Evaluation of the Opportunities to Commercialize Thermophilic Anaerobic Digestion of Broiler Litter in the Mid-Atlantic Region

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FINAL REPORT

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DISCLAIMER

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I. Introduction

Broiler production in the four-state region of Delaware, Maryland, Virginia and West Virginia is tied closely to crop production and fertilization of cropland. For many broiler growers disposal of litter is not a concern because they as well as non-broiler farms value it for its nutrient content and apply it to cropland in place of commercial fertilizer. However, a question arises frequently regarding the impact of agricultural practices on the water quality of Chesapeake Bay watershed. Excess nutrients that are not absorbed by the soil as well as pathogens that may come from raw litter make their way into the watershed's rivers and the Bay at levels that may be harmful to aquatic animal and human life. Additional concerns exist regarding the impact of litter odor and water quality on the demand for tourism in Delmarva. While agriculture is certainly not the only contributor to water degradation in the region it is a heavily scrutinized sector of the economy. Treatment systems are required that will obviate the problems associated with nutrient and other pollutants.

Thermophilic anaerobic digestion (TAD) is one option for disposing of the harmful and unpleasant qualities of broiler litter while retaining valuable nutrients. Broiler litter in its raw, non-heat treated state is quite odorous and contains harmful pathogens. TAD accomplishes several objectives for beneficial litter disposal: pathogen destruction, odor reduction and retention of some nutrients.[1]

The Bioplex project at West Virginia State University (WVSU) is an early TAD demonstration unit operating on broiler litter. As of 2007 Brinson Farm in Mississippi became the first on-farm TAD unit installed that will operate solely on broiler litter. Other anaerobic digesters around the county exist that operate on waste from other animals, primarily dairy cows and swine but also ducks and layer chickens. Due to higher liquid content these other wastes are also digested readily via TAD, a process that requires a high percentage of moisture. TAD is thus very applicable to wastes from other industries such as animal slaughter and municipal waste. A mixed waste digester based on a combination of broiler litter and other liquid waste may be the most desirable option for maximizing the TAD process.

This analysis focuses only on broiler litter and the physical potential that exists in the region based on quantities of broiler production. Attention is given to large versus other size farms, which may have more pressing disposal issues. Geographical differences between broiler farm involvement in crop production, manure application and fertilizer purchases are highlighted. This study also presents a simple financial simulation of revenue requirements that cause a commercial scale digester to be economical in terms of achieving a rate of return necessary to either break even or to attract private investment.

[1] See The Bioplex Project at West Virginia State University. http://bioplexproject.wvstateu.edu/, "Effluent as Fertilizer" and "Reduction in Pathogens" (accessed May 2, 2008).

a. Regional Litter Production

This project focuses on broiler production located between West Virginia and the Atlantic Ocean. Broiler growers are concentrated on the Delmarva Peninsula with other significant clusters in West Virginia and Virginia. Litter is disposed of via several processes. In Delaware and Maryland it is frequently traded in exchange for broiler house clean-out services. In some areas farmers also pay for litter. Overall, few growers pay to dispose of their litter in the region although it appears that a market is less established in West Virginia and Virginia, where more growers apply litter to their own land that is not for crop production.

Because of the nutrient value of litter, this type of exchange will continue until it is disallowed under Federal or State law. Disallowing the practice would dramatically change the practice of growing broilers and fertilizing farmland. Farmers would be forced to obtain more fertilizer from commercial sources, such as digested litter, and growers would be forced to dispose of broiler litter themselves, possibly paying to have it disposed. Depending on the price received for digested poultry solids and for the electricity produced, a digester of this type may not be economical without a subsidy or a tipping fee paid for litter disposal.

Broiler production in the region was sorted into seven primary clusters, with each cluster capable of supporting at least one large digester. The two Delaware counties are a single cluster, the Maryland counties two contiguous clusters, the Virginia counties three non-contiguous clusters and the four West Virginia counties a single cluster.

This report only evaluated farms that produced 20,000 broilers or more. It also excluded from the analysis several Virginia counties that had farms that did produce more than 20,000 broilers but which were not located within a defined cluster and which as a stand-alone county or cluster produced less than 20 million broilers. For this reason Suffolk County and the entire county cluster of southeastern Virginia were excluded although production could have since reached 20 million. Table 1 shows the quantity of broiler production that was included in the evaluation of potential clusters.

Table 1: Broiler Production Evaluated by State, 2002[2]

	Delaware	Maryland	Virginia	West Virginia
# of Broilers	153 million	186 million	187 million	81 million
Percent of Broilers	25%	31%	31%	13%
# of Farms	449	552	485	132
Percent of Farms	29%	35%	28%	8%

b. Discussion of Anaerobic Digestion of Broiler Litter

Anaerobic digestion is a biological process wherein biomass is broken down by bacteria in the absence of oxygen. Anaerobic digestion takes place inside a bioreactor where various

[2] The 2002 Census of Agriculture is the most recent available from the U.S. Department of Agriculture.

microscopic bacteria consume the biomass and in the process release methane and carbon dioxide as the biomass ferments. A thermophilic digester operates at a temperature of 134 degrees Fahrenheit (56.7 degrees Celsius), a considerably low temperature compared to combustion or gasification.

The benefits of anaerobic digestion of litter are pathogen elimination, odor reduction and retention of nitrogen. Compared to combustion and gasification where nitrogen is lost due to application of high heat, TAD-treated litter retains a portion of its nitrogen in the solid fraction as well as phosphorus and potassium. Combusted and gasified litter also retain phosphorus and potassium and thus have some fertilizer potential.

Several issues associated with application of TAD to broiler litter make it a less desirable substrate than other agricultural wastes. For one, litter can not be collected daily, as is the case with dairy cattle or layers. Broiler houses are typically cleaned out only once a year or less, although partial clean-outs after each flock would provide some litter six or seven times a year. Farms would have to compost to an extent in order to ensure a steady supply of litter to the digester, a process that reduces methane potential.

A second concern is the fact that broiler litter is dry and thus requires the addition of water, unlike other manures such as dairy, hog or duck waste. Combining broiler litter with wetter wastes could eliminate or reduce the need for water.

Other processes and technologies have different benefits. Composting alone can accomplish much pathogen removal but is more labor intensive than other processes and also loses nutrient value, particularly nitrogen. Compared to composting, anaerobic digestion causes higher nitrogen mineralization as a percent of the original solid. This is valuable because only mineralized nitrogen is available to plants as a nutrient.[3]

Pelletization is a method of adding value to raw litter with partial composting that also retains much of the original nutrient content of the litter. Pelletized broiler litter has a well-established niche in the organic farm and gardening markets and is also used on golf courses. Pelletization is not as effective in controlling odor compared to TAD.[4]

A separate strategy is currently employed that increases the amount of phosphorus retained by the broilers themselves by adding phytase to feed. A study published by the American Society of Agricultural and Biological Engineers recommends the combined strategy of adding phytase to the broiler feed, composting and pelletizing as the best solution for improving water quality in Delmarva.[5]

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[3] University of Florida, Water Quality Program, Soils and Fertilizers Training Guide, Module 12 – "Characteristics and Use of Natural Organics as Fertilizers," University of Florida. http://waterquality.ifas.ufl.edu/downloads.htm (Last accessed April, 18 2008).

[4] Personal conversation with John Bombardiere.

[5] Ritter, William F. and Lynette M. Stehr (2007). American Society of Agricultural and Biological Engineers, International Symposium on Air Quality and Waste Management for Agriculture, 16-19 September 2007, Broomfield, Colorado. "Environmental and Economic Sustainable Policies for the Poultry Industry in Sussex County Delaware."

Among the various options to use broiler litter and reduce the practice of land application, anaerobic digestion may be the best solution for odor and pathogen control. Anaerobic digestion is a quicker process than composting. Combustion and gasification are quick solutions for neutralizing large quantities of litter but the process retains fewer nutrients compared to composting, pelletizing or digestion. The greatest benefit of TAD may be inherent to the process itself and the flexibility of being able to include various types of waste.

It is estimated that 23 digesters each with 1.3 million gallon capacity (30 million gallons combined) could be supported in the region. A capacity of 1.3 million gallons was selected based on the decision to model a digester larger than one million gallons but smaller than two million gallons. The material quantity is based on several assumptions regarding the amount of litter that a typical broiler produces. Critical assumptions used are:

1. The number of broilers that will support a 1.3 million gallon digester is 20 million. This is based on the ratio of 30 million broilers required to support a 2 million gallon digester.[6]
2. The size of the average broiler is 5.1 pounds.
3. Each broiler produces 2.65 pounds of volatile solids per year.
4. 20 million broilers will produce 73 tons of litter per day or about 27,000 tons per year.

The quantity of litter generated in 2002 in identified clusters was calculated using the above assumptions and accounting for litter removal projects currently in place. Table 2 shows the estimated number of digesters that could be supported in the study region based on this methodology. The ability of the Maryland counties in Western Delmarva to support three digesters is dependent on whether a planned cogeneration plant is built.

Table 2: Number of Digesters Feasible by Cluster

STATE: COUNTIES	# of Broilers Sold in 2002	Tons Litter	Tons Litter Removed	# Digesters Feasible
Delaware: Sussex, Kent	153,328,510	203,314	120,000	3
Maryland: Somerset, Wicomico, Worcester	119,779,595	158,828	-	6
Maryland: Kent, Queen Anne's, Caroline, Talbot, Dorchester	65,769,175	87,210	(80,000 if planned cogen built)	3 (0 if cogen built)
Eastern Virginia: Accomack	22,642,219	30,024	-	1
Central Virginia: Amelia, Chesterfield, Cumberland, Powhatan, Buckingham, Nottaway, Prince Edward	31,932,910	42,343	-	1
Northwestern Virginia: Augusta, Page, Rockingham, Shenandoah	132,193,554	175,289	44,000	5
West Virginia: Grant, Hampshire, Hardy, Mineral, Pendleton	80,490,690	106,731	5,300	4
TOTAL	**606,136,653**	**803,739**	**169,300**	**20 (23)**

[6] Personal conversation with Dr. David Stafford of Enviro Control Ltd.

c. Existing Litter Processing Projects

Estimation of the number of digesters that could be supported in each of the clusters considers the presence of large-scale projects that currently remove litter from market. Each of the four states evaluated is engaged in or has plans to engage in an innovative litter disposal project located in their most intensive broiler producing counties.

- The Perdue AgriRecycle pelletization plant in Sussex County, Delaware can use up to 120,000 tons per year at capacity.[7] It has a capacity of 88,000 tons of finished product per year. The plant has long-term contracts of up to 10 years with contract producers for all or part of their litter, which is cleaned out and transported at no cost to the producers. This is the world's largest poultry litter to fertilizer plant.
- The Frye Farm gasification plant in Hardy County, West Virginia removes 3,000 to 3,500 tons per year at 700 to 800 pounds per hour but could get up to 5,300 tons when it reaches capacity of 1,200 pounds per hour. Compared to propane heaters this system has been able to reduce moisture in farm poultry houses, thus reducing the concentration of ammonia in the air and improving bird health.[8]
- A Virginia Cooperative Extension and Virginia Tech University sponsored demonstration pyrolysis unit in Rockingham County, Virginia will remove about 44,000 tons per year once operational. The system will initially produce slow release fertilizer and bio-oil, and eventually electricity from the gas output.
- A potential incinerator/cogenerator at Allen Family Farms in Dorchester County, Maryland would take 80,000 tons off the market if built.

d. Fertilizer Consumption

Unprocessed broiler litter has economic value as a fertilizer. In terms of the three primary fertilizer nutrients broiler litter is approximately three to five percent nitrogen (N), two to three percent phosphate (P) and two to three percent potassium (K) for a potential NPK (nitrogen-phosphorus-potassium) rating of (3-3-3). Specific estimates in the region have provided a rating of (3-2.5-2).[9] Broiler litter is lower in nutrient content than many commercial fertilizers such as those shown in Figure 1. However, due to escalating real prices of high-nutrient synthetic fertilizers the relative value of organic fertilizers such as those derived from chicken litter are likely to increase as farmers expand their options to substitute cheaper, lower nutrient fertilizers for more expensive, high nutrient fertilizers. Fertilizer imports are expected to increase to compensate for the effect of rising natural gas prices on fertilizer prices.[10] This should also increase market opportunities for organic fertilizer.

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[7] Agrirecycle, Inc. http://www.agrirecycle.com/. (Last accessed March 27, 2008).
[8] Personal correspondence with Mike McGolden of Coaltec, Inc in February 2008.
[9] Hansen, David J, "Manure as a Nutrient Source" in the *Mid-Atlantic Nutrient Management Handbook*, Mid-Atlantic Regional Water Program, February 2006.
[10] United States Department of Agriculture, Economic Research Service, Agricultural Baseline Presentation (2005-2014). http://www.ers.usda.gov/briefing/Baseline/present2005.htm (access March 18, 2003).

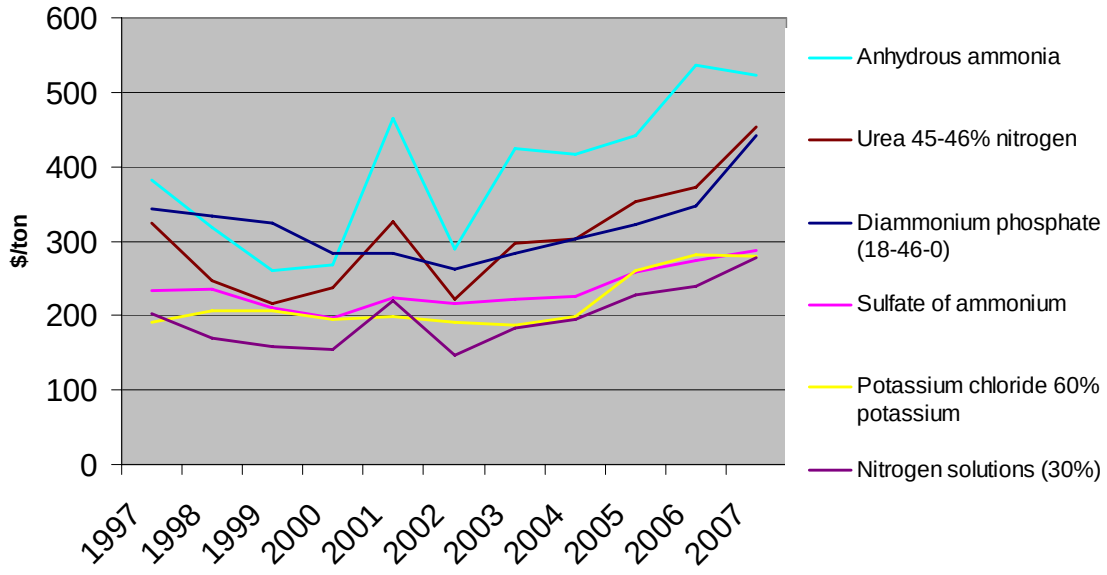

Figure 1: Selected Fertilizer Prices, 1997 to 2007[11] ($2007)

Regional consumption of fertilizer provides a basis to assess the portion of regional demand that could be supplied with digested broiler litter products. Fertilizer consumption in the four-state region is shown in Table 3. Because digested broiler litter would not be able to compete based on nutrient value with most multiple or single nutrient fertilizers the natural organics market is the appropriate comparison market. In the Mid-West the nitrogen concentration of the digested litter is beginning to form the basis of sale price.

Table 3: Fertilizer Consumption by State, By Type

	Short Tons Consumed in 2006					
STATE	Multiple Nutrient*	Single Nutrient**	**Natural Organics**	Gypsum	Other Secondary and Micronutrients	Total
Delaware	29,893	54,988	**959**	675	10,761	97,276
Maryland	199,659	176,273	**4,868**	456	1,457	382,722
Virginia	371,354	229,178	**30,129**	13,751	2,864	647,276
West Virginia	21,995	53,493	**1,361**	13,046	58	76,985
US Total	19,624,307	30,741,654	**575,783**	1,533,445	1,410,874	53,886,063

*** N-P-K, N-P, N-K and P-K fertilizers.**
**** Anhydrous ammonia, aqua ammonia, nitrogen solutions, urea, ammonium nitrate, ammonium sulfate, ammonium thiosulfate, other nitrogen fertilizers, super phosphoric acid, super phosphate, other phosphate fertilizers, potassium chloride, potassium sulfate, potassium-magnesium sulfate and other potash fertilizers.**

SOURCE: The Fertilizer Institute, 2007.

[11] United States Department of Agriculture, National Agricultural Statistics Service (2008).

A digester of the size evaluated here would produce nearly 27,000 tons of dry organic soil amendment per year. The installation of 23 digesters could supply more than the entire four-state demand for organic fertilizer provided that the litter material is considered a substitute for higher nutrient commercial organic fertilizer produced and sold in the area. The NPK content of the liquid is approximately (2.1-1-4.3) and the solid is (1-4.5-1.6) based on information obtained from fertilizer trials in production of various fruits, vegetables and grassland crops.[12] While the digested solids would compete well in the organic market regarding supply of phosphorus and potassium, the nitrogen supply would likely be one-third that of commercial organic products. The digested liquids would be able to supply about two-thirds of commercial organic nitrogen content with less phosphorus and more potassium. The need for a particular nutrient mix will depend on the soil destined to receive the fertilizer and the crop intended to be grown.

II. Broiler Farm Cluster Analysis

This analysis seeks to identify clusters of broiler farms that are best situated to provide litter to a digester based on both geographic location and farm characteristics. Not all broiler growers rely solely on broilers as their only income source but also grow a variety of crops. Several aspects of grower use of cropland provide insights into a cluster's ability to establish markets for litter and litter products. Among the characteristics evaluated here are farm size in terms of number of broilers, farm size in terms of acres, acreage of cropland, acreage of cropland harvested, acreage manured, acreage of major crops harvested (hay, feed corn, soy, winter wheat) and acreage idle. Farms that did not grow broilers were not evaluated. Thus, this analysis looks only at characteristics of broiler farms and use of litter on broiler farm land. Nutrient management regulations may reduce or prohibit use of raw litter on some farms.

Data for this project was taken from U.S. Department of Agriculture's 2002 Census of Agriculture, the most recent data available.[13] Farm-level data was obtained via a confidentiality agreement with the USDA National Agricultural Statistical Service (NASS). All figures presented here are based on this data. The clusters have different characteristics regarding farm size, acreage, presence of crop farming, energy costs and total production costs.

Within the seven identified clusters nine counties produced more than 20 million broilers and could thus alone support at least one 1.3 million gallon digester. In terms of optimum location these nine counties are best situated in proximity to growers: 1) in Delaware – Sussex; 2) in Maryland - Caroline, Somerset, Wicomico, Worcester; 3) in Virginia – Accomack, Page, Rockingham, and 4) in West Virginia – Hardy. These clusters are shown in Figure 2.

[12] Liedl, B.E., J. Bombardiere and J. M. Chatfield (2006). "Fertilizer potential of liquid and solid effluent from thermophilic anaerobic digestion of poultry waste." Water Science & Technology Vol 53 No 8 pp 69–79.
[13] The 2007 census data will be available at the end of 2008.

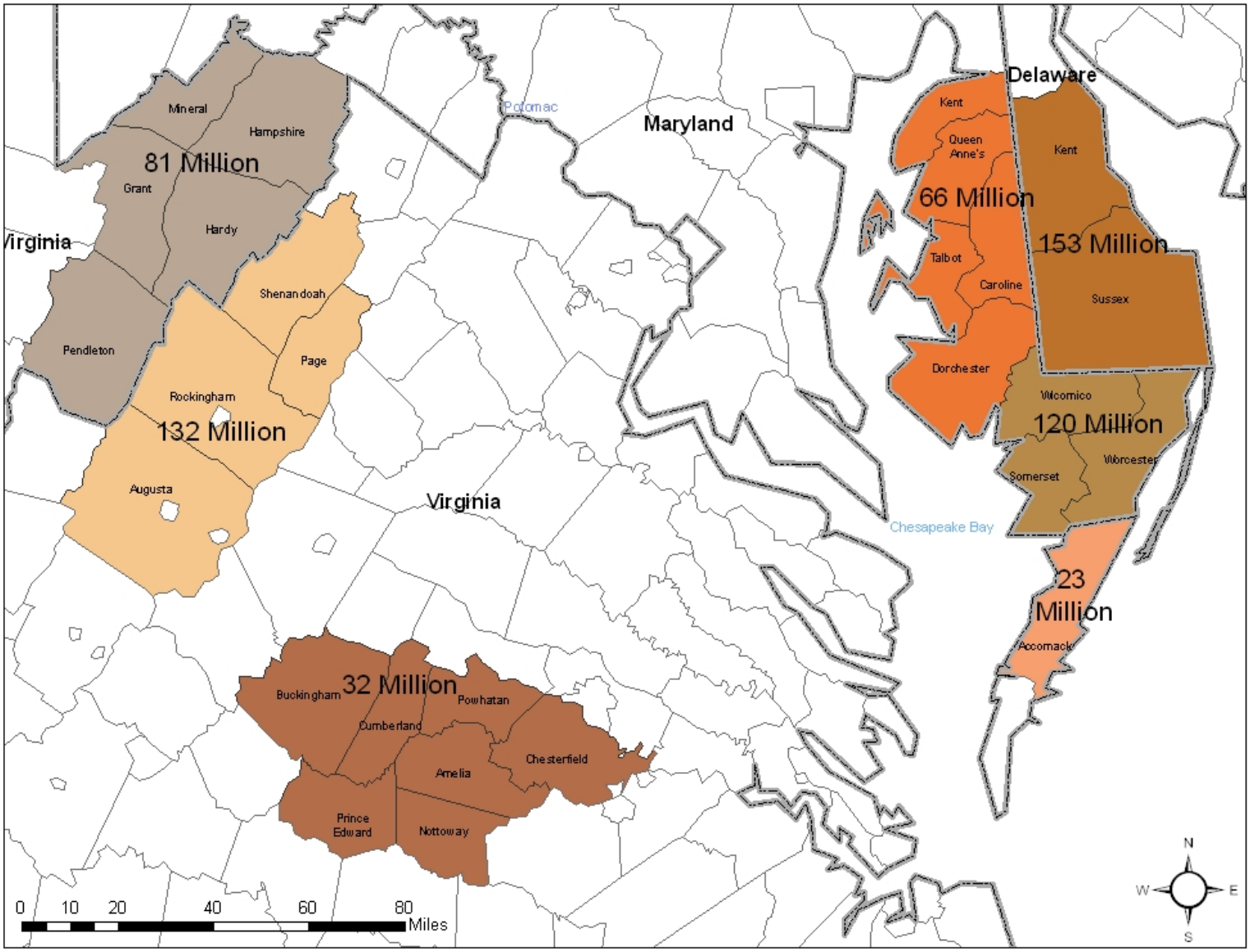

Figure 2: Regional Broiler Producing Clusters

a. Farm Size

For this analysis farms were divided into three sizes based on their 2002 production: “large” farms that produced 500,000 or more broilers, “medium” farms that produced between 200,000 and 500,000 broilers, and “small/other” farms that produced between 20,000 and 200,000 broilers. These ranges are close to those reported by the USDA. A goal of this study is to observe “large” farm characteristics. Figure 3 shows the tendency for a farm to be a medium in size except in West Virginia where there were more large farms. A total of 1,618 farms were included in the data set. Of the total 364 were large, 884 were medium and 370 were small farms.

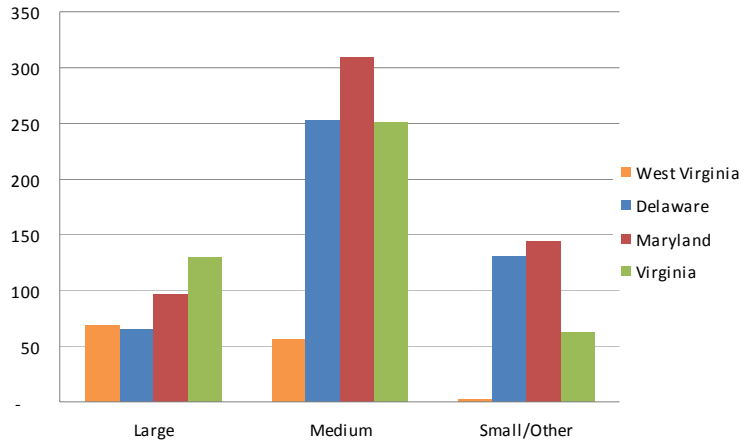

Figure 3: Number of Farms by Size, by State

In terms of total acreage, the largest broiler farms are found in two of the three West Virginia clusters, followed by western Delmarva. The smallest farms are in Northwestern Virginia, with two of the largest producing counties, Rockingham and Page, having the smallest acreage per farm. These figures correlate quite well with average total acres manured as shown in Figure 5, with the largest farms in terms of acreage applying manure to more acres of land.

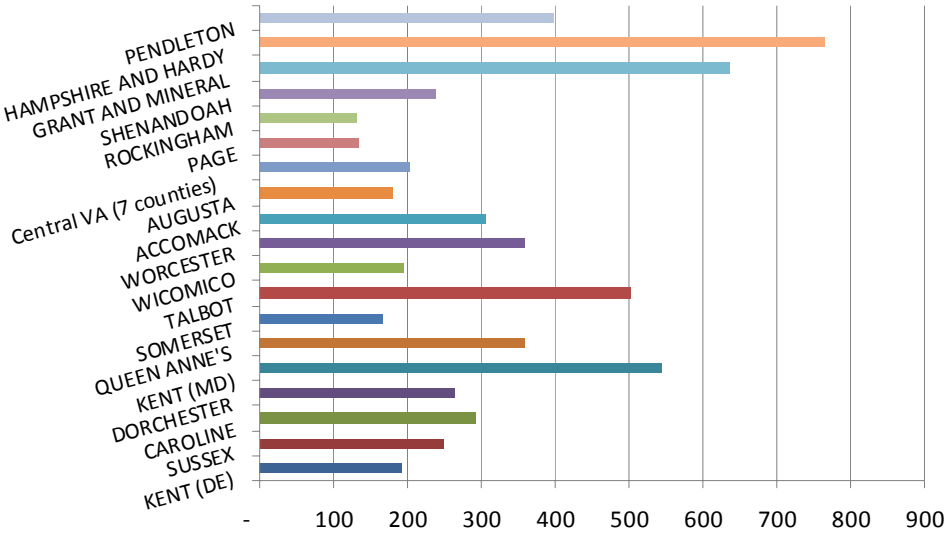

Figure 4: Average Total Acres per Farm by County/Cluster

The type of manure applied as shown in Figure 5 is not identified in the NASS data, but given the number of broilers grown on the farms it is safe to assume that most or all of the manure applied is broiler litter. Hampshire and Hardy counties in West Virginia have the largest average acreage per farm and also apply manure to the largest number of acres.

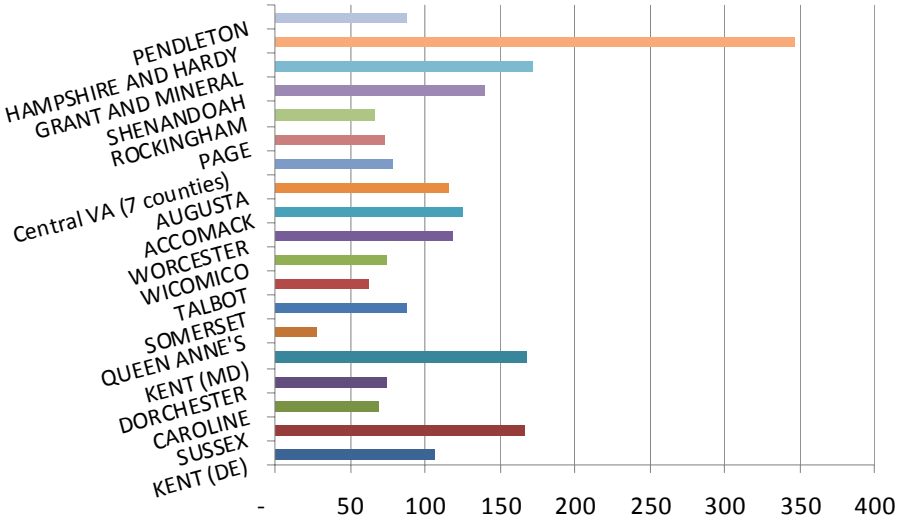

Figure 5: Average Acres Manured per Farm by County/Cluster

b. Acres Harvested and Manured

Broiler growers on the eastern shore of Delaware and Maryland are more diversified farms in terms of production of crops and harvest more acres of crops compared to farms in Virginia and West Virginia. Maryland farms especially harvest much more corn, wheat and soybeans, while West Virginia and Virginia farms harvest more hay. Figures 6 is a contrast to Figure 5 by showing average acres harvested per farm. Harvesting also varies considerably by cluster.

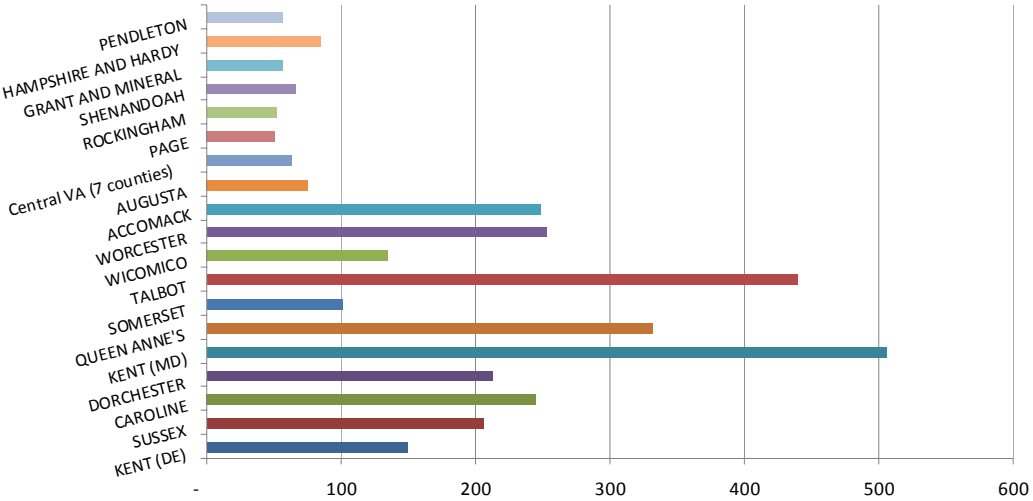

Figure 6: Average Acres Harvested per Farm by County/Cluster

Western Delmarva growers harvested the largest average acres per farm with three of the top five counties in terms of acres harvested in that cluster (Talbot, Kent and Queen Anne's). Western Delmarva also has three of the lowest counties in terms of average acres to which manure was

applied. In West Virginia Hampshire/Hardy and Grant/Mineral counties have the highest average acres of manure application per farm but are among the lowest in terms of acres harvested.

This data shows that in West Virginia broiler litter is being used less as an input to agricultural production compared to Delmarva especially. The northwestern and central Virginia clusters also manure more acres than are harvested although with a lower ratio. As shown in Table 4 all the Delmarva counties harvest some acres that are manured as evidenced by the sum of harvested and manured acres being larger than total acres. The Delaware counties have the largest overlap, with the lowest ratios of manured to harvested acreage. West Virginia has the highest ratio, with manure applied at nearly three and a half times the rate of crop harvest.

This conclusion is consistent with the results of a survey conducted of farms in primary and secondary broiler-producing Maryland counties. The survey showed that 30 percent of broiler growers in the primary counties (Somerset and Wicomico Counties) applied more litter to their own fields while 21 percent of growers in secondary counties (Caroline and Queen Anne's Counties) did so. Growers in the primary counties also averaged more litter per clean out than did growers in the secondary counties and had higher application rates per acre.[14]

Table 4: Ratio of Acres Manured to Acres Harvested by Cluster

Cluster	Total Acres at Place	Cropland Harvested	Acres Manured	Percent Acres Harvested	Percent Acres Manured	Ratio Manured / Harvested
Delaware: Sussex, Kent	107,055	87,992	70,114	82%	65%	0.80
Maryland: Somerset, Wicomico, Worcester	84,486	58,027	32,335	69%	38%	0.56
Maryland: Kent, Queen Anne's, Caroline, Talbot, Dorchester	65,614	56,117	14,110	86%	22%	0.25
Eastern Virginia: Accomack	14,014	11,444	5,735	82%	41%	0.50
Central Virginia: Amelia, Chesterfield, Cumberland, Powhatan, Buckingham, Nottaway, Prince Edward	15,444	4,789	6,025	31%	39%	1.26
Northwestern Virginia: Augusta, Page, Rockingham, Shenandoah	46,646	17,459	25,494	37%	55%	1.46
West Virginia: Grant, Hampshire, Hardy, Mineral, Pendleton	83,941	9,054	31,242	11%	37%	3.45

[14] University of Maryland (January 2006). "Poultry Litter Use and Transport in Caroline, Queen Anne's, Somerset and Wicomico Counties in Maryland: A Summary Report."

c. Fertilizer Expenditures

For purposes of this report, average fertilizer expenditures provide a picture of the relative importance of fertilizer as a cost of doing business for broiler growers in the study area. It is difficult to compare nutrient dollars expended with potential replacement of fertilizer with digested chicken litter. Most commercial fertilizers have higher nutrient content than even unprocessed litter. For some farms savings could be obtained through substitution of cheaper, lower nutrient fertilizer along with more focused nutrient management but this ability will vary by farm and crop.

Figure 7 shows that broiler growers in the Maryland counties of western Delmarva were more reliant on commercial fertilizer than were growers in eastern Delmarva as shown by the higher dollars spent per farm in Kent, Queen Anne's, Talbot, Caroline and Dorchester counties. Worchester County and Accomack County in Virginia also had relatively high average purchases. As shown in Figure 6 above, these purchases correlate highly with overall acres harvested, again reflecting the diversity of production in those areas but not so much with acres manured possibly reflecting restrictions on applying large amounts of broiler litter to crops such as wheat, which need less nitrogen than soybeans and corn.

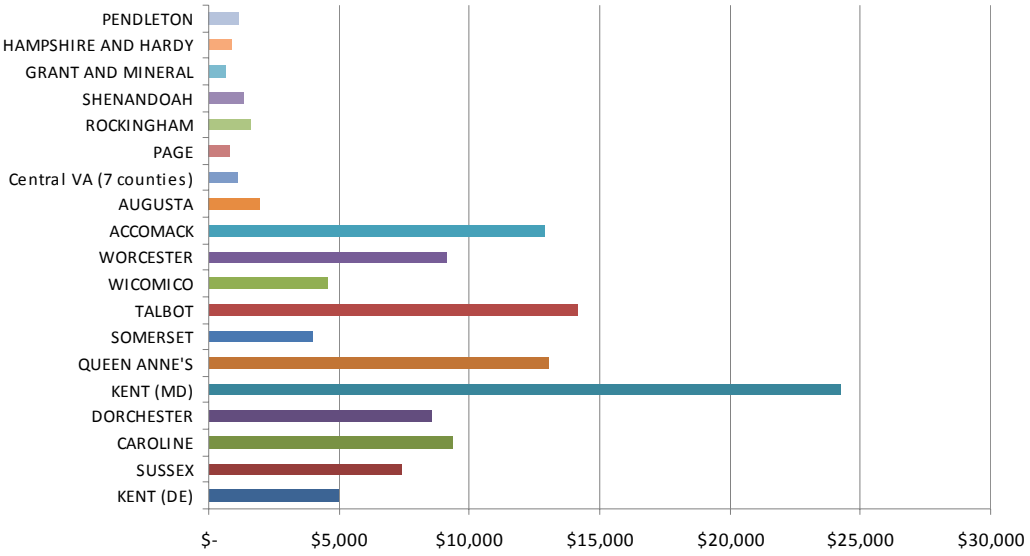

Figure 7: Average Fertilizer Expenditures per Farm by County/Cluster ($2000)

d. Energy and Total Production Costs

The NASS data also reveals some differences in production costs by region and by farm size. As expected the larger, more diversified farms have higher per broiler production costs that account for non-broiler related expenses. While it is not possible to assign the portion of costs directly related to broiler production, broiler production does incur considerable expense related to

heating and cooling the houses. Figure 8 shows that Delaware and Maryland have higher per broiler utility costs than do West Virginia and Virginia.

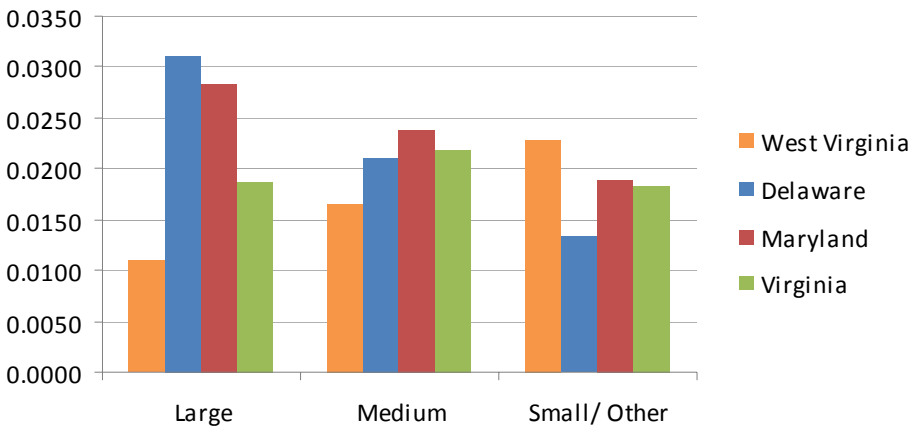

Figure 8: Average Dollars Spent on Utilities per Broiler, by Size

West Virginia growers spend more on fuels and oils per broiler compared to the other states. This may be a function of the larger average acreage and more acres manured per farm. Costs may also be a function of reliance on propane to heat broiler houses, as well as terrain and transport distances, factors that varies by state. Costs also vary from winter to summer depending on average temperatures and the efficiency of heating and cooling equipment.

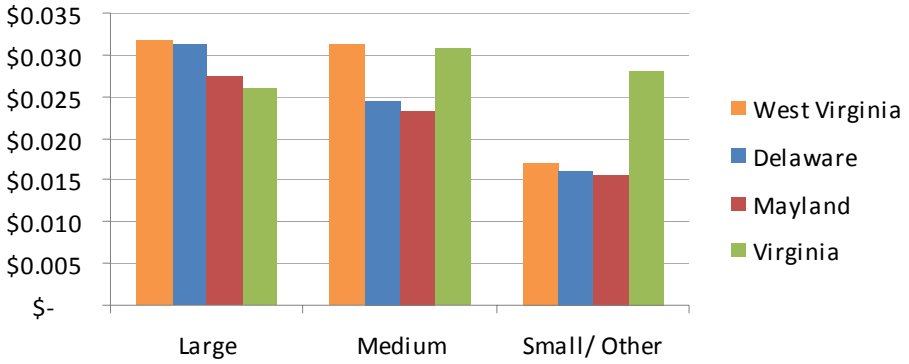

Figure 9: Average Dollars Spend on Fuels & Oils per Broiler, by Size

Energy costs as a portion of total production were low in 2002, representing market conditions that existed prior to recent large price increases. For large farms the combined cost of fuels, oils and utilities ranged from three to eight cents per broiler with energy comprising no more than six percent of total production costs. Due to combined costs for diverse farms energy costs are not truly representative of broiler growing operations alone but are indicative of relative costs, especially for large farms where broilers are a significant aspect of business. Figure 10 features costs for large farms across counties. It is assumed that only farms of this size would consider on-farm installation of a digester with energy cost offsets part of that decision. This is an increasingly important issue in 2008 as energy costs are rising disproportionately to other costs.

Between 2002 and 2007 natural gas prices doubled and propane and the prices of other petroleum-based fuels tripled. Electricity prices will rise over the next few years as coal utilities incorporate emissions upgrades, higher coal prices and transmission capacity additions into their rate bases. With energy costs potentially at 12 percent or more of total production costs this category of savings will become more important. It is especially relevant for growers who seek to reduce electricity costs, such as DE and MD farms which have the highest electricity rates in the region (see Table 6).

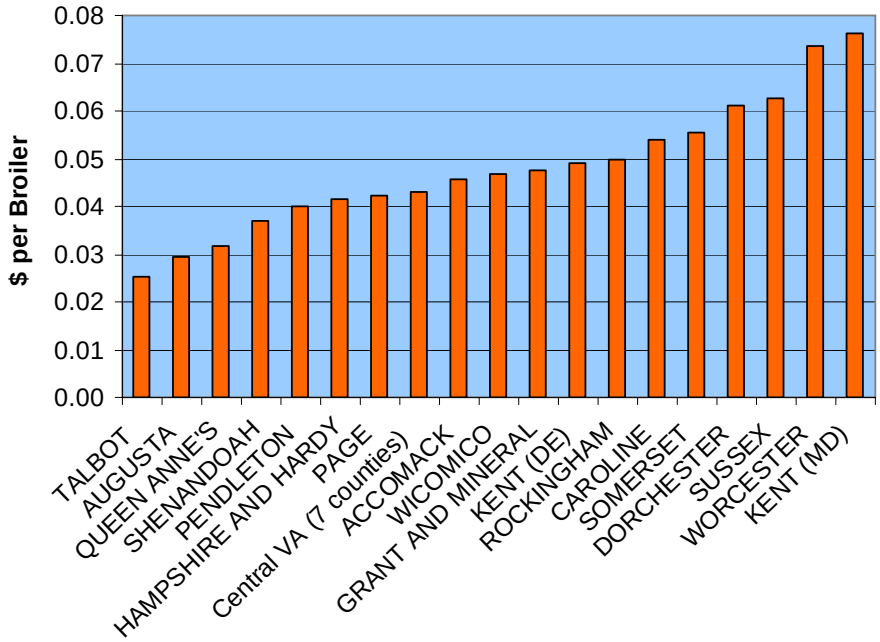

Figure 10: Large Farm Average Total Energy Costs Per Broiler ($2000)

Estimates of total production costs per broiler vary by state. Total production costs include all costs of running a farm.[15] Results show that for large growers West Virginia had the lowest cost of production at around $1.03 per bird, while Maryland and Delaware have the highest at around $1.28 per bird. Medium-sized growers in both Delaware and Maryland had lower costs per bird relative to large growers and small growers in all states had even lower per unit costs, implying that smaller farms are focused more solely on broiler production. Cost differentials for large and medium farms are explained in part by the likelihood for farms in Delaware and Maryland to also engage in more intensive crop production such as soybeans.

In the Virginia and West Virginia clusters, except for Accomack County, total costs may more closely represent broiler production alone, as those farms harvest fewer acres and the majority of harvested acreage is hay. In Delaware and Maryland two and one percent of total broiler farm harvested acreage was hay, respectively. In Virginia and West Virginia 49 and 81 percent of total broiler farm harvested acreage was hay. If Accomack County is excluded from the Virginia data the number for Virginia increases to 74 percent. Figure 11 shows the variation in total production costs per broiler by state.

[15] Includes: expenditures for fuels and oils, utilities, seeds and bulbs, commercial fertilizer and agricultural chemicals, supplies, repairs and maintenance, customwork, equipment rental, interest paid secured and not secured by real estate, cash rent paid, property taxes, hired and contract labor and breeding and other livestock purchases.

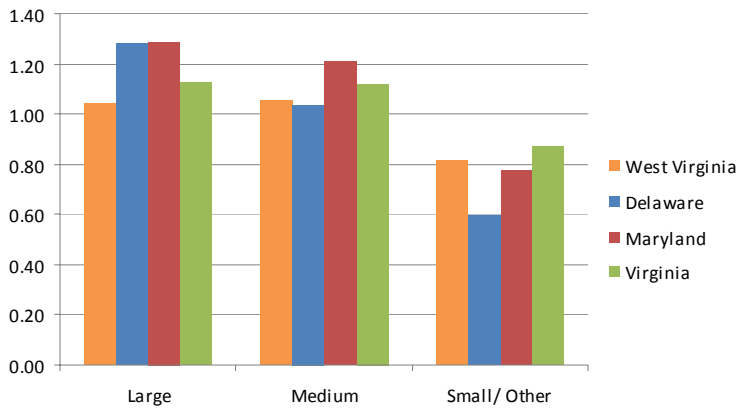

Figure 11: Average Total Production Dollars per Broiler by Farm Size, by State

III. Digester Specification

The physical size of the digester modeled is based on a system that is large enough to be efficiently operated. Interviews with industry specialists combined with a literature review of other analyses of anaerobic digestion converge on the optimal size of a digester. The size indicated to be most efficient is between one and three million gallons of capacity. For this model, a 1.3 million gallon digester is assumed. Required inputs are based on proportionate volumes of material needed to support a two million gallon digester. For comparison, the Bioplex demonstration project at West Virginia State University has a capacity of 10,000 gallons. The Brinson Farm project in Mississippi has a capacity of 250,000 gallons.[16]

A 1.5 MW electric generator is modeled as part of the facility. The generator would operate on the methane produced by the digester. The facility itself is expected to require ten percent of the electricity generated for internal needs.[17]

a. Inputs

Biomass input corresponding with a 1.3 million gallon capacity is around 73 tons of raw or wet litter per day (51 to 55 tons per day dry) or 26,645 tons per year. Based on the assumption that the average broiler weighs 5.1 lbs and produces 0.52 lbs of volatile solids per pound the resulting rate of litter produced is 2.65 lbs per bird, although some large growers are now moving towards a smaller bird to sell into the Far East market. 20 million birds is more than enough litter to support a 1.3 million gallon capacity digester. [18] [19] The quantity of volatile solids used is on the

[16] Personal conversation with Sumesh Arora in (February 2008), President of S3N Consulting, LLC and Director of Strategic Biomass Initiative for Mississippi Technology Alliance.
[17] Based on a personal conversation with John Bombardiere in April 2008.
[18] University of Georgia (2003), citing the USDA. *The Poultry Informed Professional*, September/October 2003. http://www.avian.uga.edu/documents/pip/2003/0903.pdf (accessed May 21, 2008).
[19] Alabama Cooperative Extension System states that the Alabama poultry production averages 0.5 to 0.7 pounds of litter for each pound of meat produced. http://www.aces.edu/pubs/docs/A/ANR-0839/ (accessed May 21, 2008).

low end of potential production per bird and thus generates a conservatively low estimate of total litter production. Variability in the content of litter, comprised of manure and bedding, will impact the amount of methane produced as well as the ease of digestion.

b. Outputs

The digester's primary output is biogas, along with solids and liquids. It is estimated that a digester of this size will produce 255 million cubic feet (mmcf) of methane per year, as each per pound of volatile litter solids is modeled as producing 4.8 cubic feet of methane.[20] Total electricity output is estimated at 12,483 megawatt-hours (MWh) based a gas to electricity rate of 52,000 KWh per mmcf and a capacity factor of 95 percent. Electricity available for sale is thus 11,169 MWh provided that 1500 kilowatts is used internally.

Solids output is equal to solids input at 73 tons per day and is the quantity of organic fertilizer/soil amendment product that would be produced. Actual solids output may actually be less than this amount as the carbon is converted to biogas. Liquids output is calculated at 44 tons per day based on a "Water Mass Balance" describing the initial and daily required water inputs for a two million gallon digester.[21] After the initial set up daily water input would be equal to liquid fertilizer output. These ratios result in a solids content of approximately nine percent.

IV. Economic Analysis

This report seeks to present conditions under which an anaerobic digester of the size specified above could be economical. How is "economical" defined? For this analysis it is defined two ways. Results are given for: 1) conditions that achieve a pre-tax internal rate of return of 15 percent and signify the potential for a private investor to profit; and, 2) conditions required to break even and signify the need for subsidy or additional revenue via a tipping fee.

Results vary by region based on the price expected to be received for electricity. The presence of a tipping fee would mean institution of a reduction or ban on land application of raw litter, an event that is unlikely to occur in the near future given the well-established market for litter as a substitute for some commercial fertilizers, at least in Delaware and parts of Maryland. Virginia and West Virginia could have expanded markets since 2002 but data did not indicate as much same-farm demand at the time compared to Delaware and Maryland. Nutrient control management directives may alter this situation and may stipulate digestion as a means of treatment essential for nutrient management.

[20] This figure may represent methane generation at 132-133°F rather than the higher rates possible at 134-135°F. See Chatfield, M. and John Bombardiere, "Organic Residuals Treatment for Energy and Other Products," West Virginia State University (2005).
[21] Presentation by Dr. David Stafford of Enviro-Control, Ltd http://bioplexproject.wvstateu.edu/powerpoint/AnaerobicDigestion_files/frame.htm (accessed May 7, 2008).

a. Cost Assumptions

Costs were primarily obtained from a report compiled for King County, Washington on the feasibility of installing a dairy waste digester. In 2003 that report modeled annual operating costs at around $900,000 for a 2.5 million gallon digester.[22]

Capital Costs are modeled at $7 million including the digester, electric generating equipment, solids handling equipment and engineering design. Capital costs are a determining factor in project feasibility and may be higher than this amount depending on purchase of warranties and maintenance contracts. Financing is assumed to take place at six percent interest with a 10-year debt term for a total cost of capital equal to $9.5 million

Operating Costs are modeled at around $950,000 per year. Although there will be some variance by State in transport and labor costs those are not likely to be determining factors. Transport is assumed to be $9 per ton, although actual costs would vary depending on the distance transported.[23] In terms of the clusters identified there are ample opportunities for siting that would minimize the distance needed to transport the litter, particularly in the nine largest producing counties. Due to their small size and large production counties such as Caroline, Wicomico, Worcester, Somerset and Page should be able to locate digesters so that litter would not need to be transported more than 10 miles. The Central Virginia cluster is the most dispersed of the identified clusters and because it could only support a single 1.3 million gallon digester a centrally located facility would require some transport in excess of 20 miles.

b. Revenue Assumptions

Potential revenues include fertilizer as a liquid and as a solid soil amendment, electricity sales, renewable electricity credits via the production tax credit and potentially carbon credits. Fertilizer sales comprise the bulk of potential revenues at all three of the per ton prices modeled. Electricity sales are the second largest revenue source with the associated production tax credit providing a third significant income source. Although included, carbon credits are not treated as a determining factor in project viability due to uncertainty regarding the ability to realize this income stream.

1. Fertilizer Sales

Economics of the facility are highly dependent on value of potential fertilizer sales. Rates of $35, $45 and $55 per ton were modeled for both liquid and solid products. The NPK content of the liquid is approximately (2.1-1-4.3) and the solid is (1-4.5-1.6) based on information obtained from fertilizer trials in production of various fruits, vegetables and grassland crops.[24] The liquid product could sell for more than the solid product because of its higher nitrogen content.

[22] Environmental Resource Recovery Group (June 2003). “Anaerobic Digesters for King County Dairies.”
[23] Lichtenberg, Erick, D. Parker and L. Lynch (2002). University of Maryland, Center for Agricultural and Natural Resource Policy, “Economic Value of Poultry Litter Supplies in Alternative Uses,” Policy Analysis Report No. 02-02, October 2002.
[24] Liedl and Chatfield (2006).

Commercial organic fertilizers have an average nutrient content of around (3.2-1.2-0.7) nationwide.[25] While digested poultry litter products would have below-average nitrogen content the phosphorus and potassium content is likely to exceed the average for solids and liquids respectively. Since nitrogen fertilizers are higher-priced products it is assumed that digested poultry liquids and solids would sell for less than other commercial organic fertilizers including pelletized chicken litter with a (4-2-3) nutrient mix that currently sells for $150 a ton or more.[26]

2. Electricity Sales

Electricity sales will vary by state depending on prevailing wholesale prices and net metering policies that limit the size of non-utility systems that can sell excess power back to the grid. In Delaware, a facility of the size modeled here falls under the net metering limit of 2000 KW in the territory of Delmarva Power & Light. Maryland has the same size limit and explicitly mentions anaerobic digestion as an eligible technology. The limit in Virginia is 500 KW for non-residential systems, which would not allow the total amount of available electricity to be sold from a 1.5 MW system. The West Virginia limit of 25 KW is the most restrictive.[27]

Renewable electricity production tax credits are modeled at $18/MWh based on federal incentives. Carbon credits are modeled at $5 per ton for assumed revenue of around $8,300 per year for about 1,660 tons of avoided carbon emissions.

3. Rate of Return Scenarios

Table 5 shows results of the analysis based on two internal rates of return (IRR). IRR was evaluated at a 15 percent or greater and at zero percent (break-even).

Table 5: Status of Return on Investment by State and Revenue Received

STATE	Organic Fertilizer $/ton	IRR 15% or Greater? Subsidy/Tipping Fee - $/ton					Facility Breaks Even? Subsidy/Tipping Fee - $/ton			
		$0	$5	$10	$15		$0	$5	$10	$15
Delaware	**$35**	NO	NO	NO	NO		NO	YES	YES	YES
	$45	NO	NO	**YES**	**YES**		YES	YES	YES	YES
	$55	**YES**	**YES**	**YES**	**YES**		YES	YES	YES	YES
Maryland	**$35**	NO	NO	NO	NO		NO	YES	YES	YES
	$45	NO	NO	**YES**	**YES**		YES	YES	YES	YES
	$55	**YES**	**YES**	**YES**	**YES**		YES	YES	YES	YES
Virginia	**$35**	NO	NO	NO	NO		NO	YES	YES	YES
	$45	NO	NO	NO	YES		YES	YES	YES	YES
	$55	**YES**	**YES**	**YES**	**YES**		YES	YES	YES	YES
West Virginia	**$35**	NO	NO	NO	NO		NO	NO	YES	YES
	$45	NO	NO	NO	NO		YES	YES	YES	YES
	$55	**YES**	**YES**	**YES**	**YES**		YES	YES	YES	YES

[25] The Fertilizer Institute (2007). *Commercial Fertilizers 2006.*
[26] Personal conversation with Tom Ferguson of Perdue AgriRecycle, April 2008.
[27] Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/ (accessed May 1, 2008).

At a price of $55 per ton received for the digested products a digester of this size and cost will do well in all four states even without a tipping fee or subsidy. At a price of $45 per ton for digested products the same digester would be most cost effective in Delaware or Maryland, due to the higher price that would be received for net electricity output. At $35 per ton none of the states would appear attractive to an investor even with a tipping fee or transport subsidy of $15 per ton.

From the break-even perspective it would be easy to meet all financial obligations, including expected operating costs at fixed amounts, under all combinations of product prices and tipping fees with the exception being if the product could only command $35 per ton and no tipping fee was incorporated. West Virginia would also be unable to break even with a $5 fee at $35 per ton.

c. Cluster Rankings

Table 6 provides a ranking of the seven identified clusters in terms of characteristics that may be more likely to support a digester. These characteristics represent volume of waste generated, potential electricity revenues, a willingness to apply litter to their own farm, potential avoided costs through fertilizer substitution and access to disposal space as represented by average acres per farm.

Table 6: Ranking and Summary of Clusters

Cluster	Tons of Litter Generated	Electricity Price $/MWh	Acres Manured / Harvested	Fertilizer Expenses in 2002	Average Acres Per Farm	Overall Rank
Delaware: Sussex, Kent	203,000	$57.40	0.80	$3,634,500	239	1
Maryland: Somerset, Wicomico, Worcester	159,000	$57.40	0.56	$2,003,074	243	2
Maryland: Kent, Queen Anne's, Caroline, Talbot, Dorchester	87,000	$57.40	0.25	$1,959,398	328	3
Northwestern Virginia: Augusta, Page, Rockingham, Shenandoah	175,000	$54.10	1.46	$ 454,175	145	4
Eastern Virginia: Accomack	30,000	$57.40	0.50	$ 41,014	305	5
West Virginia: Grant, Hampshire, Hardy, Mineral, Pendleton	107,000	$43.80	3.45	$ 87,576	651	6
Central Virginia: Amelia, Chesterfield, Cumberland, Powhatan, Buckingham, Nottaway, Prince Edward	42,000	$54.10	1.26	$ 64,760	203	7

V. Conclusion

This report seeks to address the confluence of issues related to the need to dispose of broiler litter, current and potential restrictions placed on that disposal, the value that broiler litter presently has in the farming market and the cost of inputs that digested litter could replace. Anaerobic digestion is one method of processing raw litter that has certain advantages over other less costly options.

1,618 farms were evaluated for the data section of this analysis. The data, as well as external interviews and survey results, show that broiler litter utilization practices vary considerably for the seven regional clusters evaluated. The most intensive crop-producing broiler farm cluster (Western Delmarva) applied manure to the least amount of acres per farm, whereas the least intensive crop-producing broiler farm cluster (West Virginia) applied manure to the most acres per farm. Raw litter appears to be more closely tied to crop production in Delaware, where broiler growers applied their own manure at a rate of about 80 percent in terms of acres manured to acres harvested. In West Virginia and most of Virginia application tends to exceed harvest so more litter is applied to pastureland. These differences in practice lead to the conclusion that while for some crops broiler litter has considerable value as a fertilizer its use is limited possibly due to incompatibility with nutrient need, odor issues, market imperfections or negatfive perceptions about using litter.

It is possible that a consistent, processed litter product would fare better than raw litter in the study area. A survey conducted of farmers in Maryland indicated that they would be more willing to use litter if it was free of weed seeds and contaminants and contained a consistent level of nutrients.[28] Overall, the commercial sale of digested fertilizers will be dependent on developing a marketing infrastructure, which does not as yet exist and where the price per ton will be controlled by the cost of delivery as well as end-use application technology. Some users will demand that the digested solids will be pelletized to a certain particle size and the cost of incorporation into the downstream processing is not included here.

Broiler producing clusters in Delaware and Eastern Maryland have the best prospects for digester adoption due to concentrated broiler production, greater ability to use litter in crop production, higher costs of operation for growers, pressure to reduce waste, higher electricity prices and higher State net metering allowances. In addition, both Somerset and Wicomico Counties generate quantities of litter in excess of those that can be applied under nutrient management plans.[29] The Central Virginia cluster may have the worst prospects due to broiler production being more disperse and of lower volume, and due to Virginia's lower electricity prices and net metering allowances.

In 2002 energy costs were a relatively small portion of total farm production costs, on average about four percent or less for all broiler farms. As electricity rates rise in these regions it will impact the cost of environmental control in broiler houses. This factor will increase the value of

[28] Mid-Atlantic Regional Water Program (2006). "Poultry Litter Use and Transport in Caroline, Queen Anne's, Somerset and Wicomico Counties in Maryland: A Summary Report."
[29] Lichtenberg, Parker and Lynch (2002).

the electricity producing capability of a combined digester and generator system such as that discussed here.

Production of pipeline quality natural gas is another potential use of the methane produced by a digester. Gas prices are also expected to remain at or above the current high prices, making that another potential cost that digestion could help avoid.[30]

All of the existing broiler litter projects are subsidized to an extent. For the West Virginia and Virginia projects assistance was provided in the form of capital purchases. In Maryland, the Poultry Litter Transportation Pilot Project has subsidized transfer of litter at a value of $20 per ton. If this subsidy were applied to digester transport costs a project of the scale evaluated here could more than break even and perhaps even make such a project desirable to an investor if fertilizer sales prospects exceeded $45 per ton of product.

Tipping fees are not presently a realistic revenue source from the industry given the value currently placed on raw litter and the potential impact on grower costs. In this analysis it is a proxy for fees that a digester could receive for disposal of other types of waste in industries that have a greater need for disposal and where waste itself has no market. Further analysis could be done to identify industries with waste disposal needs that could be used in instead of or in addition to litter as a mixed waste stream. The ability of an anaerobic digester to ferment and neutralize many types of waste makes it capable of supplying a number of industries with waste disposal needs.

Of the potential revenue sources of a digester, fertilizer sales may become an important revenue earner if the market becomes more developed. More analysis should be done to evaluate future fertilizer markets in light of rising natural gas prices and trends toward greater demand for organic fertilizer and soil amendment products. The substitutability of digested broiler litter, or digested mixed waste should be evaluated more thoroughly for nutrient content and compatibility with specific markets where a treatment fee may become important. Evaluation of the ability to increase nitrogen content through various combinations of waste would be a valuable component of such analysis.

[30] The U.S. Department of Energy currently projects natural gas prices to be no lower than 20 percent below current prices through 2030. http://www.eia.doe.gov/oiaf/aeo/excel/figure1_data.xls (accessed May 21, 2008).

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