Economic and Technical Feasibility of Energy Production from Poultry Litter and Nutrient Filter Biomass on the Lower Delmarva Peninsula

FINAL REPORT

Prepared for:
Northeast Regional Biomass Program
CONEG Policy Research Center, Inc.
400 N. Capitol Street, Suite 382
Washington, DC 20001

Prepared by:
Antares Group Incorporated
4351 Garden City Drive, Suite 301
Landover MD 20785

T.R. Miles Technical Consulting, Inc.
5475 S.W. Arrowood Lane
Portland, OR 97225

Foster Wheeler Development Corporation
12 Peach Tree Hill Road
Livingston, NJ 07039

August 2, 1999

Economic and Technical Feasibility of Energy Production from Poultry Litter and Nutrient Filter Biomass on the Lower Delmarva Peninsula

EXECUTIVE SUMMARY

August 2, 1999

Poultry litter has been used as a fertilizer on the Delmarva Peninsula for many years. However the continuos application in areas of high concentration of poultry farms has resulted in higher than necessary concentrations of some nutrients in the soil. Nutrient-rich run-off from agricultural lands has been identified as a potential cause for outbreaks of pfiesteria in the Chesapeake Bay and its tributaries. Proposed limitations on local land application of litter have created the need to develop other beneficial uses for a portion of the poultry litter generated on the Peninsula.

Energy production from poultry litter is one potentially beneficial use. Energy conversion can provide steam and electricity while providing a means of concentrating litter phosphorous and potassium in the form of ash that can be transported easily to other locations for use as fertilizer.

However the very elements that contribute to the fertilizer value of litter can also be "problem" constituents in any combustion process. The central issues for energy production are twofold:

- Can the "problem" constituents of poultry litter or switchgrass for energy production be managed or mitigated?
- Can poultry litter be economically utilized for energy production without adding new expenses for local poultry farmers?

This study examines these issues in detail, focusing on technologies that are either commercially available today or in the near future (if product demand exists). Various technical options for energy conversion have been analyzed and evaluated to determine which options offer the best potential for economic, efficient and environmentally sound production of energy.

About 660,000 tons (45 million cubic feet) of litter is generated each year on the lower Delmarva. The litter is generated over a wide area and nearly all of it is now used for land application. Under recently passed environmental legislation restricting land application of poultry litter, some land application of litter will still be permitted. Technologies are available for a range of applications suitable to peninsula energy consumers which can convert poultry litter to useful heat and/or electricity while meeting environmental requirements for air and other emissions. Successful development of the equivalent of 25 MW of energy capability would utilize as much as 280,000 tons of poultry litter per year while creating: new jobs in hauling and at the energy facilities; new income for facility owners, employees, and hauling companies; a new litter disposal option for poultry farmers; recycling of the fertilizer value of litter in a concentrated ash form for use outside the local region; and significantly reduced nutrient run-off into local rivers and the Chesapeake Bay.

Exhibit 1 -- Power Generation Potential from Total and Excess Litter Supplies for the Lower Delmarva Peninsula

State	County	Annual Broilers Raised [8] (1000s)	Estimated Annual Litter Generation		Estimated Annual Excess Litter, tons/yr [1,2,3]		
			High (ton/yr)	% of Total	High [4]	Low [5]	Long Term [6]
DE	Sussex	249,901	289,000	42%	211,000	78,000	35,000
MD	Caroline	46,267	53,000	8%	39,000	14,000	7,000
MD	Dorchester	26,202	30,000	4%	22,000	8,000	4,000
MD	Somerset	55,819	65,000	9%	47,000	17,000	8,000
MD	Talbot	15,946	19,000	3%	13,000	5,000	2,000
MD	Wicomico	101,179	116,000	17%	85,000	32,000	14,000
MD	Worcester	74,992	86,000	12%	63,000	23,000	11,000
VA	Accomack	29,694	34,000	5%	25,000	9,000	4,000
Totals		**600,000**	**692,000**	**100%**	**505,000**	**186,000**	**85,000**
Power Generation Potential (MW) [7]			**54**	**0**	**39**	**14**	**7**

NOTES:

1) Excess litter quantities are based on information in: Parker, Doug, *The Economic Costs of Implementing the Maryland Water Quality Improvement Act of 1998*, Agricultural and Resource Economics, University of Maryland, Dec. 1998.

2) Excess litter fractions (excess / generated) assumed to be uniform for each county.

3) Excess litter quantities for Delaware and Virginia are estimated based on data for Maryland:
[Excess Litter in DE = Litter Generated in DE x (Excess Litter in MD / Litter Generated in MD)]

4) High excess litter quantities are based on requirements for maximum soil phosphorus levels of 50.

5) Low excess litter quantities are based on requirements for maximum soil phosphorus levels of 300.

6) The long term equilibrium quantities indicate the excess litter generated once soil phosphorus levels have fallen below required thresholds, allowing partial re-applications of litter on crop lands (after 15 to 30 years).

7) Based on a net heat rate of 16,000 Btu/kWh, capacity factor of 85%, and ave. litter heating value of 4,600 Btu/lb (as rec'd).

8) Reference: Delmarva Poultry Industry Inc., 1999.

Exhibit 1 shows the likely range of near-term and long-term (15 to 30 years from now) excess poultry litter supplies. These quantities could be used as a fuel for potential energy conversion applications.

In addition to poultry litter, this study examines woody crops such as willow and herbaceous crops such as switchgrass which have been suggested as possible nutrient filters to protect the Chesapeake watershed. Wood or grasses could be available from these strips in the amount of 210,000 to 420,000 dry tons per year. Harvested material from woody crops is expected to provide a relatively clean wood chip source material. Switchgrass, however, is an herbaceous material which will contain higher concentrations of alkali and other potentially problematic constituents for combustion.

During this study, a survey of all major energy consumers on the lower Delmarva peninsula was conducted in order to identify the best potential opportunities for energy projects which would utilize poultry litter and/or nutrient filter biomass. These consumers include: local power plants, energy-intensive industrial facilities in and out of the poultry industry, and colleges and universities. Three case studies were performed to explore feasibility on a more site-specific basis. A separate study has been conducted by the Maryland Environmental Service to examine the feasibility of litter-fueled cogeneration at the Eastern Correctional Institute in Westover, MD. Repowering[1] existing power plants is a promising alternative to very expensive greenfield (new) power plants, but real costs (to-date) for repowering are speculative and will be site-specific. Scale for such systems would be 25 MW or greater. There is one such opportunity on the Delmarva (Vienna Station, owned by Conectiv, in Vienna, MD). Medium-scale industrial cogeneration may also be a promising alternative to a new/greenfield power plant. Scale for such systems would be about 4 MW or greater. There are 3 or 4 such opportunities on the Delmarva, including a poultry rendering plant in Linkwood, MD, the DuPont de Nemours nylon plant in Seaford, DE, and the Statoil Energy cogeneration plant which provides heat and power to the Kraft Foods plant in Dover, DE.

There are twelve poultry processing facilities and four feed mills in the lower peninsula which have large heat and power requirements relative to most other manufacturing facilities on the lower peninsula; however, case study evaluations performed during this study indicate that these facilities are not large enough to provide economically acceptable heat or power from poultry litter unless:

- The poultry integrator operates the system at a loss to provide an outlet for their grower's litter;
- Local poultry growers pay significant tipping fees to the integrator for accepting their litter;
- Significant state or federal incentives are available to the integrators; or
- The cost of electricity and/or fuels on the peninsula increases significantly.

Exhibit 2 is a simplified summary of our findings in Chapter 4 of the report. For each technology option evaluated, the table lists the price that could be paid for delivered poultry litter at the energy facility to allow the energy option to be economic. Results are given for $0 and $50 per ton net values for ash sold as fertilizer. In the bulk power generation case, both the greenfield (new power plant) case and the repowering case have reasonably low technical risk. However the repowering option could provide the economic solution that is being sought -- especially if the ash finds a suitable market and adds value to the project, and proposed incentives are made available. The simplest option, co-firing with coal in a utility boiler, has potentially good economics but with the highest technical risk/uncertainty–additional research and demonstration of co-firing coal and poultry litter is needed prior to implementing a commercial project. Gasifiers and FBCs could offer some advantages with moderate risks. At the medium- to large-scale industrial level, gasifier-boilers and gasifier-based cogeneration systems have promise if the risks associated with combustion of litter in these units can be reduced through testing and demonstration. In general, the larger the system the more economic its operation will be. The report presents detailed graphs

[1] Repowering is the addition of new equipment to an existing power plant to allow increased power generation capability or utilization of new fuels (in this case, to allow the use of poultry litter and nutrient filter biomass).

which show the economic performance (payback period or cost of electricity) of each type of system evaluated over a wide range of delivered litter prices. The economic price for poultry litter will be different than that shown in Exhibit 2 if the energy plant operator has less restrictive economic hurdles than those used for Exhibit 2.[2]

Exhibit 2 -- Summary Table of Options for Utilizing Poultry Litter for Energy

Option	Technology Risk	Ash Value per Ton	Economic Fuel Price per Ton
Bulk Power Generation			
25 MW Repowering	Low	$0	$0
		$50	< $7
25 MW Greenfield	Low	$0	Fees ($15)
		$50	Fees ($8)
Co-firing, 10 - 15 MW	High (R&D needed)	$0	< $2
Industrial Systems			
Gasifier - Boiler (8,000 pph steam and above)	Moderate	$0	Fees (> $20)
		$50	Fees (> $20)
Cogen, or Gasifier Genset (2.5 MW, 96,000 pph steam; many combinations are available)	Moderate	$0	Fees ($10-20)
		$50	Fees <($5)

NOTE: The *Economic Fuel Price per Ton* values in the table above are based on target economic hurdle rates (discussed in the report) such as required payback period or cost of electricity generation which could vary depending on corporate philosophies and other unforeseen conditions. The numbers above are based on hurdle rates suggested by industrial and utility companies on the Delmarva peninsula.

There are two potentially important offsetting factors which would significantly change the economic equation for energy production from these biomass resources:

- Substantial market value for the byproduct ash (as indicated in Exhibit 2); and
- Public or private incentives offered to energy users to use biomass materials.

The required level of offsets that might encourage potential users to make the necessary investment varies substantially depending on the circumstances. For this reason we have

[2] For example, a three year payback period was assumed to be required for implementation of a project at an industrial site in Exhibit 2. This requires a *tipping fee* of about $5/ton for litter delivered to an industrial cogeneration plant if $50/ton is received for the ash. If a payback period of six years is considered allowable for an industrial cogeneration project, the plant operator could afford to *pay* about $8/ton for litter delivered to the cogeneration plant.

developed the following relationships between potential incentive values and their equivalent added value for purchased biomass.

Exhibit 3 -- Potential Incentives for Energy Projects Fueled by Poultry Litter

Market or Proposed Incentive	**Net Income or Value to Operations**	**Equivalent Value to Biomass Fuels (as received)**
Ash sales: $50/ton	$50/ton of ash sold, ash content of litter received is 15%	$7.5/ton, or 81 ¢/MMBtu
Litter Transportation Incentive (MD)*	$0.12 to $0.15/ton-mile hauled plus $1.50/ton for loading plus$0.20/ton for litter testing	$6.20/ton, or 65 ¢/MMBtu for a 30-mile haul *(up to $20/ton is available for longer hauls)*
Production tax credit, 1.7 ¢/kWh (Federal)	$1.06 per MMBtu fuel use at 16,000 Net Heat Rate	$9.80/ton, or $1.06/MMBtu

***NOTE:** The Maryland litter transportation incentive is determined on a case-by-case basis, and may also be applicable to transportation of ash from the energy facility to market, adding more value to the project.

This study has found a variety of energy conversion options that could be successfully employed in the use of poultry litter and nutrient filter biomass as a fuel resource. For a successful energy project to be initiated at a large scale (250,000 tons processed per year) on the peninsula, a variety of issues must be resolved.

- Can producers who provide litter to energy facilities arrange clean out schedules and onsite storage that will provide the regular delivery of biomass needed for economic plant operation?
- What level of regulations will apply to shipment, storage and handling of litter supplies for protection of environmental and human health?
- What is the long term supply outlook for biomass (poultry litter, wood residues, nutrient filter biomass) on the peninsula?
- Is there a sustainable market for ash by-products, and if so, what value will ash sales bring to the energy project?
- Detailed system design and economic evaluations are needed for potential host sites.[3]

In addition to supply and handling issues that must be addressed, there are technical issues concerning process equipment that should be tackled to afford a wider range of potential energy projects. These include:

- How effective (and costly) are proposed fuel/gas treatment methods for gasifiers and fluidized bed boilers using poultry litter or switchgrass?
- What percentage of co-firing of litter can be accomplished in furnaces of varying design?

[3] The present study provides results at a feasibility level to determine which energy options are most attractive. More detailed analyses are needed at particular sites of interest.

These questions are best answered by a collaboration of R&D capabilities and programs. Potential collaborators in R&D could include the Northeast Regional Biomass Energy Program, the U.S. Department of Energy's Biomass Power Program, U.S. Environmental; Protection Agency, the Electric Power Research Institute (EPRI), the DOE National Laboratories specializing in biomass fuels and combustion science, and the engineering research programs at the Maryland and Delaware Universities. Energy projects on the peninsula have the potential to play an economic role in improving the region's nutrient management. What is done on Delmarva has national import. The technologies evaluated in this report have been tested using poultry litter, but only one has been proven in commercial operations. Cooperative work with national laboratories and state universities to resolve some key issues could pave the way for a demonstration plant in the region within two years.

Cost of a Large-scale Energy Solution to the Local Region

The benefits of a large-scale energy project fueled by poultry litter would extend to numerous local groups due to improved environmental conditions in local waterways and new economic activity within the region. These groups include: watermen and the fishing industry, the general public for fishing and recreation, state and local governments (tax revenues from maintaining the local poultry industry), other local companies who will provide services to the energy plant(s), and the tourism industry. According to estimates from this study, medium- to large-scale energy projects will not be economic in the near-term unless: 1) tipping fees are received for litter delivered to the energy plant, 2) the energy plant operator accepts a lower-than-usual rate of return on the energy plant investment (as a public or industry service), and/or 3) incentives are provided. If tipping fees are collected at the energy plant, new expenses would be imposed on local poultry farmers who already operate with relatively small profit margins. The annual cost of the incentive required to both 1) make the investment and risk associated with the energy plant acceptable for the operator, and 2) avoid burdening the local poultry industry and poultry farmers with significant added expenses, may be large in total. However, if the annual cost of the incentive is distributed over the number of people who benefit from the project, the incentive's costs would be modest.

As an example, barring any large as-yet-unforeseen costs, an incentive of about $6 million per year or less would allow a 25 MW power plant (or numerous smaller projects totaling 25 MW) to operate economically while paying a price for their litter fuel (about $8/ton) which should not over-burden local poultry farmers with new expenses.[4] While $6 million per year seems large in

total, it equates to reasonable numbers when distributed over a large group of people (local beneficiaries of the project):

- Distributed among electricity consumers on the Delmarva peninsula, the incentive would be

[4] A $6 million per year incentive for a 25 MW power plant (or equivalent smaller projects) equates to an incentive of about $20/ton for litter. For comparison, the proposed 1.7 ¢/kWh production tax credit for electricity produced from poultry litter would total about $3.0 million per year for a 25 MW power plant using about 280,000 tons of litter per year.

equivalent to an increase of about 0.05 ¢ per kilowatt-hour (kWh). This would increase the average price of electricity on the Delmarva peninsula by less than three-quarters of a percent. For the average household, this would result in an additional $4.50 per year on electricity bills.

or,

- Distributed among consumers of chicken meat produced in Delaware and Maryland, an increase of about 0.21 ¢ per pound would be required. This is an increase of less than three-quarters of a percent. Since the average per-capita chicken consumption is about 50 pounds per year, and the average household consists of about 2.64 people, the additional cost to the average household would be about $0.28 per year on food bills.

or,

- Distributed among Delmarva peninsula taxpayers (based on corporate and personal income tax collections), the incentive amount would equate to an increase of $8.54 for the average household's yearly taxes. This represents less than a one percent increase in the average household state income taxes for Delmarva residents.

The examples above are not meant to imply preferred mechanisms of paying for the required incentive. They are simply intended to place the total costs of such an incentive in tangible terms, based on the total payment being provided either by: 1) local residents who would most benefit from a large-scale energy project using poultry litter as a fuel, or 2) a slightly increased price for a locally generated commodity (energy or chicken meat) that would be closely linked to the project.

ACKNOWLEDGMENTS

This report was prepared under contract to the U.S. Department of Energy Northeast Regional Biomass Program and was jointly sponsored by: the Northeast Regional Biomass Program; the Southeast Regional Biomass Program; The Delaware Department of Agriculture; and the Maryland Energy Administration. Preparation of the report required interaction with a wide range of people and organizations, and there are many the authors wish to thank:

- Rick Handley and Phil Badger of the Northeast and Southeast Regional Biomass Energy Programs for sponsoring this work.
- Bert Bock of the Tennessee Valley Authority for his careful reviews and thoughtful feedback.
- Dorothy "Dot" Abbott-Donnelly of Delaware Department of Agriculture Forest Service, and Charles Miller at the Maryland Energy Administration for their interest and support.
- Diane Brown of the Maryland Department of Natural Resources, Power Plant Assessment Division for sharing litter characterization data that was valuable to our analyses.
- Bill Satterfield and Kenny Bounds from the Delmarva Poultry Industry, Inc. for providing information about Delmarva's poultry industry, and arranging several very helpful meetings with local industry.
- Bud Malone, of the University of Delaware, for sharing his work and thoughts on litter and nutrient management on the Delmarva.
- Case study participants Conectiv and Perdue Farms for their voluntary participation and interest.
- Elmer Swann for taking us on a tour of his poultry farm, and giving us valuable insight on nutrient management issues from a poultry grower's perspective.
- Dave Tillman of Foster Wheeler Development Corporation for his input on poultry litter combustion and cofiring feasibility in utility-scale boilers.
- Anthony Turhollow of the Oak Ridge National Laboratory for his analysis of nutrient buffer strip costs and issues.
- The ten combustion equipment vendors, especially Heuristic Engineering Inc., McBurney Energy Company, and PrimEnergy Inc., who shared technical and financial data that were critical to our analyses.

- Numerous staff at manufacturing plants, colleges and universities, and other energy-intensive facilities across the Delmarva peninsula for their helpful voluntary responses to our inquiries.
- All others who attended our project review briefings in Washington, DC and Easton, Maryland.
- And lastly to Michael Panich and Patrick Arthur of the Antares Group who were instrumental in awakening the Antares Group and local government interest in poultry litter and nutrient filter biomass as a potential fuel source for industrial and utility-scale boilers on the Delmarva peninsula.

We believe that largely due to the contributions of the parties listed above, this report will help provide a comprehensive view of the costs and potential for utilizing poultry litter and nutrient filter biomass for energy on the Delmarva peninsula and beyond, and hope that farm communities and the environment will be the ultimate beneficiaries.

Edward E. Gray, P.E.,	Kevin S. Comer	Tom R. Miles, Jr.
President	Project Engineer	President
Antares Group Inc.	Antares Group Inc.	T.R. Miles Consulting Inc.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

1. MARKET OPPORTUNITIES FOR BIOMASS ENERGY ON THE DELMARVA PENINSULA . . . . . -1
1.1 ENERGY USAGE AND COSTS ON THE DELMARVA PENINSULA . . . . . -1
1.2 POTENTIAL POULTRY LITTER SUPPLIES . . . . . -3
1.3 POTENTIAL NUTRIENT FILTER BIOMASS COST AND SUPPLIES . . . . . -6
1.4 ENERGY USER PROFILES . . . . . -9
1.4.1 Private Sector Power Plants . . . . . -9
1.4.2 Industrial Facilities . . . . . -12
1.4.3 Public Sector Heat and Power Plants . . . . . -17
1.5 MARKET OPPORTUNITY SUMMARY . . . . . -17

2. FEEDSTOCK ACQUISITION AND PROCESSING . . . . . -19
2.1 POULTRY LITTER SUPPLY AND MANAGEMENT ISSUES . . . . . -19
2.1.1 Supply . . . . . -19
2.1.2 Biosecurity . . . . . -20
2.1.3 Costs . . . . . -21
2.2 LITTER COMPOSITION . . . . . -21
2.2.1 Physical Characteristics and Handling Systems . . . . . -21
2.2.2 Chemical and Biological Composition . . . . . -24
2.3 FUEL PROCESSING OPTIONS . . . . . -29
2.3.1 Receiving, Storage, Processing and Reclaim . . . . . -30
2.3.2 Drying . . . . . -32
2.3.3 On Farm Composting . . . . . -33
2.3.4 Anaerobic Digestion . . . . . -33
2.3.5 Blending . . . . . -34
2.3.6 Gasification and Staged Combustion . . . . . -35
2.3.7 Summary of Components and Costs of a Litter Handling and Preparation System . . . . . -36
2.4 BIOMASS NUTRIENT FILTER SUPPLY AND MANAGEMENT ISSUES . . . . . -37

3. ENERGY CONVERSION OPTIONS . . . . . -38
3.1 COMBUSTION ISSUES . . . . . -38
3.1.1 Nitrogen Oxides . . . . . -39
3.1.2 Corrosion . . . . . -40
3.1.3 Slagging and Fouling . . . . . -40
3.2 COFIRING AND PARTIAL REPOWERING OPTIONS . . . . . -41
3.3 STOKER-GRATE FIRING SYSTEMS . . . . . -43
3.4 FLUIDIZED BED BOILERS . . . . . -45
3.5 BIOMASS SYNGAS-FIRED BOILERS: GASIFICATION AND STAGED COMBUSTION . . . . . -46
3.6 COMBUSTION BYPRODUCTS . . . . . -48

4. MATCHING TECHNOLOGIES TO PROSPECTIVE APPLICATIONS . . . . . -49
4.1 BULK POWER PRODUCTION APPLICATIONS . . . . . -50
4.2 COGENERATION AND STEAM PRODUCTION AT INDUSTRIAL FACILITIES . . . . . -54

Appendix A: Manufacturers in Lower Delaware and Maryland with 50 or More Employees

Appendix B: Fertilizer Nutrient Value of Broiler Litter Ash

Appendix C: Vendor Profiles and List of Vendors Providing Quotes for the Project

Appendix D: Economic Performance Results for Utility-Scale Applications

Appendix E: Economic Performance Results for Industrial-Scale Applications

Appendix F: Repowering Vienna Station, Vienna, MD

Appendix G: New Gasifier -Boiler for a Feed Mill, Bridgeville, MD

Appendix H: New Gasifier -Boiler for a Poultry Processing Facility, Georgetown, DE

1.0 MARKET OPPORTUNITIES FOR BIOMASS ENERGY ON THE DELMARVA PENINSULA

Opportunities for bioenergy exist on the Delmarva peninsula in the industrial, public, and private heat and power generation markets. Coal is the source of fifty-four percent of energy consumed by electric utilities in Delaware. In total, there is about 920 MW of large-scale, coal- or oil-fired power generation capacity on the lower Delmarva peninsula. The entire annual lower Delmarva poultry litter generation (550,000 to 700,000 tons) is enough to fuel more than 40 MW of power generation capacity. This is about four percent of the utility power generation capacity on the Delmarva. Cofiring operations have been designed to allow as much as fifteen percent of a power plant's heat to come from biomass. Although to date no cofiring operations have been commercialized using poultry litter, the relative amounts of poultry litter production and power generation capacity indicate that cofiring is an option for consideration on the peninsula.

Furthermore, significant opportunities for poultry-litter combustion exist in Delmarva's industrial sector, including the poultry processing industry. Three of Delaware's top twenty-five employers are poultry processors. These facilities have heat and power requirements that are well-suited for cogeneration. They have significant heat requirements almost continuously due to wash-down and process steam needs, and a *continuous* need for electricity resulting from their large refrigeration requirements. Annual heat requirements for the lower peninsula's poultry industry is estimated at about 700 billion Btu per year, a figure equivalent to the heat energy contained in about 70,000 tons of litter (per year). The industry's annual electricity requirements exceed 200 million kWh per year-- two-thirds of the total electricity generation potential for all poultry litter on the peninsula. It is clear that energy uses on the peninsula that are potentially compatible with poultry litter and other biomass are significant.

The purpose of this section is to review energy usage on the lower peninsula as a whole, then provide more detailed information on specific opportunities for energy projects using poultry litter or nutrient filter biomass. Information on energy use was obtained with cooperation from facility managers on the peninsula, for utility power plants, industrial facilities (especially in the poultry industry), municipal buildings, and colleges and universities. These are discussed in terms of their energy usage, energy costs, existing energy-conversion equipment, and general suitability for biomass energy. Potential availability of poultry litter and nutrient filter biomass is also reviewed. In combination with information on technical capabilities of biomass energy systems (Sections 2 and 3), this information was used to help determine proper matches between technologies, potential users, and available biomass supplies (Section 3). Finally, a list of issues and concerns from potential users is provided based on conversations with facility managers.

1.1 ENERGY USAGE AND COSTS ON THE DELMARVA PENINSULA

Exhibit 1-1 summarizes energy usage and prices on the Delmarva peninsula. Information is divided into four user classes: utility, industrial, commercial, and residential. These costs are used for economic analyses conducted in Section 3. As shown in Exhibit 1-2, forty-seven percent of

Exhibit 1-1 Annual Energy Usage and Prices on the Delmarva Peninsula

Energy Source	DELAWARE		EASTERN MARYLAND [1]		DELMARVA PENINSULA			
	Total Usage (billion Btu)	Total Cost (million $)	Total Usage (billion Btu)	Total Cost (million $)	Total Usage (billion Btu)	Total Cost (million $)	Unit Cost ($/MMBtu)	Unit Cost (c/kWh)
Utility Sector					***Utility Sector***			
Coal	47,407	76.8	0	0.0	47,407	76.8	1.62	- - - - -
Natural Gas	27,885	63.3	0	0.0	27,885	63.3	2.27	- - - - -
LPG / Propane	0	0.0	0	0.0	0	0.0	- - - - -	- - - - -
Light Fuel Oil	938	3.5	1,162	4.3	2,100	7.8	3.73	- - - - -
Heavy Fuel Oil	8,419	21.3	2,235	5.7	10,654	27.0	2.53	- - - - -
Biomass	0	0.0	0	0.0	0	0.0	- - - - -	- - - - -
Total (Fuels)	**84,650**	**164.9**	**3,397**	**10.0**	**88,047**	**174.9**	- - - - -	- - - - -
Industrial Sector					***Industrial Sector***			
Electricity	11,686	161.5	6,027	83.3	17,713	244.8	13.82	4.7
Coal	4,841	6.1	2,497	3.1	7,338	9.2	1.26	- - - - -
Natural Gas	19,261	54.7	9,934	28.2	29,194	82.9	2.84	- - - - -
LPG / Propane	1,189	9.8	613	5.1	1,803	14.9	8.24	- - - - -
Light Fuel Oil	1,853	9.1	956	4.7	2,809	13.8	4.91	- - - - -
Heavy Fuel Oil	7,137	18.7	3,681	9.6	10,818	28.3	2.62	- - - - -
Biomass	1,065	1.8	549	0.9	5,562	9.4	1.69	- - - - -
Total (Fuels) [2]	**35,347**	**100.2**	**18,230**	**51.7**	**57,525**	**158.5**	- - - - -	- - - - -
Commercial Sector					***Commercial Sector***			
Electricity	9,895	208.1	5,103	107.3	14,999	315.4	21.03	7.2
Coal	< 40	< 0.05	0	0.0	< 40	< 0.05	1.26	- - - - -
Natural Gas	5,941	30.3	3,064	15.6	9,005	45.9	5.10	- - - - -
LPG / Propane	548	5.6	283	2.9	831	8.5	10.21	- - - - -
Light Fuel Oil	1,576	6.4	813	3.3	2,389	9.7	4.06	- - - - -
Heavy Fuel Oil	840	2.2	433	1.1	1,273	3.3	2.62	- - - - -
Biomass	0	0.0	0	0.0	0	0.0	- - - - -	- - - - -
Total (Fuels) [2]	**8,906**	**44.5**	**4,593**	**23.0**	**13,499**	**67.5**	- - - - -	- - - - -
Residential Sector					***Residential Sector***			
Electricity	10,800	287.8	5,570	148.4	16,370	436.2	26.63	9.1
Coal	0	0.0	0	0.0	0	0.0	3.34	- - - - -
Natural Gas	8,800	56.1	4,539	28.9	13,339	85.0	6.37	- - - - -
LPG / Propane	3,100	39.2	1,599	20.2	4,699	59.4	12.60	- - - - -
Light Fuel Oil	6,300	39.4	3,249	20.3	9,549	59.7	6.27	- - - - -
Heavy Fuel Oil	0	0.0	0	0.0	0	0.0	- - - - -	- - - - -
Biomass	2,100	2.9	1,083	1.5	3,183	4.4	3.53	- - - - -
Total (Fuels) [2]	**20,300**	**137.6**	**10,470**	**71.0**	**30,770**	**208.6**	- - - - -	- - - - -

SOURCE:
Energy Information Administration, 1997, State Energy Data Report 1995, DOE/EIA-0214(95), Washington, DC, December.
NOTES:
1) Eastern Maryland figures are estimates based on power plant data, Delaware totals, population and industrial employment.
2) Totals do not include electricity.

total fuel use on the peninsula occurs at utility power plants, followed by the industrial sector at thirty percent. In general, average fuel prices are lowest and fuel usage at a single site is highest in the utility sector, followed by the industrial, commercial, and residential sectors, in that order. The utility and industrial sectors were the focus of market opportunities explored in this study. The average size of each site is larger in terms of fuel usage, allowing these facilities to take advantage of economies of scale and access to the personnel needed to safely manage large quantities of biomass at a minimum number of installation sites.

Coal is used for 54% of heat needs in the utility sector, followed by natural gas and heavy fuel oil at 32% and 12%, respectively. Average prices for coal, natural gas, and heavy fuel oil in the

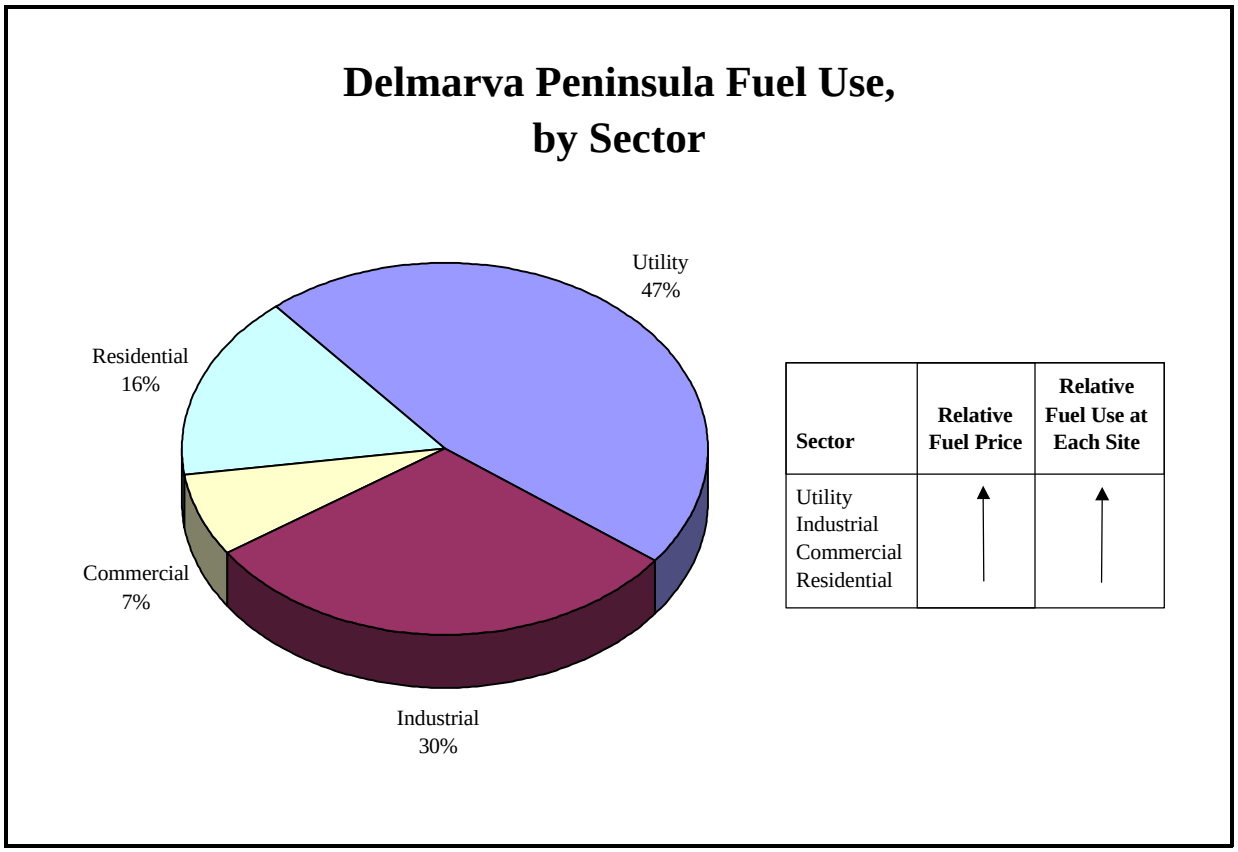


Exhibit 1-2 Delmarva peninsula fuel use, by sector

utility sector are $1.62, $2.27, and $2.53 per million Btu, respectively. The fuel mix is different in the industrial sector. The most-used fuel in the industrial sector is natural gas, accounting for 51% of the total heat requirements. Heavy fuel oil and coal are second and third at 19% and 13%, respectively. Average prices for natural gas, heavy fuel oil, and coal in the industrial sector are $2.84, $2.62, and $1.26 per million Btu, respectively. The average electricity price for the industrial sector is 4.7 ¢/kWh. Total electricity usage on the peninsula, for all sectors, is about 14.4 trillion kWh per year. The overall average price for electricity on the peninsula is 6.9 ¢/kWh.

1.2 POTENTIAL POULTRY LITTER SUPPLIES

Exhibit 1-3 shows estimated poultry litter generation in tons per year by county based on annual broiler production for the lower Delmarva peninsula.[5] Annual litter generated was estimated using an average generation rate of 2.3 lbs of litter per broiler raised. That number includes bedding and manure and is based on published results for typical practices on the Delmarva peninsula (one brood chamber clean-out every year and a whole house clean-out every three

[5] U.S. Bureau of the Census, 1998, *Census of Agriculture, 1997*, Washington, DC.

Exhibit 1-3 Estimated poultry litter generation on the lower Delmarva peninsula

State	County	Annual Broilers		Estimated Annual Litter Generation			Estimated Annual Excess Litter, tons/yr [1,2,3]		
		Low [8] (1000s)	High [9] (1000s)	Low (ton/yr)	High (ton/yr)	% of Total	High [4]	Low [5]	Long Term [6]
DE	Sussex	188,782	249,901	218,000	289,000	42%	211,000	78,000	35,000
MD	Caroline	34,951	46,267	40,000	53,000	8%	39,000	14,000	7,000
MD	Dorchester	19,794	26,202	23,000	30,000	4%	22,000	8,000	4,000
MD	Somerset	42,167	55,819	49,000	65,000	9%	47,000	17,000	8,000
MD	Talbot	12,046	15,946	14,000	19,000	3%	13,000	5,000	2,000
MD	Wicomico	76,433	101,179	88,000	116,000	17%	85,000	32,000	14,000
MD	Worcester	56,651	74,992	65,000	86,000	12%	63,000	23,000	11,000
VA	Accomack	22,432	29,694	26,000	34,000	5%	25,000	9,000	4,000
Totals		**453,256**	**600,000**	**523,000**	**692,000**	**100%**	**505,000**	**186,000**	**85,000**
Power Generation Potential (MW) [7]				**40**	**54**		**39**	**14**	**7**

NOTES:

1) Excess litter quantities are based on information in: Parker, Doug, *The Economic Costs of Implementing the Maryland Water Quality Improvement Act of 1998*, Agricultural and Resource Economics, University of Maryland, Dec. 1998.

2) Excess litter fractions (excess / generated) assumed to be uniform for each county.

3) Excess litter quantities for Delaware and Virginia are estimated based on data for Maryland:
[Excess Litter in DE = Litter Generated in DE x (Excess Litter in MD / Litter Generated in MD)]

4) High excess litter quantities are based on requirements for maximum soil phosphorus levels of 50.

5) Low excess litter quantities are based on requirements for maximum soil phosphorus levels of 300.

6) The long term equilibrium quantities indicate the excess litter generated once soil phosphorus levels have fallen below required thresholds, allowing partial re-applications of litter on crop lands (after 15 to 30 years).

7) Based on a net heat rate of 16,000 Btu/kWh, capacity factor of 85%, and ave. litter heating value of 4,600 Btu/lb (as rec'd).

8) Reference: U.S. Bureau of the Census, 1998, *Census of Agriculture, 1997*, Washington, DC.

9) Reference: Delmarva Poultry Industry Inc., 1999.

years).[6] Depending on the data source, total estimated litter generation on the lower peninsula is between 523,000 and 692,000 wet tons per year (totals are suspected to be closer to the 692,000 tpy figure according to the local poultry industry representatives), with the largest quantity (42%) generated in Sussex County, Delaware. Fifty-three percent of the total is generated in Maryland counties, forty-two percent in Delaware, and five percent in Virginia.

Regulations restricting soil phosphorus levels are under consideration in Maryland. Depending on the limits set and their implementation, a portion of the litter generated will continue to be locally land applied. The remainder (or excess) will have to be transported to other uses out of the region

---

6 Malone, G., Sims, T., and Gedamu, N., 1992, *Quantity and Quality of Poultry Litter Produced Under Current Management Programs*, University of Delaware, pp.19, Table 4.

or put to alternative productive use in the region. Energy applications for litter are not necessarily limited to use of the excess litter. Recovery of the phosphorus (P) and potassium (K) nutrients in the ash will generate a compact form of fertilizer that can be either used locally or easily shipped to other areas. However, it is the need to dispose of excess quantities that is driving the study of energy applications. Because these excess quantities may have to be disposed at a higher cost, they generate the economic opportunity for enterprise to find a productive use such as energy production. Information used to develop excess estimates is based on an analysis by the University of Maryland (UMD).[7] The UMD estimates combined information on the total number of acres currently receiving poultry litter with estimates of acreage restrictions under different soil phosphorus limits. Soil test data from the UMD's Soil Testing Lab were used to estimate the number of cropland acres with excessive soil phosphorus levels.

The final three columns in Exhibit 1-3 are estimates of excess litter availability for three scenarios: high supply (very restricted land application), low supply, and long-term. Excess litter quantities for Delaware and Virginia are estimated based on data for Maryland. The high supply estimates in Exhibit 1-3 are based on a very restrictive soil phosphorus level of 50. The low supply estimates are based on maximum soil phosphorus levels of 300, a value closer to where regulations will likely be set. After a number of years of reduced litter application to land , soil phosphorus levels are expected to decrease below regulated limits. Once-restricted acreage will again be available for land application. The last column in Exhibit 1-3 shows estimates for long-term equilibrium excess litter supplies. If soil phosphorus is regulated to a maximum level of 300, near-term excess litter supplies will be about 186,000 wet tons per year. Long-term equilibrium supplies, regardless of the regulated soil phosphorus levels, are estimated to be about 85,000 wet tons per year. Uncertainty about the amount of litter that could be available and economically used is one of the biggest hurdles to implementation of a capital intensive energy development project.

The bottom row in Exhibit 1-3 gives the estimated power generation potential corresponding to each litter supply estimate. If all of the litter generated each year were used as a fuel, about 40 MW of power generation capacity could be supported (assuming an average heat rate of 16,000 Btu/kWh, capacity factor of 85%, and a heat content of 4600 Btu per wet pound of litter). This is equivalent to the electricity used each year by about 32,000 average U.S. homes. Near-term excess litter supplies at regulated phosphorus levels of 300 would support about 15 MW, and long-term excess supplies would support about 7 MW. This is equivalent to the electricity used each year by 11,000 and 5,000 average U.S. homes per year, respectively.

---

[7] Parker, Doug, 1998, *The Economic Costs of Implementing the Maryland Water Quality Improvement Act of 1998*, Agricultural and Resource Economics, University of Maryland, Dec.

1.3 POTENTIAL NUTRIENT FILTER BIOMASS COST AND SUPPLIES[8]

A riparian buffer strip is an area of trees and/or shrubs and/or grasses adjacent to and upslope from water bodies. A filter strip is a strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater. Note that filter strips and buffer strips are defined differently.

The purposes of riparian forest buffers are:

- Create shade to lower water temperatures to improve habitat for aquatic organisms.
- Provide a source of detritus and large woody debris for aquatic organisms and habitat for wildlife.
- Reduce excess amounts of sediment, organic material, nutrients and pesticides in surface runoff and reduce excess nutrients and other chemicals in shallow ground water flow.

Riparian forest buffers consist of three zones. Zone 1 begins at the normal water line or top of the bank and extends a minimum of 15'. Dominant vegetation consists of trees and shrubs. Occasional removal of some tree and shrub products is permitted as long as the intended purposes are not compromised by the loss of vegetation or disturbance. Zone 2 begins at the edge of zone 1 and extends a minimum of 20'. The minimum combined widths of zones 1 and 2 is 100' or 30% of the geomorphic flood plain, whichever is less, but not less than 35'. Dominant vegetation in Zone 2 also consists of trees and shrubs. Removal of trees and shrubs on a periodic and regular basis is permitted. Zone 3 is up-gradient of zone 2 and its purpose is to control concentrated flow erosion or mass soil movement.

A filter strip is defined as: “a strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and waste water.” Its purpose is: “to remove sediment and other pollutants from runoff by filtration, infiltration, absorption, adsorption, decomposition, and volatilization, resulting in improved water quality and protecting the environment.”

In Delaware, field filter strips are designed with trees with a dense ground cover and/or a thick sod of grass with a minimum width of 24' if the slope is less than 6% and (4*%slope)' if the slope is greater than 6% (e.g. if the slope is 8% then width is 4*8=32'). Grass species that are approved for planting are: tall fescue (Ky 31) at 60 lb/acre, reed canarygrass at 20 lb/acre, and a mixture of reed canarygrass at 10 lb/acre and tall fescue (Ky 31) at 30 lb/acre. Fertilization is done according to soil tests. Harvest is permitted.

One proposed means of reducing nutrient runoff from fields where poultry litter is applied is to establish biomass crops as riparian buffer strips to intercept both overland and ground water flows. However, over time nutrients may build up in buffer strips to the point where the capacity to absorb nutrients is saturated, at which point in time the buffer strips lose their effectiveness.

---

[8] This section is paraphrased from work performed by Anthony Turhollow from Oak Ridge National Laboratory. For more information on costs and potential quantities of nutrient filters for the Delmarva peninsula, consult the following report:
Anthony, Turhollow, 1999, *Costs of Producing Biomass from Riparian Filter Strips*, Oak Ridge National Laboratories, Oak Ridge, TN, May. (available for download at http://www.nrbp.org)

This is especially true of phosphorus. (Nitrogen may be an exception, because under appropriate conditions denitrification can occur and nitrogen is given off to the atmosphere as a gas.) One means of removing some nutrients from the buffer strips would be to periodically harvest biomass from the strips.

There are a number of federal and state programs to help pay for establishing and maintaining riparian buffer strips. One means of addressing issues relating to sedimentation and water quality has been the Conservation Reserve Program (CRP). It was initiated by Congress in 1985 and initially was directed toward reducing soil erosion on highly erodible cropland. The 1990 Farm Act changed the goals of the CRP toward addressing water quality and other environmental concerns. Under the CRP, participants (land owners or operators) voluntarily remove land from crop production for 10 to 15 years and establish a permanent cover (usually grasses or trees) in exchange for an annual rental payment and half the cost of establishing the permanent cover (USDA/ERS 1997). Land in the CRP is not allowed to be harvested except under emergency circumstances. Where one is trying to prevent nutrients from reaching water bodies, this may be counter productive. If harvest of grasses and trees during the tenure of a CRP contract is desired, then the provisions of the CRP would have to be changed. Because part of the purpose of the CRP is to enhance wildlife habitat and concerns during the nesting period, no harvest is allowed from April 15 to August 15.

In 1998 in Maryland an enhanced CRP program, known as the Conservation Reserve Enhancement Program, was instituted. In this program the federal CRP and Maryland state programs, in cooperation with the Chesapeake Bay foundation and Ducks Unlimited, pay up to 95% of establishment costs for riparian filter strips, make rental payments of 170% of prevailing rental rates for land planted to trees and 150% of prevailing rental rates for land planted to grasses, and pay a $5/acre annual payment for buffer strip maintenance. For a riparian forest buffer strip up to 100% of establishment costs are reimbursed and for a vegetative buffer up to 95% of establishment costs are reimbursed. Up to $575/acre and $400/acre of establishment costs are reimbursed for hardwood trees and warm season grasses, respectively. (For a vegetative buffer, up to $575/acre*0.95 = $546/acre are reimbursed.)

There is a goal of enrolling 100,000 acres in Maryland (Maryland Department of Agriculture, c. 1998). The potential production of biomass from riparian buffer strips in the Delmarva Peninsula ranges from 210,000 to 420,000 dry tons per year. Harvesting 85% of buffer strip area with a yield of 5 dry tons/acre-year produces 210,000, 301,000, and 420,000 dry tons of biomass per year for 49,400, 70,900, and 98,700 acres, respectively.

It is possible that regulations could be promulgated that require riparian buffer strips to be established if poultry litter is to be spread on agricultural fields or for other reasons. This would change the economics of biomass production from riparian buffer strips because the cost of establishing and maintaining the crops established in the buffer strips would be attributed to activities that contribute to nutrient and pollutant runoff. Only the costs of enhancing yields (e.g. fertilization if advantageous and not degrading the function of the buffer strip), harvest, and transportation would be borne by the grower (or user) of the buffer strip biomass. If periodic harvest is required by regulation to remove nutrient buildup from the buffer strip, then only the costs of enhancing yields and transportation would be borne by the biomass grower (or user).

Without any payments from the CRP programs, at 5 dry tons/acre-year, delivered costs (1999$) (i.e. total economic costs) of willow are $76 to $98/dry ton ($4.50 to $5.75/million Btu), poplar are $69/dry ton ($4.00/million Btu), and switchgrass are $50/dry ton ($3.30/million Btu). Costs can be converted from dollars/dry ton to dollars/million Btu by using 17 million Btu/dry ton for willows and poplars and 15 million Btu/dry ton for switchgrass. With CRP payments, delivered costs decrease significantly to $35 to $68/dry ton ($3.30 to $4.00/million Btu) and with enhanced CRP payments, delivered costs are $26 to $44/dry ton ($1.80 to $2.60/million Btu). Willow costs are significantly higher than switchgrass costs because establishment costs are nine times greater, and harvest costs are about $5/dry ton higher. However, switchgrass may not produce the same environmental benefits as with SRWC because of differences in rooting depths and their possible impacts on treating groundwater contaminants, abilities to cause sediment deposition from surface water runoff, and wildlife habitat impacts.

If buffer strips are required to prevent nutrient runoff into water bodies, but harvesting is not required to remove nutrients from the buffer strips, delivered biomass costs are significantly less than total economic costs. Delivered costs range from $28 to $54/dry ton ($1.85 to $3.15/million Btu), a range slightly lower than costs with CRP payments. These costs are primarily for establishment costs above those of establishing the least cost buffer with switchgrass, some fertilizers assumed required for optimal yields, harvest, and transportation. If in addition harvest is required to remove nutrients, then delivered biomass costs are low and range from $12 to $27/dry ton ($0.80 to $1.60/million Btu). These costs are primarily for establishment costs above those of establishing the least cost buffer with switchgrass, some fertilizers assumed required for optimal yields, and transportation. Costs are low because significant costs are required regardless of whether the biomass is harvested and delivered.

1.4 ENERGY USER PROFILES

This section reviews the characteristics of existing facilities on the peninsula that would be most likely to use poultry litter or nutrient filter biomass as a fuel for energy end-uses. Electric utility, industrial, and public-sector facilities were identified and screened for their general suitability for using biomass fuels. Efforts were focused on larger-scale, energy-intensive facilities on the lower Delmarva peninsula which have the best potential for economically using significant quantities of biomass. Potential small-scale applications on farms, residences, and primary and secondary schools were not considered. Phone interviews were conducted with staff at pre-screened facilities to identify types of energy used, annual usage for each energy source, typical energy conversion equipment, typical hours of operation, energy costs, general interest in using biomass (particularly poultry litter) as a fuel source, and important issues which could impede implementation of a biomass project at their site.

1.4.1 Private Sector Power Plants

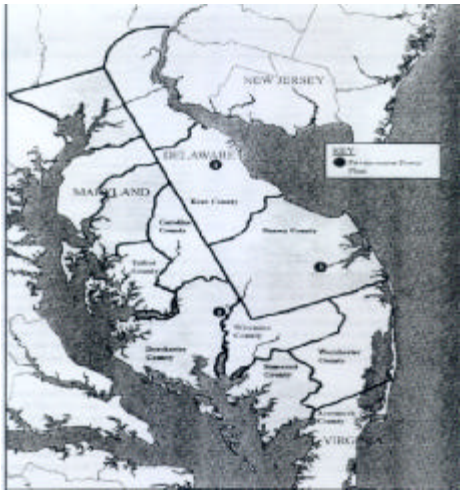
Three presently operating power plants on the lower Delmarva peninsula are candidates for using some form of biomass fuel. Two are owned and operated by Conectiv (formerly Delmarva Power): Indian River and Vienna Power Stations. Statoil Energy, a subsidiary of the Norwegian state oil company Statoil, operates the third. Characteristics of these plants are shown in Exhibit 1-4 and plant locations are shown in Exhibit 1-5. The first column ("Map No.") in Exhibit 1-4 corresponds to the plant number on the map (Exhibit 1-5). The combined capacity of these units is about 916 MW and they use an estimated total of 40 trillion Btus of heat per year. The amount of heat available from all of the poultry litter generated on the peninsula is equal to 12% of that requirement. Modifying any one of these facilities to use poultry litter or nutrient filter biomass to satisfy part of their heat requirements could consume all or a large portion of the excess poultry litter supply on the peninsula.

The largest of these plants is Indian River, which has a combined coal-fired power generation capacity of about 747 MW and operates as a baseload plant (50% capacity factor). As shown in Exhibit 1-5, this unit is located near the center of Sussex County, Delaware--the highest poultry producing county on the peninsula. There are four separate power generation units at the plant, with net capacities of about 82 MW (2 units), 162 MW, and 412 MW. The three smallest boilers were built by Babcock & Wilcox and are rated to provide 1800 psig steam at 1000°F. The

Exhibit 1-4 Characteristics of lower Delmarva private sector power plants

Map No.	Plant Name / Location	Owner / Operator	Plant Capacity (MW & pph steam)	Fuels Used	Estimated Capacity Factor	Annual Fuel Use	Estimated Ave. Fuel Costs, $/MMBtu [1]	Estimated Annual Fuel Costs, $
1	Dover Cogen Dover, DE	Statoil Energy	18 MW 200,000 pph	Coal	60%	1,400,198 MMBtu 53,854 tons	1.62	2,268,321
2	Vienna Station Vienna, MD	Conectiv	151 MW	FO #6	15%	2,182,554 MMBtu 14,550,360 gallons	2.53	5,521,862
3	Indian River Station Millsboro, DE	Conectiv	747 MW	Coal	50%	35,990,460 MMBtu 1,384,248 tons	1.62	58,304,545
		TOTALS	**916 MW**			**39,573,212 MMBtu**		**66,094,728**

NOTES:
1) Average fuel costs are based on published averages shown in Exhibit 1-1 to avoid disclosure of proprietary information.


NEW JERSEY
DELAWARE
MARYLAND
KEY

largest unit was constructed by Riley-Stoker and can provide 2400 psig steam at 1000°F. All units have a single reheat stage. Steam turbines are Westinghouse and General Electric models.

Vienna 8 is an oil-fired power station rated at 151 MW. It is located in Vienna, Maryland, near the center of the lower Delmarva peninsula. The station is currently used as a peaking unit that also provides system transmission and distribution stability support for the Delmarva Peninsula. The primary fuel is No. 6 (Bunker C) oil, with No. 2 oil used for startup. The boiler was built by Combustion Engineering in 1971 and is capable of producing 1,160,000 pounds of steam per hour at 1940 psig and 953°F. The boiler supplies a Westinghouse condensing steam turbine with a reheat loop. Conectiv has conducted preliminary studies on the feasibility of burning poultry-derived fuel (PDF) at both the Indian River and Vienna stations. Partially because of its central location on the peninsula, they believe Vienna provides the better option. To convert the Vienna station to economically burn PDF, it must be used as more of a base-loaded power generation asset.

Exhibit 1-6
Top 20 Lower-Delmarva Manufacturing Companies,
Ranked by Number of Employees

Company	City	County	State	Primary SIC	Description	# of Employees
DuPont, E I DE Nemours & Co.	Seaford	Sussex	DE	2824	Organic fibers, noncellulosic	1420
Mountaire of Delmarva Inc.	Selbyville	Sussex	DE	2015	Poultry slaughtering and processing	1250
Perdue Farms Inc.	Georgetown	Sussex	DE	2015	Poultry slaughtering and processing	1200
Perdue Farms Inc.	Milford	Sussex	DE	2015	Poultry slaughtering and processing	1200
Black & Decker USA	Easton	Talbot	MD	3546	Power driven hand tools	1200
Townsend's Inc.	Millsboro	Sussex	DE	2015	Poultry slaughtering and processing	1000
Pacific Tomato Growers Ltd.	Westover	Somerset	MD	7389	Business services, n.e.c.	1000
Allen Family Foods Inc.	Harbeson	Sussex	DE	2015	Poultry slaughtering and processing	739
Perdue Farms Inc.	Salisbury	Wicomico	MD	2015	Poultry slaughtering and processing	700
Philips Technologies	Cambridge	Dorchester	MD	3679	Electronic components, n.e.c.	700
Dresser Industries	Salisbury	Wicomico	MD	3561	Pumps and pumping equipment	650
K & L Microwave Inc.	Salisbury	Wicomico	MD	3679	Electronic components, n.e.c.	640
Tyson Foods Inc.	Berlin	Worcester	MD	2015	Poultry slaughtering and processing	600
Perdue Farms Inc.	Salisbury	Wicomico	MD	2015	Poultry slaughtering and processing	550
Dentsply International Inc.	Milford	Sussex	DE	3842	Surgical appliances and supplies	550
Allen Family Foods Inc.	Cordova	Talbot	MD	2015	Poultry slaughtering and processing	500
Perdue Farms Inc.	Showell	Worcester	MD	2015	Poultry slaughtering and processing	500
Coldwater Seafood Corp.	Cambridge	Dorchester	MD	2092	Fresh or frozen packaged fish	475
Allen Family Foods	Hurlock	Dorchester	MD	2015	Poultry slaughtering and processing	450
Draper-King Cole Inc.	Milton	Sussex	DE	2033	Canned fruits and vegetables	450

Statoil Energy purchased the Dover cogeneration plant, in Dover, Delaware about three years ago. It burns pulverized coal and is rated to provide about 18 MW of power and 200,000 lb. of steam per hour. The plant receives its fuel by rail and has covered fuel storage and handling facilities (a feature which could be advantageous for using PDF. Its proximity to its sole customer, a Kraft Foods plant, is the only potential drawback mentioned by plant management to the use of a poultry litter fuel. One of Statoil Energy's employees was said to have made a preliminary investigation of poultry litter firing, but the details or findings of this investigation were not relayed.

Other privately operated power plants were considered, but those facilities were not good candidates due to site-specific issues such as location or plant design. In addition, several refuse-derived-fuel (RDF) fired power plants had once been planned for construction on the peninsula. These facilities would have been good candidates for consideration for use with PDF; however, the plans for these facilities have been indefinitely suspended.[9]

1.4.2 Industrial Facilities

Industrial facilities require heat and electricity to run their operations and are potential sites for cogeneration. Large, energy-intensive facilities have good potential for utilizing chicken litter as fuel. Energy intensive industries on the lower Delmarva that have the potential to use biomass include poultry processors and feed mills, a chemical plant (DuPont), and the forest products industry. A complete listing of manufacturers in lower Delaware and Maryland is provided in Appendix A, for companies with 50 or more employees. Companies in Appendix A are sorted by county, number of employees, SIC code, and gross annual sales. Exhibit 1-6 shows the top twenty manufacturing facilities, ranked by number of employees (one measure of facility size). Eleven of the area's twenty largest manufacturing companies are poultry processors. Other companies in the top 20 include those involved in synthetic fibers (chemicals), power driven hand tools, electronic components, pumps and pumping equipment, surgical appliances and supplies, fresh or frozen packaged fish, and canned fruits and vegetables. Companies thought to be good potential candidates for using biomass were contacted regarding their energy usage and costs, existing energy conversion equipment, typical hours of operation, and their general interest in using biomass (particularly poultry litter) as a fuel source.

Poultry Industry

There are twelve poultry processing companies in the lower Delmarva counties surveyed, eleven of which are on the list of 20 largest manufacturing companies (based on number of employees). Half of the facilities are located in Sussex County, Delaware and the other six are spread across Wicomico, Worcester, Talbot, and Dorchester counties in Maryland (see Exhibits 1-7 and 1-8). Collectively, these twelve companies employ nearly 9,000 people, or an average of 750 employees per facility. Poultry feed mills are also shown in Exhibits 1-7 and 1-8.

---

[9] Based on an interview with staff at the Delaware Solid Waste Authority.

Exhibit 1-7 Lower Delmarva poultry processing plants and feed mills

Map No.	Company	City	County	State	# of Employees
	Poultry Processing Facilities				
4	Mountaire of Delmarva Inc.	Selbyville	Sussex	DE	1250
5	Perdue Farms Inc.	Georgetown	Sussex	DE	1200
6	Perdue Farms Inc.	Milford	Sussex	DE	1200
7	Townsend's Inc.	Millsboro	Sussex	DE	1000
8	Allen Family Foods Inc.	Harbeson	Sussex	DE	739
9	Perdue Farms Inc.	Salisbury	Wicomico	MD	700
10	Tyson Foods Inc.	Berlin	Worcester	MD	600
11	Perdue Farms Inc.	Salisbury	Wicomico	MD	550
12	Allen Family Foods Inc.	Cordova	Talbot	MD	500
13	Perdue Farms Inc.	Showell	Worcester	MD	500
14	Allen Family Foods	Hurlock	Dorchester	MD	450
15	Eastern Shore Poultry Co. Inc.	Georgetown	Sussex	DE	305
	Feed Mills and Rendering Facilities				
16	Perdue Farms Inc. (feed mill)	Bridgeville	Sussex	DE	80
17	Perdue Farms Inc. (feed mill)	Hurlock	Dorchester	MD	75
18	Darling International Inc. (rendering)	Linkwood	Dorchester	MD	75
19	Perdue Farms Inc. (feed mill)	Berlin	Worcester	MD	40
20	Mountaire Feed Mill	Frankfort	Sussex	DE	40

Energy data was obtained from a poultry processing facility and a feed mill. Both facilities were said to be typical of others on the peninsula. The processing facility operates 24 hours per day, five days per week. Processing departments operate about 17 hours per day (first and second shifts) and clean-up is performed for 10 hours per night (third shift). The product distribution areas operate 24 hours a day. Two 500 hp Cleaver-Brooks boilers burn fuel oil to produce 80 psig steam for processes and washdown–one boiler is for back-up. Since processing is performed on the first two shifts and washdown on the third, some steam is needed 24 hours a day. Highest steam demands occur during first and second shifts. Due to the large amount of refrigeration required and 24 hour facility occupation, electricity demands are high throughout the day. Electricity demands peak at midday. The annual per-employee electricity requirements of the poultry processing facility were 23,333 kWh/yr/employee and 80 kWh/yr/employee, respectively. Assuming these numbers are typical from one plant to the next, and applying them to the employment numbers for each company shown in Exhibit 1-7 yields the estimates shown in Exhibit 1-9 for poultry processing facilities on the peninsula.

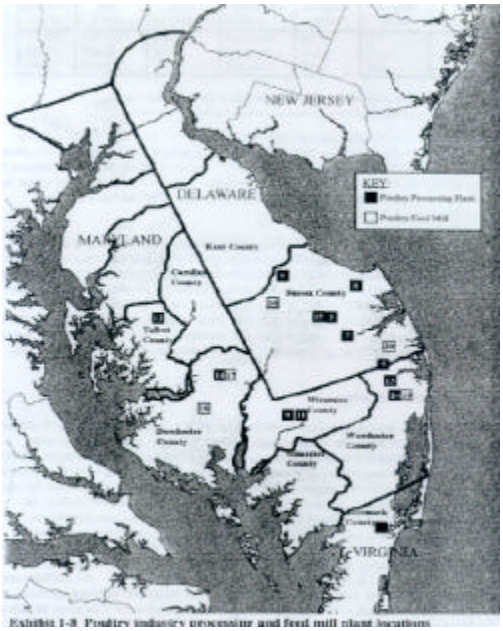


Exhibit 1-8. Poultry industry processing and feed mill plant locations

Exhibit 1-9 Estimated energy use and costs at poultry processing facilities

Facility Size	Minimum Electric Demand (kW)	Maximum Electric Demand (kW)	Annual Electricity Use (kWh/yr)	Annual Fuel Use (MMBtu/yr)	Annual Electricity Cost ($/yr)	Annual Fuel Cost ($/yr)
Large	3,100	5,700	29,200,000	99,000	1,600,000	220,000
Average	2,200	4,000	20,600,000	70,000	1,100,000	160,000
Small	800	1,400	7,100,000	24,000	400,000	50,000

NOTES:

1) Numbers in the table assume similar energy-intensity and usage trends at all processing facilities.

2) Numbers in the table are estimates based on one processing facility and number of employees.

Electric demands for a large facility are estimated to range from 3.1 MW to 5.7 MW, with an annual electricity consumption of about 29 million kWh/yr. Fuel usage is estimated to be about 100,000 million Btu (MMBtu) per year at a large facility. Annual bills are about $1.6 million for electricity and $220,000 for fuel, or about $1.8 million total. Estimated annual energy usage for all lower peninsula poultry processing facilities combined is about 200 million kWh for electricity and 700,000 MMBtu for heat.

From an energy usage perspective, feed mills and poultry rendering facilities could also be promising sites for biomass-fueled cogeneration systems because of their continuous operation (24 hours per day, 7 days per week) and steady requirements for heat and electricity. Staff from one feed mill were interviewed. Two 350 hp Cleaver-Brooks boilers provide 110 psig process steam at the mill -- one is a standby unit. The primary boiler uses #6 fuel oil and the standby uses #2. Steam and electricity demands were said to be fairly constant. Electricity use at the mill is about 7 million kWh per year with maximum electric demands of about 1.3 MW. Fuel use is about 60,000 MMBtu per year. Energy costs total $505,000 per year: $390,000 for electricity and $115,000 for fuel.

Other Energy-Intensive Industries

As shown in Exhibit 1-6, several industries aside from the poultry industry have large facilities on the lower peninsula. Of these, the DuPont organic fibers facility is considered the best potential application because it is very large, energy-intensive, and has significant steam needs in addition to large electricity requirements. Food processing facilities were also considered to be a potential application, especially the largest such facilities. The remaining industries on the top 20 list are not as energy-intensive and are not familiar with handling biomass materials. In addition, manufacturing facilities with 50 or more employees that produce wood products, industrial gases, organic fibers, and fertilizers were contacted. These facilities were chosen because they are either familiar with handling biomass materials or they have products similar to by-products of a biomass energy system (gases or fertilizers). Exhibit 1-10 summarizes the characteristics of the sites which could be potential users of biomass energy – the facilities are also shown on a map in Exhibit 1-11. The other sites that were contacted were not suitable candidates either because of lack of heat requirements, seasonal production schedules, or lack of interest in a bioenergy system.

Exhibit 1-10 Summary of Industrial Heat and Power Plants *(Non-Poultry Industry)*

Map No.	Company Name / Location / Primary Product	Number of Employees	Maximum Electric Demand (MW)	Steam Demand (lb/hr)	Type of Fuel
21	DuPont Seaford, DE (nylon plant)	1420	30 to 50 MW self-gen.; up to 30 MW from grid	300,000	Coal
22	Chesapeake Forest Products, Inc. Princess Anne, MD (chipping mill)	55	Not available; Purchase all electricity from grid	17,250	Sawdust
23	Chesapeake Forest Products, Inc. Pocomoke City, MD (chipping mill)	12	Not available; Purchase all electricity from grid	none	none
1	Kraft Foods Dover, DE (misc. food products)	900	18 MW (from Statoil Energy Cogen Plant)	200,000	Coal

The E. I DuPont de Nemours nylon plant in Seaford, Delaware has both a large electrical demand (including as much as 30 MW delivered by Conectiv, in addition to the 30 to 50 MW they self-generate) and a large steam load (300,000 pounds per hour). Their boiler is coal-fired and, while their unit fuel cost is low, there have been times when they have purchased electricity more cheaply than they were able to generate it. The plant steam demand could be met with low-pressure steam, but they have elected to operate the boiler at its design (high) pressure and generate electricity rather than throttle the steam to a lower pressure. DuPont has experience corporately with contract cogeneration and is comfortable with such arrangements. Company spokesmen indicate that economics will drive DuPont's decisions in the future regarding how it meets its energy needs, and they are open to proposals from outside energy providers. There could be land available for siting a cogen plant on the Seaford site.

Chesapeake Forest Products' two sites both have significant electrical demand, but only the Princess Anne, Maryland mill has an on-site steam demand, also. At this location, a 500-horsepower boiler is fired with sawdust generated at the plant, whose principal product is chipped pulpwood for paper making. This plant is the Delmarva's largest *producer* of poultry bedding, which accounts for the sawdust not burned on site. Plant personnel expressed no interest in firing a litter fuel. They have explored cogeneration and indicated that a cogen plant owned and operated by others would be of interest to them if it improved plant economics. This plant has several thousand electric motor horsepower installed. At the company's other plant, in Pocomoke City, Maryland (which also produces pulpwood chips), bark from the debarking operation is sold as landscape mulch. This site, too, has a significant electrical demand (over 2300 motor horsepower) and cogeneration has been explored, but lack of on-site steam load has impaired project economics. Personnel at the Pocomoke City plant informed us the company is working with the local Extension Service to assess the feasibility of using poultry litter as a soil amendment on its pine plantation acreage.

Finally, one of the wood products industry facilities that supplies pine sawdust and shavings for bedding (J.V. Wells Inc., Sharptown, MD) also consumes some litter as fuel to produce steam for

their dry kiln. The smallest scale potential users would consume 1 ton per hour to generate 1 MW or about 10,000 pph process steam (if litter is the only fuel). An application of this size would consume about 6,000 tons per year, or the litter from about 125 farms.

1.4.3 Public Sector Heat and Power Plants

Government Buildings

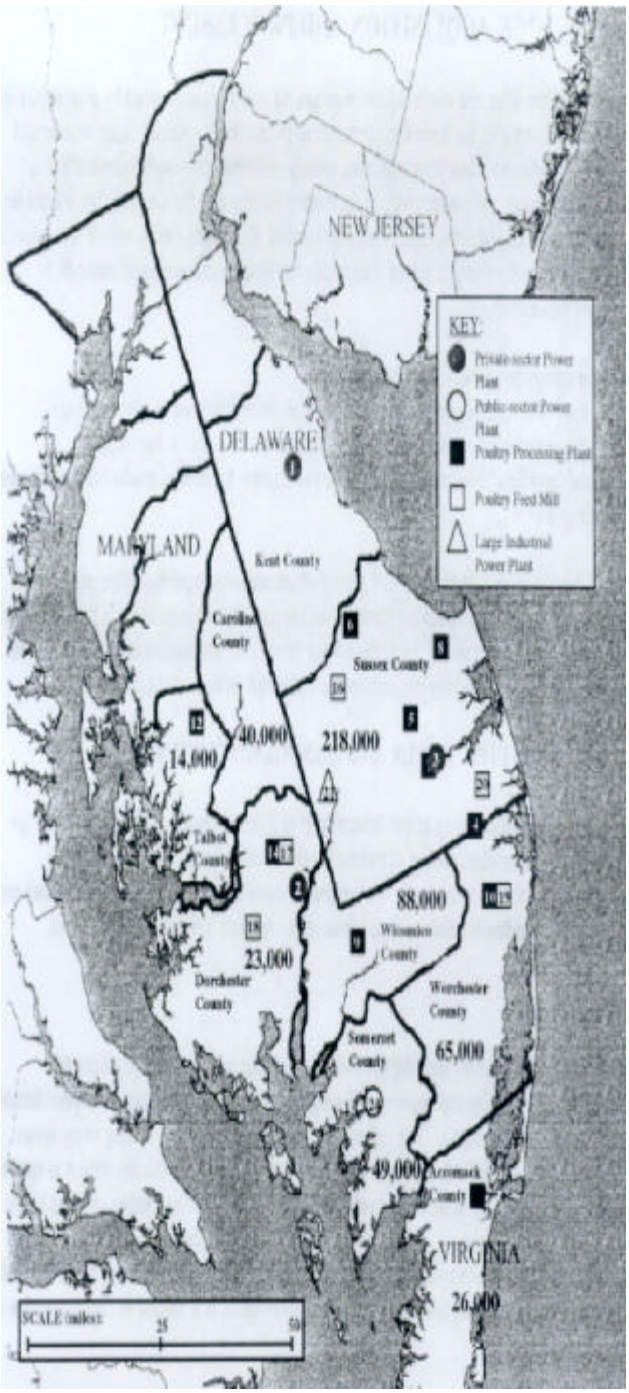
The Eastern Correctional Institute (ECI) represents an intermediate-scale system generating both power and process steam. This facility has energy demands in the same range as poultry processing, feed mills, and the wood industry on the peninsula. The ECI power plant is the subject of an ongoing investigation into the feasibility for converting the existing wood-fired boiler to burn poultry litter (McBurney). Its location is shown as #24 on the map in Exhibit 1-11.

Universities and Colleges

All universities and colleges on the peninsula were contacted. Due to their seasonal needs for steam and several other factors, these facilities were not considered promising potential sites for bioenergy systems. Several are located in areas where increased truck traffic for bio-fuel delivery would be a problem, and several are either presently using natural gas or have plans to switch.

1.5 MARKET OPPORTUNITY SUMMARY

Opportunities for using poultry litter or nutrient filter biomass as a fuel on the lower Delmarva peninsula were investigated. Emphasis was placed on larger-scale applications which could utilize enough poultry litter or nutrient filter materials to have a significant impact on local nutrient management. Facilities with the best potential are shown in Exhibit 1-11, along with estimated county-level litter generation rates (tons per year). Facilities shown on the map are utility power plants, poultry feed mills and large poultry processing facilities, and solid-fueled industrial and public-sector cogeneration plants. As shown on the map, there are potentially suitable users within less than 25 miles of all litter supplies on the lower peninsula. The facilities on the map could utilize poultry litter as a fuel in various annual volumes: 8,000 tons per year for a poultry feed mill, 130,000 tons per year for a poultry processing facility or large industrial or public sector cogeneration facility, and 250,000 tons per year for a utility-scale project. The entire annual Delmarva poultry litter generation is estimated at 550,000 tons per year. If delivered prices for poultry litter are low enough, energy applications could utilize all or any fraction of the peninsula's litter supplies.


NEW JERSEY
KEY:
Private-sector Power Plant
Public-sector Power Plant
Poultry Processing Plant
Poultry Feed Mill
Large Industrial Power Plant
DELAWARE
MARYLAND
Kent County
Caroline County
Sussex County
40,000
218,000
14,000
Talbot County
88,000
Wicomico County
23,000
Dorchester County
Worcester County
Somerset County
65,000
49,000
Accomack County
VIRGINIA
26,000
SCALE (miles)
25
50

2.0 FEEDSTOCK ACQUISITION AND PROCESSING

Utilization of poultry litter and nutrient filter biomass for energy is influenced by availability and fuel characteristics. Among the three fuels considered in this study - poultry litter, willow and switchgrass - chips from willow plantings most closely resemble the woody biomass that is currently used for steam and power production. Poultry litter is like the sawdust that is used for bedding but the manure and urine complicate combustion. Switchgrass may require some special processing equipment for firing. Each of these fuels has its own characteristic methods of harvesting and processing.

The issues for energy production are twofold:

- Can litter or nutrient filter biomass be collected and transported to central energy production facilities economically and as a relatively continuous fuel supply?
- Can the "problem" constituents of litter or switchgrass for energy production be managed or mitigated?

This section describes the composition and supply characteristics of poultry litter and nutrient filter biomass. The current methods for handling and processing the biomass as a fuel for power and steam generation are presented. In Section 3 the options for production of energy from the processed fuels in both bulk power generation and industrial facilities are examined.

2.1 POULTRY LITTER SUPPLY AND MANAGEMENT ISSUES

Litter management practices are a major determinant of litter composition and availability for energy conversion. An understanding of current practices and proposed changes to those practices is essential to this assessment. Assessment of conversion systems for poultry litter must also address poultry industry needs such as biosecurity, operator health and odor control.

2.1.1 Supply

The Delmarva poultry industry has adapted bedding and litter management practices to accommodate costly bedding replacement and restricted litter disposal. There are approximately 1800 poultry farms on Delmarva. They remove a manure crust from the bedding every seven weeks, after each flock. This cake, crust or litter is placed in temporary storage until it is spread on the fields. Crust breaking or de-caking operations also involve redistribution of some of the bedding between flocks. In some circumstances the bedding is dressed with aluminum sulfate (alum) or bisodium phosphate to control odor and ammonia which is toxic to the birds. The cake has been described as a dense mass similar to a plug of tobacco. It is similar in fuel properties to the litter.

Since it is more expensive to clean and disinfect a broiler house on Delmarva than in other parts of the country, poultry farms have developed techniques that allow them to use the same bedding for up to three years. They replace the poultry bedding in one third of their broiler houses with fresh

sawdust and shavings in a “total clean-out” in the spring or sall of each year. The three-inch layer of fresh bedding amounts to about 5,500,000 cubic feet or 60,000 tons of fresh bedding per year which is supplied by 15 local sawmills on the Eastern Shore. Fresh bedding costs about $0.30/ft^3, or $40/ton. The supply of bedding is perceived to be in balance with the demand. There is no clear demand for new sources of bedding such as chipped wood from nutrient filter biomass.

Litter clean-out can be adapted to supply a continuous use such as energy even though farms differ in the timing and frequency of total clean-out. Some companies prefer to clean out in the fall and winter to take advantage of cooler weather, lower pathogen activity and slack time for farm labor. Others prefer cleaning in the spring. Litter removed from houses is sometimes moved to covered storage at least 100 yards from the houses where it is kept for four to six weeks and composted (to 170°F) in order to kill pathogens. In Maryland these storage facilities are subsidized as environmental control facilities since they prevent leaching into the soil. For a potential energy consumer they are a form of distributed storage where fuel can be kept before delivery to a conversion facility.

Poultry litter is composed of about one third bedding and two thirds manure, averaging 2.3 pounds per bird or 1.15 tons per 1,000 birds per year, for a total of more than 550,000 tons of litter per year or 1500 tons per day. Fresh manure and litter from layer or brood houses could also be added to this litter. Litter is generated over a wide area. All of it is now used in land applications and in one composting facility. Litter has been tested in at least one energy conversion plant and several companies on the peninsula are considering litter as a fuel. If it were all converted to energy it could generate 40 MW electricity or about 400,000 lb/hr of process steam. Long term excess supplies were estimated in Section 1 at about 85,000 tons, or 200 tons per day, equal to 7 MW or 70,000 lb/hr steam (Exhibit 1-3). This long-term excess is equal to the energy demand of the largest feed mills, poultry processing facilities and local sawmills.

2.1.2 Biosecurity

Biosecurity is an important issue for poultry producers. Disease can be transmitted between farms or houses by contaminated litter transport. Some disease-causing organisms can live for weeks, months or even years away from birds. Since litter transport has been a source of disease when delivering litter from several houses to a single end-use, traffic poses one of the greatest risks to bird health. Traffic control and sanitation are two methods that poultry producers use to protect their farms from infectious disease. Traffic control includes both the traffic onto the farm and the traffic patterns within the farm. Litter removal must be organized to prevent contact with live birds. Delivery trucks may also need to be sanitized between farms sufficiently to convince growers that their flocks will be protected.

Composting on the farm has been suggested as a means of destroying organisms before litter is loaded for transport. While the bacterial action in composting contains odors and prevents the spread of pathogens, the pathogen removal efficiency (PRE) of composting may be inadequate as sole process for biosecurity.

2.1.3 Costs

Litter clean-out and disposal costs have been estimated at $8-10/ton, equal to about $0.80/MMBtu. The litter contractor is often a neighbor farmer who exchanges the clean-out service for the value of the litter as fertilizer. Since litter is exchanged for services it carries no disposal or economic value. In other cases a contractor may service several farms. The University of Delaware has identified litter contractors in a recent survey. Some have indicated that they would expand operations if a use were developed. The Maryland Department of Agriculture has recently initiated a cost share program valued at $20/ton. Called the "Poultry Litter Transportation Pilot Project" it is designed to encourage litter removed from land application in high density production areas – Dorchester, Somerset, Wicomico or Worcester counties – to be transported other areas of the state. (Maryland Department of Agriculture) This incentive may help develop the logistics of biosecurity during transport necessary to supply energy uses and potentially offset costs of transporting the ash fertilizer to markets outside the region.

The low value of litter has probably suppressed development of other technically suitable alternative uses such as composting. Composting will develop as an alternative since Delmarva has access to large suburban populations where composted or pelletized litter can be sold for up to $200/ton. However the volumes of litter available are far greater than the identifiable compost markets.

2.2 LITTER COMPOSITION

To understand the issues associated with preparing litter as a fuel for energy production its physical and chemical characteristics must be understood and potential handling and combustion problems identified. It is then possible to suggest alternate means of handling and processing that could mitigate these problems and provide a better fuel product. In Section 3 the means for dealing with problem constituents from the burner to the stack are considered.

2.2.1 Physical Characteristics and Handling Systems

Size, Density and Transportation

The physical characteristics of the litter are similar to those of the wood sawdust and shavings that are used for bedding (Exhibit 2-1). Bulk density is similar to wet sawdust at 28 lb/ft^3. The litter can be transported by truck at about 20 tons per load. Automated unloading requires either a truck tipper at the energy facility or use of live-bottom vans. The unloading area and trucks must be cleaned or disinfected to protect litter suppliers from disease. The cake or crust may need to be sized in a hammer mill but the bulk of the litter is suited to reclaim and feed directly from a storage bin or silo. Wood chips from nutrient filter biomass could be used to add bulk to the litter to improve handling.

Exhibit 2-1 Basic Physical Characteristics of Poultry Litter as Fuel

Source	***Tyson***	***Perdue***	***Mountaire***	***Average***
Moisture	18.5%-32.5%	17.3%-33.6%	17.8%-43.4%	27.4%
Ash	12.0%-16.4%	12.0%-21.3%	12.9%-24.1%	15.7%
Density	22.0-30.7	24.3-31.9	19.6-30	27.9 lb/ft3
HHV as fired	4,350-5,200	4,270-5,770	3,430-5,280	4,637 btu/lb
Passing 1/4 inch	93.8%-97.9%	97.1%-100%	86.5%-99.4%	96.1%%

SOURCE: Maryland Department of Environmental Resources, 1998, samples taken by the McBurney Corporation for the Eastern Correctional Institute's Cogeneration Facility.

When dried, litter can be very fine and dusty. More than 96% of litter sampled in the Georgetown area from Perdue, Mountaire, Tyson farms will pass a ¼ inch screen. Fuel size is important in conversion because it takes time for combustible gases to diffuse through solids. Large pieces burn slowly. Thin pieces heat rapidly and the remaining char can be mixed readily with oxygen. Litter would make a suitable suspension fuel if inorganic compounds in the ash can be cooled and captured.

A good suspension burner will sustain ignition without a pilot flame if the fuel is milled so that at least 25% will pass a 100 mesh screen (<150 microns). The theoretical burning time for fuel particles of this size is 2 seconds: ½ second to devolatilize and 1 ½ seconds for char combustion. In practice most burner designs, like those used with litter, only partially burn fuel in suspension and depend on sufficient residence time at high temperatures in the firebox to complete combustion. If the firebox is too small, as in many retrofit HRT boilers, then CO, unburned hydrocarbons and unburned char result.

Particle size must be controlled if nutrient biomass wood chips or straws are blended with poultry litter. A boiler operates best with a uniform range of fuel sizes that can be controlled by processing on site. When fine particles are introduced with larger sized chip fuel into a cell, spreader stoker or circulating fluidized bed, the difference in size can create emissions. The fines devolatilize rapidly in the high-velocity air needed to burn the chip-sized fuel, but the char elutriates out of the high-temperature zone of the furnace producing carbon particles and excess CO in the flue gas. If the boiler does not have enough secondary air capacity or boiler volume to completely burn this excess CO, then the boiler steaming capacity must be reduced (de-rated) to comply with CO emissions standards.

Moisture

Biomass fuels burn best and create less dust when air-dried to 15% to 20% moisture. Moisture sampled at the Delmarva farms ranged from 8% to 35%. Samples taken for the ECI energy facility show that moisture is fairly uniform below the manure crust or cake. The housing environment is effective in stabilizing litter moisture. Poultry bedding is intended to absorb and accumulate moisture and manure from the poultry. Ventilation is controlled to remove odors and evaporate moisture while economizing the heating and cooling needs. After the first two flocks the bedding stabilizes at about 29% moisture content. Once litter is removed from the houses it must be stored under cover, otherwise moisture will increase rapidly up to 60%, causing problems in handling and combustion.

Moisture content is the most variable component of litter that must be managed to control emissions. High moisture absorbs heat, lowering flame temperatures. This reduces NO_x generation but reduces furnace efficiency and creates unstable ignition. This promotes volatile species that are not completely burned. When moisture is too high in a large volume furnace with no auxiliary fuel, temperatures drop and the fire will flame out, creating a dangerous situation as heat in the furnace produces combustible gases which can reignite or explode. Combustible gases from wet, smoldering fuel also cause unstable flaring in the boiler, usually recognized as puffing or flashing when a door is opened that lets in fresh air. The unstable air flows that are created within a puffing boiler entrain particles and unburned gases into the flue gas, increasing emissions.

While some designs accommodate a wide range of moisture content, a specific boiler is often tuned to operate at rated capacity within a narrow range of fuel moisture. Moisture regulates the rate of combustion as it evaporates and diffuses through wood. It determines the maximum flame temperatures and combustion efficiencies that can be achieved. Average gas temperatures in the main flame of a spreader stoker firing wet biomass may be 1400°F-1800°F while dry fuel at the same point may reach 2000°F-2400°F. Variations in moisture can make it difficult to maintain minimum furnace exit gas temperature required for complete combustion, so combustion air is often preheated to offset the heat loss from moisture. Fuel dryers are sometimes used to reduce fuel moisture, especially where stack gas or other sources of waste heat are available.

Wet fuel must be thoroughly blended with dry fuel and distributed uniformly onto a grate or into a fluidized bed to offset the effect of moisture. Concentrations of wet fuel will blanket a grate, disturbing air flow and causing surges in gas flow as described above. Wet fuel requires high-velocity air to penetrate the fuel mass and “wipe away” the boundary layer of moisture and gases created by evaporation and volatilization. Concentrations of dry fuel, especially dry fines, can cause explosions at the grate or fuel feeder, creating high temperatures, slagging or other effects. Incomplete fuel blending can cause an imbalance of air and fuel, leading to incomplete combustion.

Drying would enhance the fuel value of the litter and make it possible to densify or use it directly for fuel or fertilizer. But litter drying operations are dirty, dusty and potential health hazards. Dryers would generate odor and volatile organic compounds (VOCs) which would need to be thermally incinerated in a combustion system. It is better to temporarily store the litter on the

farm, leaving the odor, pathogen and moisture problems to stabilize through heating and then deliver the finished product to an energy facility.

Odor

Odor is a serious challenge to poultry litter conversion. Wet or dry poultry manure has a persistent odor that is difficult to eliminate. Poultry litter handling facilities must be adequately ventilated and located away from other activities.

2.2.2 Chemical and Biological Composition

Proximate, ultimate and ash elemental analyses are presented here to help identify important considerations for energy conversion from poultry litter, coal and other biomass.

Biomass fuels burn in three familiar steps. First, heat from the furnace evaporates moisture in the fuel. Second, as the dry fuel heats to 400°F, the volatile carbon burns to gas. These gases burn when mixed with air. Third, the remaining fixed carbon burns without flame by direct contact with air. The combustion of carbon and carbon monoxide (CO) to carbon dioxide (CO_2) releases heat which drives the drying and devolatilization. These stages can be seen in the combustion of large particles. They occur simultaneously as fuel particles of varying size and moisture content are fed continuously to a furnace. Moisture in the incoming fuel evaporates as it absorbs heat from the furnace. Gases that evolve from a bed of burning fuel are a mixture of water vapor, carbon dioxide, combustible gases, unburned char and inert ash particles. Part of the ash remains in the fuel bed with the burning char. Some ash and char particles are suspended and carried out in the flue gas.

Oxygen for combustion is supplied from combustion air and air in the fuel itself. The minimum amount of oxygen necessary to completely convert the carbon and the volatile compounds in the fuel to carbon dioxide and water is called the theoretical air or stoichiometric air. It takes approximately six pounds of air to completely burn one pound of dry litter. In practice seven to nine pounds of air are used. The excess air is necessary to ensure adequate mixing for complete combustion. About one third of the air is required to gasify the volatiles, converting the solids to carbon monoxide (CO) and hydrogen (H_2). This air is usually introduced through a grate under a layer of fuel. Fuel can also be gasified in a separate chamber or reactor. The remaining air is introduced above the burning fuel by means of high-velocity jets to complete the conversion of carbon monoxide and unburned hydrocarbons to carbon dioxide and water. This air-induced turbulence helps mix oxygen with combustible gases to improve combustion efficiency.

Proximate Analysis

The 15% ash and 28% moisture in litter results in about 57% combustible fuel valued at about 4,600 btu/lb (6,400 btu/lb dry). It is similar in heating value to wet sawdust. Exhibit 2-2.

Exhibit 2-2. Proximate Analysis of Poultry Litter

Source	As Received %	Dry %
Volatile Matter	47.30%	62.73%
Fixed Carbon	9.80%	13.87%
Ash	15.70%	23.40%
Moisture	27.40%	0.00%
Total	100.00%	100.00%

SOURCE: Maryland Department of Environmental Resources, 1998, samples taken by the McBurney Corporation for the Eastern Correctional Institute's Cogeneration Facility.

Volatile and fixed carbon in the fuel is an indication of how air must be distributed for complete combustion. Approximately a third of the combustion air is required to gasify the volatile carbon which makes up about 60% of the dry litter. Volatiles are released between 400°F and 800°F by heat produced from burning part of the fuel. Volatile gases can be seen burning in the flow of gas streaming from the fuel bed or from large chunks of fuel. The rate of combustion of the volatile gases is limited by the diffusion or mixing with air (oxygen). This air is introduced below the grate or in a fluidized bed and converts the solid fuel to gases: carbon monoxide (CO) and hydrocarbons (HC), with some carbon dioxide (CO_2). Secondary air is added above the fuel bed or in the vapor space above a fluidized bed in high-velocity jets to complete combustion of the gases and char. It is usually the most overlooked part of biomass combustion. Improvements in combustion efficiency and emissions have mostly come from increasing overfire air and jet velocity. This strategy allows furnace excess air to be reduced, increasing boiler temperatures. Furnaces that have insufficient volume or air capacity for complete gas combustion have difficulty meeting CO or HC emissions requirements.

Fixed carbon makes up about 14% of dry litter. It burns by direct contact with air in the fuel bed, with the rate of combustion limited by the diffusion of oxygen to the solid fuel surface. Heat from char combustion dries incoming fuel and volatilizes the gases from it. Fixed carbon burns at high temperatures, above 2000°F. When inorganic ash contained within the litter is subjected to these high temperatures it melts, forming slag, or vaporizes to form an ash fume in the boiler.

Industrial biomass systems produce steam by transferring the heat through radiation to tubes built into boiler walls and by convection to tubes that are placed in the path of the flue gas. As much as 40% of the heat transfer is by radiation to tubes in direct "view" of the flame. This cools the combustion gases so that furnace exit gas temperatures in typical biomass power plants are 1650°F to 1700°F. Vaporized ash condenses as heat is removed from the flue gas in the boiler convective passes, air heater and economizer. Combustion ceases when any unburned gases cool below about 1200°F. Particle-laden flue gases enter pollution control devices at about 300°F, above the dewpoint for moisture and acid gases. Most pollutants that form in the furnace, such as the products of incomplete combustion, must be completely burned before they exit the furnace. The high moisture and ash composition of poultry litter indicates a high potential of generating inorganic pollutants and products of incomplete combustion.

Ultimate Analysis and Potential Emissions

Exhibit 2-3 shows the chemical composition of poultry litter and provides an indication of potential pollutants from litter combustion. Eight to ten pounds of flue gas are produced for each pound of dry litter burned. Unburned gases and other pollutants make up less than 1% of the flue gas by volume. These are the regulated emissions which include particulate matter, carbon monoxide, hydrocarbons, oxides of nitrogen and sulfur oxides. In an efficient combustor there is very little unburned carbon or char in the flyash that is separated from the flue gas or the ash that is removed from the bed.

Exhibit 2-3. Ultimate Analysis of Delmarva Poultry Litter, Bedding, and Filter Biomass

Source	Sawdust	Poultry Litter	Willow	Switchgrass
Carbon	24.17	27.22	44.07	44.70
Hydrogen	2.75	3.72	5.29	5.57
Oxygen (by diff.)	18.25	23.10	39.21	36.98
Nitrogen	.22	2.69	.32	.29
Sulfur	.02	.33	.03	.05
Chlorine	--	.71	--	.08
Ash	1.96	15.7	.85	4.53
Moisture	52.63	27.4	10.23	7.88
HHV	4,150	4,637	7,478	7,370
HHV Dry	8,760	6,394	8,330	8,000

SOURCE: Maryland Department of Environmental Resources, 1998, samples taken by the McBurney Corporation for the Eastern Correctional Institute's Cogeneration Facility.

Principal products of biomass combustion include: carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), sulfur oxides (SO_x), inorganic bottom ash and flyash. When these products exceed local standard levels, they become pollutant emissions that must be controlled through good combustion practices and, in some cases, emissions control devices. Complete combustion, with the lowest practical amount of excess air (maximum fuel efficiency) and the lowest emission of air pollutants, requires control of the fuel properties, as well as boiler operating parameters. Particulate matter (PM) is the major emission of concern. Carbon monoxide (CO) and organic compound emissions (HC) are important indicators of incomplete combustion. Efficient combustion of litter at high temperatures will result in formation of nitrogen oxides (NO_x). Acid gases evolve from sulfur (SO_x) and chlorine (HCl) in the litter. These gaseous organic compounds and possibly some heavy metals such as lead (Pb) or cadmium (Cd) in flue gas require emission control devices.

Poultry litter is very high in nitrogen, sulfur, chlorine and ash. Fuel-bound nitrogen readily converts to nitrogen oxide. Elevated nitrogen levels may require ammonia or catalytic NO_x control devices on energy conversion systems. Sulfur in the fuel may be captured by sodium and potassium in the fuel. Chlorine presents a very significant and potentially costly element in litter. Chlorine combines with alkali in the fuel, leads to corrosion and may require acid gas emissions control such as a wet or dry scrubber. The high percentage of ash combined with the fine particle size limits the kinds of gasifier or combustor that may be used for energy conversion.

Ash Composition

Exhibit 2-4 compares the elements in poultry litter ash with constituents in wood bedding, willow and switchgrass. The concentration of alkali (Na_2O, K_2O) is readily apparent at 9.33 lb alkali per MMBtu. Poultry litter requires special boiler designs to capture and remove this ash without impacting the boiler performance. This is handled differently in each reactor described in Section 3.

A boiler designed to burn wood will not be equipped to handle the high ash and high alkali in poultry litter. Clean wood has a very low ash content, often less than 1% of the dry wood. It usually burns cleanly and inorganic compounds do not interfere with the operation of the boiler. Inorganic elements in wood are principally silica, calcium and potassium, as shown in the composition of sawdust and willow chips in Exhibit 2-4. They are dispersed throughout the structure of the wood, with higher concentrations of soluble elements like potassium in the cambium layer or growth areas of the plant including bark, leaves, twigs and branches.

Recycled wood that is sold for bedding can contain problematic ash and nitrogen. Wood fuel with more than 1% ash usually contains adventitious inorganic matter such as sand, rocks, dirt, limestone (which is added to prevent slagging), debris from construction or demolition or contaminants from processing such as construction adhesives or wood treatments. As the quantity of leaves, twigs and annual growth increases, volatile elements such as potassium increase. These vaporize at combustion temperatures and condense on walls, flyash and fine particulate that is transported through the boiler by the flue gas. Rocks, sand and dirt are usually separated with the

bottom ash or in simple cyclones and do not interfere with combustion if means are provided to remove them. Over time, however, they can accumulate and slag. This mentioned can block undergrate air, overfire air nozzles, and fuel feeders, causing imbalances in the combustion system. Operators can often identify the source of a fuel by the nature of the ash removed from a furnace.

Sulfur, chlorine, phosphorous, metals such as zinc, lead or mercury, and other volatile inorganic compounds vaporize and oxidize during combustion or combine with alkali (sodium or potassium) and alkaline earths (calcium and magnesium compounds) and condense as fine particulates as the combustion gases are cooled. These fine particulates, such as alkali chlorides can be observed as a fine particulate plume from stacks of boilers and burners. They are smaller than can be efficiently captured in cyclones or wet scrubbers.

Exhibit 2-4 Elemental Composition of Bedding, Poultry Litter and Nutrient Filter Ash

Source	Sawdust	Poultry Litter	Willow	Switchgrass
SiO2	35.6	8.10	8.08	68.18
Al2O3	11.54	1.90	1.39	.49
TiO2	.92	.20	0.06	.01
Fe2O3	7.62	1.16	0.84	.62
CaO	24.90	17.30	45.62	6.51
MgO	3.81	5.00	1.16	2.78
Na2O	1.71	9.20	2.47	.20
K2O	5.75	16.30	13.2	8.38
P2O5	1.90	24.40	10.04	5.30
SO3	.78	6.70	1.15	1.81
CO2/other	5.71	9.74	15.99	5.74
Total	100.00	100.00	100.00	100.00
lb alkali/MMBtu	.35	9.33	0.18	.53

These are the major inorganic “problem” constituents for combustion. They are also potentially valuable nutrients when they can be separated from the ash as a byproduct of combustion. Nitrogen and sulfur are oxidized to NO_x and SO_x, both of which contribute to acid rain and are controlled by the Clean Air Act. Sodium and potassium are easily vaporized alkali metals which contribute to fouling of boiler heat exchanger surfaces. Switchgrass is low in alkali compared with poultry litter but the amorphous silica in switchgrass ash combines with the alkali in the litter to form low-melting alkali silicates. Chlorides in the exhaust gases are highly corrosive to boiler tubes and other metal surfaces in the boilers. These issues are discussed further in Section 3.

Ash in the litter is a result of inefficient feed utilization by the birds. Energy conversion offers a means of concentrating phosphorous and potassium in a form that can be removed from the Delmarva ecosystem and transported easily to other locations for use as fertilizer. Exhibit 2-5 shows the concentrations of the major ash constituents in the feed and litter and their typical sources. Feed modification has been suggested as a means of reducing the nutrient excretion and thereby improving the manure and litter for land application and combustion. The phytase treatment of corn, for example, will change the form of the phosphorous available for plants but is not likely to improve the impact of phosphorous on combustion equipment. Feed modification will not reduce the concentrations of these elements in the litter or reduce their impact on energy conversion equipment.

Exhibit 2-5 Major Constituents in Feeds and Litter

Constituent	Feed lb/ton	Feed %	Litter lb/ton	Litter %	lb/MMBtu	Sources
Nitrogen	75	3.8%	53.4	2.7	4.2	soy, corn, fish, alfalfa
Phosphorous	12	0.6%	33.5	1.7	2.6	soy, corn, phosphate
Potassium	12	0.6%	117.9	5.9	9.2	soy, fish, alfalfa
Sodium	5	0.3%	121.2	6.1	9.5	salt, soy,
Chlorine	6	0.3%	14.0	0.7	1.1	salt, soy, alfalfa
Sulfur	4	0.2%	6.7	0.3	0.5	soy, corn, fish, alfalfa

2.3 FUEL PROCESSING OPTIONS

Fuel processing in bioenergy systems can include sizing, drying, blending with other fuels, or pre-processing by gasification or pyrolysis to improve the fuel characteristics for energy conversion. Fuel blending and gasification or staged combustion may offer the best means to dilute the effects of high ash and moisture in poultry litter or to separate problem constituents before firing.

Fuel handling impacts both emissions and boiler operation. Fuel processes that improve operations and ash management include:

- sizing and blending
- fuel drying
- anaerobic digestion
- gasification

Size uniformity is essential for even fuel distribution on a grate or in a fluidized bed. Variations can lead to rapid burnout and grate cooling problems. Fuel size, density and moisture most affect combustion system feeding. Oversize material can cause bridging and blockage in fuel bins. When dropped into a bin large particles roll to the outside of a pile. This segregates fines at the center of the pile which can cause imbalances in fuel feed to the furnace. Small-scale combustion systems that are fed with undergrate stokers or ram feeders push fuel out onto a fixed or traveling grate with little vertical drop or opportunity airborne. They operate best with rough chunky fuels that

make porous fuel beds but are sometimes sensitive to ash content. Stokers with air-swept spouts in large (>1 tph) systems suspend fine particles that are easily airborne. Air-cooled grates require a uniform layer of ash to protect the grate.

Fuel size also affects operation and emissions of fluidized beds. Fuel entry must be designed to develop a uniform plume of fuel within the fluidized bed. Overfeeding poorly mixed areas of a fluidized bed can lead to concentrations of CO. These lead to operational problems, blocking flow causing further imbalance in combustion and excess emissions. To feed into fluidized beds, fuel must pass through a rotary airlock that isolates the fuel system from the pressure in the combustor. Oversize fuels or fine wet fuels can block or jam rotary airlocks. The feed injection screws that follow these airlock must also be sized to handle the fuel.

Poultry litter received from 1800 farms is likely to arrive in variety of qualities from wet compacted manure to dry and dusty powder, so some amount of processing will be necessary for energy conversion.

2.3.1 Receiving, Storage, Processing and Reclaim

Fuel selection for biomass combustion often results from availability and reliability of supply first, and price and fuel quality second. Most biomass plants have found it beneficial to have some fuel processing on site for reprocessing off-spec fuel and handling special circumstances. Fuel receiving and handling will be a major source of fugitive emissions from poultry litter. Odor, dust and health considerations suggest that litter should be received and fired in as coarse and unprocessed a form as possible with a minimum of fuel handling.

Designers of the poultry litter plants in England have taken a simple approach to fuel receiving. The poultry litter is collected in enclosed vehicles each carrying about 20 tons. The loads are weighed on site and analyzed for moisture content, ash and heating value, before being tipped into enclosed reception pits. Loads with excessive moisture content are rejected. The litter is stored under negative pressure, maintained by induced draft fans, to prevent noxious odors from escaping into the atmosphere. The litter is discharged into reinforced concrete pits, storing ten days' supply (400,000 ft^3 or about 5,600 tons). It is sorted by moisture content, enabling the overhead grab crane to recover a consistent blend of wet and dry material, thus giving a reasonably constant heating value at the furnace. There are four in commercial operation. US poultry producers who have visited these plants have commented that they would require additional controls to ensure operator health and biosecurity.

Receiving systems should handle unloading without delay, handle dust control for dry fuels and preliminary processing to separate oversize material and trash (metal objects or rocks). Since a variety of qualities of litter will be received, it may be necessary to:

- have a versatile receiving facility
- be capable of segregating into different storage bins
- provide bypass capability for special conditions

- be able to selectively blend out of storage
- accommodate unpredictable quantities of oversize and fine fuel.

The receiving design capacity should be sized to reduce delay in truck unloading and may include: live bottom receiving capacity, primary disc screen, self-cleaning magnetic separation, oversize feed to a hammer mill, possible bypass to alternate bins, means to reintroduce fuel to screen from yard, dust collection system. Storage and reclaim can be based on the amount of processing required for the fuel (segregation, screening, drying, resizing) and the number of very different fuels to be blended. The ability to separately vary a marginal fuel that contains sulfur or other contaminants can reduce operational and emissions problems.

Processing of wood from nutrient filter biomass and recycled wood may require at least two stages of screening. A scalping screen is required to separate oversize and-non wood material. The prepared fuel as received at the plant may need to be further screened if the fuel feeding system includes a rotary airlock, injection feed screw, or if the fuel contains contaminants that can be removed by screening. Coarse screens are typically disk screens in the fuel feed to storage or in the main reclaim line. The latter is preferred since the material flow rate is low compared with the truck unloading. Final screening of the fuel serves two purposes: to remove oversize fuel passed by the primary screen including objects or tools dropped from the machines into the reclaim equipment and to establish a uniform fuel hence stable operating conditions.

Dry poultry litter is a fine fuel. Wood fuel both from mill and urban sources increasingly contain a high percentage of fines. Often fuel supplies contain 30% less than 1/4 inch. It may be convenient to screen wet fines before a dryer bypassing directly to fuel blending with larger dry material. This reduces the potential fine particulate load on the dryer exhaust and reduces dust. Fines have two kinds of impacts on biomass fuels. In storage, fines absorb moisture due to their high specific surface area. Sawdust and litter in outside storage can exceed 60% moisture. Dry fines from the fuel or from a dryer cyclone can cause unstable firing due to explosions on a grate. In a stoker, fluidized bed or circulating fluidized bed, fines can travel to the upper furnace before igniting and create CO problems. A large percentage of fines may result in higher unburned carbon and PM emissions.

Blending or mixing should take place before the fuel enters the final feed bin, unless fuels are fired separately, like dry fines from a dryer that can be fired in suspension burners above a spreader stoker traveling grate.

2.3.2 Drying

Biomass fuels dry in the boiler as water vapor is released with the flue gases. Excessive moisture, however, can result in incomplete combustion or poor use of boiler capacity. Fuel dryers improve boiler efficiency where stack gases can be recovered to reduce overall moisture content. Drying is often necessary for gasification or suspension burning applications, where moisture must be below 20%. While increasing fuel efficiency, fuel dryers can add to the pollution load since both combustible hydrocarbons and fine particulates are carried off with the water vapor in exhaust

gases. Fuel dryers are often fired with recycled boiler flue gas, suspension fired burners, fluidized bed burners or gasifiers. Rotary drum dryers and vibratory fluidized bed dryers are the main dryers used for particle and fuel drying in the biomass industry. In rotary drum dryers, an inclined cylinder rotates on bearing wheels. Wet particles are fed into one end of the drum and cascade through a counter-current hot air stream with the aid of particle lifting flights. Dust entrained in the drying gas is removed in cyclone dust collectors. A cyclone suspension dryer is also used for fuel drying by recycling boiler stack gases. Wet fuel is fed with exhaust gases into the base of a cyclone. The dried fuel elutriates and is conveyed to the boiler. One cyclonic dryer reduces moisture from 60% to 35%.

Poultry litter is best handled in the form it is received from the poultry houses. At 25% to 30% moisture, the operating and capital costs for drying outweigh the benefits in energy conversion. In co-firing with coal the inefficiencies due to moisture at 35% moisture are very low. Poultry manure and litter are often dried for direct use as feed or fertilizer, but drying is not feasible at this moisture. Since wet litter is the result of poor management at the farm, power plants in England reject litter that exceeds moisture specifications. Drying does not kill pathogens, reduce odor or improve handling. Dry litter can be dusty and create housekeeping, health and potential explosion problems. Dryer exhaust from poultry litter may need to be thermally treated to destroy odors and volatile organic carbons.

Biomass is heated sufficiently in drying to drive off some volatile compounds. The primary emissions from fuel drying are solid particulate matter and hydrocarbons, organic aerosols, organic gaseous compounds, small amounts of fiber, inorganic particulates and char. Among the hydrocarbons there are those that remain volatile and those which condense at ambient conditions. The former are a combination of combustion products and terpenes similar to those emitted naturally by vegetation. The latter condense into submicron droplets (aerosols) upon cooling in ambient air and are the principal cause of visible blue-haze.

Terpenes are the principal component of particle dryer emissions, making up 70 to 95% of the total mass of emitted substances. Very high drying temperatures result in very short drying times and extremely low final moisture contents. Thermal degradation products such as formaldehyde, furfural, formic and acetic acid have been observed. As drying intensity increases, the amount of terpenes decreases. Fuel particles reach temperatures of 450°F to 700°F. At these temperatures small particles dry rapidly early in the drying process and can pyrolyze. Visual pollution can be seen as blue haze. Uncontrolled emissions can have 40-60% opacity.

Fuel dryers subject fine particles to temperature that will volatilize carbon and velocities through the dryer are high enough to entrain dirt and flyash. Where fuel dryers are used to precondition flue gas some flyash carryover can be eliminated to stack gas cleaning devices. Particulate carryover from dryers is usually too high for wet scrubbers.

Typical control requirements for fuel dryers are:
1. Particulate matter - 0.01 to 0.04 gr/dscf (23-92 mg/Nm^3)
2. Opacity - regulated to 20% or less

2.3.3 On-Farm Composting

Composting appears to have limited use as a fuel pretreatment. It has been proposed to reduce health risk and improve biosecurity. Poultry litter undergoes some composting during the seven weeks or longer that it remains in the broiler house and in storage on the farm. Active windrow methods of composting are sometimes used to dispose of dead birds. On-farm composting prior to shipment has been shown to eliminate most pathogens. While these techniques generally kill pathogens, a grower cannot guarantee the 99% pathogen reduction efficiency (PRE) required for some consumer products or health agencies. Composting actually reduces the fuel value and increases the ash in the litter as the volatile carbon is converted to CO_2. Composting facilities are also sometimes difficult to site, due to the emission of odors and respirable bacteria which can travel several miles in low-velocity plumes.

2.3.4 Anaerobic Digestion

Animal manures are often treated by processing by anaerobic digestion. In anaerobic digestion abut 50% of the volatile solids are converted to methane gas which can be cleaned and used directly in boilers or in engines to generate power. There are about 30 commercial digesters in use in the US that convert animal manures to electricity. Anaerobic digestion can achieve pathogen reduction efficiencies (PRE) above 99%. Poultry manure from caged layers has been used for anaerobic digestion where convenient sources of wastewater such as dairy effluent are used to dilute solids to 13% or less. However, Delmarva poultry litter is too high in solids (65-75%) for commercially demonstrated anaerobic digestion systems. High-solids anaerobic digestion systems are under development which could be used for poultry litter in the future. Investigators at University of California, Davis have developed a multi-stage anaerobic digestion system capable of processing rice straw. This system provides a total mass reduction of 60%, yielding about 5800 cubic feet of biogas per ton of straw. The residue is mainly lignin (60%) and ash (40%), and is highly suitable for land application and soil amendment. A commercial design currently under consideration is a modular system of 1 MW that would process 16,000 tons of straw per year, which is equal to the litter from 100 broiler houses. Designers estimate a net generation cost of $0.02/kWh with feedstock costs of $30-$40 per ton.

2.3.5 Blending

Dilution with other biomass fuels has been suggested as a method of offsetting adverse qualities of poultry litter. Blending with sawdust or wood such as willow provides the best dilution alternative. Wood fuels are larger in size, which improves their behavior in burners and gasifiers, permitting adequate gas flows in reactors, and the concentration of moisture and ash are low enough to improve litter combustion and conversion. Wood fuels would be blended with the litter as it is fed to the boiler or gasifier. Blending would not remove the offending elements but would improve the operation of gasifiers or combustors and delay problems that may occur.

Blending with switchgrass would not have the benefits that might be expected due to the form of the silica present in switchgrass. The amorphous silica present in switchgrass would react with the abundant potassium and sodium in the poultry litter. This would promote fireside slagging and tenacious deposits on heat exchangers. Ash elements in grasses volatilize quickly in combustion or gasification and would react instantly with the ash in the litter.

There may be some advantages to blending with coal. Exhibit 2-6 compares the composition of poultry litter ash with coal ash and projects ash composition of a 5% blend. Such projections cannot predict all that may occur in the boiler, since elements like chlorine and sulfur can form compounds that can cause corrosion or deposits out of proportion to their relative contribution in a blend. However, benefits from blending would come from the increase in sulfur-to-chlorine ratio, and the potential to absorb excess sulfur by potassium, sodium or calcium.

Exhibit 2-6 Elemental Composition of Poultry Litter and Coal Ashes

Source	Poultry Litter	Coal	5% Litter w/Coal
SiO2	8.10	43.18	39.86
Al2O3	1.90	22.64	20.68
TiO2	.20	.92	.85
Fe2O3	1.16	16.68	15.21
CaO	17.30	4.87	6.05
MgO	5.00	.83	1.22
Na2O	9.20	1.37	2.11
K2O	16.3	1.69	3.07
P2O5	24.40	0.57	2.83
SO3	6.70	11.20	10.77
CO2/other	9.74	3.95	2.65
Total	100.00	100.00	100.00
lb alkali/MMBtu	9.33	0.18	.35

2.3.6 Gasification and Staged Combustion

Gasification offers a potential means to remove or reduce the amounts of inorganic constituents before they are fired in the boiler. A gasifier is a separate reactor where poultry litter is largely converted from a solid to a gas by using one-third of the amount of air required for complete combustion. The resulting “producer gas”, or low-btu gas, can be burned in an existing or new boiler. Gasification systems that would be suitable for poultry litter are described in Section 3. Gasification systems range from 24 tpd to 300 tpd. Gasifiers have been used for combustion and power generation from rice hulls, wood and agricultural residues. Systems up to 200 BHP are retrofitted to existing gas or HRT boilers. The largest wood-fired gasifiers in the US generate 5 MW electricity. Both bubbling fluidized and circulating fluidized beds have been operated as gasifiers in systems where the wood gas is burned in power boilers or lime kilns. Bubbling fluidized beds have been used to gasify sewage sludge where the gas is burned in stages above the

bed to reduce NO_x emissions. Gasification has been suggested to capture contaminants from high ash or high alkali fuels. The clean product gas would be fired into an existing boiler.

This has been demonstrated at the industrial scale with densified refuse-derived fuel (RDF) in Italy. Current pilot plants use fluidized bed gasifiers to generate power from wood by burning the gas in gas turbines instead of a boiler. Emissions control is similar to an equivalent sized boiler. Gasifiers often require dry fuels in the 15-20% moisture range.

Staged combustors have a higher tolerance for fuel moisture. They can be fixed or fluidized beds that separate the combustion process into gasification or pyrolysis followed by secondary combustion in an afterburner. Staged combustion has been applied to poultry litter in fixed grate cell burners, underfeed and stoker fired traveling grates, rotary kiln reactors and suspension fired pyrolyzers. Stage combustors such as modular or multiple chamber incinerators have been used with refuse-derived fuels to take advantage of the lower temperatures (1400°F). Lower air flow and hence lower velocities are required for gasification and partial combustion. This prevents slagging and reduces particle carryover.

Temperature control is the main benefit of staged combustion. Temperatures in the primary chamber can be maintained at 1200°F to 1500°F. In this stage the volatile carbon (60% of the fuel) is converted to combustible gases. Some of the fuel is consumed to provide the heat for the process. The remaining fixed carbon (15%) stays with the ash (25%) residue. The lower temperatures limit vaporization of the alkali, which should remain with the ash. The gases that evolve from the first chamber are partially burned at higher temperatures (2200°F to 2400°F) in the secondary chamber. The expanding combustion gases and water vapor carry some of the ash and carbon into the secondary chamber. The low temperature and reducing atmosphere of a gasifier makes it possible to recover ash from the poultry litter as the carbon is converted to a combustible gas. Removal can occur from the gasifier vessel.

In a second stage, the mostly gaseous products of CO, HC and char particulate are combusted at high temperatures (1800°F). In the case of wet fuels or refuse, an auxiliary burner is sometimes provided in the secondary chamber. Two-stage combustion has been used to control NO_x emission with high nitrogen fuels such as sewage sludge or pulp mill waste. Staged combustion appears to leave ash in the primary stage and make it possible to burn dirty wastes. Emission control concerns are similar to direct combustion and control devices are often required, especially for fine particulates.

Emissions from gasification and staged combustion come from the incomplete combustion of the low-Btu gas (which is mostly carbon monoxide and hydrogen,) and the exhaust from fuel driers. Low-Btu gas burners are designed for complete combustion and low NO_x. Small-scale, fixed-bed gasifiers are regulated like the boilers they fire. Even small-scale, fluidized bed gasifiers require particulate emissions control equipment. Innovative gas cleaning techniques may make it possible to gasify poultry litter at the small scale.

A portion of the volatile elements such as sulfur, chlorine and metals vaporizes or becomes

entrained in the gas. Volatile species such as chlorine and sulfur can be captured by reacting them with calcium and filtering them with solids from the hot gas. Gas can be cooled and quenched by direct water spray which collects the soluble or precipitated compounds. Hot gas cleaning systems are in development that use ceramic cone filters to capture fine particulate matter including compounds condensed on the particulate. Unfortunately, all of these approaches need development and testing with litter fuels to assess their effectiveness.

2.3.7 Summary of Components and Costs of a Litter Handling and Preparation System

The basic components of a litter collection and handling system for energy production are outlined below. Odor and sanitary restrictions are the primary elements that distinguish poultry litter from wood or other biomass fuels.

Operation	Cost	Issues	Comment
Transportation - Truck	$8-10/ton	Health, odor	Litter contractor owned
Receiving - Truck dump	TBD	Health, odor	Disinfectant, Isolation, cleaning
Storage Silo	TBD	Health, safety	Vent and biofilter
Mechanical conveyors	TBD	Dust control	Fine fuel and manure particles
Sizing - Grizzly or hammer mill	TBD	Minimal process needed	95% of fuel passes ¼ inch screen
Blend system	$500/kW $4/ton	Ash, slag impact, NO_x	Need co-fire tests
Gasification	$1,000/kW $8/ton (fuel gas)	Developmental status with respect to litter	Gasifiers convert solid fuel to gaseous fuel to remove problem constituents, Need gas cleaning tests

2.4 BIOMASS NUTRIENT FILTER SUPPLY AND MANAGEMENT ISSUES

Biomass fuels, such as poultry litter, all have unique characteristics in terms of composition, availability and combustion properties. Biomass fuels already produce 7000 MW of power in the United States today. The most readily used biomass fuels are clean wood chips which are relatively easy to handle and burn in a variety of conventional and specialty boiler configurations. Harvested nutrient filter biomass could be used to supplement poultry litter as a fuel.

In addition, this study examines woody crops such as willow and herbaceous crops such as Switchgrass which have been suggested as possible nutrient filters to protect the Chesapeake watershed by taking up excess nutrients from land applied litter before they reach waters. Wood or straw could be available from these strips in the amount of 88,000-100,000 tons per year or about 30 tons per day. Harvested material from woody crops is expected to provide a relatively clean wood chip source material of the kind described above. Switchgrass, however, is a herbaceous material which will contain higher concentrations of alkali and other potentially problematic constituents for combustion.

Both willow and Switchgrass are under development as potential crops in the DOE herbaceous and wood energy crops programs. To date there are no commercial operations harvesting either

of these crops for fuel. Costs for nutrient biomass are projected at $30-$36/ton or $2.00-$2.25 per million Btu.

3. ENERGY CONVERSION OPTIONS

Energy technologies considered in this preliminary assessment would apply to large commercial and industrial scale operations. These technologies have been tested on poultry litter, willow or Switchgrass and in most cases demonstrated in commercial operations with biomass fuels that have characteristics which are similar to poultry litter or nutrient filter biomass. With two notable exceptions, none of these technologies have extended operating history with the fuels considered in this study. A local lumber mill on the Peninsula has burned litter as a small portion of its drying kiln fuel. There may be more of examples of this type of minimal cofiring of litter and conventional fuels in other mills. Three large-scale, 12-to-40 MW litter-fired power plants are in operation in England. All three are designed for litter fuels and use a stoker-grate firing configuration. The conversion technologies of interest to this study include direct-fired stoker furnaces, co-firing biomass with conventional fuels, fluidized bed boilers and gasifiers coupled with a variety of furnace/boiler components. Technologies and applications are listed in Exhibit 3-1. An assessment is made of the characteristics of firing systems; the scale of the operation; and the technical feasibility of firing the poultry litter and/or fuel blends with nutrient biomass. Performance of the systems depends on the fuels, boilers, operation and environmental compliance. Descriptions of the technologies and the technical approach are provided in the following sections, with details on systems and the companies provided in the appendix.

Exhibit 3-1. Technologies and Applications

Technology	Scale	Application
Power boiler conversion for Cofiring	400 - 2000 tpd 10 - 50 MW	Utility Boilers
	40 - 200 tpd 1 - 5 MW	Industrial/ Institutional Boilers
Stoker/Spreader Furnace - Power boiler	1200 tpd 30 MW	Bulk Power Generation
Fluidized Bed Power Boiler	1000 tpd 25 MW	Bulk Power Generation
Updraft Gasifier- Power Boiler	40 - 200 tpd 1 - 5 MW	Industrial Cogeneration
	20 - 40 tpd 0.5 - 1 MW	Institutional Boilers, Small Industrial
Suspension Pyrolysis Gasifier, Power Boiler	40 tpd 1 MW	Institutional Boilers, Small Industrial

3.1 COMBUSTION ISSUES

Biomass fuels as a whole are very reactive. Clean wood wastes which represent the bulk of biomass fuels currently in use, are low in sulfur and other potential problem constituents. Nutrient filter willow-based fuels are representative of the relatively clean nature of most biomass fuels in use today. Poultry litter by comparison contains an array of both organic and inorganic chemical

species that require careful attention in combustion system design. Herbaceous biomass nutrient filter materials also require attention, though to a lesser degree than litter. Thus the discussion of combustion issues centers on litter based fuels though some of the same considerations will apply to Herbaceous biomass materials. In the previous chapter, techniques for preprocessing fuels to remove problem constituents was discussed. In this chapter, each conversion technology will be evaluated in terms of its ability to deal with these problems.

3.1.1 Nitrogen Oxides Emissions

Oxides of nitrogen are comprised of two compounds, nitric oxide (NO) and nitrogen dioxide (NO_2). Both are formed in the combustion process. Most flue gas contains higher concentrations of NO than NO_2. They react chemically when they are emitted to the atmosphere. Nitrogen can come from the fuel or the combustion air. A portion of atmospheric nitrogen can oxidize if combustion temperature reaches 2600°F or higher, as in co-firing. The latter is referred to as thermal NO_x and can be controlled by modifying the combustion process. Nitrogen oxide emissions from poultry litter are very high when compared to fossil fuels. The combustion temperatures for litter firing are typically lower than for fossil fuels and a minimal amount of thermal NO_x is formed from the nitrogen in the air.

Nitric oxide emissions are strongly dependent on combustion-zone oxygen concentration and the nitrogen content of the biomass fuel. Nitric oxide emission increases dramatically with increases in excess air and fuel nitrogen, however it is relatively insensitive to either temperature or moisture content. More NO_x is formed from fuel bound nitrogen than from excess air, air staging or heat release rate. Fuel bound nitrogen increases as wood fuel decays, or as extraneous sources of nitrogen are introduced as in resins and glues, litter or manure.

Nitrogen in the litter is very high compared to clean woody biomass fuels. Fuel bound nitrogen must be converted to N_2 or it will convert directly to NO_x emissions. NO_x formation should be highest in co-firing applications where the high nitrogen fuel reacts at high temperatures, adding thermal NO_x formation. Suspension burners can also generate high NO_x. Low NO_x suspension burners with staged combustion and flue gas re-circulation have not been tested at an industrial scale with poultry litter.

Poultry litter characteristics show significant potential for increasing NO_x emissions. Fuels that contain approximately 3% nitrogen, or more than 6 lb fuel N/ million Btu, have significant NO_x potential. Much of this nitrogen exists as free ammonia, which generates NO_x when introduced into an oxidizing environment at temperatures at 2500°F - 2750°F that is common for utility boilers fired with either coal or oil. Firing the chicken litter into a dedicated facility or gasifying the chicken litter can reduce this potential. Tests of gasification systems, with effectively severe combustion staging, have shown some success in managing NO_x.

3.1.2 Corrosion

Litter contains significant amounts of chloride. Introducing a fuel with about 0.5 percent chlorine- or more than 1 lb Cl/MMBtu invites corrosion problems if the fuel provides any significant fraction of the total fuel feed. Alkali chlorides are very stable and carry throughout the boiler and heat exchange surfaces. High sulfur levels are beneficial in forming alkali sulfates in the place of alkali chlorides. However sulfur-to-chlorine ratios must be 4:1 to be effective. The ratio for litter alone is 1:2. Chlorides represent a significant operating and maintenance cost for energy conversion.

High pressure utility boilers, with expensive superheat and reheat sections, could find significant increases in maintenance costs due to corrosion. The Cl content can be managed, and designed for, if known ahead of time. Utility boilers, however, were not designed with chicken litter in mind. Lower-temperature combustion and lower-pressure steam cycles can mitigate this condition.

Of particular concern when cofiring dissimilar fuels is the chemistry and reactions of chlorine, potassium, and sulfur. The potassium will react with chlorine to form a highly corrosive potassium chloride. If sulfur is abundant (from coal or oil), the corrosivity can be reduced as the sulfur displaces the chlorine and potassium sulfate is formed. The chlorine then is released as HCl, which can either cause low-temperature corrosion or be discharged from the stack. The potassium chloride can react with the heat transfer surfaces to form iron chloride, which melts at low temperatures. The fuel compositions of the chicken litter suggest that there would be high potential for such corrosion, particularly in boilers operating at the elevated temperatures and pressures of utility boilers.

Vendors recommend operating heat exchange equipment above the dewpoint of phosphoric acid (450°F) to minimize corrosion. They have detected levels of phosphoric and sulfuric acid in litter gases that would preclude their use in internal combustion engines.

3.1.3 Slagging and Fouling

Poultry litter and herbaceous nutrient filter biomass fuels have a high potential to slag and foul boilers. This issue affects capital and maintenance costs and operating efficiency. Litter contains high quantities of volatile inorganic compounds of sodium, potassium, phosphorous and sulfur. These materials melt or vaporize at gasification and combustion temperatures (800°F-2000°F) and react with other elements in the hot gas, sometimes condensing on other inorganic particles that are suspended in the gas stream. This leads to slagging in the furnace and fouling in the convective tube passes. As they condense and stick to boiler tubes, these compounds form deposits that initiate corrosion, block the gas stream, and inhibit heat transfer. Since the concentrations of these volatile inorganic materials in litter are greater than in most fuels, the litter cannot be burned in many of the boilers installed at Delmarva but must be relegated to new or retrofit gasifiers or boilers. Deposits can be a significant operating problem in cofiring with coal or oil since rates of heat release in the furnace are high and tube spacings are tight. Suitable energy conversion technologies must separate these ash materials for recovery or use as fertilizer.

The fine fuel size is suitable for suspension pyrolysis or co-firing (Brightstar, Foster Wheeler). While it could be fired directly in suspension, the nutrient concentrations create problems of suspending inorganic material in a boiler. In a spreader stoker the fines ignite (or melt) in the hottest part of the flame. The resulting fumes can cause slagging and deposit problems in convection passes. This can present a problem for the stoker systems being evaluated (McBurney, Foster Wheeler, Fibrowatt).

Chicken litter ash interacts with coal ash to cause fouling when cofired. An example of this is the Base/Acid ratio (ash fusion temperature) issue. If chicken litter has a B/A ratio of 3.94 and an ash concentration of 15.5%, and if coal has a B/A ratio of 0.35 and an ash concentration of 7%, then a cofiring at 10% by mass of chicken manure produces an ash that is 20% chicken litter ash and 80% coal ash. The combined B/A ratio, then is 1.07. If the cofiring is 20% by mass, then the B/A ratio is 1.64. The general rule is that ash products with a B/A ratio approaching 1.0, from either side, have the lowest ash fusion temperatures and consequently the largest fouling potential.

Phosphorous (P_2O_5) makes up 4% of the litter as fired. In combustion it reacts to other phosphates that adhere to boiler walls. In gasification and combustion it forms phosphoric acid that will condense in the cold economizers, causing corrosion. Phosphates are hard deposits that are difficult to remove. The first plants in England to fire poultry litter reported severe problems with phosphate deposits that were similar to the experience of almond processors in California. In England, the Fibrowatt power plants depend on collecting large quantities of phosphorus and potassium as deposits on waterwalls for recovery and sale as a major constituent in their "fiberphos" fertilizer product (N-P_2O_5-K_2O of 0-24-14).

3.2 COFIRING AND PARTIAL REPOWERING OPTIONS

Modifying an existing plant to accept litter and nutrient filter fuels is attractive because of the potentially significant installation cost savings. Some of the possible variations are summarized in Exhibit 3-2. There are potential problems for an existing plant if yard workers have to deal with odor and concerns about pathogens. The combustion issues, and the generation of NO_x, are significant. The corrosion and fouling issues are most severe in high-pressure and temperature utility boilers. The primary advantage of cofiring in utility boilers is the presence of sulfur which can slow down the rates of corrosion at high temperatures by forming the more stable potassium sulfates. While cofiring tends to be a lower cost option, adding the new firing systems to an existing boiler still requires all of the fuel receiving, storage and handling systems common to other options.

Exhibit 3-2. Cofiring and Partial Repowering Options

System	Investment	Advantages	Issues
Mixing litter and solid fuels for cofiring with coal	Storage facilities for odor control	Very low cost option Works well when primary fuel is biomass (wood residues)	Limited to a few percent of heat input to prevent fouling problems esp. with non-wood primary fuels
Separate fuel feed and injection system	Receiving, processing, conveying, burners, grate	Potential for higher rates of firing with other fuels at a modest investment	Fouling, corrosion and slagging will sharply decrease boiler life and efficiency
Auxiliary boiler supplying steam to IP or LP turbine	Receiving, processing, conveying, power boiler	Boiler designed for the fuel	Controls, matching boiler output to turbine requirements
Feedwater Heater	Receiving, processing, conveying, water heater	Water heater designed for fuel	Controls, impacts on the turbine of reducing extraction steam

Using a separate combustion system for the litter seems to be the best option for an existing facility, despite the added cost. Prospective units for this type of application are reviewed in the following sections. For partial repowering, a boiler specifically designed for litter combustion would be added in tandem with the existing boiler. Steam generated in this boiler would be piped to the intermediate or low pressure turbine to boost output. This modification will work if there is sufficient excess generator capacity or if the primary boiler is derated or turned down to permit use of the steam from the PDF boiler. This design approach avoids problems of mixing fuels in the existing boiler while taking advantage of the common steam turbine to reduce costs with respect to a greenfield installation. The ash from litter combustion is kept separate from the ash produced in the primary boiler, allowing recovery for fertilizer use. There are control issues that need to be addressed for operation of the dual boilers supplying steam to a single steam generator.

3.3 STOKER-GRATE FIRING SYSTEMS

The spreader stoker with a stationary or traveling grate is typical of most biomass power boilers larger than 100,000 lb/hr steam generation Exhibit 3-3. Heat input is often 250 MMBtu/hr or more. Fuel is introduced to the boiler through feeders that mechanically or pneumatically distribute fuel across the grate. A traveling, or more recently vibrating, grate conveys the unburned fuel and ash that falls to the grate toward the feeders. Fine fuels burn in suspension as they exit the feeders. Coarse particles fall to the grate. Secondary air jets complete gaseous and particulate combustion as the flue gases carry flyash particles to the upper furnace chamber and into the convection passes. Moisture evaporation, burning of volatile matter and burning of fixed carbon occur in a single chamber. Designers estimate how much fuel will burn on the grate and how much will burn in suspension. A layer of ash is needed on the grate to insulate and protect the grate elements. Natural gas or wood fines are sometimes burned in auxiliary burners for startup or to maintain heat rates when burning wet fuels.

Exhibit 3-3. Stoker-Grate Firing Systems

System	Investment	Advantages	Issues
10 to 30 MW Stoker-grate fired boiler	greenfield plant $2800 per kW repowering option $1500 per kW	Designed to minimize impacts of alkalis and acids. Commercially demonstrated with litter.	Only moderate efficiency achievable by this lower-temperature system.

Spreader stokers have been versatile for biomass firing, especially with the variety of hogged fuel and relatively clean wood fuels. Most operators maintain mixed fuel moisture within design limits to operate at full capacity for process steam or power generation. If the boiler is not properly sized, then high velocities can carry fines and condensed fine particulates out through the convection passes where they must be captured by a series of pollution control devices. Due to the action of the spreader stoker, fines enter the boiler at the level of the fireball in the hottest zone of the furnace. Non-combustible contaminants in the fuel will melt, fuse or vaporize. As they travel up the boiler they will condense on flyash particles or form fine particles. Poultry litter or fuels containing high annual growth such as forest residues or urban tree trimmings, or fuels containing resins from adhesives, contain sufficient alkali to create a "fume" of submicron particles that will carry through the convection passes and must be captured in an electrostatic precipitator or filter bed. Potassium or alkali fumes in spreader stokers have created emissions control problems for spreader stokers with wet scrubbers.

Stoker-grate firing systems have proven their ability to fire a wide range of alternate fuels. There are numerous examples of stokers firing biomass fuels comparable to the nutrient filter biomass. The power plants built by Fibrowatt in England are the only examples of large-scale, operating

systems designed for litter. The Fibrowatt plant, supplied by Foster Wheeler, is designed to maintain moderate firing temperatures to minimize vaporization of potassium and phosphorous. Their high internal surface area permits condensation and collection of suspended ash particles. At the same time flue gas exit temperatures are maintained well above the dew point to avoid corrosion. Fine litter is porous and therefore not suited to fixed or deep bed burning without a moving grate. A thin moving or rotating bed is recommended that will permit complete carbon burnout without the fuel crusting or caking as it burns. Particulate control is achieved in the Fibrowatt systems using a baghouse. It is possible that the baghouse is used as a collection point for alkaline earths in the fuel to absorb acid gases, since no other acid gas removal is used.

It is possible to use other grate configurations for poultry litter but they have not been thoroughly tested. Examples include small modular, spreader stokers with internal recirculating combustion zones (McBurney) or underfeed stokers with fixed grates (Hurst). Their use depends on the fuels available and heat or steam demand of the site. Small scale systems feed fuel onto a fixed grate where it burns in a pile. Combustion is staged so that about one third of the air, or primary air, required for complete combustion enters through the grate to dry and convert volatile carbon to combustible gases. The remainder of the air is introduced as secondary or overfire air to burn the volatile gases. Another example is the Dutch oven or the multiple chamber furnace where combustion is separated into two combustion chambers. Two systems that have been recently proposed for poultry litter use a primary chamber to gasify the fuel and a secondary cyclonic afterburner to complete combustion.

The fixed grate or pile burner is a simple system to operate and maintain. It will accept a wide variety of fuels and moisture contents but works best with a rough, chunky fuel with a bulk density of about 16 lb/cubic foot. The firebox is often kept small to maintain a high heat release. This increases gas velocities which carries fine particles off the fuel bed into suspension. Turbulent overfire air is important to achieve complete combustion. Pile burners with a vertical chamber are also used where fuel is dropped on the pile in a semi stoker arrangement. Once airborne, the fine particles need an even larger settling chamber. These burners often have a low turndown rate measured by the ratio of maximum firing rate to the lowest firing rate. Auxiliary burners are sometimes used for wet fuels. These burners have higher CO emissions than other designs. The tolerance of these systems of high ash fuels depends on the grate design and the ability to remove inert material.

A variation of the fixed grate and pile burners are the small reciprocating grates, often used in Europe. The grate slopes down to an ash pit from which ash is removed continuously. The reciprocating grate continuously or periodically turns the fuel, exposing unburned fuel. Air velocities and temperatures at the grate are low. High-temperature combustion occurs in the gas phase above the grate. These grates are excellent for a wide variety of fuels because they leave most of the fuel and ash on the grate. These can handle biomass fuels up to 6 tph and produce up to about 5 MW. A baghouse or ESP is used with these units for power generation or district heating. Experience in Europe with poultry litter has shown that these systems work best with a thin layer of fuel.

Small grate systems are also fed with spreader stokers, or with mechanical or air-swept spouts that deliver the fuel onto the grate. While it is possible to get a uniform feed to the grate they also purport to burn the fuel in suspension. If furnace volume is too small or if the fuel is too large, too wet or unevenly fed they become inefficient suspension burners. This results in significant carryover and high CO. Small scale (1 tph) burners sometimes struggle to meet emission limits because inert materials in the small semi-suspension systems carry over with the flue gas, plugging boiler passages or emitting out the stack. These boilers operate best with clean dry fuels.

3.4 FLUIDIZED BED BOILERS

Fluidized bed boilers are reactors borrowed from the chemical industry (Exhibit 3-4) They were adapted to coal combustion to allow removal of potential air pollutants concurrently with combustion. Additives injected into the fluidized reactor bed combine with the target pollutant species, forming solids that are removed with the ash. Combustion temperatures are moderated (1450°F to 1700°F) and thermal NO_x production is thus reduced. Slagging and fouling potential is reduced. Fuel size requirements are well matched to poultry litter particle size. However, the reactor vessel and heat exchange tuning submerged in the combustor bed are subject to erosion by the bed components. Downstream heat exchangers are protected by cyclone filters that return particulates and bed materials to the reactor. As long as the recycling systems are efficient, combustion efficiency is very good (greater than 99% carbon conversion). Biomass-fired fluidized bed boiler efficiencies are in the 60 to 80% range, depending on the specific fuel characteristics.

Exhibit 3-4. Fluidized Bed Combustion Systems

System	Investment	Advantages	Issues
10 to 30 MW fluidized bed boiler and generator	greenfield plant $ 3500 per kW retrofit option $ 2000 per kW	Minimizes impacts of alkalis and acids. Potentially higher efficiency (lower heat rates).	Increased complexity Erosion and fuel feed problems Higher ash volumes with bed material and ash mixed

Bubbling fluidized beds and circulating fluidized beds are the most recent technologies to be employed in biomass combustion. Consisting of a bed of sand or other inert media, the fluidized bed receives fuel from above the bed or has it injected directly into the hot sand bed. When fuel contacts the hot bed media it is pyrolyzed faster than on a grate and so combustion can be rapid and complete. Fuel that is introduced into the bed migrates upward in a gaseous plume as the carbon and volatile compounds burn. In-bed tubes are sometimes used to control bed temperatures. Secondary combustion air is provided above the bubbling bed to complete combustion. An ample "freeboard”or vapor space above the bed provides space for gaseous combustion and heat transfer. As in the spreader stoker gases exit the furnace into convection

passes. Alternatively, fuel can be fed through a chute above the bed. Dense or partially burned fuel falls into the bubbling bed. Fines burn in suspension above the bed or are carried out of the furnace. Ash is removed by withdrawing some of the media from the combustor and screening flyash from the media. Flyash is collected from hoppers below the convection passes, air heaters and ESP or baghouse.

The bubbling fluidized bed has been a reliable system for biomass combustion. It is feasible for systems of 60 million BTU/hr or greater (5 dry tph). There are power stations generating 25 MW from a single fluidized bed boiler. It will burn a variety of fuels with variable ash content. However, it burns better with a minimum of fines or inert material. Operators tend to manage fuel to keep the fuel ash content below 5% when possible. It is convenient to introduce reactants such as limestone into the bed to aid in sulfur capture. This also serves to keep the bed material from agglomerating when fuels with alkali or other slagging elements accumulate. Fluidized beds have been efficient incinerators for a variety of urban wastes and residues including plastics and sewage sludge. Fly ash carryover can be high and emissions control equipment is required. Some data suggest that an overfed bubbling bed may not be as efficient in capturing sulfur and other contaminants as a circulating fluidized bed.

Air and gas velocities in a circulating fluidized bed (CFB) are several times higher than in a bubbling bed. Fuel is introduced into the bed and circulated with the hot sand. A cyclone is used to disengage the char and media particles from the combustion gases and recirculate them into the bed. This circulation provides a thermal mass that allows the CFB to accept a wide variety of fuels and fuel moisture contents. In practice, the CFB operates very much like a suspension burner and is set for a given fuel moisture and particle size distribution to maintain a uniform flame throughout the boiler. It is possible to stage combustion with a very uniform temperature profile in a CFB from 1200°F at the introduction of the fuel to 1650°F at the furnace exit. While the CFBs appear to have good potential for sulfur capture, the high exit temperature requires that all volatile elements exit the furnace, so that extensive emission control equipment is required. CFBs have been used for burning high-alkali fuels and combinations of wood or straw with coal.

The disadvantage of using a fluidized bed for poultry litter is the need to add sequestrants or additives such as lime to prevent the alkali in the litter from agglomerating the bed. This dilutes the ash so that it cannot be recovered and sold as a fertilizer.

3.5 BIOMASS SYNGAS FIRED BOILERS: GASIFICATION AND STAGED COMBUSTION

Biomass gasifiers usually require fuels in the 15-30% moisture range. They have been applied to small-scale wood combustion and power generation. Systems up to 200 BHP (6500 pph) are retrofit to existing gas or HRT boilers. The largest biomass-fired gasifiers in the U.S. generate 5 MW from wood and agricultural residues. These and other systems in Europe have demonstrated the commercial reliability of gasification.

Both the bubbling and circulating fluidized beds have been operated as gasifiers. They have been used to fire power boilers or lime kilns. Bubbling fluidized beds have been used to gasify sewage sludge. Where, the gas is burned in stages above the bed to reduce NO_x emissions. Gasification has been suggested for high-ash or high-alkali fuels to capture contaminants in a fluidized bed located next to an existing spreader stoker where the clean product gas would be fired into the boiler. This has been demonstrated at the industrial scale with densified refuse-derived fuel in Italy. Current pilot plants use fluidized bed gasifiers to generate power from wood by burning the gas in gas turbines instead of a boiler. Emissions control is similar to an equivalent-size boiler.

Staged combustors can be fixed or fluidized beds that separate the combustion into a gasification or pyrolysis stage followed by secondary combustion in an afterburner. Staged combustors such as modular or multiple-chamber incinerators have been used with refuse-derived fuels to take advantage of the lower temperatures (1400°F), lower air requirements and hence lower velocities required for gasification and partial combustion while in the first stage. Lower temperatures and gas velocities prevent slagging and reduce particle carryover. In a second stage, the mostly gaseous products of CO, HC and char particulate are combusted at high temperatures (1800°F). In the case of wet fuels or refuse an auxiliary burner is sometimes provided in the secondary chamber. Staged combustion has been proposed or applied to poultry litter in fixed and moving grates (Heuristic, PrimEnergy), and rotary pyrolyzers (Callidus). Two-stage combustion has been used to limit NO_x emission with high nitrogen fuels such as sewage sludge or pulp mill waste and with fuels like rice hulls and crop residues that have a potential for slagging. While staged combustion appears to leave ash in the primary stage and make it possible to burn dirty wastes, emission control concerns are similar to direct combustion and control devices are often required, especially for fine particulates. One vendor has also proposed using a baghouse, like the English plants. Another uses a steam quench to condense the submicron particulates (<10 microns) so that they can be more easily removed in an electrostatic precipitator. A third incorporates mechanical and electrostatic gas cleaning in their combustible gas system.

Emissions from biomass gasification and staged combustion come from the incomplete combustion of the low-Btu gas, which is mostly carbon monoxide and hydrogen, and the exhaust from fuel driers. Low-Btu gas burners can be developed for low NO_x emissions. Small-scale fixed bed gasifiers are regulated in the same manner as the boilers they fire. Even small-scale fluidized bed gasifiers require particulate emissions control equipment.

Gasifiers can reduce NO_x formation through staged combustion to convert a high percentage of

the fuel nitrogen to N_2 in reducing conditions. Typical control levels are 0.6 lb NO_x /MMBtu. A rotary kiln gasifier achieves 0.18 lb NO_x /MMBtu in a staged combustor. These levels were also achieved with high (8%) nitrogen sewage sludge in a fluidized bed gasifier in California. A fixed bed gasifier achieved 0.78 lb NO_x/MMBtu in poultry litter tests for TVA. All technology suppliers have requested extended test firing to verify NO_x control performance.

Small scale gasification and pyrolysis systems manufacturers (e.g., Thermogenics, Brightstar) intend to cool and quench combustible gases so that particulate chemicals can be recovered in an electrostatic precipitator. Their proposed technologies are currently being tested.

3.6 COMBUSTION BYPRODUCTS

The single most import byproduct of combustion is the ash. Ash can be either a disposal problem and cost or a valuable byproduct generating revenue for the project. As a first approximation, broiler litter ash is expected to have a wholesale fertilizer replacement value of about $70-85/ton, depending on solubility of the ash P_2O_5 and K_2O and the carbon content of the ash. These fertilizer replacement values are based only on the available P_2O_5 and soluble K_2O in the ash as specified by U.S. fertilizer labeling laws. Experience using broiler litter ash as a fertilizer in the United Kingdom indicates that the above estimates of ash fertilizer value are conservative, and that with adequate documentation some of the less soluble ash P_2O_5 and K_2O not included in U.S. fertilizer labels may have market value. A minimum of $20/ton may be required to granulate the ash into a form acceptable for use in the existing fertilizer infrastructure and the cost of transporting the ash out of the local area with phosphorus surpluses is estimated at $15/ton.

After subtracting granulation and transportation costs, the net value of the ash as fertilizer at the energy conversion facility is estimated in the range of $35-50/ton. The fertilizer value at the energy conversion facility may be greater if the less soluble forms of P_2O_5 and K_2O have market value. Also, other macronutrients, especially S, and some micronutrients may have additional fertilizer nutrient value in some situations. Use of phytase enzyme in broiler diets or treating broiler litter with alum will reduce the amount of plant-available P_2O_5 in broiler litter ash and reduce the fertilizer nutrient value of the ash. An ash fertilizer value of $50/ton corresponds to $10/ton of broiler litter (dry basis), assuming the broiler litter contains 20% ash on a dry basis. An ash fertilizer value of $50/ton at the energy facility ($10/ton of boiler litter) may offset most or all of the broiler litter feedstock costs. Therefore, the fertilizer value of broiler litter ash is projected to be an important factor affecting the economics of using broiler litter for energy. The precise value of broiler litter ash in the United States will not be known until ash products are produced and characterized from specific commercial-scale processes and until markets have developed for the ash.

Regulations being considered by EPA on metal loading from land-applied by-products are not expected to limit use of broiler litter ash as a fertilizer.

4. MATCHING TECHNOLOGIES TO PROSPECTIVE APPLICATIONS

Biomass is used to generate nearly 7 GW of electric power in the U.S. The majority of that power is generated by the pulp and paper industry where biomass is a natural fit. The industry's resource for fiber is biomass and the residues it generates in processing pulp are an important energy resource. About 50% of the industry's heat and power needs are generated from biomass. Using the pulp and paper industry as a model, it might seem that the poultry industry on the peninsula is in a similar position to turn a waste product into a resource. However there are significant differences in the operations of these industries and in the quality of their respective resources that make this less of a natural match. This study examined a range of potential users, from local institutions with existing central heating boilers to bulk power producers. Each potential user has different decision criteria with respect to choosing energy resources. All are naturally cautious regarding a much more difficult fuel to handle. Exhibit 4-1 summarizes the types of issues and criteria that each prospective class of user will consider with regard to use of the PDF and nutrient biomass fuels.

Exhibit 4-1. Issues and Decision Criteria

User Classification (sub-category)	Issues and Decision Criteria	
	Issues	**Criteria**
Private Sector Power Plants (existing)	Permitting, effect of fuel on current operations, long term fuel supply outlook, safety, public support, truck traffic	12 to 20% return on capital Competitive wholesale power production costs
Private Sector Power Plants (new)	Permitting, long term fuel supply outlook, safety, public support, truck traffic	15 to 25% return on capital Competitive wholesale power production costs or guaranteed sales
Industrial Heat and Power Plants (Poultry Industry)	Health safety, operating reliability and ease of use, management support, truck traffic	3 to 5 year payback
Industrial Heat and Power Plants (Other Industry)	Ease of use, cost savings potential, truck traffic	2 to 3 year payback
Public Sector Heat and Power Plants (state and county government buildings, prisons)	State support of project, public safety, low risk, truck traffic	Positive life cycle costs
Public Sector Heat and Power Plants (Universities & Colleges)	State support of project, public safety, low risk, truck traffic	Positive life cycle costs
Public Sector Heat and Power Plants (Primary and Secondary Schools)	County and state support of project, safety, low risk, truck traffic	State grant or county budget authority for capital improvement

Based on the foregoing sections characterizing the fuels and the conversion systems, it is very

unlikely that any of the public sector applications would make sense for the first-of-a-kind installation. Power companies and local industry are better equipped to deal with the potential risks of managing this fuel and operating and maintaining the facilities required to process it. A successful demonstration of the application could change that perception if the safety issues and risk concerns are shown to be manageable. The one exception is the Eastern Correctional Institute which has already a track record in producing energy from biomass. This exception is the subject of a separate study. Preliminary results from that study are used here simply to suggest the potential this application has vis-à-vis the other choices.

The best opportunities for the use of these fuels rests with the private power producers, the poultry industry and selected other industries that have the capability to handle these resources. In the sections that follow the general cases for use of poultry litter fuels are outlined in terms of applicable conversion systems and economics of energy production. Supporting these general conclusions are three case studies that were perfromed. These case studies examine three potentially fessible applications and are included as self contained appendices to the report:

- Repowering Vienna Station, Vienna, MD
- New Gasifier -Boiler for a Feed Mill, Bridgeville, MD
- New Gasifier -Boiler for a Poultry Processing Facility, Georgetown, DE

4.1 BULK POWER PRODUCTION APPLICATIONS

U.S. power producers have become adept at using a variety of opportunity fuels that are by-products or wastes from other industries. The primary motivation of power generators for using these fuels is the possibility of reducing power production costs. A secondary motivation in some cases is the desire to cement good relationships with the industry producing the waste to garner some loyalty to the producer when it comes to choosing providers of electric power. The principal advantage offered by power producers is the possibility of achieving economies of scale by building a single facility capable of consuming a large fraction of the litter and nutrient biomass produced on the peninsula. In addition, they employ the types of engineering and operations staff with the skills to operate and maintain a conversion system with the complexities of PDF generation. Finally, they can provide the required measures to safely handle and process these biomass resources. The two existing power plant properties on the peninsula situated in the heart of the poultry producing region are the Vienna and Indian River Power Stations.

Conectiv's preliminary technical studies show that the Vienna plant has the potential to use both oil and PDF . Two basic approaches were identified for further evaluation. The first approach entailed retrofitting the oil-fired boiler with a stoker grate and ash removal system for the PDF. If the system required Vienna to provide more power, the Unit 8 boiler would exclusively fire oil to produce 155 MW. The second approach entailed the installation of a stand-alone boiler that would supply steam to the existing turbine in tandem with the existing oil-fired boiler. The oil-fired boiler would continue to be available for peak loads.

Using these sites to cofire or partially repowering the existing facilities to utilize biomass fuels can

save significantly on capital costs and permitting costs associated with the project. Based on the technical evaluations presented above and the discussions with Conectiv representatives the option of greatest interest is the partial repowering of the Vienna facility. The following discussion could apply to either station. Exhibit 4-2 lists the characteristics of a repowering retrofit using a separate, biomass-fired boiler providing enough steam to generate 25 MW of power.

Exhibit 4-2. Repowering Retrofit at an Existing Power Station

Installation	Repowering - Receiving, handling, processing, storage, boiler, steam connections to turbine, controls
Capital Cost @$1500/KW	$37.5 Million
Heat Rate (Efficiency)	15,500 Btu/kWh (22%)
Power Production @ 70% capacity factor	153,000 MWh per year
Fuel/Litter Consumption	248,000 tons per year

The second alternative is the construction of a new, dedicated facility for PDF and biomass conversion, Exhibit 4-3. The advantages to this approach are that the facility is built from top to bottom with these fuels in mind. There are no compromises to match output to existing turbines. However, the cost of a greenfield facility is substantially more than the repowering case.

Exhibit 4-3. Developing a Greenfield Biomass Generating Station

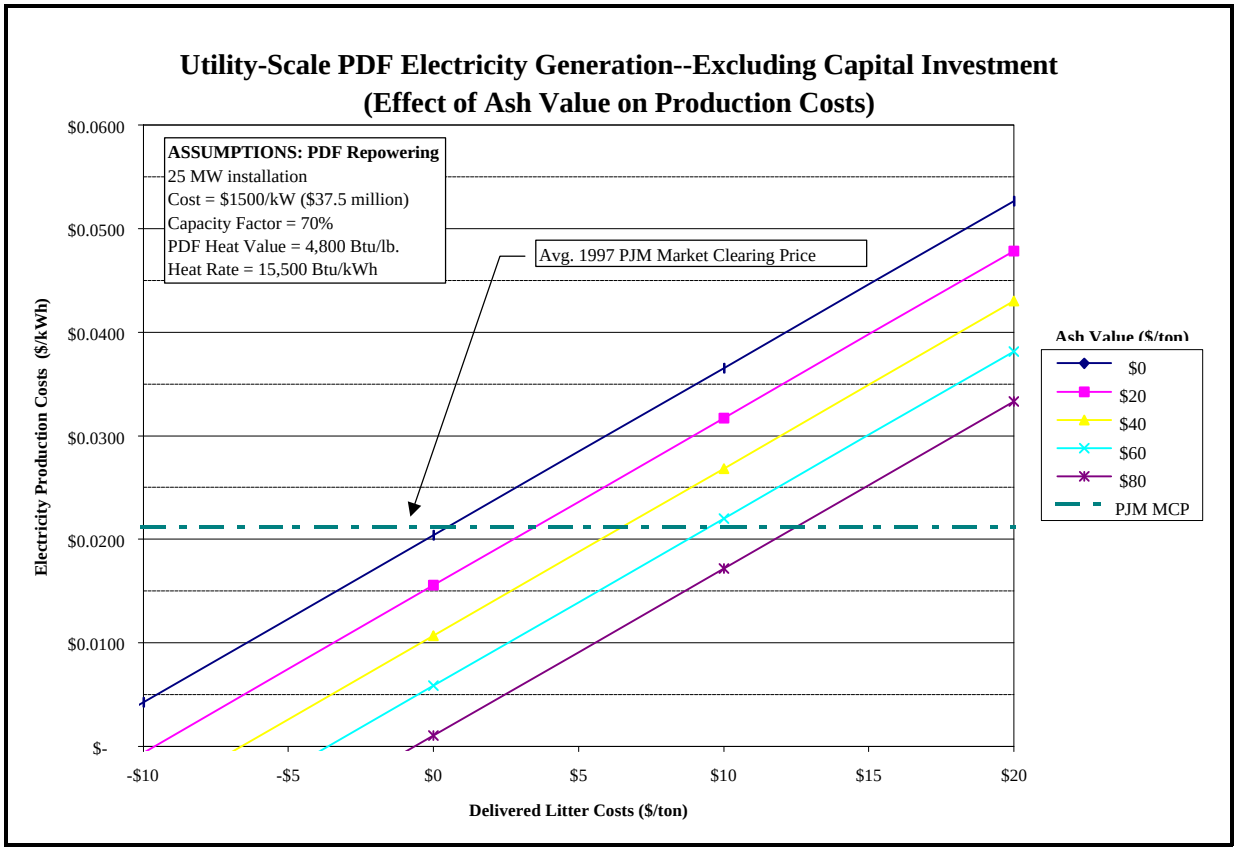
Installation	Site, receiving, handling, processing, storage, boiler, steam turbine, generator, cooling towers, switchyard, controls, facilities
Capital Cost @$2500/KW	$62.5 Million
Heat Rate (Efficiency)	15,000 Btu/kWh (23%)
Power Production @ 70% capacity factor	153,000 MWh per year
Fuel/Litter consumption	240,000 tons per year

To evaluate the potential economics of this installation we estimated the power production costs for the facility as described above. We have produced a family of curves to represent the Cost of Electricity (COE) as a function of delivered cost (or fee) for poultry litter. There are two ways for power companies to view production costs. Once a plant is built, the owners will usually sell power as long as the current selling price exceeds operating costs of the plant where fuel, operating and maintenance costs are the basis for determining the floor for the bid. Under these conditions the plant can sell power at a profit. However to recoup the investment costs over the

life of the project, the selling margins or profits must be sufficient each year cover the investment costs for producing power amortized over the life of the project. This case can also be compared to the current competitive alternative for new generation capacity -- the gas fired turbine generator. If the repowering option can compete with a new gas turbine installation then it is likely to be a good choice for adding new capacity. We have presented results for both cases below.

Exhibit 4-4 shows the relationship between litter costs and power production costs excluding the investment costs for the repowering case. As a benchmark for competitive wholesale power, the average market clearing price for the PJM power pool is shown as a dashed line. The range of possible cost for delivered biomass extends from minus $20/ton to plus $20/ton. Negative costs represent a fee paid by poultry producers to the power companies to dispose of the wastes. Positive costs represent the opposite condition, where the power company pays the poultry producer for delivered litter. The family of curves represents the effects of potential byproduct ash sales for fertilizer. The range of prices for ash sold for fertilizer is from $0 to $80 per ton of ash. For this case the power company can produce power in the competitive range if it receives biomass at the plant gate at no cost and gives the ash by-product away to ash marketers. When the ash is sold to marketers at the high value of $80 per ton the economic situation improves and fuel values increase to about $10 per ton for a competitive production cost. In this case the plant

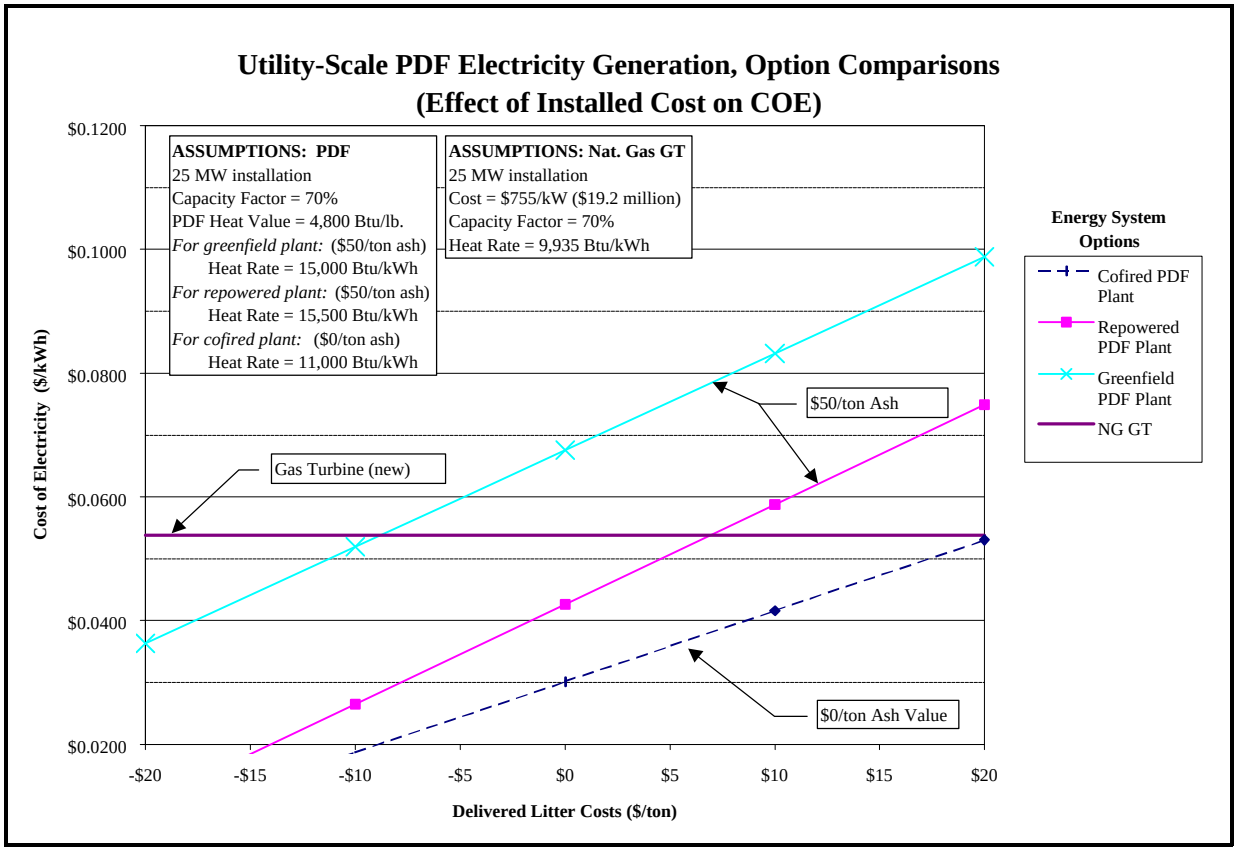
Exhibit 4-4. Production Costs for a Repowering Project (Fuel and O&M)



will generate the margin of income needed to compensate investors only if the fuel costs are below the breakeven price of $10 per ton. If the ash cannot be used for beneficial purposes, the opposite will be true and power producers would be looking for a modest tipping fee for the litter to cover their ash disposal costs.

The series of curves in Exhibit 4-5 represents the case in which investment and operating costs for several alternatives are compared to evaluate options for meeting increased demand on the system. In this case we have compared the costs of a greenfield station for biomass, the costs of repowering an existing station for biomass and the current benchmark for competitive power in this size range - a combustion turbine fired on natural gas. For this comparison an ash value of $50/ton is used for the repowering and greenfield cases. Since, in a cofiring application the ash from poultry litter will be commingled with coal ash it has been assumed that no market value will be available for ash in the cofiring case. The COE for repowering matches the combustion turbine COE at a delivered fuel cost of under $7 per ton. For the greenfield plant to compete with this benchmark a tipping fee for delivered biomass near $8 per ton is required. This differential is only maintained if the retrofit costs estimated are attained. Frequently, repowering projects do not go smoothly and unforeseen engineering problems can add to costs quickly. The key to achieving the potential cost savings will be the condition of the existing equipment and the experience of the design team in dealing with both this fuel and integration issues for repowering.

Exhibit 4-5. Production Costs for New Sources of Power (Investment, Fuel and O&M)



As indicated in the exhibit, the simple cofiring option could be economically the most attractive option if the plant owners could be assured that the deleterious effects described in Section 3 can be mitigated. This will require a concerted R&D effort to resolve.

4.2 COGENERATION AND STEAM PRODUCTION AT INDUSTRIAL FACILITIES

Industrial facilities have one major advantage over bulk power producers - they can make good use of the heat not used for power production to meet process needs. Overall conversion rates of fuel to steam and power can be quite high -- up to 85%. Another advantage is that electricity produced at industrial facilities offsets electricity purchases priced at about 4.7 cents/kWh (or more); whereas electricity generated at a utility power plant must compete with wholesale priced electricity at an average of about 2.2 cents/kWh. On the other hand, industry will not enjoy the economies of scale that can be achieved by power producers and will not have the engineering and personnel resources to deal as effectively with these specialty fuels. Yet they will need to provide all of the same operations for handling and processing the fuel as a larger power plant. Industry will invest in capital improvements that enhance productivity and product value first and then supporting facilities and services. The common hurdle for internal investments in energy producing facilities is a three-year payback. Nearly all industry representatives contacted would be willing to entertain offers from private energy companies who would make the investment in energy facilities and provide energy services at reduced cost to the industry.

In this study, three types of installations were evaluated for industrial applications:

- A new gasifier genset for a poultry processing plant or feed mill
- A gasifier-packaged boiler installation at a feed mill and at a processing plant
- A new cogeneration facility for poultry processing plant or other manufacturing plant

Option 1 provides self-generation for the facility. The PDF system is sized below the maximum facility load and primarily displaces power purchased at the retail cost (Exhibit 4-6). Any excess generating capability at times of low load is valued at the wholesale cost of electricity. The relatively low efficiency for the generator option is due to a number of factors for commercially available equipment. Future systems that have a higher carbon conversion efficiency at the proposed scale could improve results substantially.

Exhibit 4-6. Option 1 - New Gasifier Genset for a Poultry Processing Plant or Feedmill

Installation: 1 MW Capacity	New facility – Receiving, handling, processing, storage, gasifier, boiler, steam connections to turbine, steam turbine, generator, controls
Capital Cost @$2760/KW	$2.76 Million
Heat Rate (Efficiency)	28440 Btu/kWh (12%)
Power Production @ 90% Capacity factor	7900 MWh per year
Fuel/Litter Consumption	18,900 tons per year

Option 2 is the lowest capital cost option (Exhibit 4-7). This option avoids the additional capital costs associated with power generation equipment. All of the costs of litter handling and processing are still included.

Exhibit 4-7. Option 2 - New Gasifier Boiler at a Poultry Processing Plant or Feedmill

Installation: 8000 to 16,000 lb/hr steam output	New Gasifier - Receiving, handling, processing, storage, gasifier, boiler, controls
Capital Cost	$1.2 to $1.8M
Thermal Efficiency	65 %
Fuel/Litter Consumption	6000 to 16,000 tons per year

Option 3 is a cogeneration facility that benefits from the production of steam and power (Exhibits 4-8 and 4-9). The overall investment is lower than for a pure power application (at a similar scale) but substantially higher than Option 2. The larger scale system described in

Exhibit 4-8. Option 3 - New Small-scale Cogeneration Facility

Installation: 0.125 MW Capacity and 6000 lb/hr steam output	New facility - Receiving, handling, processing, storage, gasifier, boiler, steam connections to turbine, steam turbine, generator, steam connections
Capital Cost	$1.77 Million
Overall Efficiency	(61%)
Power Production @ 90% Capacity factor	985 MWh per year plus
Fuel/Litter consumption	7900 tons per year

Exhibit 4-9 is the most economic to operate (as shown in Exhibits 4-10 ans 4-11) and would be

suitable for the largest manufacturing plants described in Chapter 1.

Exhibit 4-9. Option 3 - New Medium-scale Cogeneration Facility

Installation: 2.5 MW Capacity and 96000 lb/hr steam output	New facility - Receiving, handling, processing, storage, gasifier, boiler, steam connections to turbine, steam turbine, generator, steam connections
Capital Cost	$9.9 Million
Overall Efficiency	(59%)
Power Production @ 90% Capacity factor	19,710 MWh per year
Steam Production @ 90% Capacity factor	756.8 million lb per year, 681 billion Btu/yr
Fuel/Litter consumption	131,400 tons per year

Exhibit 4-10 provides a family of curves for the above options relating simple payback to fuel cost where ash is provided to ash marketers at no charge. To make these projects feasible, a tipping fee for litter delivered to the plant gate would be charged in the range of $10 to $20 per ton (or more for some systems).

When ash sales are taken into account at the levels suggested in section 3.6 of this report, the economics of energy production are substantially improved. Exhibit 4-11 presents those cases. The most attractive options involve cogeneration, where the tipping fee for litter delivered to the plant gate could be in the range of $0 to $10 per ton. For the other options the fee charged for taking the litter fuel would still be above $20 per ton.

Exhibit 4-10 Industrial Scale PDF System Economics Without Ash Sales

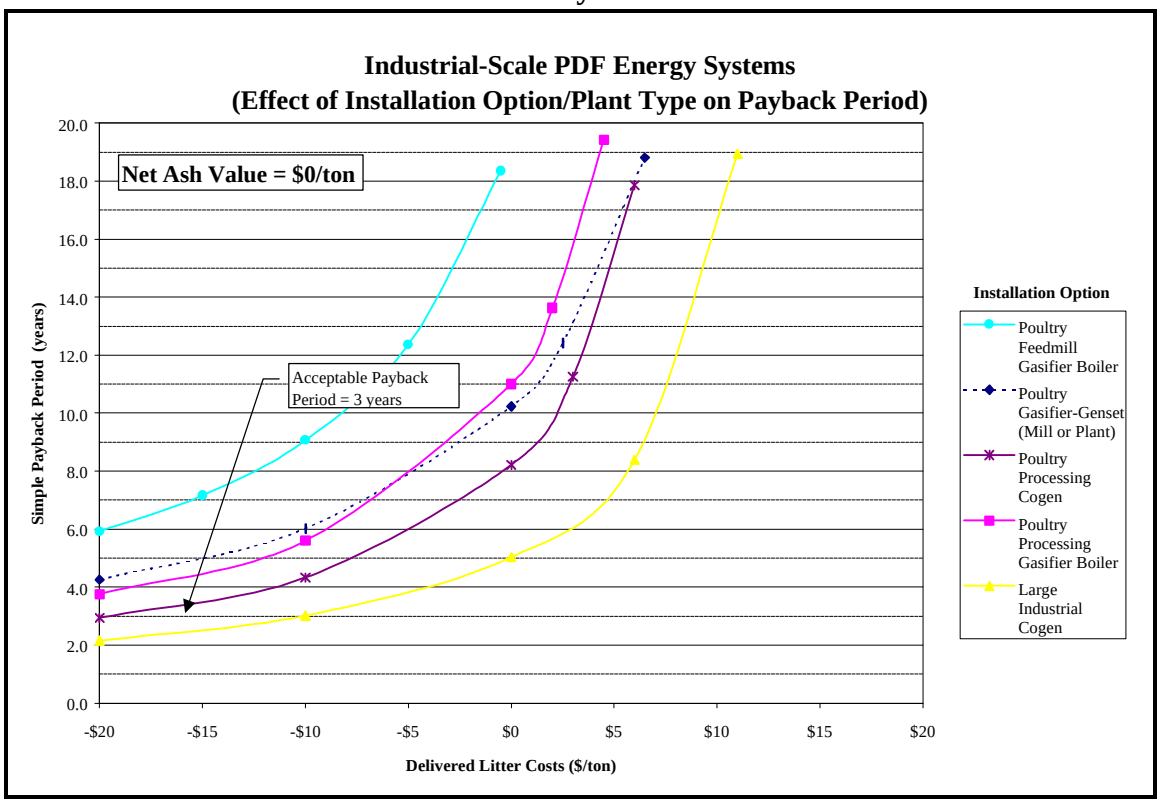
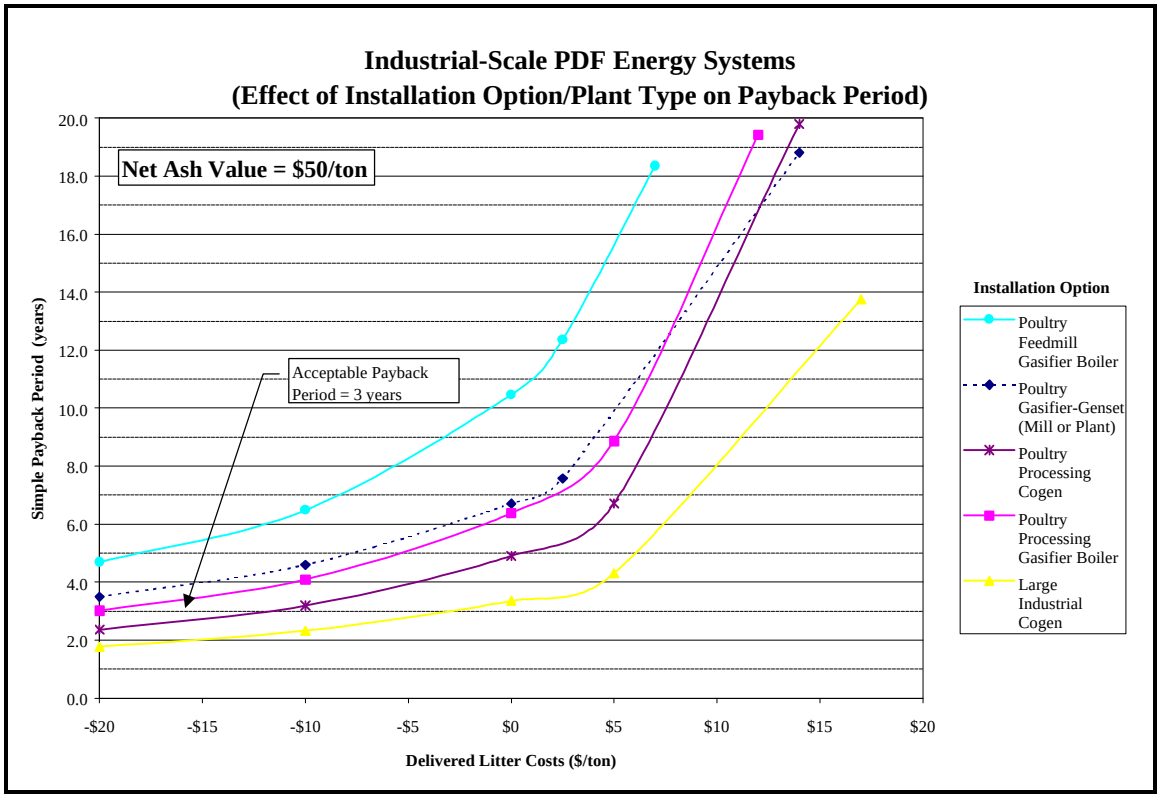


Exhibit 4-11 Industrial Scale PDF System Economics With Ash Sales At $50/ton



-	MW
8.0	MMBtu/hr
24.0	tpd
8,000	lb/hr
$ 1.148	million
0.055	/kWh
2.5	/MMBtu
$ 387,965	/yr
$ 116,568	/yr
6,953,408	kWh/yr
48,204	MMBtu/yr
#DIV/0!	/kW
$ 144	/pph steam
$ 47,833	/tpd PDF
5%	of capital costs per year
$ 0.1	million
75%	
77%	
$ -	/ton
4,800	Btu/lb
-	kWh/yr
53,961,600	lb/yr
48,565	MMBtu/yr
0%	
100%	
6,745	tons/yr
15%	
1,011.78	tons/yr
$ 50	/ton
$ 50,589	/yr
$ -	/yr
$ 57,400	/yr
$ 50,589	/yr
$ -	/yr
$ 116,568	/yr
$ 109,757	/yr
$ 10.46	years