litter in compost production was quite small, however. An on-farm operation producing bulk compost could afford to pay only $1.10 per ton and still earn a normal rate of return on investment. The estimated value of poultry litter to a medium or large sized facility producing bagged compost was on the order of only $2.67 to $4.39 per ton.

In contrast, off-farm operations producing bulk compost and small off-farm operations producing bagged compost would only be profitable if they charged a disposal fee for poultry litter. The estimated implicit value of poultry litter in an off-farm operation producing bulk compost was negative at all scales of operation and ranged from less than -$6.50 per ton to almost -$13 per ton. The estimated value of poultry litter in a small (10,000 ton) operation producing bagged compost was also negative at over -$8 per ton.

Electricity Generation

A number of entities have proposed using poultry litter as a fuel source for electricity generation. Several studies have investigated the technical and economic feasibility of producing electricity for sale into a wholesale power grid using poultry litter as a fuel (Antares Group 1999, Pierson and Wyvill 2001, Dagnall 1992). Technical options considered range from direct-fired stoker furnaces to fluidized bed boilers to gasifiers coupled with various furnace/boiler components. Several power plants based on gasification are currently in operation in England (for a description see Pierson and Wyvill 2001). Proposals for the Delmarva Peninsula currently under consideration include retrofitting Connectiv’s Vienna and Indian River power plants with a separate boiler to be used in conjunction with existing oil-fired boilers; replacing those power plants with systems designed expressly for the use of poultry litter as a fuel; and Fibrowatt’s gasification-based system. All would utilize large amounts of poultry litter. The former pair would utilize 240-250,000 tons of poultry litter annually. The 12.6 MW

Fibrowatt plant in operation in England since 1992 uses almost 141,000 tons of poultry litter annually. Fibrowatt operates two other poultry litter fueled power plants in England, one with a capacity of 13.5 MW in operation since 1993 and one with a capacity of 38.5 MW in operation since 1998. It has proposed building a 40 MW plant on the Delmarva Peninsula that would utilize 500,000 tons of poultry litter annually.

The Antares Group (1999) has estimated the costs of producing electricity under first two of these systems. Dagnall (1992) presents estimates of the costs of producing electricity using the 12.6 MW Fibrowatt system. ElectroTek Concepts (2001) presents estimates of the costs of producing electric power using the 40.0 MW FibroShore project that Fibrowatt has proposed building on the Delmarva Peninsula. The Antares Group study includes estimates of revenue to be earned from the sales of ash (which has a high phosphorus and potassium content) for fertilizer. None of these studies considers the costs of cleanout and transporting poultry litter from chicken houses to the power plant.

The implicit value of poultry litter for use in electric power generation was assumed to equal the maximum amount users could pay without losing money, that is, the amount they could pay and just break even. Table 11 presents estimates of the implicit value of poultry litter for electric power generation with and without a 1.7 cent per kilowatt-hour renewable energy tax credit. The costs of cleanout and transportation are estimated to be $4.00 and $10.00 per ton, respectively, as indicated by information provided by Mike Ferguson of AgriRecycle and Joe Malizia of Litter Management, entities actively involved in commercial cleanout and transport on the Delmarva Peninsula. The costs of generating electric power at a 25 MW plant like the Connectiv Vienna plant (under a retrofit and under greenfield construction) are derived from the Antares Group. The costs of generating electric power at the proposed 40.0 MW FibroShore plant are derived combining estimates of capital and operation and maintenance costs and of power production presented by ElectroTek Concepts (2001) with estimates of project lifetime, rate of return on capital, and poultry litter use as shown in Table 11. The cost of electricity in a 12.6 MW Fibrowatt plant is estimated using information from Dagnall, converted to U.S. dollars using the current exchange rate of $1.53 per British pound. Since the dollar has been relatively weak (by historical standards) recently, the use of this exchange rate may understate the actual cost. Dagnall's cost estimates were for updated for inflation using the producer price index for construction to convert capital costs from 1992 to 2001 dollars. The employment cost index (total compensation) for private manufacturing industry was used to convert operation and maintenance costs from 1992 to 2001 dollars. Estimated revenue generated by ash sales is based on data presented by the Antares Group (see Table 12 for details), combined with more recent estimates of phosphorus and potassium prices, transportation costs, and application costs. The resulting estimates are quite close to those presented elsewhere (Antares Group 1999, Pierson and Wyvill 2001). The wholesale price of electricity was assumed to equal the average locational marginal price paid in the PJM wholesale market during 2001. That price, 3.2 cents per kilowatt-hour, is higher than in any of the three preceding years (2.8 cents per kilowatt-hour in 1999 and 2000, 2.2 cents per kilowatt-hour in 1998). The use of a historically high price of electricity, a historically low exchange rate, and engineering efficiency estimates likely overstate the profitability of electric power generation for the wholesale market.

Despite these likely upward biases in the estimation of profitability, the estimated implicit value of poultry litter is negative in all three cases, indicating that a firm using poultry litter for wholesale electric power generation could not pay a positive price for poultry litter and remain profitable (Table 11). Without a renewable energy tax credit, power generators would have to be paid a subsidy or disposal charge (tipping fee) ranging from $10 to $55 per ton of poultry litter delivered. Such a subsidy or disposal charge would be needed even if the renewable energy tax credit of 1.7 cents per kilowatt-hour were passed on to growers in the form of a higher price for poultry litter. With this tax credit, power generators would need a subsidy or disposal charge (tipping fee) ranging from $7 to $49 per ton of poultry litter in order to break even.

Electric power generators would not be able to afford to pay a positive price for poultry litter because electricity produced using poultry litter under these technologies is expensive relative to the alternatives available. The capital and operation and maintenance costs alone amount to between 5.1 and 8.4 cents per kilowatt-hour. Ash sales should bring in only between 0.7 and 1.3 cents per kilowatt-hour, while cleanout and transport costs amount to between 2.0 and 2.3 cents per kilowatt-hour. The before-tax net cost of producing electricity thus ranges between 5.1 and 9.5 cents per kilowatt-hour, far more than the wholesale price of electricity on the Delmarva Peninsula even with a renewable energy tax credit.

Cogeneration and Steam Production

Two poultry integrators have explored the possibility of using poultry litter to produce heat. Tyson's has considered a gasification system at its Temperanceville, Virginia rendering plant to produce steam needed for the production process. There appears to be very little possibility that this system will be built due to local regulatory constraints. Allen Family Foods is currently planning to build a cogeneration facility at its rendering plant in Hurlock, Maryland. This facility would produce steam and electricity for the plant's operations. Additional electricity would be available for sale to the electric power grid. This facility is expected to be operational within approximately two years.

When completed and fully operational, the Allen cogeneration facility would supply its rendering plant with 100 percent of its steam needs and up to 5 MW of electricity (Enders, 2002). Initially, the facility would operate at a lower capacity that will meet the rendering plant's electricity needs of 2.5 MW. In the long run, Allen expects to increase electric power production at the cogeneration facility to 5 MW. The plant would operate continuously. Allen would sell the 2.5 MW of electricity not needed at the rendering plant to the wholesale power grid during weekday operations. It would sell to the wholesale power grid the entire 5 MW of electricity generated during weekends when the rendering plant is not operating. The facility is expected to contract with growers for 80,000 tons of poultry litter. The facility expects to obtain poultry litter from growers within a radius of 35 miles from the plant at an average cost of cleanout and transportation of $8 per ton.[1] According to Larry Enders of Allen Foods, the cogeneration facility will cover costs and a normal rate of return on capital investments if it is able to operate at full capacity, selling the excess power to the grid and the ash to a fertilizer producer at that cost obtaining poultry litter.[2] Thus, the implicit price of poultry litter is zero for the fully operational cogeneration facility. During the start-up phase of the project (when the cogeneration facility may operate at 50 percent capacity), the implicit price of poultry litter would be negative.

Allen Foods did not plan to rely on income generated from the renewable energy tax credit when considering costs and revenues for the cogeneration facility. It does plan to apply for the credit but has set a corporate goal for the project that does not rely on the credit to make production possible. If the renewable energy tax credit is factored in, and the cogeneration

[1] The lower estimate of poultry litter delivery costs as compared with the Perdue AgriRecycle numbers suggests that Allen expects to get a higher percentage of their poultry litter from growers close in to the facility.
[2] Due to proprietary concerns as well as uncertainties in engineering designs and estimates, capital, and operation and maintenance costs are not presented here.

facility operates at its targeted goal of 5 MW electricity production with a 95 percent uptime, the facility could generate an additional $454,738 in revenues (Table 13). Accounting for the facility's input need of 80,000 tons of poultry litter per year, this increased revenue translates into an implicit price for poultry litter of $5.68 per ton.

Forest Fertilization

Another potential use for poultry litter is to fertilize forest land. A number of studies have shown that fertilizing forests at replanting and at mid-rotation (when stands are thinned in order to promote growth) increases tree growth rates substantially (Henry 1986, Edmonds and Cole 1977, Allen 1994, Allen and Lein 1998). The Eastern Shore of Maryland (excluding Cecil County) has 678,470 acres of forest land, most of which is located near the main centers of broiler production in Wicomico, Worcester, Somerset, and Dorchester Counties (Table 14). An average of 1-1.5 percent of that forest land is harvested and replanted each year while an additional 1-2 percent is thinned, suggesting that poultry litter could be applied to almost 24,000 acres each year.

Poultry litter would be applied to forest land primarily as a substitute for commercial phosphorus fertilizer such as diammonium phosphate (DAP). DAP costs about $15 per acre while aerial application costs between $10 and $15 per acre, so that the cost of applying DAP ranges from $25 to $30 per acre (Lewis 2002). The value of poultry litter used for forest fertilization was assumed to equal the price that would equate the cost of applying poultry litter with that of DAP. The literature suggests that the optimal phosphorus application rate is 50 pounds per acre at planting time and 50 pounds per acre at mid-rotation (Allen 1994). Poultry litter in Maryland averages about 59 pounds of phosphorus per ton (Table 4), suggesting litter application rates of 1 ton per acre at planting time and 1 ton per acre at mid-rotation.

The cost of spreading poultry litter on forest land has been estimated to be about $10 per acre, corresponding to $10 per ton for poultry litter assuming an application rate of 1 ton per acre. The cost of cleanout was assumed to be $4 per ton. These figures suggest that using poultry litter as a phosphorus source at either planting time or mid-rotation would cost $11 to $16 per acre less than DAP, suggesting a value of poultry litter of $11 to $16 per ton, less the cost of transporting the poultry litter from the chicken house to the forest site. As noted above, the main broiler producing counties in Maryland contain a substantial amount of forest land, suggesting that transportation costs would be modest. As discussed earlier, the average cost of loading and hauling poultry litter is likely on the order of $2.85 per ton from sites located within a 10-mile radius and $4.55 per ton for sites located within a 15-mile radius. Thus, the value of poultry litter used for forest fertilization is likely in the range of $6 to $13 per ton.

At application rates of 1 ton per acre for both planting time and mid-rotation applications, the use of poultry litter for forest fertilization on the Eastern Shore would be limited to no more than between 13,600 and 23,750 tons per year. As not all forest owners expressed interest in fertilizing their forest land with poultry litter (Lynch and Tjaden 2002), actual usage is likely to be lower.

Conclusions

The estimates of the value of poultry litter in alternative uses calculated here suggest that application to nearby cropland is the highest value use of poultry litter and could account for 80 percent or more of the poultry litter generated on the Delmarva Peninsula in any year. Long distance transport off the Peninsula does not appear to be necessary. Data on the soil phosphorus status of Peninsula soils indicate that there is more than enough cropland on the Peninsula to absorb all of the poultry litter generated there when litter is applied at legally permissible rates.

Moreover, the distances involved in out-of-county transport appear quite modest, most likely on the order of no more than 10-15 miles and frequently less, suggesting that transport costs would be quite low. As a result, application of poultry litter to cropland as fertilizer is likely the highest value use even in most cases where out-of-county transport would be required.

The use of poultry litter as fertilizer on cropland could be limited by factors not considered in the calculations performed in this report, including difficulties encountered in arranging poultry litter sales and the desire of some farmers to avoid regulatory scrutiny associated with poultry litter use. Efforts to improve manure matching services and the emergence of brokers handling poultry litter could reduce difficulties encountered in arranging transactions for this and other uses.

The value of poultry litter in forest fertilization is also quite high relative to other uses. The amount that can be used for this purpose is limited by forest acreage being replanted or reaching mid-rotation in any year, however, so that it could account for no more than 2-3 percent of the poultry litter generated on the Delmarva Peninsula in any year.

The value of poultry litter in pelletization appears to be lower than the value of fertilizing either cropland or forestland but is still positive. Perdue AgriRecycle currently uses 60-70,000 tons of raw litter annually, or 8-10 percent of the total quantity generated annually on the Delmarva Peninsula.

The value of poultry litter in compost appears to be relatively low, suggesting that the use of poultry litter for this purpose is unlikely to expand much beyond the 10-15,000 tons (1-2 percent of the total poultry litter supply) used at present.

Claiming the renewable energy tax credit could make the value of poultry litter in cogeneration of steam and electric power positive. In that event, the value of poultry litter in this use appears to be lower than its use in pelletization but somewhat higher than its use in compost. Allen Family Foods plans to contract for an amount equal to about 11 percent of the poultry litter generated annually on the Peninsula. It remains to be seen whether obtaining that amount will prove feasible.

The value of poultry litter in electric power generation appears to be negative. As numerous studies have indicated, this use would be economically viable only if the generator were able to charge growers for disposing of poultry litter. Since poultry litter has a reasonable economic value in uses that can easily absorb the total amount produced by the Delmarva broiler industry, there is little chance that generators would be able to charge growers for this purpose. Thus, electric power generation in unlikely to be a viable use of poultry litter.

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Table 1. Broiler Production and Poultry Litter by County, Delmarva Peninsula

	Land Area (Acres)	Corn Planted (Acres)	Farms with Broiler Sales	Number of Broilers Sold	Litter (Tons)
Maryland					
Caroline	204,889	22,600	138	38,539,026	46,247
Cecil	222,805	20,300	-	-	-
Kent	178,837	42,100	12	3,953,882	4,745
Queen Anne's	238,210	47,100	33	11,389,932	13,668
Talbot	172,248	34,900	35	13,282,962	15,940
Dorchester	356,824	20,100	71	21,826,885	26,192
Somerset	209,416	10,500	150	46,496,103	55,795
Wicomico	241,389	21,300	283	84,278,399	101,134
Worcester	302,871	34,600	233	62,466,511	74,960
Delaware					
Kent	378,048	38,600	136*	43,899,605*	52,680*
Sussex	600,128	98,400	669	240,100,395	288,120
Virginia					
Accomack	290,944	21,500	61	22,971,405	26,919
Delmarva	3,396,610	443,700	1,821	589,205,105	706,399

* Includes New Castle County.

Table 2. Estimated Distribution of Soil Phosphorus Runoff Potential

	Share of Land Classified with Runoff Potential as:			
	Very High	High	Medium	Low
Maryland				
Upper Eastern Shore				
Caroline	0.0331	0.0993	0.1126	0.755
Kent	0.0331	0.0993	0.1126	0.755
Queen Anne's	0.0331	0.0993	0.1126	0.755
Talbot	0.0331	0.0993	0.1126	0.755
Lower Eastern Shore				
Dorchester	0	0.1185	0.1852	0.6963
Somerset	0	0.1185	0.1852	0.6963
Wicomico	0	0.1185	0.1852	0.6963
Worcester	0	0.1185	0.1852	0.6963
Delaware				
Kent	0	0.172	0.266	0.563
Sussex	0	0.172	0.266	0.563
Virginia				
Accomack	0	0.061	0.106	0.833

Source: University of Maryland FIV and PSI data, evaluated by university scientists.

Table 3. Poultry Litter Absorption Capacity of Cropland on the Delmarva Peninsula

	Poultry Litter Absorption Capacity (Tons) of Land with Runoff Potential Classified as					Total Litter Generated	Surplus Capacity	Excess Requiring Out-of-County Transport
	Very High	High	Medium	Low	Total			
Maryland								
Upper Eastern Shore								
Caroline	-	2,244	5,090	51,189	58,523	46,247	12,276	
Kent	-	4,181	9,481	95,357	109,018	4,745	104,273	
Queen Anne's	-	4,677	10,607	106,682	121,965	13,668	108,298	
Talbot	-	3,466	7,859	79,049	90,374	15,940	74,434	
Lower Eastern Shore								
Dorchester	-	2,382	7,445	41,987	51,814	26,192	25,622	
Somerset	-	1,244	3,889	21,933	27,067	55,795		28,728
Wicomico	-	2,524	7,890	44,494	54,907	101,134		46,227
Worcester	-	4,100	12,816	72,276	89,192	74,960	14,232	
Delaware								
Kent	-	6,639	20,535	65,195	92,370	52,680	39,690	
Sussex	-	16,925	52,349	166,198	235,471	288,120		52,649
Virginia								
Accomack	-	1,312	4,558	53,729	59,598	26,919	31,084	
Total Delmarva	**-**	**49,693**	**142,518**	**798,087**	**990,298**	**706,399**	**411,504**	**127,605**

Table 4. Assumptions Used to Calculate Nutrient Value

Nitrogen Price	$0.25 per pound
Phosphorus Price	$0.25 per pound
Potassium Price	$0.15 per pound
Nitrogen Content of Poultry Litter	70.44 pounds per ton
Nitrogen Availability Year 1	50.0%
Nitrogen Availability Year 2	20.0%
Nitrogen Availability Year 3	5.0%
Phosphorus Content of Poultry Litter	59.42 pounds per ton
Phosphorus Uptake of Corn	50 pounds per acre
Phosphorus Uptake of Soybeans	60 pounds per acre
Phosphorus Uptake of Wheat	60 pounds per acre
Potassium Content of Poultry Litter	46.86 pounds per ton
Potassium Uptake of Corn	70 pounds per acre
Potassium Uptake of Soybeans	50 pounds per acre
Potassium Uptake of Wheat	60 pounds per acre
Discount Rate	10.0%

Table 5. Nutrient Value of Poultry Litter

	Nutrients Used by Crops (pounds per acre) in Year			Total Value	
	1	2	3	per Acre	per Ton
Continuous Corn					
Phosphorus-Based Nutrient Management Plan					
Application Rate	1 ton per acre				
Nitrogen	35.22	14.088	3.522	$12.73	$12.73
Phosphorus	50	0	0	$12.50	$12.50
Potassium	46.86	0	0	$7.03	$7.03
Total				$32.26	$32.26
Nitrogen-Based Nutrient Management Plan					
Application Rate	3 tons per acre				
Nitrogen	105.66	42.264	10.566	$38.20	$12.73
Phosphorus	50	0	0	$12.50	$4.17
Potassium	46.86	0	0	$7.03	$2.34
Total				$57.73	$19.24
Corn-Soybean Rotation					
Phosphorus-Based Nutrient Management Plan					
Application Rate	1 ton per acre				
Nitrogen	35.22	0	3.522	$9.53	$9.53
Phosphorus	50	9.42	0	$14.64	$14.64
Potassium	46.86	0	0	$7.03	$7.03
Total				$31.20	$31.20
Nitrogen-Based Nutrient Management Plan					
Application Rate	3 tons per acre				
Nitrogen	105.66	0	10.566	$28.60	$9.53
Phosphorus	50	60	0	$26.14	$8.71
Potassium	70	50	0	$17.32	$5.77
Total				$72.05	$24.02
Corn-Wheat-Soybean Rotation					
Phosphorus-Based Nutrient Management Plan					
Application Rate	1 ton per acre				
Nitrogen	35.22	14.088	3.522	$12.73	$12.73
Phosphorus	50	9.42	0	$14.64	$14.64
Potassium	46.86	0	0	$7.03	$7.03
Total				$34.40	$34.40
Nitrogen-Based Nutrient Management Plan					
Application Rate	3 tons per acre	1 ton per acre			
Nitrogen	105.66	42.264	25.654	$49.12	$12.28
Phosphorus	50	120	0	$39.77	$9.94
Potassium	70	110	0	$25.50	$6.38
Total				$114.39	$28.60

Table 6. Value of Poultry Litter as a Fertilizer Substitute (Net of Application and Testing Cost)

	Nutrient Value	*Application Cost*		*Testing Cost*	*Cleanout*	*Net Value*	
		Low	*High*			*Low*	*High*
Continuous Corn							
Phosphorus-Based Nutrient Management Plan	$32.26	$ 7.31	$14.63	$ 0.20	$ 4.00	$13.44	$20.75
Nitrogen-Based Nutrient Management Plan	$19.24	$ 3.63	$ 7.26	$ 0.20	$ 4.00	$ 7.78	$11.41
Corn-Soybean Rotation							
Phosphorus-Based Nutrient Management Plan	$31.20	$ 7.31	$14.63	$ 0.20	$ 4.00	$12.37	$19.69
Nitrogen-Based Nutrient Management Plan	$24.02	$ 3.63	$ 7.26	$ 0.20	$ 4.00	$12.56	$16.19
Corn-Wheat-Soybean Rotation							
Phosphorus-Based Nutrient Management Plan	$34.40	$ 7.31	$14.63	$ 0.20	$ 4.00	$15.58	$22.89
Nitrogen-Based Nutrient Management Plan	$28.60	$10.28	$20.56	$ 0.20	$ 4.00	$3.84	$14.12

Table 7. Maximum Distances (Miles) Needed to Transport Poultry Litter by Phosphorus Status, Base Case

	Soil Phosphorus Status			
	Very High	High	Medium	Low
Maryland				
Upper Eastern Shore				
Caroline	0.16	0.22	0.36	0.77
Cecil				
Kent	0.50	0.70	0.97	0.97
Queen Anne's	0.34	0.49	0.80	0.88
Talbot	0.28	0.40	0.66	0.81
Lower Eastern Shore				
Dorchester	0.00	0.54	0.87	1.24
Somerset	0.00	0.29	0.46	0.83
Wicomico	0.00	0.22	0.36	0.65
Worcester	0.00	0.28	0.44	0.76
Delaware				
Kent	0.00	0.49	0.78	1.00
Sussex	0.00	0.28	0.44	0.67
Virginia				
Accomack	0.00	0.38	0.63	1.12

Table 8. Maximum Distances (Miles) Needed to Transport Poultry Litter by Phosphorus Status Assuming All Houses Located in County Center

	Soil Phosphorus Status			
	Very High	High	Medium	Low
Maryland				
Upper Eastern Shore				
Caroline	1.84	2.60	4.27	9.03
Cecil				
Kent	1.72	2.43	3.35	3.35
Queen Anne's	1.98	2.80	4.60	5.04
Talbot	1.68	2.38	3.91	4.81
Lower Eastern Shore				
Dorchester	0	4.56	7.34	10.46
Somerset	0	3.51	5.62	10.21
Wicomico	0	3.77	6.04	10.96
Worcester	0	4.22	6.76	11.67
Delaware				
Kent	0	5.69	9.07	11.62
Sussex	0	7.17	11.43	17.29
Virginia				
Accomack	0	2.97	4.92	8.65

Table 9. Production Costs for Composting Poultry Litter for Bulk Market

	On-Farm	Off-Farm		
Capacity (tons)	10,000	10,000	40,000	80,000
Litter (tons)	6,500	6,500	26,000	52,000
Sawdust (tons)	3,500	3,500	14,000	28,000
Finished Product (tons)	8,920	8,920	35,920	71,840
Land Required (acres)	7.2	3.7	10.1	19.7
Annual Capital Cost, per Ton Compost	$3.66	$16.59	$9.05	$7.92
Annual Variable Cost, per Ton Compost	$3.63	$2.59	$2.59	$2.59
Cost for Sawdust, per Ton Compost	$6.30	$6.30	$6.30	$6.30
Clean Out Costs, per Ton Compost	$3.00	$3.00	$3.00	$3.00
Hauling Litter to Facility, per Ton Compost	-	$7.29	$7.29	$7.29
Total Cost per Ton Compost	$16.59	$35.77	$28.23	$27.10
Average Price for Bulk Compost	$18.10	$18.10	$18.10	$18.10
Implicit Value Poultry Litter, per Ton Compost	$1.51	-$17.67	-$10.13	-$9.00
Implicit Value Poultry Litter, per Ton Litter	$1.10	-$12.88	-$7.38	-$6.56

Sources: "Composting Poultry Litter - Economics and Marketing Potential of a Renewable Resource," North Carolina State University, 1990.[3] "Poultry Litter Compost Market Development: A Literature Review," University of Maryland, College Park, No Date. Personal Communication, Herbert Brodie and Lewis Carr, University of Maryland.

- All dollar figures adjusted to 2001 dollars.
- No on-site storage of inputs.
- On-Farm system is windrow, turned 10 times over 16 weeks, on flat, bare ground with a pond retention system.
- Off-Farm systems are also windrow, turned 17 times in 9 weeks. Initial process performed under open-sided building with paved floors, final curing and storage performed outside on bare ground. Includes pond retention system.
- Differences in compost quality between the two systems and between the small off-farm system and the two larger off-farm systems may exist.
- No marketing costs are included.

[3] The figures from this table are from the 1990 North Carolina State University study and are modified to fit Maryland conditions using the other information sources.

Table 10. Production Costs for Composting Poultry Litter for Screened and Bagged Market

	Off-Farm		
Capacity (tons)	10,000	40,000	80,000
Litter (tons)	6,500	26,000	52,000
Sawdust (tons)	3,500	14,000	28,000
Finished Product (tons)	8,920	35,920	71,840
Land Required (acres)	3.7	10.1	19.7
Annual Capital Cost per, Ton Compost	$27.90	$12.98	$10.62
Annual Variable Cost per, Ton Compost	$11.59	$11.59	$11.59
Cost for Sawdust, per Ton Compost	$6.30	$6.30	$6.30
Clean Out Costs, per Ton Compost	$3.00	$3.00	$3.00
Hauling Litter to Facility, per Ton Compost	$7.29	$7.29	$7.29
Total Cost per Ton Compost	$56.08	$41.16	$38.80
Average Price for Bulk Compost	$44.82	$44.82	$44.82
Implicit Value Poultry Litter, per Ton Compost	-$11.26	$3.66	$6.02
Implicit Value Poultry Litter, per Ton Litter	-$8.21	$2.67	$4.39

Sources: "Composting Poultry Litter - Economics and Marketing Potential of a Renewable Resource," North Carolina State University, 1990.[4] "Poultry Litter Compost Market Development: A Literature Review," University of Maryland, College Park, No Date. Personal Communication, Herbert Brodie and Lewis Carr, University of Maryland.

- All dollar figures adjusted to 2001 dollars.
- No on-site storage of inputs.
- On-Farm system is windrow, turned 10 times over 16 weeks, on flat, bare ground with a pond retention system.
- Off-Farm systems are also windrow, turned 17 times in 9 weeks. Initial process performed under open-sided building with paved floors, final curing and storage performed outside on bare ground. Includes pond retention system.
- Differences in compost quality between the two systems and between the small off-farm system and the two larger off-farm systems may exist.
- No marketing costs are included.

[4] The figures from this table are from the 1990 North Carolina State University study and are modified to fit Maryland conditions using the other information sources.

Table 11. Value of Poultry Litter in Electric Power Generation

	Vienna Retrofit	Vienna Greenfield	Fibrowatt	FibroShore
Capacity (MW)	25.0	25.0	12.6	40.0
Capital Cost	$37,500,000	$62,500,000	$36,372,214	$104,000,000
Annual Power Production (MWH)	153,000	153,000	100,800	321,600
Annual Poultry Litter Consumption (Tons)	248,000	240,000	140,800	500,000
Levelized Capital Cost	$5,991,055.14	$9,985,091.90	$5,810,878.35	$16,615,192.92
Annual Operation and Maintenance Costs	$1,875,000	$3,125,000	$1,999,979	$8,664,225
Ash Fraction	0.157	0.157	0.100	0.100
Ash Generated	38,936	37,680	14,080	50,000
Ash Value (at $49.60 per ton)	$1,931,225.60	$1,868,928.00	$698,368.00	$2,480,000.00
Total Cleanout and Transport Cost	$3,472,000.00	$3,360,000.00	$1,971,200.00	$0.008
Levelized Capital Cost/KWH	$0.039	$0.065	$0.058	$0.052
O&M Cost/KWH	$ 0.012	$ 0.020	$ 0.020	$0.027
Total Capital and O&M Costs	$0.051	$0.086	$0.077	$0.079
Ash Value/KWH	$0.013	$0.012	$0.007	$0.008
Cleanout/Transport Cost/KWH	$ 0.023	$0.022	$0.020	$0.022
Electric power cost including ash sales revenue and litter transport cost	$ 0.061	$ 0.095	$ 0.090	$0.093
Implicit Value of Poultry Litter (per ton)	-$10.14	-$32.38	-$36.34	-$56.64
Value of Poultry Litter with 1.7 cent/KWH renewable energy tax credit	-$7.44	-$29.33	-$29.13	-$48.66

Annualization of capital costs based on a 15.0% rate of return on capital and a 20 year financing period. Price of electricity assumed to equal the 2001 PJM wholesale electricity price of 3.2 cents per kilowatt-hour. Cleanout cost assumed to equal $4.00 per ton. Transportation cost assumed to average $10.00 per ton. Fibrowatt capital costs adjusted from 1992 to 2001 dollars using the producer price index for manufacturing. Fibrowatt operation and maintenance costs adjusted from 1992 to 2000 dollars using employment cost index (total compensation) for manufacturing. FibroShore operation and maintenance costs and power production based on year 15 estimates.

Sources: Antares Group (1999), Dagnall (1992), ElectroTek Concepts (2001).

Table 12. Estimation of Ash Value

		Value per Ton
Phosphorus Price (per pound)	$0.25	$500.00
Potassium Price (per pound)	$0.15	$300.00
Nitrogen Content	0	
Phosphorus Content	24.4%	$122.00
Potassium Content	16.3%	$48.90
Available Phosphorus Content	12.2%	$61.00
Available Potassium Content	8.2%	$24.60
Nutrient Value		$85.60
Processing Cost		$20.00
Application Cost		$6.00
Average Transport Cost		$10.00
Net Ash Value		$49.60
Net Ash Value per Ton of Poultry Litter		$7.79

Sources: Content and processing cost from Antares Group (1999). Transport costs from Ferguson and Malizia, Application cost from Maryland Cooperative Extension.

Table 13. Value of Poultry Litter in Cogeneration Facility

Capacity (MW)	5
Annual Power Production (MWH)	41,610
Annual Poultry Litter Consumption (Tons)	80,000
Implicit Value of Poultry Litter ($/Ton)	$0.00
Implicit Value of Poultry Litter with 1.7 cent per KWH renewable energy tax credit	$5.68

Source: Larry Enders, Allen Family Foods

Table 14. Forest Acreage on the Eastern Shore, Maryland

County	*Forest Acreage*
Kent	41,824
Queen Anne	60,805
Caroline	61,874
Talbot	42,328
Dorchester	125,071
Wicomico	104,157
Somerset	83,113
Worcester	159,298
Total	678,470

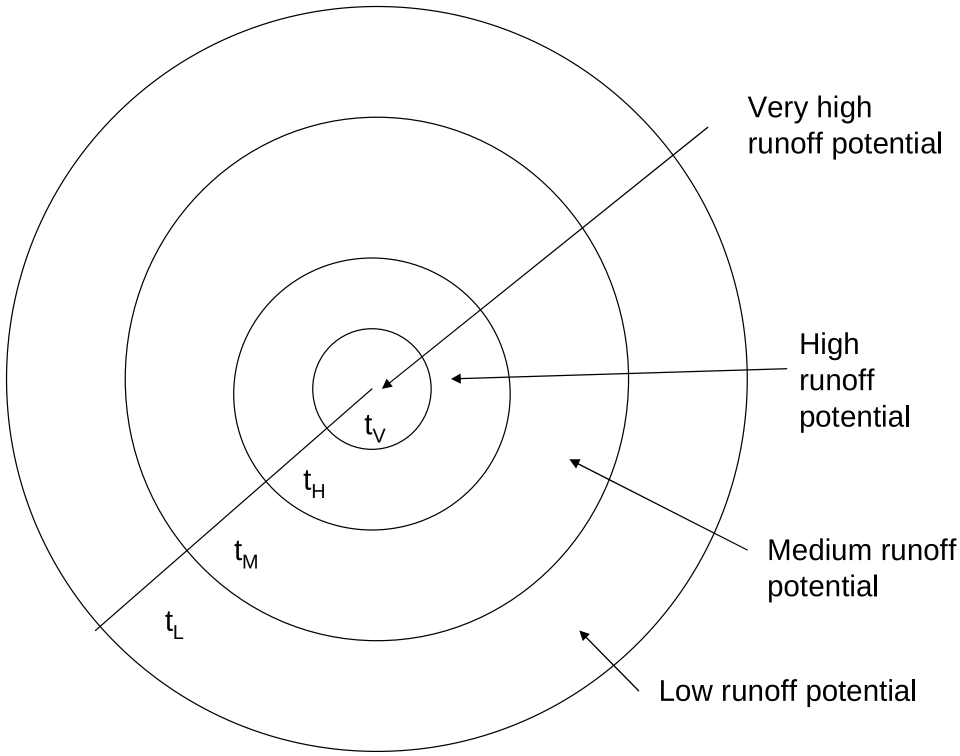

Figure 1. Assumed Spatial Distribution of Soil Phosphorus Runoff Potential.