The Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia's Chesapeake Bay Watershed

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(ABSTRACT)

Nutrient runoff from excess land application of poultry litter in the Chesapeake Bay Watershed has caused damage to the Chesapeake Bay and lead to the need for alternative poultry litter disposal methods. This study provided an economic feasibility analysis of the use of poultry litter as a partial replacement of coal at an electrical generating unit in Virginia's Chesapeake Bay Watershed. Previous research on the feasibility of converting litter to energy failed to include uncertainty in benefit-cost variables, therefore, this study used risk analysis to incorporate variable uncertainty. Project net worth in previous studies was measured under a public investment scenario with risk neutral preferences but did not take into account risk averse preferences common in private investment. This paper compared benefits under both public risk neutral and private risk averse investor preferences. NPV results showed the proposed project to be feasible but sensitive to the acquisition cost of poultry litter, the unit ash value of litter, and future coal price projections. The maximum level of risk aversion required for feasibility increased when expected returns were measured on an investment scale compared to an annual income scale. Poultry litter combustion produced lower levels of NOx and SO_2 emissions compared to coal, therefore, emission allowance trading through the EPA market based trading programs generated additional benefits to the model and increased the maximum level of risk aversion permitted for feasibility. Results suggested the potential to dispose of 110 thousand tons of poultry litter per year from the Chesapeake Bay Watershed without violating EPA emission standards.

DEDICATION

To my parents for giving me the drive and confidence needed to continue my education. To my wife for providing me with her strength, support, and patience throughout my graduate education. I could not have completed this without her. Last but not least, to my dog Scarlet for her unconditional support during the toughest times.

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Acronyms

AAP	Annual Ash Production
AAPS	Ash Production in Summer
AAPW	Ash Production in Winter
ACC	Annual Cleaning Cost
ALAC	Annual Litter Acquisition Cost
ALC	Annual Labor Cost
ALR	Annual Labor Requirement
ALTC	Annual Litter Transportation Cost
AMRC	Annual Maintenance Repair Cost
ARI	Alternative Resources Inc
ARS	Agricultural Research Service
AUC	Annual Utility Cost
Btu	British Thermal Unit
CARA	Constant Absolute Risk Aversion
CBP	Chesapeake Bay Program
CC	Cleaning Cost
CHP	Connected Horse Power
CRF	Capital Recovery Factor
DEQ	Department of Environmental Quality
DOE	Department of Energy
ECI	Eastern Correctional Institute
EEM	Environmental Resource Management, Exeter Associates Inc., and McBurney Corp.
EGU	Electrical Generating Unit
ENPV	Expected Net Present Value
EPA	Environmental Protection Agency
HAHE	Hall Associates and Heuristic Engineering
HI	Heat Input
HR	Hours of Operation
HV	Heating Value
LUC	Litter Utilization Capacity
LUCS	Litter Utilization Capacity in Summer
LUCW	Litter Utilization Capacity in Winter
MC	Monte Carlo Simulation
MES	Maryland Environmental Service
MMBtu	Millions of British Thermal Units
MRF	Maintenance and Repair Factor
MTPP	Maryland Transportation Pilot Project
MWe	Megawatts of Energy
NATS	NOx Allowance Tracking System account
NMP	Nutrient Management Plan
NOx	Nitrous Oxide
NPV	Net Present Value
NSCR	Non-Selective Catalytic Reduction
OLS	Ordinary Least Squares
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
PPRP	Maryland Power Plant Research Program
SA_n	Surplus NOx Allowances
SA_s	Surplus SO_2 Allowances
SCR	Selective Catalytic Reduction
SIP Call	State Implementation Plan Program
SO_2	Sulfur Dioxide
TAOC	Total Annual Operating Cost
TAR	Total Annual Revenue
UAV	Unit Ash Value
UF	Utilization Factor
ULAC	Unit Litter Acquisition Cost
ULV	Unit Litter Value
UNIDO	United Nations Industrial Development Organization
VDPB	Virginia Department of Planning and Budget
VOC	Volatile Organic Compounds

The Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia’s Chesapeake Bay Watershed

Thesis Introduction

Poultry litter is responsible for 8 thousand tons of phosphorous and 29.5 thousand tons of nitrogen production per year in the state of Virginia (Poultry Waste Management Report, 1998). Current estimates indicate that 271 thousand tons of poultry litter containing high levels of phosphorous and nitrogen is produced in Rockingham County, VA each year (Martens, VA Tech Extension Agent). Due to the concentration of poultry operations in Rockingham County and the high cost of litter disposal, farmers take advantage of poultry litter's nutrient content and apply it directly to farmland as fertilizer. Unfortunately, poultry litter nutrient runoff from excessive land application pollutes the Chesapeake Bay watershed and has been blamed for reductions in fish and plant life in the Bay (Chesapeake Bay Program, Overview page).

Research on disposal alternatives for poultry litter are underway. Some of these disposal methods include utilizing litter as cattle feed or converting litter to compost, which can then be applied to soils that do not contain excessive nutrients. A disposal alternative that has had some success in the United Kingdom (UK) is the conversion of poultry litter to energy. Power plants have been constructed in the UK, which use poultry litter as a primary fuel in the production of energy. Recent US studies further analyze the feasibility of this disposal alternative.

Existing feasibility studies on the use of poultry litter as an energy source do not take uncertainty in benefit-cost variables important to the feasibility analysis into account and fail to assess the investment decision through alternative risk preferences on the part of the investor. A probability distribution of values for benefit and cost variables can provide a more accurate estimate of expected returns on this type of project and offers a better representation of the project's probability for generating positive net returns. The feasibility of a project converting litter to energy would tend to be different for a risk averse private investor when compared to a risk neutral government investor.

An examination of the use of poultry litter as a fuel source should also evaluate the potential benefits and costs of changes in the emission rates at the electrical generating unit resulting from the combustion of poultry litter. If Sulfur Dioxide (SO_2) and Nitrous Oxide (NOx) emissions are determined to be lower for poultry litter when compared to coal, additional revenue could be generated through the EPA's emission allowance cap and trade market systems and incorporated into the feasibility model. However, if emissions from poultry litter are expected to be higher than the fossil fuel it is replacing, a project proposing its use as a replacement fuel could incur higher costs.

The objectives of this study are twofold. The first objective is to analyze the economic feasibility of utilizing poultry litter from Rockingham County to partially replace coal at the Bremo Bluff power plant in Fluvanna County, Virginia without government subsidies or tipping fees. Feasibility is evaluated from both a private risk averse investor preference and public risk neutral investor preference. The maximum allowable level of risk aversion required for feasibility is determined using a constant absolute risk averse utility function. Risk analysis through Monte Carlo simulations on important variables is conducted in order to get an estimate of the project's expected net present value (ENPV) and probability distribution of positive net returns. Sensitivity analyses is used to determine the variables that have the most effect on the economic feasibility of utilizing poultry litter to generate electricity. Since coal is the fossil fuel source to be replaced, ENPV is evaluated under three different projections for coal prices per short ton. Second, the expected feasibility and sensitivity analysis under a private investment scenario is compared to an investment scenario that includes potential benefits and costs from emission allowance trading resulting from changes in the quantity of SO_2 and NOx emissions from the combustion of poultry litter. This comparison also includes an evaluation of changes in the project's feasibility when viewed through a risk averse investor's preference function.

PART I

The Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia's Chesapeake Bay Watershed

Background

According to a 1998 report (Poultry Waste Management, VA Department of Environmental Quality), as of 1996, broiler production in the state of Virginia had reached 259 million birds with 933 poultry operations. Estimates that same year showed 98 percent of the poultry operations were located in the Chesapeake Bay watershed with the Potomac/Shenandoah and Appomatox river basins containing the largest portion. Rockingham County, situated in the center of the Shenandoah Valley in the Chesapeake Bay watershed, contained 567 of the broiler operations. Current estimates indicate that 271 thousand tons per year of poultry litter containing high levels of phosphorus and nitrogen are produced in Rockingham County (Martens, VA Tech Extension Office, Harrisonburg VA). Poultry litter is responsible for producing 16 million pounds of phosphorous per year and 59 million pounds of nitrogen per year for the state of Virginia (Poultry Waste Management Report, 1998).

Due to poultry litter's rich nutrient content and the high cost of disposal, litter is generally directly applied to farmland as a fertilizer. Unfortunately, the spatial concentration of poultry operations has led to an excess land application of nutrients. As a result, nutrient runoff works its way into the Chesapeake Bay watershed with some of the largest contributions coming from Rockingham County.

Current studies show that nutrient run-off, in the form of nitrogen and phosphorous, has been polluting the Chesapeake Bay and diminishing its population of fish and plant life (Chesapeake Bay Program, Overview Page). Surplus nutrients cause excessive growth in surface algae blooms, which deprive sunlight to filtering grasses below. At the time of death and decomposition, algae consume high quantities of dissolved oxygen, further depleting the fish and plant population.

Studies, which show that agriculture contributes 39 percent of nitrogen and 40 percent of phosphorous entering the bay, have led to the establishment of Nutrient Management Plans (Magnien *et al*., Chesapeake Bay Program Website, 1996). These Nutrient Management Plans (NMP) have been initiated to limit the amount of nitrogen and phosphorous applied to farmland soil. Due to the spatial concentration of poultry operations, the most effective method of reducing the excess nutrient content appears to be to decrease the amount of poultry litter directly applied to the soil.

In order to provide alternative poultry litter disposal methods to land application, several options have been suggested. Some of these suggestions include converting litter into cattle feed. Another option is transforming litter into compost, which can be used as fertilizer and applied to soils that do not contain excess nutrients. An additional alternative, which has been recently evaluated and has had some success in the United Kingdom (UK), is the conversion of poultry litter to energy. Conversion of poultry litter to energy is generally conducted either through some form of direct combustion, gasification, or gasification through staged combustion. A description of these three conversion techniques is provided below.

Direct Combustion

During the direct combustion procedure, the Biomass fuel source (poultry litter) is inserted into a furnace and ignited at high temperatures before being ducted into a boiler. Biomass is combusted in the furnace and converted to thermal energy which takes the form of flue gas. Thermal energy is then transmitted to a boiler and converted into steam. The steam is then used as an energy source (Knoef *et al*.)

Fibrowatt, a British firm, currently operates three power plants in England, which use a version of direct combustion to convert poultry litter to energy. A plant is also located in Minnesota (Fibrominn), which directly combusts turkey litter. Fibrowatt uses a fixed bed combuster commonly referred to as a spreader stoker-grate system. In this procedure Biomass, which is the fuel source, is mechanically fed to the boiler, distributed across a grate, and burned in suspension.

As ascertained from Antares *et al.*, although Fibrowatt has had success using this conversion method, direct combustion of poultry litter is not without its problems. The litter contains organic and inorganic chemicals, which complicate the combustion process. High levels of chloride in poultry litter can lead to an increased likelihood of corrosion in boilers operating at high temperatures. Furthermore, litter's high content of phosphorous, potassium, sodium, and sulfur generally vaporize during combustion and compress with other inorganic material. The end result is slagging in the furnace and fouling in the boiler tubes, which creates further corrosion. According to Antares *et al.*, unless a boiler is constructed specifically for poultry litter, maintenance cost on an existing boiler may prove to be high.

Although Fibrowatt's plants are large and designed specifically for burning ample quantities of poultry litter in order to avoid corrosion problems, financial feasibility is still achieved only with high levels of government aid. The UK exacts a surcharge to electricity users under the country's Non-Fossil Fuel Obligation contracts which then provides funding to plants producing electricity without the use of fossil fuels (PPRP, Section 2.3). Fibrowatt, which uses poultry litter, fits this category. Funding similar to that provided by the UK may prove difficult to obtain in Virginia.

Gasification and Staged Combustion

Gasification converts solid biomass in the form of carbon fuels into carbon monoxide in a separate gasification unit through a thermochemical process (Turare, Biomass Gasification Technology and Utilization Webpage). In the case of poultry litter conversion, it uses one third the amount of air generally required for direct combustion (Antares *et al*., pg. 24). Inorganic material is reduced or removed and the gas produced is then burned in an existing boiler (Antares *et al*., pg. 24).

According to studies conducted by Antares *et al*., due to temperature levels, gasification requires a fuel source with a moisture content no greater than 15 to 20 percent. Higher moisture content levels, common in poultry litter, can reduce the temperature of the boiler and increase the volatility of combustion. Attempts to lower temperatures by blending wet litter with dry litter can result in incomplete combustion.

Staged combustion generally uses a separate combustion unit to externally cofire an existing boiler. The Biomass is gasified in the first stage and the gas is combusted once again but at higher temperatures in the second stage. The first stage output rises up to the second stage located directly above in the "external co-firing" unit (Lefcourt and Martin, pg. 2). Output from the second stage is then ducted directly into a furnace, which is used to co-fire the boiler. It is expected that staged combustion can displace up to 20 percent of the fossil fuel used in the facility without generating additional maintenance costs (Lefcourt and martin, pg. 2).

According to Antares *et al.*, staged combustion permits more flexibility with temperature levels, therefore, it is usually the preferred poultry litter gasification system. Allowing for staged combustion gives the operator more temperature control than with alternative combustion methods. Temperatures in first stage combustion range between 1,200 degrees and 1,500 degrees Fahrenheit while second stage combustion is performed at 1,800 degrees. Therefore, staged combustion not only has a lower probability of slagging, fouling, and corrosion in its boiler system but also reduces the volatility in the combustion process.

Staged combustion's ability to accept litter with higher moisture content can reduce costs involved with litter drying. Drying litter prior to combustion in order to use it as an energy source has been determined to be inefficient since the cost from drying is greater than the benefits from energy conversion at 25 to 30 percent moisture rates (Antares *et al*., pg. 32). Moisture rates at 25 percent or greater are common in Chesapeake Bay Watershed poultry operations.

Ash produced during the combustion process can then be pelletized and sold as a fertilizer. Residual combustion ash still contains quantities of phosphorous and potassium which can be sold as an effective fertilizer to farmers outside the watershed. However, it should be noted that nitrogen is lost during combustion and amounts of P_2O_5 and K_2O are lower than conventional fertilizers, therefore, residual ash might not be considered as effective a fertilizer in terms of yield as the direct land application of poultry litter, unless supplemented with the deficient nutrients (Lefcourt and Martin, pg. 9).

Conversion Attempts

Studies have been conducted which analyze litter conversion through the three methods described above. The Maryland Power Plant Research Program (PPRP) conducted one such study for the Maryland Environmental Service (MES) on the Correctional Institute (ECI) of the state's Eastern Shore. It analyzed the technical and economic feasibility of various conversions and firing methods. The study found direct combustion to be an economical and technologically preferable alternative for converting litter to fuel under specific scenarios. However, capital costs for each scenario were greater than $10 million.

Antares Group Incorporated, T.R. Miles Technical Consulting Inc., and Foster Wheeler Development Corporation prepared an analysis of conversion and handling options of poultry litter for the Northeast Regional Biomass Program on the lower Delmarva Peninsula (Delaware and the Eastern Shores of Maryland and Virginia). The study concluded that direct combustion of poultry litter increased the probability of boiler corrosion. It illustrated that poultry litter's inorganic nutrient content had a tendency to cause slagging and fouling in the tube system. On the other hand, conversion through gasification required strict constraints on moisture content and heat levels which meant a fuel source with varying levels of moisture content, such as poultry litter, could increase uncertainty in a feasibility assessment. Their conclusions were that direct combustion required large maintenance cost while gasification represented a high-risk production process. Secondly, results on the feasibility demonstrated conversion was not attainable without government subsidies and/or tipping fees.

Finally, Heuristic Engineering of Vancouver, BC and Hall Associates of Delaware analyzed the feasibility of conversion through the use of a stand-alone, two-stage external combuster, which co-fires an existing fossil fuel boiler at a poultry-processing plant without the use of tipping fees or government incentives. Initial investment was estimated at $1 million. The proposed fuels to be co-fired were coal, propane gas, residual fuel oil, distillate fuel, and natural gas. Their conclusions showed broiler litter was cost effective when used as a replacement fuel for residual fuel and/or natural gas.

Problem Statement

The findings of the Hall Associates and Heuristic Engineering study (HAHE) were dependent on several factors including the fuel source chosen for replacement, the distance litter had to be transported to the boiler, the value of residual ash as a fertilizer, and the acquisition cost of poultry litter. Probability distributions on important parameters were not available; as a result, uncertainty or risk was not addressed in their study. Variations in the price of the replaced fossil fuel or litter acquisition costs might have altered their conclusions.

A thorough assessment of the variables in the HAHE study provides justification for a reevaluation of the feasibility analysis with the incorporation of uncertainty. Failure to include uncertainty in crucial variables may lead to accepting a project that has a negative return to initial investment over the project life and thus is economically unfeasible. As previously mentioned, poultry litter contains varying degrees of moisture, therefore, heating values used to derive key variables in a feasibility analysis vary according to moisture content. The probability distribution used for heating values can prove to be a consequential element in the NPV (Net Present Value) model. For example, the use of a triangular distribution for this variable when running Monte Carlo simulations will yield different net benefits than the use of a normal distribution. The choice of distribution becomes more important when one notices heating value's effects on variables such as litter utilization capacity, residual ash production, unit value of litter, and the residual ash value.

Depending on the structure of poultry litter property rights, funding for a project could be provided by the private or public sector. If the private broiler operators are held responsible for determining an alternative litter disposal method to direct land application then the incentive exists for the project to be initiated by a private investor, consequently, it might be more appropriate to measure project Net Present Value under a range of risk averse preferences. If the responsible party is the state of Virginia then, as is a common practice with public projects, expected NPV is derived under risk neutral preferences (UNIDO, Guidelines for Project Evaluation, pg. 110). The public sector can be considered risk neutral due to its ability to diversify its investments in other sectors.

Objective

The fundamental objective of this paper is to assess the viability of a litter disposal alternative for Rockingham County by incorporating risk in the evaluation of the economic feasibility of converting poultry litter to energy, under both private and public sector investment scenarios, through a gasification process which uses a stand-alone staged external combuster to co-fire a coal-fired boiler at a nearby power plant. Due to lower investment costs and technical feasibility of the stand-alone staged combuster, this study modifies the Hall Associates and Heuristic Engineering model to the specifications of Rockingham County and the Bremo Bluff power plant in Fluvanna County, Virginia. Therefore, an assessment of the project's potential for a positive return to capital on the partial replacement of coal with poultry litter without the need for government subsidies and/or tipping fees is carried out. Through the use of Monte Carlo simulations to conduct risk analysis, the probability distribution of expected returns along with the effects on feasibility resulting from uncertainty in the values of benefit-cost variables will be determined. In addition, since the objective of the study does not target a particular type of investor, the project's value to a private investor in comparison to a public investor is determined by measuring the expected returns under both risk averse and risk neutral preferences.

Assumptions

In order to conduct the proposed research the following assumptions are included:

- Poultry litter source is from Rockingham County, VA while the boiler is situated 96.9 miles away in Fluvanna County.
- Litter transport costs within the county will not be affected by the additional demand from the proposed project.
- Trucks will be used specifically for the transport of poultry litter with no back haul necessary.
- Since this is a study on the economic feasibility of converting poultry litter to fuel, technical feasibility from sources researched is not critiqued and is assumed to be correct.

Part I, Chapter 2
Conceptual Framework and Review of Previous Studies

Recent increases in the production of poultry litter as well as a growing demand for alternative energy sources have spurred a rise in studies relating to the use of poultry litter as a fuel source. Unfortunately, the majority of the studies are not publicly accessible and those available fail to provide sufficient historical data to conclude, with certainty, technical or economic feasibility. This is the case for large-scale direct combustion technologies such as the one utilized by Fibrowatt's power plants in England and Fibrominn of Minnesota. Feasibility studies open to public viewing focus on small scale projects such as the direct combustion report prepared by PPRP on the use of poultry litter as a primary fuel source in the Eastern Correctional Institute (ECI) in Maryland or Hall Associates and Heuristic Engineering's (HAHE) analysis of using poultry litter to cofire an existing fossil fuel boiler.

This section focuses on three studies and attempts to shed some light on the issues involved with the economic feasibility of converting poultry litter to energy. Antares Group Inc. in cooperation with T.R. Miles Technical Consulting Inc. and Foster Wheeler Development Corporation prepared a report analyzing the market opportunities for Biomass energy in the Delmarva Peninsula, the acquisition of poultry litter for combustion, and the energy conversion options available to achieve its primary objective. In order to preserve the focus of this paper on the economic feasibility, the discussion will center on section four of the report, which matches technologies to applications such as bulk power and cogeneration at small-scale industrial facilities. The second report to be discussed is the study prepared for the Maryland Environmental Service by PPRP on Maryland's Eastern Shore, which compares results from three alternative poultry litter direct combustion scenarios with benefits accruing over a 20 year period. Finally, Hall Associates and Heuristic Engineering (HAHE) provide the foundation for the analysis to be conducted later on in this paper. HAHE measure the feasibility of utilizing a separate combuster to cofire an existing fossil fuel boiler with poultry litter.

Matching Technology to Application

Antares Group *et al.* (pg. 49) prepare their report with the assumption that each "potential user has a different decision criterion with respect to choosing energy resources." The study concludes that public sector operations would be less attractive than private industrial facilities, therefore, the examination centers on the private facilities located in Vienna MD, Bridgeville MD, and Georgetown DE.

Bulk Power

Two alternative bulk power proposals are summarized in Table 2.1. The first involves a retrofit at an existing power station with a capital cost of $37.5 million and a fuel/litter utilization of 248 thousand tons per year. The second scenario suggests the construction of a new plant specifically designed for poultry litter. The capital cost is $62.5 million and the litter utilization is 240 thousand tons per year.

Each scenario is dependent on the commercial sale of residual ash as a fertilizer as well as the purchasing price or acquisition cost of the litter. Feasibility is measured by the project's ability to produce profit to cover the initial investment. Antares *et al.* compare the ash value and litter cost necessary for feasibility in each scenario. For the retrofit, ash values are estimated to range from zero dollars to a maximum of $80 per ton. If demand for ash is nonexistent, litter must be acquired at no cost, including delivery, for positive net gains. A maximum ash value of $80 per ton allows a litter cost up to $10 per ton while a litter cost of $5 per ton is cost effective with an ash value of $40.

Ash value is fixed at $50 per ton in order to compare the retrofit with a new facility while an additional scenario, which proposes directly co-firing a plant with poultry litter, is added to the comparison. At a $50 per ton ash value, the retrofit covers investment costs with a litter cost less than or equal to $7 per ton while the new facility, specific to poultry litter, fails to cover investment without offsetting delivery costs with tipping fees. Direct cofiring results in ash that is not useful as a fertilizer, therefore, has no value. In the co-firing case, the project is operational for a litter cost of up to $20 per ton assuming no additions to maintenance costs during combustion.

Cogeneration and Steam Production at an Industrial Facility

It is the general belief of Antares *et al.* that the cogeneration of an industrial facility may be more advantageous than a bulk power facility due in large part to the likelihood the industrial facility will save on operating costs by generating its own electricity.[1] Handling, storage, and processing costs are assumed to be the same as with a bulk power plant. A three-year internal investment payback period is set for four different installations. The first two installations are a

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[1] Cogeneration: Production of electricity from steam, heat, or other forms of energy produced as a by-product of another process. (Glossary of Energy Market Terms).

new gasifier genset generator and a new gasifier boiler at a poultry processing plant or feedmill, the third installation is a small-scale cogeneration facility, while the fourth installation is a medium-scale cogeneration facility.

Table 2.1 provides capital cost and litter consumption data for each of the four installations. The new gasifier boiler has the lowest possible capital cost with rates ranging from $1.2 to $1.8 million followed closely by the new small-scale cogeneration facility with a capital cost of $1.77 million. The medium-scale cogeneration facility has the highest capital cost at $9.9 million but also consumes/utilizes a significantly larger quantity of litter, at 131.4 thousand tons per year, than the other three installations. When measured in terms of litter utilization, the lowest rates are from the new gasifier boiler and the small-scale cogeneration facility. The gasifier genset consumes nearly 19 thousand tons of litter per year and has a capital cost of $2.76 million.

A common theme for all four installations is a dependency on tipping fees. With a zero ash value, the projects demand a tipping fee on litter delivery ranging from $20 per ton to $40 or greater for investment payback. When comparing the four installations at an ash value of $50 per ton, the cogeneration facilities are more feasible with tipping fees ranging from $0 to $10 per ton. When distinguishing between the two cogeneration facilities, the conclusion is that a new medium scale cogeneration facility is the more economically acceptable.

Both bulk power and cogeneration in the Antares *et al.* study demonstrate the need for establishing a market for residual ash as a fertilizer. An ash market can offset the variability in poultry litter acquisition costs, which appears to be the most influential parameter. A significantly low ash value often results in the need for tipping fees on the delivery of litter.

Table 2.1 Comparison of Poultry Litter Power Production Facilities

	Bulk Power		**New Gasifier**		**Cogeneration Facility**	
	Retrofit	**New Facility**	**Genset**	**Boiler**	**Small-Scale**	**Medium-Scale**
Capital Cost ($ Millions)	38	63	2.76	1.2 - 1.8	1.77	9.9
Fuel/Litter Consumption (tons/year)	248,000	240,000	18,900	6,000 - 16,000	7,900	131,400

Data Source: Antares *et al.*

Direct Combustion at Maryland's Eastern Correctional Institute

The study prepared by the Maryland Power Plant Research Program analyzes the technical, environmental, and economic feasibility of using the direct combustion of poultry litter to power Maryland's Eastern Correctional Institute in Princess Anne, MD. In 1997, two wood-fired cogeneration units provided the steam and electrical power to ECI. The study presents the economic assessment of replacing the wood fired boilers by comparing the life cycle costs for three scenarios (Table 2.2). Each scenario allows for changes in returns and production at different times during a 20-year life cycle with a 2.5 percent annual inflation rate and a 7 percent discount rate. The cost of litter including transportation is estimated at $20 per ton with a residual ash value of $5 per amount produced from the combustion of one ton of poultry litter. The supply of poultry litter is located in the Maryland counties of Somerset, Wicomico, and Worcester which produce an estimated 290 million broilers per year (PPRP, Sections 1.2 and 2.6.1). Implications from the literature are that litter handling for each scenario is similar to the methods used by Fibrowatt which means litter is stored in bunkers for up to ten days with air ventilated directly to the furnace in order to facilitate combustion.

It should be noted that the authors feel gasification represents a higher risk for the ECI compared to direct combustion due in large part to the belief that significant development work and commercial experience is still needed in gasification technology (PPRP, Section 2.2). Sentiments are that controlling nitrogen oxide (NO_x) emissions from gasification may prove a more challenging task than under direct combustion. Therefore, the procedure analyzed in this study is the direct combustion of poultry litter at the ECI cogeneration facility.

The three scenarios are presented on Table 2.3 with an additional branch attached to scenario 3 that takes into account costs for controlling NO_x emissions. A base case scenario, which assumes no change in fuel source during the life cycle, is presented as a comparison to the three poultry litter options. Scenario 1 requires a total life-cycle cost of $31.92 million, with $14.14 million comprising of life-cycle capital costs, and utilizes almost 37 thousand tons of litter per year while scenario 2 requires a life-cycle cost of $29.17 million ($9.8 million capital cost) and a litter utilization capacity of 10 thousand tons a year. As mentioned above, scenario 3 is split into two branches with a capital cost of $10 million for scenario 3 and $10.7 million for scenario 3A and total life-cycle costs of $20.65 million and $21.28 million, respectively. Annual litter utilization rates for both scenarios total 81.11 thousand tons per year. When comparing costs in terms of life cycles, scenario 3 has the lowest cost at $20.65 million, which is $9.4 million less then the base case cost of $30.04 million. As can be seen by Table 2.3, scenarios 1 and 2 fare only slightly better in terms of life-cycle costs than the base case. Therefore, the PPRP study concludes scenarios 3 and 3A not only have the lowest life cycle cost but also have the highest poultry litter utilization capacity.

Table 2.2 Life Cycle Scenarios for Power Production from Direct Combustion of Poultry Litter at Maryland's Eastern Correctional Institute

Scenario 1	1) Install two 2-MW electricity generating facilities in 1998. 2) Use Wood-Fired Boiler for Thermal Requirements. 3) Replace wood-wired boiler with 40,000 lb./hr. Poultry-fired Boiler in 2008.
Scenario 2	1) Install 40,000 lb./hr. Boiler fueled by poultry litter in 1998. 2) Use wood-fired cogeneration facility for electricity requirements. 3) Replace cogeneration facility with a wood-fired facility in 2008.
Scenario 3	1) Modify wood-fired cogen. In 1998 to burn poultry litter. 2) Install litter-fired 40,000 lb./hr. Boiler in 2002 for thermal needs. 3) Replace modified cogen. with two litter-fired 2-MW facilities in 2008.
Scenario 3A	Similar to scenario 3 except with the inclusion of costs to control NO_x emissions.
Base Case	Costs under continuation of current operations for the supply of thermal and electric requirements to ECI.

Information Source: PPRP

Table 2.3 Cost and Poultry Litter Consumption for Life Cycle Scenarios Powering Maryland's Eastern Correctional Institute with Poultry Litter

	Scenario 1	Scenario 2	Scenario 3	Scenario 3A	Base Case
Total Life Cycle Cost ($ Millions)	31.92	29.17	20.65	21.28	30.04
Life Cycle Capital Cost ($ Millions)	14.14	9.795	10.07	10.70	
Fuel/Litter Consumption (tons/year)	36,660	10,033	81,114	81,114	0

Data Source: PPRP

Cofiring Using a Separate Two-Stage Combuster

The Hall Associates and Heuristic Engineering study analyzes feasibility from an alternative angle in comparison to the direct combustion method used by PPRP and the cogeneration-gasification technique determined feasible under Antares *et al*. The study proposes the use of a separate two-stage stand-alone 10 million Btu/hr poultry litter combuster to replace up to 20 percent of the fossil fuel used to fire an existing boiler. It does not suggest poultry litter be the sole source of fuel. The separate combustion unit is considered more appropriate by providing the fuel producer additional control of temperature, NO_x emissions, maintenance costs, and by furnishing the combuster the ability to separate the ash for fertilizer revenues. Secondly, the working hypothesis in their study is financial feasibility with a return to capital greater than $1 million, the amount required to generate 10 million Btu/hr of process steam using poultry litter, at a discount rate of 10 percent without the need for government subsidies and/or tipping fees.

In order to prepare estimates for benefits and costs, the value of poultry litter is estimated by comparing its fuel characteristics, such as heating values, to those of five other conventional fuels. Due to differences in moisture content, heating value is determined by averaging values derived from five separate studies. A heating value average of 4,613 Btu/lb. is used to derive values for manure utilization capacity and the monetary manure value per ton (Appendix A). Estimation of the monetary value of poultry litter is completed through the cost and quantity of the fuel poultry litter replaces. The five fuels that are suggested for possible replacement include: coal, No. 2 distillate fuel oil, residual fuel oil, propane gas, and natural gas. However, the focus of the study is on residual fuel oil and natural gas. As previously stated, in addition to the heating value of poultry litter, residual ash, which still contains phosphorous and potassium after combustion, is expected to provide additional benefits through its use as a fertilizer.

The model is set up with monetary values in U.S. dollars at a 10 percent capital recovery rate.

Benefits: TAR = (LUC*ULV) + (AAP*UAV)

TAR: Total Annual Revenue ($)
LUC: Litter Utilization Capacity (tons)
ULV: Unit Litter Value based on the unit energy cost of fuel replaced ($)
AAP: Annual Ash Production (tons)
UAV: Unit Ash Value or disposal cost ($)

Costs: TAOC = ALAC + ALTC + ALC + AUC + AMRC

TOAC: Total Annual Operating Cost ($)
ALAC: Annual Litter Acquisition Cost ($)
ALTC: Annual Litter Transportation Cost ($)
ALC: Annual Labor Cost ($)
AUC: Annual Utilities Cost ($)
AMRC: Annual Maintenance and Repair Cost ($)

Results for the partial replacement of low sulfur residual fuel illustrate that the justifiable litter acquisition cost increases from $4 per ton to $10 per ton on capital investment when the life of the project changes from 7 years to 15 years with a zero ash value (Lefcourt and Martin, pg. 18). An ash value of $25 per ton increases the acceptable litter acquisition cost to $8 per ton for a 7-year term while an ash value of $50 per ton allows for a litter acquisition cost up to $12 per ton.

The replacement of natural gas does not provide a sufficient return on investment to approve a project over a 7-year life (Lefcourt and Martin, pg. 21). In fact, feasibility, with no demand for ash as a fertilizer, is only met for a project life of 15 years and litter acquisition costs no greater than $2 per ton. An ash value of $25 per ton permits a $4 increase in the litter acquisition cost for a 15-year project but in order to afford a litter acquisition cost close to $10 on a 15-year term, ash value is constrained to a minimum of $50 per ton.

When comparing the two conventional fuels to be replaced, low sulfur residual fuel proves to be more beneficial than natural gas. In both cases, ash value proves to be a vital ingredient in feasibility. HAHE conclude that the replacement of low sulfur residual fuel with poultry litter is cost effective without government subsidies and/or tipping fees while natural gas requires a high ash value and a stricter constraint on litter acquisition cost and project life.

After reviewing the feasibility assessments in the three studies, co-firing with an external two-stage combuster appears to be the most appropriate method to generate power from an investment standpoint. Historical information on direct combustion is fragmented, but evidence suggests it requires a significant level of initial investment when compared to staged combustion. In the case of gasification, the moisture content of poultry litter and the constraints on the maximum acceptable temperature and moisture levels, demonstrate that technically and economically it also does not emerge as the most suitable choice. As previously mentioned, co-firing with a staged combuster not only reduces the slagging and fouling costs of direct combustion but it loosens the constraints on maximum allowable heat during combustion and permits higher moisture content levels in litter. A separate staged combuster is also able to retain 99 percent of the residual ash in the first stage, making it easier to obtain revenue from the sale of ash as a fertilizer. Therefore, this paper will perform a feasibility analysis on the use of a separate two-stage combuster to co-fire an existing fossil fuel plant.

Risk Analysis

Studies conducted on project appraisal techniques show risk analysis to be an important tool in the assessment of expected feasibility when uncertainty exists in the values of consequential input variables. Risk analysis is conducted in order to determine the likelihood of feasibility given the probability of occurrence for different values of the input variables. Publications prepared by the World Bank and the United Nations Industrial Development Organization (UNIDO) explain the significance of risk analysis in project appraisal and evaluation. The World Bank publications detail project scenarios that require risk analysis in their feasibility assessment. UNIDO then makes a distinction between a public investor and a private investor when evaluating returns on a project.

Louis Pouliquen, in his publication entitled *Risk Analysis in Project Appraisal*, describes risk analysis in project appraisal as a technique that permits the use of a great deal of information from uncertain variables which would otherwise be lost if the modeler were restricted to a single value judgment on the input variables (Pouliquen, pg. 2,74). The information provided by risk analysis is made available through the assignment of probability distributions to each uncertain input variable and used in the estimation of a probability distribution for the output variable. The probability distribution of outcomes is useful in a scenario where a project is marginally feasible or likely to produce negative returns under standard uncertainty conditions (Pouliquen, pg. 74). Pouliquen asserts the importance of risk analysis when uncertainty in input variables is large enough that the possibility exists for negative returns if the value of an input variable is not accurately estimated.

Once the distribution of ENPV is derived using risk analysis, UNIDO suggests the project evaluation from a public investment standpoint be distinguished from the private investment standpoint. The public or government investor is generally considered to have risk neutral preference while a private investor has risk averse preferences (United Nations, Industrial Development Organization, *Guidelines for Project Evaluation*, pg. 110). A risk neutral or public investor views a project investment as a well endowed individual would view a small gamble (Reutlinger, pg. 51). Net returns from a project are small relative to the income level and are likely offset by negative returns in another investment. Risk aversion in the private investor is due to the fact that failure in a proposed project will result in a significant decrease in the investor's aggregate income (United Nations, Industrial Development Organization, *Guidelines* *for Project Evaluation*, pg. 110). The private investor does not have the wealth or investment opportunities to reduce risk by diversifying funds among several projects and, therefore, can not offset losses with success in other investments like a government investor (United Nations, Industrial Development Organization, *Guidelines for Project Evaluation*, pg. 111).

Since the project proposing the partial replacement of coal with poultry litter does not target a particular type of investor, a distinction between risk averse and risk neutral preferences is important in measuring feasibility. The high level of uncertainty surrounding the values of several of the variables in the project suggests that the use of probability distributions can provide significant information on the expected value of these variables. Therefore, risk analysis appears to be an essential instrument for this study's feasibility analysis.

Part I, Chapter 3
Methods

This section presents the feasibility model and explains its development under conditions of uncertainty by highlighting the model's critical variables and their probability distributions. Probability distributions for benefit-cost variables were estimated using the range of values from the three studies described in the previous section. The distributions were then used when performing risk analysis through Monte Carlo simulations on the feasibility model.

The methodology behind the feasibility model presented below is preceded by a description of Monte Carlo simulation using *Palisade @RISK 3.5, Advanced Risk Analysis for Spreadsheets by Palisade Corporation* as well as the rationale behind the choice of the project location. The description of the model begins with derivations for three 20-year coal price forecasts that are each used to compute litter values essential to the calculation of the project's NPV under uncertainty conditions. It is followed by a description of the range of values along with the probability distribution of variables important to the model's outcome. The remainder of the model methodology includes a brief description of risk averse preferences and the development of the test for determining the maximum level of risk aversion possible for project funding from a private investor.

Feasibility Model

Similar to the HAHE model, setup of the feasibility model was as follows:

Benefits: TAR ($) = (LUC*ULV) + (AAP*UAV)

TAR: Total Annual Revenue
LUC: Litter Utilization Capacity (tons)
ULV: Unit Litter Value based on the unit energy cost of fuel replaced
AAP: Annual Ash Production (tons)
UAV: Unit Ash Value or disposal cost

Costs: TAOC ($) = ALAC + ALTC + ALC + AUC + ACC + AMRC

TOAC: Total Annual Operating Cost
ALAC: Annual Litter Acquisition Cost
ALTC: Annual Litter Transportation Cost
ALC: Annual Labor Cost
AUC: Annual Utilities Cost
ACC: Annual Cleaning Cost
AMRC: Annual Maintenance and Repair Cost

Risk Analysis through Monte Carlo Simulation

Risk analysis on the feasibility model is conducted using Monte Carlo (MC) simulation, which is an uncertainty propagation sampling method used on input variables of varying distributions in order to estimate an expected value and probability distribution for an output variable. A value is randomly selected from a specified probability distribution and used in a specific model for the computation of the expected value for the output variable (Henrion and Morgan, pg. 199). The procedure is repeated until convergence or the required precision is obtained and calculates an equal number of output values which "constitute a random sample from the probability distribution over the output induced by the probability distribution over the inputs"(Henrion and Morgan, pg. 199). If a particular model contains multiple uncertain variables, then MC simulation is conducted on each variable according to their assigned probability distribution before their expected values are used for the model output calculation. An overall probability distribution is then derived for the model's output taking into account the expected values of the input variables.

In this particular study, Monte Carlo simulations were run on @Risk using Latin Hypercube sampling[2] and a random seed equal to one. @Risk selected values for benefit and cost variables randomly from a predetermined probability distribution for use in the computation of net benefits in the NPV equation. This procedure was repeated until convergence which was determined as a change in mean and simulation statistics for net benefits less than 1.5 percent from the previous iteration. Probability distributions were determined by matching the characteristics specific to the data of the uncertain variables with the most appropriate distribution available in *@RISK*. Statistical techniques were then used to determine rank correlation and sensitivity analysis between the input variables and the output variable (net revenue).

Location and Choice of Fuel

The coal fired power plant in Bremo Bluff, Virginia was chosen as the location for the external combuster due to its proximity to Rockingham County. Bremo Bluff, in Fluvanna County, is currently the closest power plant (96.9 miles) from the Rockingham county seat

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[2] Latin Hypercube Sampling: A stratified sampling technique in which "input values are obtained by sampling separately from within each stratum instead of from the distribution as a whole."(Henrion & Morgan, p. 204). This generally results in a faster convergence than under Monte Carlo sampling.

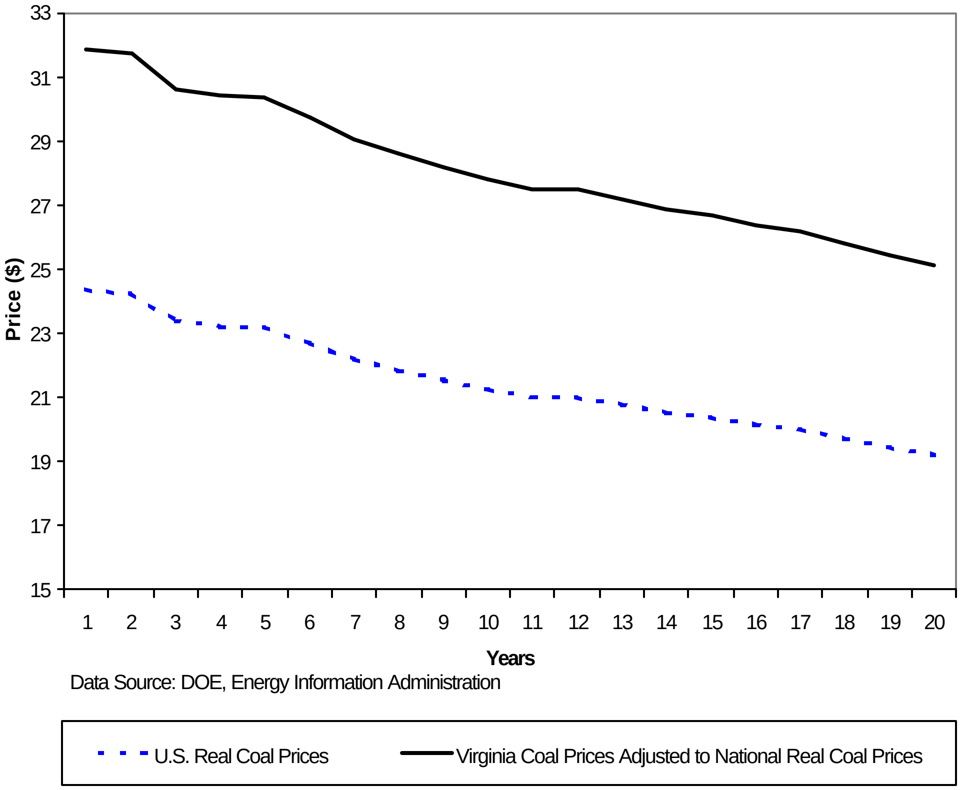
located in Harrisonburg, Virginia (Mapquest Website) and contains two coal fired units (Bremo Power Station Website) with generating capacity of 80 MW_e (Megawatts of energy) and 170 MW_e per hour. The next closest power plant to Harrisonburg is a wood fired plant in Altavista, VA a distance of almost 120 miles (Mapquest Website).

Methods for the Feasibility Model

Coal Prices

Virginia coal prices for electrical generation, provided by the U. S. Department of Energy (DOE), were used to represent the value of coal displaced. In order to test the project's sensitivity to coal prices, three different sets of 20-year forecasts (Table 3.1) were derived from an initial coal price of $31.89 per short ton in Virginia for the year 2000. The first set of projected coal prices for the state was derived by following the pattern of price changes from the forecast of national real coal prices (Base Year = 2000) estimated by the DOE. Figure 3.1 shows a decreasing trend in future real coal prices. Two other sets of coal prices were estimated for the purpose of testing the model's sensitivity to increasing coal prices. In one case, a 2.5 percent annual price increase equal to the inflation rate used on monetary values in the model, was added to the set of real coal prices generated by the DOE. In the third scenario, coal prices were increased annually by a consistent rate of 2.5 percent for twenty years beginning with $31.89 per ton in 2000. Net Present Value was estimated and compared using each of the three sets of coal prices.

Figure 3.1 U.S. Real Coal Prices and Virginia Adjusted Coal Prices



Data Source: DOE, Energy Information Administration

Table 3.1 Comparison of the Three Sets of Coal Prices Used in the Feasibility Model

Virginia Coal Prices, Based on National Real Coal Prices[1] (Base Year = 2000)	Virginia Real Coal Prices Adjust Up by 2.5 Percent	Coal Prices Increasing by 2.5 Percent Annually
31.89	31.89	31.89
31.72	32.47	32.69
30.63	32.15	33.50
30.40	32.70	34.34
30.33	33.44	35.20
29.70	33.57	36.08
29.05	33.65	36.98
28.60	33.96	37.91
28.20	34.32	38.85
27.83	34.72	39.83
27.52	35.18	40.82
27.49	36.03	41.84
27.20	36.54	42.89
26.89	37.02	43.96
26.67	37.63	45.06
26.38	38.16	46.19
26.18	38.82	47.34
25.82	39.24	48.52
25.45	39.65	49.74
25.15	40.16	50.98

[1] Data Source: U.S. Department of Energy, Energy Information Administration

Heating Values

Poultry litter heating value, the measure of energy chemically bound in litter, varies according to bedding material and moisture content, therefore, a proper estimate of the probability distribution for the heating value numbers is vital to the calculation of benefits and costs in this particular feasibility analysis (Lefcourt and Martin, pg. 4). The paper presented by HAHE uses an average heating value from five different studies and locations. A socioeconomic assessment of using poultry litter as a fuel at ECI in the Delmarva Peninsula, prepared by Environmental Resource Management with Exeter Associates Inc and McBurney Corporation (EEM), estimates a range of heating values with moisture contents during both summer and winter months (Table 3.2). It should be noted that since heating values were not available for fall and spring, annual figures were split between summer and winter seasons only. An average poultry litter heating value from Rockingham County was available, however, a range of heating values was not available to incorporate uncertainty for Monte Carlo simulations. Therefore, this study applied the heating values from the Delmarva Peninsula (EEM) to estimate the distribution needed for uncertainty evaluation.

Given the thermal efficiency of coal to heat and the boiler efficiency of electrical generating units similar to those at Bremo Bluff (Shannon, pg. 25), the total thermal efficiency of coal was estimated to be 30 percent (Table 3.3). According to Heuristic Engineering, a 75 million Btu/hr external combuster, fueled by poultry litter, generates 9 MW_e of electricity. Using this figure, the amount of coal per hour to be replaced was calculated at 3.75 tons (31,500 tons/year). The heating values of poultry litter coupled with a total thermal efficiency of 24.9 percent (Table 3.3), were used to derive the amount of litter per season/year needed to partially replace coal for the 80 MW_e unit at Bremo Bluff using a 75 Million Btu/hr external combuster. According to these figures, poultry litter could displace 3.6 percent of the coal utilized at Bremo Bluff.

Poultry litter heating values were then used to derive components in the benefit-cost analysis. Following the calculations from the HAHE study and incorporating uncertainty into the model, probability distributions for litter utilization capacity (LUC), annual ash production (AAP), and unit litter value (ULV) needed for benefit-costs analysis were estimated from

Table 3.2 Poultry Litter Heating Values and Moisture Content for the Delmarva Peninsula

	Heating Values (Btu/lb.)					Moisture Content (%)	
	Summer		Winter				
Statistics	Dry	Wet	Dry	Wet		Summer	Winter
	6,250	4,700	7,404	5,790		24.80	21.80
	6,130	4,440	6,485	4,890		27.57	24.60
	6,380	5,200	6,672	4,410		18.50	33.99
	6,650	5,130	6,796	2,970		22.86	56.30
	6,790	4,580	4,520	3,720		32.55	17.70
	6,330	4,350	6,523	3,640		31.28	44.20
	6,690	4,850	5,772	4,110		27.35	28.80
	6,610	4,950	5,364	3,760		25.11	29.90
	6,440	4,850	5,348	3,920		24.69	26.79
	6,430	4,270	4,717	2,750		33.59	41.70
	7,280	3,350	5,649	4,050		53.98	28.30
	6,650	5,120	6,540	4,140		23.01	36.70
	7,180	5,770	7,221	4,910		19.64	32.00
	6,680	5,180	6,974	5,670		22.75	18.70
	6,440	4,930	6,784	5,380		23.45	20.70
	5,940	4,910	6,675	5,120		17.34	23.30
	6,280	4,720	6,410	5,250		24.85	18.10
	6,040	4,160	6,779	3,410		31.13	49.70
	6,420	5,280	6,328	4,740		17.76	25.10
	5,030	3,740	5,882	4,500		25.65	23.50
	6,060	3,430	6,116	5,070		43.40	17.10
	5,880	4,440				24.49	
	6,560	4,790				26.98	
	6,460	4,160				35.60	
Min	**5,030.00**	**3,350.00**	**4,520.00**	**2,750.00**		**17.34**	**17.10**
Max	**7,280.00**	**5,770.00**	**7,404.00**	**5,790.00**		**53.98**	**56.30**
Mean	**6,400.00**	**4,637.50**	**6,236.14**	**4,390.48**		**27.43**	**29.48**
Variance	**200,843.48**	**340,845.65**	**597,335.73**	**726,044.76**		**68.34**	**118.65**
S.D.	**448.16**	**583.82**	**772.87**	**852.08**		**8.27**	**10.89**

Data Source: EEM

Table 3.3 Methodology Behind Litter Utilization Capacity (LUC), Annual Ash Production (AAP), and Unit Litter Value (ULV)

1) General Energy Transfer Information

1 Btu/hr = .293 Watts

250 MW = 853,825,137.5 Btu/hr

Source: www.convert-me.com

75 million Btu/hr External Combuster generates 9MWe

Source: Malcolm Lefcourt, p. 5.

2) Coal to be Replaced

9MWe/250MWe = 0.036

2500 tons of coal/day generate 6000 MWe/day at Bremo Bluff Power Plant

104.16 tons/hr generate 250 MWe/hr

104.16*.036 = 3.75 tons of coal/hr. to be replaced.

3) Total Efficiency = Thermal Efficiency (Coal & Poultry Litter)*Boiler Efficiency

	Thermal Efficiency[1] (Fuel to Heat)	Boiler Efficiency[2] (Heat to Electricity)	Total Efficiency
Poultry Litter	0.7300	0.3410	0.2489
Coal	0.8810	0.3410	0.3004

[1] Lefcourt and Martin, p. 14.

[2] Robert H. Shannon, p. 25.

4) Amount of litter needed to replace 3.75 tons of coal per hour

Heating Value of Coal (HV_C) for Virginia = 12,715 Btu/lb.

Source: DOE, Energy Information Administration

Tons of litter needed to replace 3.75 tons of coal per hour.

(Note: The equation yields a range of values and a distribution in accordance to the values and distribution for poultry litter heating values HV_L.)

$$\left(\frac{3.75\,tons/hr}{HV_L / HV_C}\right) \times \left(\frac{.3004\,Therm.Effiency_{Coal}}{.2489\,Therm.Efficiency_{Litter}}\right)$$

5) Variables Derived Using Heating Values

Annual Capacity Utilization of Poultry Litter (HAHE, pg. 15)

LUC = [Replacement Litter/hr (**Winter**) * 24 * 175] + [Replacement Litter/hr (**Summer**) * 24 * 175]

Annual Ash Production (HAHE, pg. 15)

AAP = $.169 * LUC_W + .169 * LUC_S$

Unit Litter Value (HAHE, pg. 15)

ULV =[Replaced Coal/Replacement Litter] * [Coal Price ($)/ton]

Table 3.4 Range of Values for Variables Derived from Heating Value of Poultry Litter for the Incorporation of Model Uncertainty

	LUC		**AAP**		**ULV**	
	Litter Utilization Capacity		**Ash Production**		**Unit Litter Value**	
	Tons/year		**Tons/year**		**($/ton, year 1)**	
Statistics	Summer	Winter	Summer	Winter	Summer	Winter
	51,424.98	41,743.94	8,690.82	7,054.73	9.77	12.03
	54,436.35	49,426.87	9,199.74	8,353.14	9.23	10.16
	46,480.27	54,806.66	7,855.17	9,262.33	10.81	9.16
	47,114.50	81,379.59	7,962.35	13,753.15	10.66	6.17
	52,772.36	64,972.42	8,918.53	10,980.34	9.52	7.73
	55,562.62	66,400.38	9,390.08	11,221.66	9.04	7.56
	49,834.51	58,807.15	8,422.03	9,938.41	10.08	8.54
	48,827.75	64,281.22	8,251.89	10,863.53	10.29	7.81
	49,834.51	61,657.50	8,422.03	10,420.12	10.08	8.15
	56,603.60	87,889.96	9,566.01	14,853.40	8.87	5.71
	72,148.47	59,678.37	12,193.09	10,085.64	6.96	8.42
	47,206.52	58,381.01	7,977.90	9,866.39	10.64	8.60
	41,888.63	49,225.54	7,079.18	8,319.12	11.99	10.20
	46,659.73	42,627.41	7,885.49	7,204.03	10.76	11.78
	49,025.84	44,925.16	8,285.37	7,592.35	10.24	11.18
	49,225.54	47,206.52	8,319.12	7,977.90	10.20	10.64
	51,207.07	46,037.60	8,654.00	7,780.35	9.81	10.91
	58,100.33	70,879.00	9,818.96	11,978.55	8.64	7.09
	45,776.02	50,991.01	7,736.15	8,617.48	10.97	9.85
	64,624.97	53,710.53	10,921.62	9,077.08	7.77	9.35
	70,465.71	47,672.07	11,908.71	8,056.58	7.13	10.54
	54,436.35		9,199.74		9.23	
	50,458.74		8,527.53		9.95	
	58,100.33		9,818.96		8.64	
Mean	53,008.99	57,271.42	8,958.52	9,678.87	9.64	9.12
Min	41,888.63	41,743.94	7,079.18	7,054.73	6.96	5.71
Max	72,148.47	87,889.96	12,193.09	14,853.40	11.99	12.03
Variance	56,035,253.67	151,818,327.27	1,600,422.88	4,336,083.25	1.47	3.14
S.D.	7,485.67	12,321.46	1,265.08	2,082.33	1.21	1.77
Expected Value	57,344.16	64,103.22	9,691.16	10,833.44	9.43	8.96

Delmarva's poultry litter heating values for both summer and winter seasons. In line with the HAHE study, an assumption of 350 working days per year (175 summer + 175 winter days) was used to calculate annual levels for Annual Litter Utilization Capacity (LUC) and Annual Ash Production (AAP). Annual Litter Utilization Capacity was estimated by adding the replacement litter needed for 175 winter days with the replacement litter needed for 175 summer days. According to HAHE, annual production of residual litter ash from combustion equaled 16.9 percent of total utilization capacity. Therefore, AAP was equal to the product of 0.169 and total LUC. The unit value of litter (ULV) was equal to the price of coal multiplied by the ratio of coal replaced (3.75 tons/hr) and the amount of litter needed for replacement. Table 3.3 provides details on calculations for the amount of coal replaced and the derivations for LUC, AAP, and ULV.

Summer and winter values for LUC, AAP, and ULV were both calculated separately in order to maintain the same distribution as heating values and were then added to acquire annual amounts. Table 3.4 provides a listing of the values for these variables. Also included in Table 3.4 are the expected values for LUC, AAP, and ULV based on the same probability distribution used for poultry litter heating values.

The probability distribution used in the feasibility model to represent heating values was determined as follows. A specific probability distribution was not available for the summer and winter heating values, therefore, a histogram was prepared for both sets of data and used to give an estimate of the distribution for each season (Figures 3.2 & 3.3). A careful review of the probability distributions available in @RISK and the descriptions of their applications led to the conclusion that a Histogram probability distribution (Appendix C) would provide the best distribution approximation for data dependent on summer and winter heating values. According to @RISK, a Histogram distribution, which requires the input of minimum, maximum, and actual values or their probability estimates, could be applied to grouped data with a non-specified probability distribution for the purpose of "approximation of arbitrary probability distributions" (Palisade, pg. 227).

Figure 3.2 Distribution for Summer Poultry Litter Heating Values

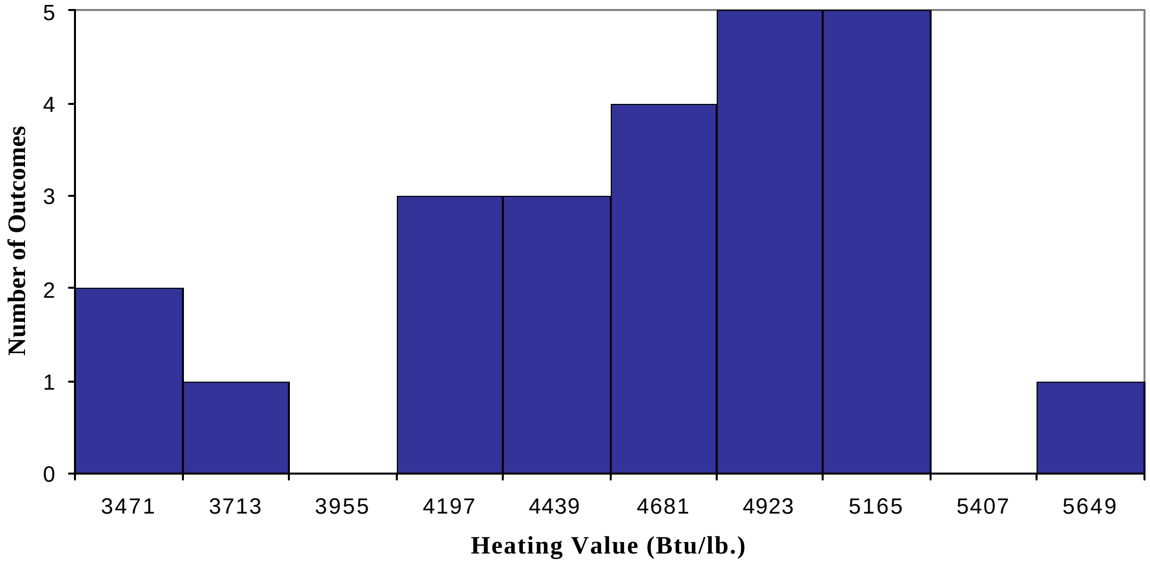
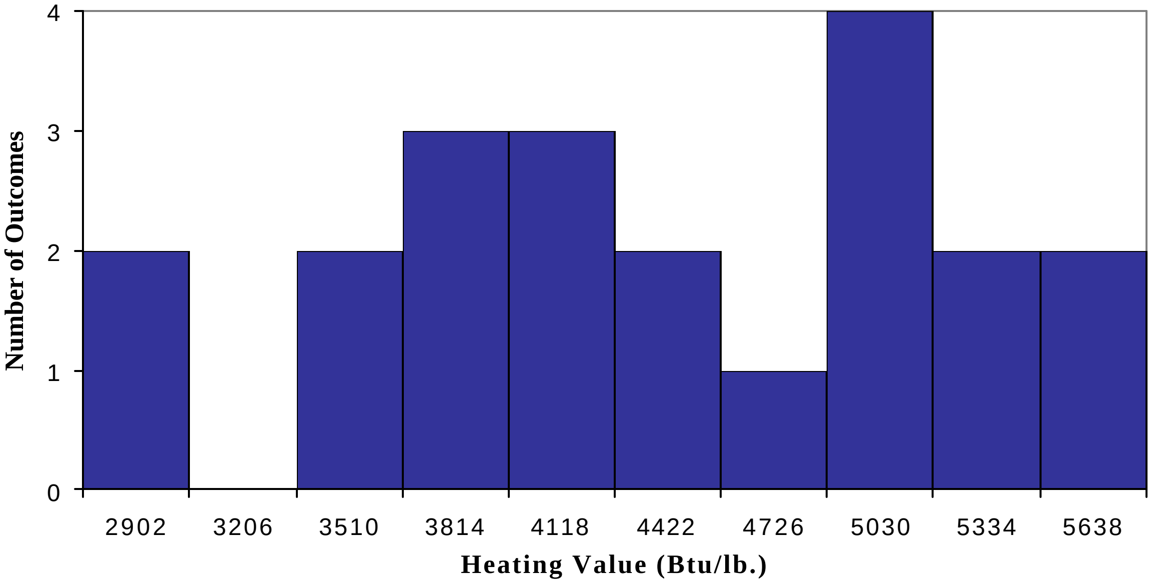


Figure 3.3 Distribution for Winter Poultry Litter Heating Values



Unit Ash Value (UAV)

The Agricultural Research Service (ARS) in cooperation with the Maryland Department of Natural Resources concludes, through its experiments with litter ash, that poultry litter's residual ash from combustion could be used as a fertilizer due to its elevated levels of inorganic material remaining after combustion (Chavez, "New Nest Egg. Poultry Litter as a Fertilizer"). The ARS successfully grew wheat in lime and non-limed soil using poultry litter residual ash and potassium phosphate. In addition, EEM concludes litter ash is free of the negative aesthetic aspects and concerns of biosecurity when using poultry litter as fertilizer.

Part of the difficulty in including returns from litter ash as a fertilizer in benefit-cost assessment has been the determination of a market value for the product. Based on calculations of ash value as a fertilizer replacement from both Fibrowatt Inc. and Primenergy Inc., Antares *et al.* estimates ash value ranges between $35 and $50 per ton after taking into account a $20 per ton granulation cost and a $15 per ton transport cost out of an area with high levels of phosphorous soils (Appendix D). They conclude the use of phytase in the broiler feed, a common practice in Rockingham County, could lower the value of ash by reducing the amount of P_2O_5 in the final product (Antares *et al.*, pg. 62).

HAHE are less sure in their assessment of the value of litter ash. Their uncertainty centers on the percentages of P_2O_5 and K_2O in residual ash, which it estimates to be 13.6 percent and 18.6 percent, respectively. Although lower levels of nutrients could deem residual ash to be more advantages than poultry litter for direct land application in excess nutrient locations, it may be disadvantageous in areas capable of absorbing higher levels of nutrients. As HAHE assert, conventional fertilizer generally contains 54 percent P_2O_5 and 48 to 60 percent K_2O. Moreover, the physical or "fluffy" make-up of the ash may require a binding element before granulation (Lefcourt and Martin, pg. 10). As a result, HAHE do not provide an estimate for ash value but instead test a range of values from 0 to $75 per ton. HAHE contends disposal cost might need to be added to the model if litter ash contained a zero value.

Although estimates were provided by PPRP, only unit ash values (UAV) from Antares *et al.* were used in the feasibility study due to the fact that its values were partially based on data from the Delmarva Peninsula as opposed to data most likely derived from Fibrowatt's British plants. Since values from Antares *et al.* were used without a probability estimate, a uniform distribution was determined to be the most suitable for the incorporation of uncertainty. A 2.5

percent annual inflation rate, equal to the average growth in the United States' consumer price index during the 1990's (International Monetary Fund, *International Financial Statistics*) and similar to the rate used in the PPRP study, was incorporated into the expected ash values.

Once the expected unit ash value per ton was determined, revenues from the sale of residual ash as fertilizer were added to the benefits of the model. As previously mentioned and in accordance with the HAHE study, the quantity of ash produced was estimated to be 16.9 percent of total litter utilization capacity (LUC). Revenues generated from AAP along with the quantity of LUC used to replace coal, made up the total annual revenue for the model.

Litter Acquisition Costs

After reviewing previous studies on the conversion of poultry litter to fuel, one variable which contained a significant degree of uncertainty but carried a great deal of weight in the project evaluation was the litter acquisition cost. Table 3.5 provides data on the litter acquisition costs for the PPRP study, Antares *et al.*, and estimates provided the Virginia Tech Cooperative Extension office in Harrisonburg, VA. PPRP refers to acquisition cost as a removal cost for litter from the poultry farm. They estimate a removal cost of $8 per ton in the Delmarva region but note that the price of litter would be expected to increase due to rising demands from its use as a fuel. Antares *et al*. include clean out costs with their litter disposal estimates and arrive at an estimate ranging between $8 and $10 per ton. In this case, litter contractors, who indicated a willingness to expand services if additional uses developed, provide cleaning services. The Virginia Tech Cooperative Extension office estimates litter acquisition costs at $6 to $8 per ton for Rockingham County with the individual farmer taking care of clean up. Future Nutrient Management Plans[3] could help lower the cost of litter acquisition by enforcing tighter constraints on litter land application and, therefore, leave farmers with a greater incentive to use disposal alternatives. Figures for acquisition costs (ULAC) from these three studies made up the histogram probability distribution used for Monte Carlo simulations. An inflation rate of 2.5 percent was also incorporated into the annual litter acquisition cost (ALAC).

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[3] Nutrient Management Plans: A plan to manage the amount, form, placement, timing and application of animal manure, chemical fertilizer, biosolids (sewage sludge), or other plant nutrients used in the production of agricultural products to prevent nonpoint source pollution, improve water quality, maintain soil productivity, and achieve realistic yield goals. (Maryland Department of Agriculture, Office of Conservation website).

Litter Transportation Costs

According to Pelletier 1999, transportation of litter in Virginia could be accomplished through the use of trucks capable of carrying 25 tons of litter at .11 cents per mile. Transport cost estimates from PPRP are similar at $.10 per mile while figures based on surveys collected by the Maryland Transportation Pilot Project (MTPP) average $.12 per mile. Since only three values were available, a triangular distribution for unit litter transportation costs (ULTC) averaging $.11 per mile was used in this study for a distance of 96.9 miles (M), the distance between Harrisonburg, Virginia and Bremo Bluff. Annual litter transportation costs (ALTC) increased continuously based on a 2.5 percent inflation rate. Using data from the daily litter utilization capacity, it was determined that roughly 13 trucks per day would be needed to transport litter.

Also included in the model but separate from transportation costs was the cost of truck clean up after hauling. Cleaning costs (CC) were estimated at $.53 per ton (Pelletier, pg. 76). Similar to other pricing variables, an annual inflation rate of 2.5 percent was assumed for clean up cost over the life of the project.

Remaining Variables

A list of the remaining consequential variables in the model can be viewed in Tables 3.5 and 3.6. Included in this table are values for: Unit Labor Cost (ULC), Connected horsepower (CHP), Hours of Operation (HR), Electricity Cost (EC), Maintenance and Repair Factor (MRF), Utilization Factor (UF), and Annual Labor Requirement (ALR). Heuristic Engineering and Hall Associates provided a majority of the values for these variables.

Calculations

Table 3.7 provides a complete breakdown of the NPV model along with equations used to derive key components. The primary difference between the HAHE model described in Section II of this report and the one listed earlier in this section was the incorporation of uncertainty through the use of probability distributions on selected variables. Similar to the PPRP study, a social time preference discount rate of 7 percent was used to discount NPV in order to simulate a public investment scenario and compared to the social time preference rate of

10 percent, which was more suitable for private investment and equal to the rate used in the HAHE report. The initial investment in the 75 Million Btu/hr external combuster was estimated at $2.7 million (Lefcourt, pg. 5). Project returns were measured for 20 years under a public investment scenario and compared to a private investment scenario of 15 years. Finally, since this site would require 13 trucks per day for litter hauling purposes, a truck clean up cost of $13.25 per truck was estimated based on results from Pelletier (pg. 76) and added to the feasibility analysis.

Table 3.5 Range of Values for Feasibility Model Variables not Derived Using Heating Values

		UAV*		ULAC		ULTC
Statistics	**Source**	**Litter Ash Cost ($/Ton of Fert.) Summer & Fall**	**Source**	**Acquisition Cost ($)/Ton**	**Source**	**Trans. Cost ($)/Mile**
	Antares *et al.*	35	PPRP	8	PPRP	0.1
		40	Antares *et al.*	8	Pelletier	0.11
		45		9	MTPP	0.12
		50		10		
			VT Coop. (Harrisonburg,VA)	6		
				7		
				8		
Min		**35.00**		**6.00**		**0.10**
Max		**50.00**		**10.00**		**0.12**
Mean		**42.50**		**8.00**		**0.11**
Expected Value		**42.50**		**8.49**		**0.11**

Table 3.6 Feasibility Model Variables Without Probability Distributions

Acronym	Variable	Value
CC*	**Cleaning Costs/Ton**	0.53
M*	**Distance (Miles)**	96.9
ULC	**Unit Labor Cost ($/yr./worker)**	35000
CHP	**Connected Horsepower**	500
HR	**Hours of Operation (Annual)**	8400
EC	**Electricity Cost ($/kWh)**	0.047
MRF	**Maintenance & Repair Factor**	0.05
UF	**Utilization Factor**	0.6
ALR	**Annual Labor Requirement**	2

Notes: Data provided by Hall and Heuristic Engineering
* Data Specific to Virginia and Bremo Power

Table 3.7 Feasibility Model Benefit-Cost Variable Calculations

Total Annual Revenue* ($)

TAR = [(LUC*ULV) + (AAP*UAV)]

Total Annual Costs* ($)

ALAC = ULAC*LUC

ALTC = ULTC*LUC*M

ALC = ULC*ALR

AUC = CHP*UF*HR*EC*(0.746kW/hp)

ACC = (350 days)*(13 Trucks)*CC

AMRC = CI*MRF
s.t.: CI = **[**(LUC*ULV) + (AAP*UAV) - (ULAC*LUC) - (ULTC*M*LUC) - (ULC*ALR) - (CHP*UF*0.746*HR*EC)**]/**(CRF+MRF)

TOAC = [ALAC + ALTC + ALC + AUC + ACC + AMRC]

Discount Rate

1) Public Investment: 7%
2) Private Investment: 10%

Project Life

1) Public Investment: 20 years
2) Private Investment: 15 years

Inflation Rate 2.5 percent

Net Benefits (Sum)

(TAR – TAOC)/(1 + Discount Rate)^{i}

1) Public Investment: i = 1, ..., 20
2) Private investment: i = 1, ..., 15

*Information Source (Except for ACC): Hall Associates and Heuristic Engineering

Risk Aversion

Risk averse preferences in an investment decision refers to the situation in which the investor prefers lower returns with certainty over uncertain higher returns (Chambers and Quiggen, pg. 94). If the investor's preferences are represented by a utility function, then the expected utility from net returns can be derived using the probability distribution of expected values. Risk aversion can then be defined as the scenario where the expected utility from the net returns on the investment is less than the utility of the expected value of the net returns.

In this particular model, risk aversion was represented by a strictly concave utility function that had a net return certainty equivalent[4], which was less than the expected value of the net return. Inserting a set of expected returns or income values, each with an estimated probability, into the utility function, derived each value's expected utility. The sum of the individual expected utilities multiplied by their probabilities formed a Von Nuemann-Morgenstern expected utility function[5] that equaled the certainty equivalent. The difference between the certainty equivalent level of returns and its expected value yielded the risk premium.[6] In this case, a positive risk premium signified risk averse preferences on the part of the private investor. A risk premium equal to zero signified the investor was risk neutral or indifferent to risk, such as a government investment scenario (United Nations, Industrial Development Organization, *Guidelines for Project Evaluation*, pg. 11).

$$u(y) = -e^{-cy}$$

y = Net Returns (Income)
c = Risk Parameter

The concave utility function used to represent constant absolute risk aversion[7] in investor preference for the project was the negative exponential function presented above. If the certainty equivalent or utility from the sum of expected net returns was greater than or equal to zero, then the project was deemed feasible to a private or risk averse investor. A utility value less than zero signified an aversion to the project under a private investment scenario.

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[4] Certainty Equivalent: The minimum certain income that provides an equivalent level of satisfaction as the original state contingent income set.

[5] Von Nuemann-Morgenstern Expected Utility Function: A utility function that represents the weighted sum of a set of utility functions where the weights are given by a set of probabilities that sum to 1 (Varian, Intermediate Microeconomics, pg. 214). $U(X) = u(x_1)p_1 + ... + u(x_n)p_n$

[6] Risk Premium: "The maximum amount that one can subtract from mean income and still have the resulting income, occurring with certainty, preferred to the original state-contingent income vector."(Chambers & Quiggen pg. 94)

Determination of the Expected Utility Function and Risk Averse Parameter

Using the distribution of expected net return derived from the Monte Carlo simulation in @Risk, the income probabilities were broken down into 19 intervals of 5 percent each, totaling 95 percent of all outcomes. In addition, in order to include the tails of the distribution, a 1 percent chance of occurrence was added for both the minimum and maximum results along with a 1.5 percent chance of an outcome occurring midway between the extremes and their next closest outcome. Once these expected values were included, the probability of outcomes totaled 100 percent.

The expected return values along with their probabilities were then summed to determine the expected utility of net returns or certainty equivalent given the utility function:

$$u(y) = -e^{-cy}$$

The level of risk aversion which would leave the private investor just indifferent between investing in the litter project or not investing was estimated by adjusting the risk parameter until the risk premium equaled the total expected net return or until the certainty equivalent approached zero. The risk parameter per dollar of output was then estimated by dividing the coefficient by the 15-year NPV of a dollar in order to adjust it from an annual income scale to a 15-year investment scale (Cochran and Raskin, pg. 207).

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[7] Constant Absolute Risk Aversion: The condition in which the risk premium of a utility function remains unchanged despite changes in income. (Chambers & Quiggen).

Part I, Chapter 4
Results

The following section contains the results from Monte Carlo simulations on the economic feasibility of partially displacing coal with poultry litter under a public investment scenario (20 year project life at 7 percent discount rate) and under a private investment scenario (15 year project life at 10 percent discount rate). The section provides a comparison of the overall project net present value for three sets of coal prices: real coal prices (Base Year = 2000), real coal prices adjusted annually by a 2.5 percent increase, and coal prices increasing at a constant 2.5 percent rate. In addition, sensitivity analysis and a synthesis of input scenarios is performed on the distribution of expected returns under real coal prices. The section continues with a discussion of uncertainty by comparing the descriptive statistics for heating value in both summer and winter months and further examining conditions that could alter their values. Based on results from Monte Carlo simulations, values for residual ash are fixed in order to determine the sensitivity of litter acquisition cost to ash value. The section concludes with a measurement of the maximum degree of risk aversion possible to maintain project feasibility.

Simulation Results

As detailed in the previous section, three sets of NPV simulations were run based on different forecasts for future coal prices. Table 4.1 contains statistics on each NPV simulation. Tables 4.2 and 4.3 provide results from the sensitivity analysis using real coal prices.

Net Present Value Using Real Coal Prices (Base Year = 2000)

Results from the Monte Carlo simulations demonstrated that, despite uncertainty conditions, the use of poultry litter as a fuel source during the production of energy was feasible when partially displacing coal at both a seven and ten percent discount rate (Table 4.1). Under private investment conditions (10 percent discount rate), expected returns to investment exceeded $1.63 million over the 15-year life of the project with minimum expected returns at $-3.20 million and maximum returns at $6.97 million while the standard deviation was $1.90 million. When conditions were examined for public investment (20 years at 7 percent discount rate), expected net returns were $2.71 million with a minimum of $-4.39 million and a maximum of $10.1 million. Standard deviation under public investment conditions was $2.78 million. Both investment scenarios broke even after the fifth year.

Table 4.1 Expected Net Present Value of the Feasibility of Partially Replacing Coal with Poultry Litter Under Private and Public Investment Scenarios for Three Sets of Coal Prices ($ *thousands*)

	Real Coal Price (2000)		Real Coal Prices Adjusted Up by 2.5 Percent Annually		2000 Coal Prices Increasing Annually by 2.5 Percent	
	Private 15 yr., 10%	Public 20 yr., 7%	Private 15 yr., 10%	Public 20 yr., 7%	Private 15 yr., 10%	Public 20 yr., 7%
Statistics						
Minimum	-3,198.0	-4,386.0	-1,767.0	-2,443.0	-960.0	-614.0
Mean	1,634.0	2,712.0	2,859.0	4,615.0	3,675.0	6,102.0
Maximum	6,975.0	10,099.0	9,857.0	13,689.0	10,785.0	15,375.0
S.D.	1,900.0	2,784.0	1,969.0	2,677.0	1,996.0	2,663.0
Break Even Year	6	6	5	5	5	5

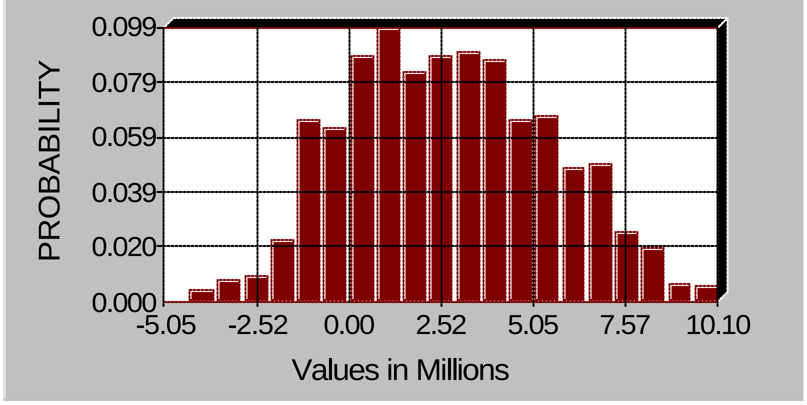


Figure 4.1a Distribution for ENPV of Feasibility Model at 7% Discount Rate for 20 Years ($) Using Real Coal Prices
(Base Year =2000)

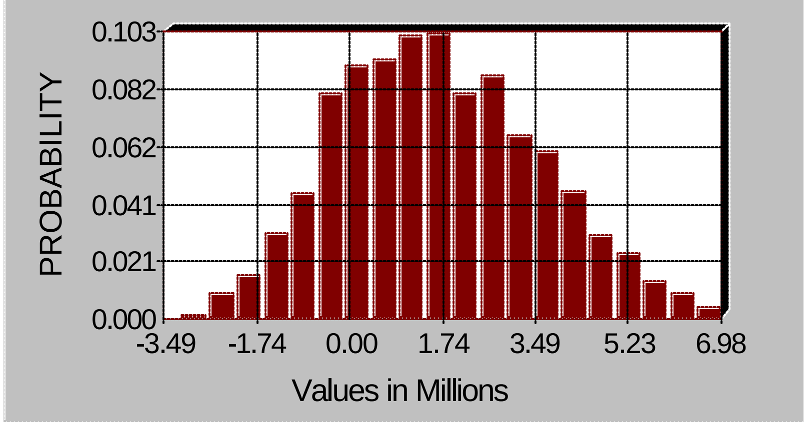


Figure 4.1b Distribution for ENPV of Feasibility Model at 10% Discount Rate for 15 Years ($) Using Real Coal Prices
(Base Year = 2000)

A closer examination of the probability distributions for net returns is presented in figures 4.1a and 4.1b. Using a 7 percent discount rate, returns were expected to be equal to or less than $2.54 million with a 50 percent probability. At a 10 percent discount rate and a 50 percent probability, returns were expected to be equal to or less than $1.50 million. A lower value for net returns is expected under private investment conditions due in large part to the shorter term of the project. Net returns for government investment could be expected to be greater than or equal to $539 thousand with a 75 percent probability but equal to at least $4.72 million with 25 percent likelihood. A private investor measuring the same probabilities could expect values to range between $198 thousand and $2.98 million. The probability of breaking even was almost 80 percent for the private investment case and just over 80 percent for a government or public investment.

Net Present Value Using Real Coal Prices Increased Annually by 2.5 Percent

When real coal prices were increased annually by 2.5 percent, returns grew dramatically for both private and public investment scenarios (Table 4.1). The mean ENPV for a publicly funded project was $4.62 million with a maximum of $13.70 million and a potential minimum value of $-2.44 million while a privately funded project under these same coal price conditions achieved a mean ENPV equaling $2.86 million with a maximum of $9.86 million and a minimum of $-1.77 million. Standard deviations for the publicly funded and privately funded projects were $2.68 million and $1.97 million, respectively.

When comparing net returns for both types of investments under fixed probabilities, at 50 percent, the expected outcome for a publicly financed project was $4.39 million while a privately financed project had a 50 percent probability of acquiring net returns totaling $2.75 million. Further examination of outcome probabilities demonstrated a 75 percent chance of yielding returns less than or equal to $1.52 million for a private investment and $2.70 million for a public investment. When outcome probabilities decreased to less than 25 percent, ENPV figures for the private investment case were computed at $4.21 million and $6.26 million for the government investment scenario. The probability of breaking even was almost 100 percent in the public investment case and approached 95 percent in the private investment case. Under the annual adjustment to real coal prices, the project was expected to break even after the fourth year or one year earlier than under real coal prices for both investment scenarios.

Net Present Value Using Coal Prices Increasing at 2.5 Percent Annually

As expected, when the third set of coal prices, which increased at a constant 2.5 percent rate, were inserted in the model, the mean value of the model achieved its highest value at $6.10 million for the public investment scenario and $3.67 for the private investment scenario. The expected returns at a 10 percent discount rate ranged in values from a minimum of $-960 thousand to a maximum of $10.80 million. A 7 percent discount rate returned a range of values from $-613 thousand to $15.40 million. Standard deviations were similar in both investment scenarios with the private investment value equaling $2.00 million and the public investment value equaling $2.66 million.

Both investment scenarios had an expected probability of breaking even that approached 100 percent yielding positive returns during the fifth year. Given a 50 percent probability, NPV outcome totals were $3.58 from private funding and $5.85 from public funding. Under 25 to 75 percent probabilities, the private investment case could expect NPV outcomes to range from a low of $ 2.28 million to a high of $4.74 million. Public investment values were far greater with a 25 percent likelihood of returns at $7.73 million or less and a 75 percent likelihood of returns less than or equal to $4.16 million.

Opportunity for Project Feasibility Based on Future Coal Prices

Real Coal Prices

From the equation for unit litter value (Table 3.2), the attainment of positive returns to investment were dependent on the price of fuel replaced which in this case was the price of coal. Since real coal prices were expected to decline over the next 20-years (DOE), values for ULV followed a similar decreasing trend. As a result, annual net revenue declined with the price of coal (Figure 4.2). In fact, an increase in ULAC to greater than $11 per ton or a drop in UAV below $30 per ton not only produced a negative NPV but also resulted in negative future returns for both investment scenarios due to the declining litter replacement value (Figure 4.3). Implications were that a decrease in the real price of coal coupled with a steady price of poultry litter could eventually result in future litter costs becoming too expensive to be used as a replacement fuel source for coal. Extending the life of the project to thirty years demonstrated that under real coal price conditions, positive annual returns would cease after the 26th year for both investment scenarios.

Figure 4.2 Annual Net Returns for the Feasibility Model vs. Real Coal Prices (Base Year = 2000)

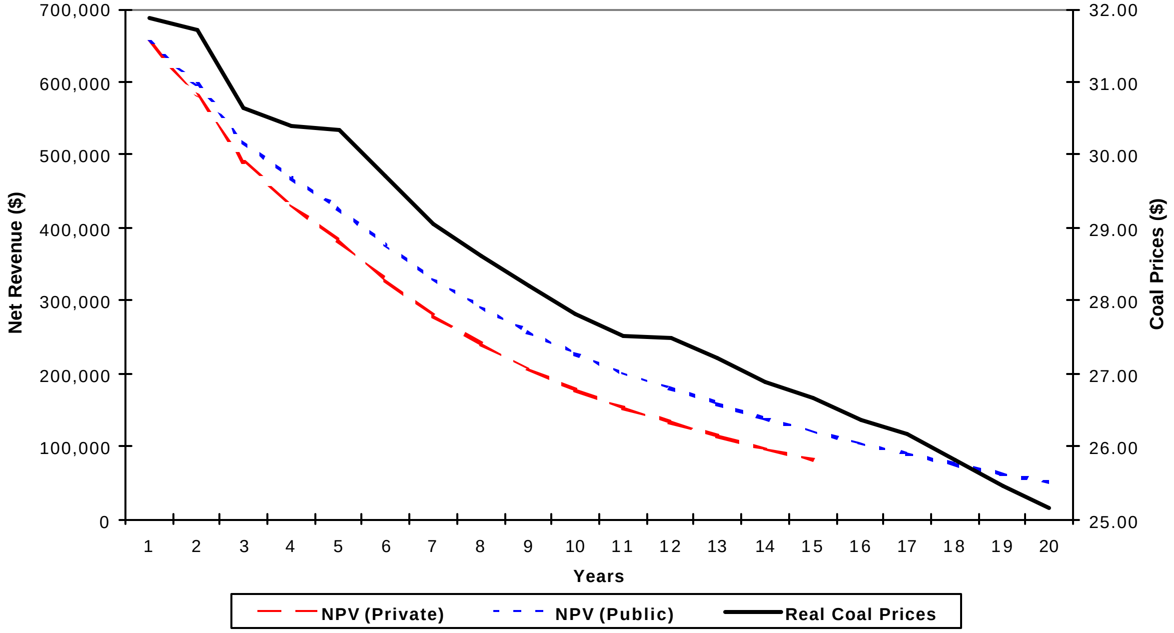
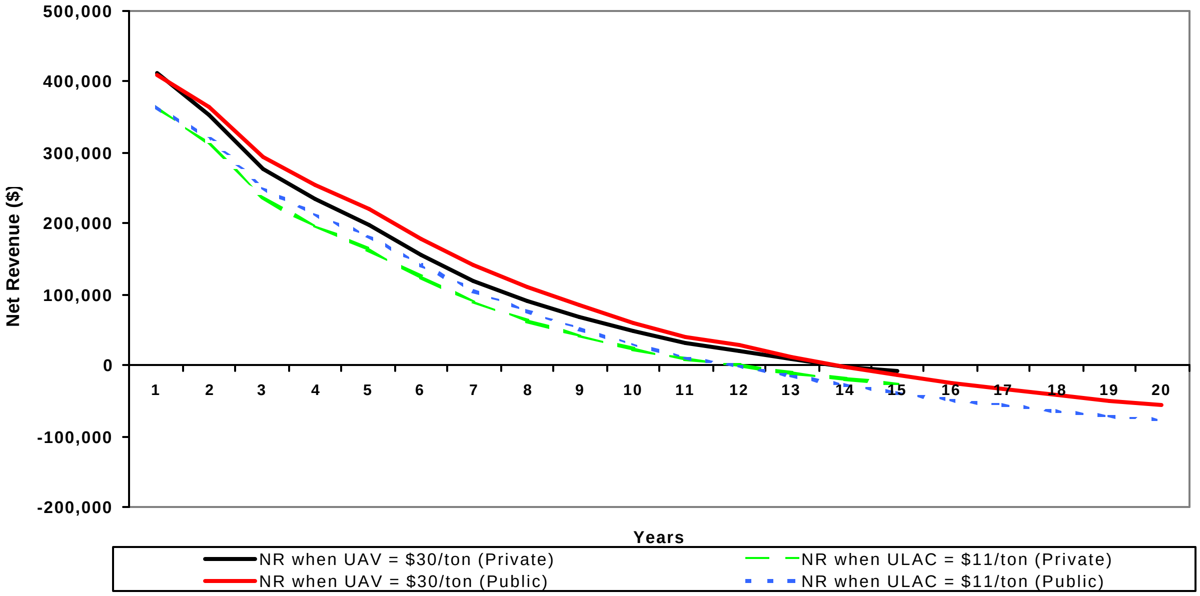


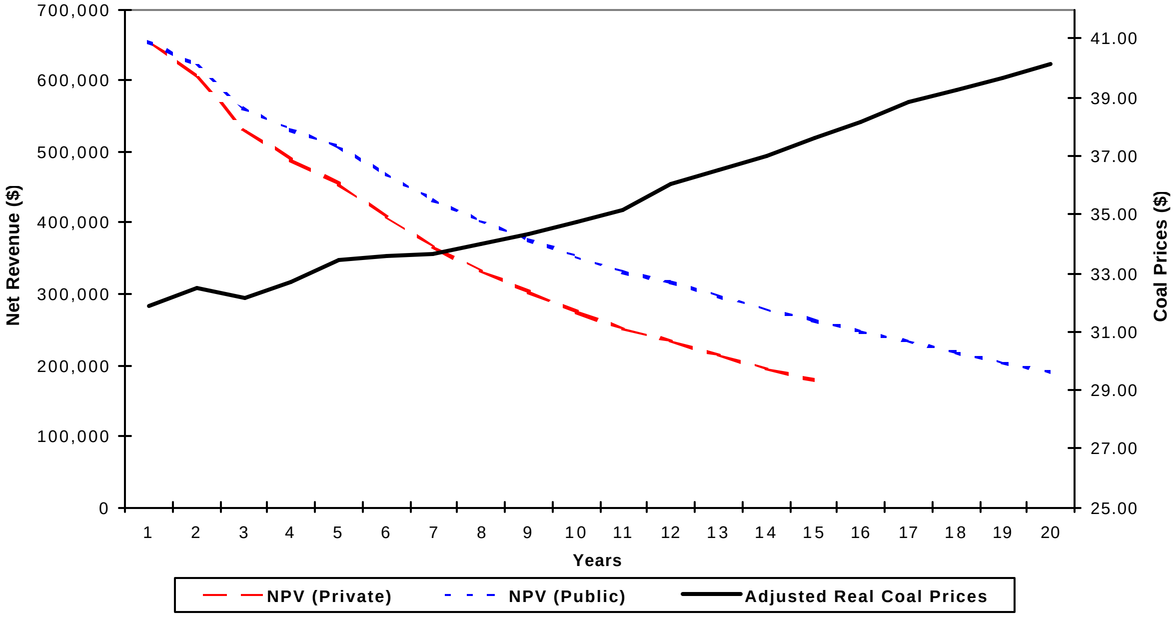
Figure 4.3 Future Net Revenue (NR) for the Feasibility Model when Unit Litter Acquisition Cost (ULAC) at $11 or Unit Ash Value (UAV) at $30



Real Coal Prices Adjusted Annually by 2.5 Percent

When real coal prices were adjusted to incorporate an inflationary trend of 2.5 percent, litter's replacement value increased while NPV for both investment scenarios decreased at a lower rate than under real coal prices (Figure 4.4). Unit litter acquisition cost could increase to $12.75 per ton before yielding negative future annual returns while unit ash value could decrease to less than $18 per ton. Extending the life of the feasibility model showed the window of feasibility for the project was greater than 30 years and was well beyond the 26-year limit found for real coal prices.

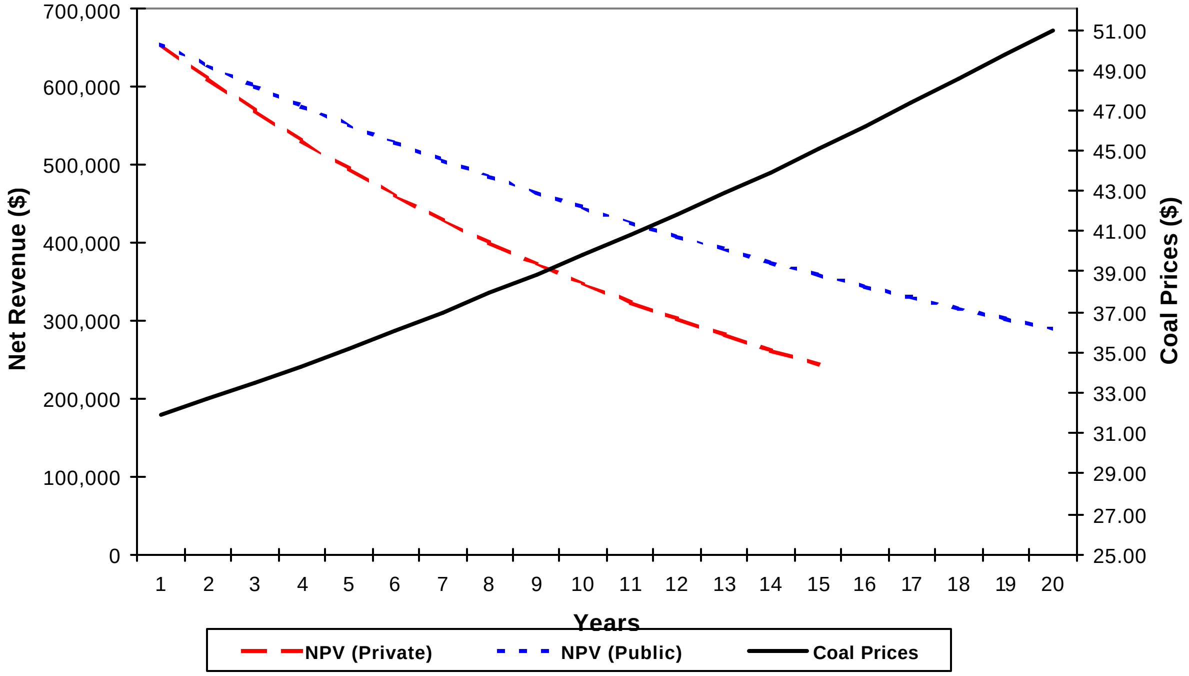
Figure 4.4 Annual Net Returns for the Feasibility Model vs. Real Coal Prices (Base Year = 2000) Adjusted to a 2.5 Percent Annual Increase



Coal Prices Increased at a Constant Rate of 2.5 Percent

As expected, NPV results when coal prices increased annually by a constant 2.5 percent rate beginning at $31.89 per ton in 2000, were greater in value than under the previous two sets of coal prices. Since coal prices increased at the same rate as other price variables in the model, decreases in NPV were solely due to the increasing denominator in the feasibility equation (Figure 4.5). Therefore, determination of the threshold that produced negative future annual returns for ULAC and UAV was not applicable. Similar to NPV results from the inflation adjusted coal prices, the opportunity of feasibility for the project was well beyond 30 years.

Figure 4.5 Annual Net Returns for the Feasibility Model vs. a Constant 2.5% Increase in Coal Prices



Input Scenario Analysis

Input scenario analysis in @Risk provides the combination of input variables that significantly contribute to an output target (Palisade pg. 48). For example, if the target is a high level of NPV, possibly in the 90th percentile, then @Risk lists the combination of input variables that most influence the target outcome as well as the input percentiles[8] required to achieve the target. Sensitivity in an input variable is determined by measuring the change in the input variable simulation median required to meet the specific output target. Scenario analysis determines the significant input variables by taking the subset of iterations of the simulation that achieved the output target then compares the median value of the input variables in that subset to the median values for the input variables in the entire set of iterations. If the subset median for the input variable differs by at least one-half of a standard deviation from the overall median of the input variable then the input variable is deemed significant. A subset median of an input variable less than its overall simulation median is considered to have a negative significance, while a subset median greater than its overall median implies a positive significance. The significance coefficient equals the difference between the subset median and the overall median divided by the standard deviation of the input variable in the entire simulation (Palisade, pg. 148).

Table 4.2 provides input combination scenario results required for the achievement of three NPV percentile targets for both types of investments: percentile targets greater than 75, greater than 90, and less than 25. At a target in the 75th percentile of Expected Net Present Value (ENPV), the significant input combination was slightly different for a public investment when compared to the private investor, due to the exclusion of summer ash production (AAPS). The remaining variables in the input combination required expected values with similar percentiles. A low litter acquisition cost (ULAC_{public} = 17th percentile; $\text{ULAC}_{private}$ = 16th percentile) proved to be the most significant input variable. This meant ULAC had the largest difference between its subset median and its overall median when the output target was in its 75th percentile. A high unit ash value (UAV) in the 69th percentile for both cases was the least significant variable in the public investment scenario (0.61) and only slightly more significant than AAPS in the private investment scenario with a ratio of 0.67. A comparison of significance level (ratio of median difference to simulation standard deviation) showed little difference in input order when total annual ash production for both seasons was viewed as a group. As the target value for ENPV was increased to the 90th percentile, summer ash production entered the input combination for the public investment but at a lower significance level (0.52) compared to (0.68) in the private investment. Implications were that in the public investment case, AAPW had a higher difference between its subset median and its overall median and, therefore, was more important to achieving a model feasibility target compared to AAPS.

As expected, when a low ENPV was targeted (25th percentile), input scenario results showed high litter acquisition costs coupled with low ash production (AAP) and ash value (UAV) to be the most significant combination. In both investment conditions, ULAC was in the 76th percentile of its expected value and slightly more significant than the least significant variable to both investment situations, AAPS. Both private and public investment scenarios displayed ash production for summer and winter below their 34th and 29th percentiles,

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[8] Input Percentile: Provides information on the value of the input variable. For example, an input variable in the 75th percentile suggests the values of the significant variable needed to achieve an output target are in its upper quartile.

respectively, with AAPW having the second highest significance level. Input variable UAV, which required a similar percentile (below 29 percent) in both cases, had the highest significance level with a median differential to standard deviation ratio of (-0.74) for the private investment case and (-0.88) for the public investment case. At a low output target (25th percentile), UAV showed not only the highest median differential to standard deviation ratio but also its subset median value was below its overall simulation median resulting in a negative coefficient.

Table 4.2 Input Combination Scenario Analysis on Expected Net Present Value Targets for the Feasibility Model Using Real Coal Prices
(Base Year = 2000)

	Private 15 yr., 10%	
	Percentile	**Ratio Median to Std. Deviation**
Target > 75%		
Summer Ash Production (AAPS)	65.93%	0.66
Winter Ash Production (AAPW)	71.73%	0.82
Unit Ash Value (UAV)	69.93%	0.67
Unit Litter Acquisition Cost (ULAC)	16.40%	-1.72
Target < 25%		
AAPS	32.46%	-0.52
AAPW	27.57%	-0.68
UAV	28.43%	-0.74
ULAC	76.77%	0.56
Target > 90%		
AAPS	66.76%	0.68
AAPW	77.76%	1.10
UAV	71.24%	0.73
ULAC	10.10%	-1.96
	Public 20 yr., 7%	
	Percentile	**Ratio Median to Std. Deviation**
Target > 75%		
AAPW	72.43%	0.86
UAV	69.71%	0.61
ULAC	17.43%	-1.64
Target < 25%		
AAPS	33.36%	-0.53
AAPW	28.64%	-0.71
UAV	27.84%	-0.88
ULAC	76.22%	0.56
Target > 90%		
AAPS	63.88%	0.52
AAPW	78.42%	1.11
UAV	75.93%	0.79
ULAC	12.24%	-1.80

Regression Sensitivity and Rank Correlation

Rank order correlation is conducted by assigning a different rank to each data point of a variable, generated through the number of MC iterations, in accordance to the data point's position within the minimum-maximum range of possible sample values for the variable (Palisade, pg. 146). For example, the 5th lowest data point in a sample receives the 5th lowest rank while the 5th highest data point receives the 5th highest rank. Once this is completed, the rank values are correlated in order to determine the relationship between values of different variables. @Risk ranks each input variable and correlates the rankings with rankings assigned to the output variable ENPV. In addition, @Risk provides a multivariate stepwise regression coefficient or sensitivity value for each input variable in the model.[9]

Table 4.3 Sensitivity Analysis and Rank Correlation for Net Present Value Using Real Coal Prices (Base Year = 2000) and Input Variables

Input Variable*	Regression Coefficient	Rank Correlation Coefficient
Private Investment (15 yr., 10%)		
ULAC	-0.694	-0.664
AAPW	0.444	0.452
UAV	0.422	0.404
AAPS	0.305	0.318
LUCW	-0.102	-0.098
LUCS	-0.059	-0.025
ULTC	0.000	0.008
Public Investment (20 yr., 7%)		
Input Variable	**Regression Coefficient**	**Rank Correlation Coefficient**
ULAC	-0.713	-0.692
AAPW	0.441	0.434
UAV	0.414	0.395
AAPS	0.297	0.237
LUCW	-0.132	-0.181
LUCS	-0.077	-0.064
ULTC	0.000	-0.036

*Variables
ULAC: Unit Litter Acquisition Cost ($)
AAPW: Winter Ash Production
UAV: Unit Ash Value ($)
AAPS: Summer Ash Production
LUCW: Winter Litter Utilization Capacity
LUCS: Summer Litter Utilization Capacity
ULTC: Unit Litter Transportation Cost ($)

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[9] Multivariate Stepwise Regression: A technique for calculating regression values with multiple input values. Coefficients for each input value are normalized. A regression value or coefficient equal to 0 means no significance exists with the output variable while an absolute value of 1 means a significant 1 unit standard deviation change in the output variable exists due to a 1unit standard deviation change in the input variable. (Palisade, Guide to @Risk. P. 145).

Figure 4.6a Regression and Rank Correlation Coefficients from Sensitivity Analysis on the Feasibility Model Using Year 2000 Real Coal Prices (10%, 15 Yr.)

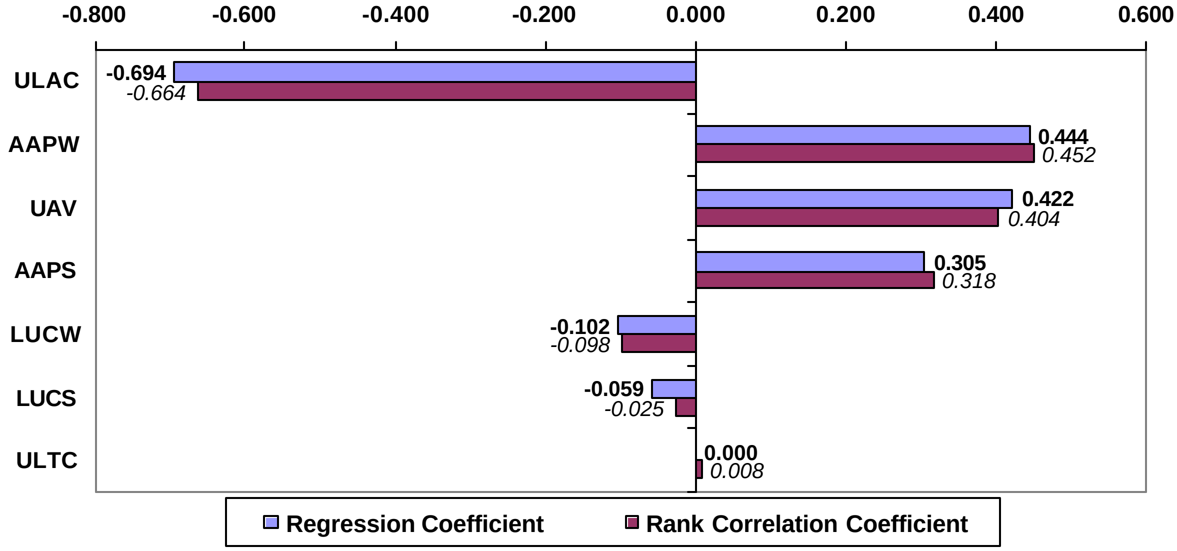
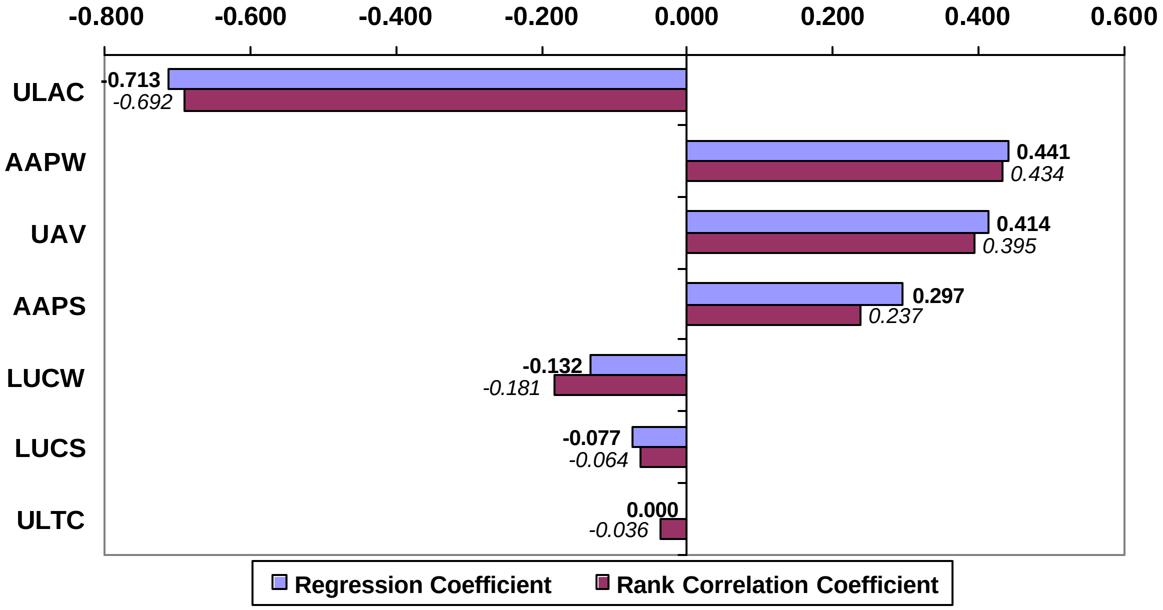


Figure 4.6b Regression and Rank Correlation Coefficients from Sensitivity Analysis on the Feasibility Model Using Year 2000 Real Coal Prices (7%, 20 Yr.)



Sensitivity analysis for both public and private investment scenarios can be viewed on Table 4.3. In both cases, ULAC had the highest rank correlation coefficient at –0.66 for the private investment and –0.69 for the public investment. Regression coefficients or sensitivity values for the private and public investment cases were –0.69 and –0.71, respectively (Figures 4.6a and 4.6b). A view of the tornado graphs show ash production in the winter to be the variable with the second highest correlation coefficient equaling 0.45 under private investment and 0.43 under public investment along with regression sensitivity values of 0.44 for both investment scenarios. Figures 4.6a and 4.6b also demonstrate summer ash production is the fourth most sensitive variable with a regression coefficient equal to 0.30 in both cases. Once again winter production levels for litter utilization capacity and residual ash from combustion proved more significant than during summer. This can also be observed when examining the higher rank correlation coefficient for LUC, the variable used to derive AAP, during winter months for both investment scenarios. Investment conditions proved equally dependent on unit ash value (UAV) with a regression sensitivity coefficient value of 0.42 and rank correlation of 0.40 for the private investor and a sensitivity coefficient of 0.41 and rank correlation of 0.39 for the public investor.

Summer and Winter Heating Value Comparison

Although simulation results showed little difference in input variable significance between private and public investment cases, scenario and sensitivity analysis demonstrated that seasonal differences could play a part in the project feasibility. Table 3.1 compares descriptive statistics for heating value, used in the derivation of LUC, AAP, and ULV, for both summer and winter seasons in wet and dry litter conditions. During wet litter conditions, such as the situation used for this particular study, winter months showed a higher range in heating values (3,040 Btu/lb.) compared to 2,420 Btu/lb. during summer months. This result was also apparent when a comparison of standard deviations was conducted. Despite similar mean heating values in wet conditions, 4,637.5 Btu/lb. in the summer and 4,390.5 Btu/lb. in the winter months, the standard deviation for the winter was substantially higher at 852.1 Btu/lb. compared to 583.8 Btu/lb. in the summer months. An analysis of dry litter showed similar characteristics with winter heating values ranging from 4,520 to 7,404 Btu/lb. while summer heating values ranged from 5,030 to 7,280 Btu/lb. Simulation results for expected net present value (ENPV) coupled with its descriptive statistics imply the ratio of median to standard deviation during input scenario analysis and rank correlation coefficient was greater for winter months due in large part to its increased level of uncertainty in heating values. As expected, the uncertainty differences in heating values during summer and winter months were passed on to variables derived from heating values such as LUC and AAP which were influential in project feasibility.

Contributing to the uncertainty in heating values was the percentage of moisture content in litter, which was more volatile in winter months. A comparison of litter moisture content proved it to be higher during the winter (29.5 percent) than during summer (27.4 percent). Differences between minimum and maximum percentages were higher during winter months (39.2 percent) than during the summer months (36.6 percent). A moisture content standard deviation of 10.89 during winter was also higher than the 8.27 standard deviation during summer.

Ordinary least squares (OLS) regression analysis demonstrated a dependency of heating values on moisture content when regressing wet heating values on the litter moisture content, however, it failed to provide evidence to suggest winter months were more influential than summer months. Results of regression analysis run on moisture content alone verified a high level of significance for moisture composition (T-statistic = –8.03) with poultry litter heating values declining by –60 Btu/lb. for every percentage increase in moisture content. Therefore, an increase in moisture content would result in a decrease in net revenue through a decrease in heating value's effect LUC and AAP. Seasonal dummy variables showed no significance when testing if their coefficients were different than zero with T-statistics equal to 0.88 for both seasons. These results failed to provide sufficient evidence to support a hypothesis that annual heating value averages were more dependent on one season than the other.

1) $HV = 6145.7*C - 59.5*Moisture + 122.6*Summer$

$$(25.09) \qquad (-8.03) \qquad (0.88) \qquad R^2 = 0.63$$

2) $HV = 6268.4*C - 59.5*Moisture - 122.6*Winter$

$$(28.07) \qquad (-8.03) \qquad (-0.88) \qquad R^2 = 0.63$$

Results from mispecification tests on the regression model are provided in Appendix E. Unfortunately, mispecification tests revealed that normality tests on the residuals led to evidence against a null hypothesis of a normal distribution in the model's residuals. Therefore, a statistically adequate OLS model was not available for the empirical analysis measuring heating values' dependency on moisture content.

Unit Ash Value with Unit Litter Acquisition Cost

Similar to the HAHE study but in this case testing the sensitivity of litter acquisition cost to ash value, the range of possible fertilizer ash values was fixed in order to determine the maximum litter acquisition cost permitted for positive net returns on investment (Table 4.4). At the expected ash value of $42.50 per ton for the private investment case, unit litter acquisition cost needed to be restricted to less than or equal to $9.97 per ton including clean up at the farm site. Under the same investment scenario, a maximum ash value of $50 per ton increased the allowable litter acquisition cost to $11.24 per ton while an ash value of $35 per ton decreased viable litter acquisition cost to $8.70 per ton. When compared to the government investment scenario (7 percent discount rate for 20 years), the expected ash value of $42.5 per ton yielded a maximum unit litter acquisition cost of $10.14 per ton (Table 4.4). Ash values at $35 per ton under a public investment decreased acceptable acquisition costs to $8.87 per ton while maximum ash values raised the acquisition cost to its highest point for the two investment scenarios ($11.41 per ton). If ash was unable to be sold as a fertilizer, then ULAC dropped significantly in order to maintain feasibility ($2.79 per ton at a 10 percent discount rate and $2.96 per ton at a 7 percent discount rate). It should be noted that ULAC values when UAV equaled zero, did not take into account an ash disposal cost to the project. Constraints on UAV, when ULAC equaled its expected value of $8.49 per ton, were restricted to greater than or equal to $32.72 per ton for the public investment case and $33.71 per ton for the private investment case.

Transportation Costs

Based on figures from previous studies, transportation cost did not prove to be a decisive variable in the economic feasibility of partially replacing coal with poultry litter. Although transportation costs would be expected to increase with the utilization capacity of litter (LUC), both investment cases proved unit litter transportation cost (ULTC) to be the least significant variable in terms of sensitivity and rank correlation (Table 4.3). The inclusion of truck cleaning (CC) did not significantly alter this result.

Table 4.4 Effect of Ash Value on Required Litter Acquisition Cost when NPV Estimated Using Real Coal Prices (Base Year = 2000)

ULAC* ($)	Net Present Value (NPV) ($)	Ash Value (UAV)** ($)
Private Investment (15 yr., 10%)		
9.97	6,907.21	42.50
11.24	4,124.55	50.00
8.70	9,689.87	35.00
2.79	4,124.55	0.00
Public Investment (20 yr., 7%)		
ULAC	NPV	Ash Value
10.14	5,155.80	42.50
11.41	1,179.28	50.00
8.87	9,132.31	35.00
2.96	1,179.28	0.00

*ULAC: Unit Litter Acquisition Cost ($)
**UAV: Unit Ash Value ($)

Risk Aversion

Table 4.5 provides numbers for the expected value and expected utility of each outcome from the proposed project. Note the expected net present value of $1.626 million in net returns is close to the expected net present value of $1.634 million from the Monte Carlo simulations. With an Arrow-Pratt coefficient[10] or risk parameter equal to 1.014 x 10^{-6}, the total benefits just surpassed total costs. The certainty equivalent at that level of risk aversion was scarcely greater than zero at $261.56 while the risk premium of $1.62 million converged on the expected value of net returns.

Implications from these results were that a private investor with this level of risk aversion would just favor investment and would therefore decide to fund a project proposing the partial replacement of coal with poultry litter. In fact, at this level of risk aversion, the investor would be willing to pass up an expected but uncertain return of $1.62 million if he or she can be guaranteed to just break even on the project. In other words, the risk averse investor would prefer returns slightly greater than zero with certainty to uncertain returns that are less than or equal to $1.62 million. By comparison, a risk neutral investor with indifference to uncertainty

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[10] Arrow-Pratt Coefficient: A measure of the absolute risk aversion of a utility function whereby the second derivative of the utility function is divided by the first derivative and multiplied by negative one. As the value of the coefficient increase, the level of absolute risk aversion increases (Varian, Microeconomic Analysis, pg. 178). Arrow-Pratt = $-u''(x)/u'(x)$

would prefer a gamble that potentially yields $1.62 million in returns despite the risk of failure. For the risk averse investor, expected returns less than $1.62 million yielded an expected utility less than zero which was equivalent to a net loss on the project once viewed through the concave utility function. In this case, the project would be determined to be unfeasible and rejected by the private investor. At a level of risk aversion defined by a risk parameter larger than 1.014×10^{-6}, the risk averse investor would be willing to pay or give up an amount greater than $1.62 million in order to pursue the project. As a result, the investor's expected utility would be negative. Therefore, as the risk parameter increased, the certainty equivalent became negative and the expected return on the project was no longer enough to offset the investor's risk averse preferences. The private investor once again would reject the proposed project. Conversely, as the risk parameter decreased, the certainty equivalent value increased, and the risk premium approached zero meaning the incentive for private investment increased or the project became less risky.

Table 4.5 Expected Income Values and Values for Expected Utility Under Private Investment with Feasibility Model Output Using Real Coal Prices (Base Year = 2000) Measured Under Constant Absolute Risk Averse Preferences

Income Outcome ($)	Probability	Expected Value ($)
-3,198,495.00	0.01	-31,984.95
-2,275,747.50	0.015	-34,136.21
-1,353,000.00	0.05	-67,650.00
-697,874.90	0.05	-34,893.75
-365,116.40	0.05	-18,255.82
-74,840.52	0.05	-3,742.03
198,303.90	0.05	9,915.20
465,385.20	0.05	23,269.26
754,155.70	0.05	37,707.79
982,974.80	0.05	49,148.74
1,253,305.00	0.05	62,665.25
1,504,718.00	0.05	75,235.90
1,748,715.00	0.05	87,435.75
2,064,109.00	0.05	103,205.45
2,332,477.00	0.05	116,623.85
2,657,817.00	0.05	132,890.85
2,980,600.00	0.05	149,030.00
3,311,655.00	0.05	165,582.75
3,690,282.00	0.05	184,514.10
4,239,984.00	0.05	211,999.20
4,966,996.00	0.05	248,349.80
5,971,160.00	0.015	89,567.40
6,975,324.00	0.01	69,753.24
Totals:	**1.00**	**1,626,231.77**
Certainty Equivalent ($):	**261.56**	
Risk Premium ($):	**1,625,970.21**	

Marginal Utility of the Absolute Risk Averse Parameter

The risk parameter provides useful information on the marginal utility of the investor. It can be shown, with some mathematical manipulation, that the absolute risk averse parameter is equivalent to the percentage change in marginal utility per dollar of output (Cochran and Raskin, pg. 205). Consequently, on an annual income scale it can be interpreted that a decision maker's marginal utility decreases at the rate equal to the Arrow-Pratt coefficient (Cochran and Raskin, pg. 205).

Arrow-Pratt (absolute) risk averse coefficient r(x) defined as the percentage change in marginal utility per unit of outcome space (Cochran and Raskin, pg. 205):

$$r(x) = -\frac{u''(x)}{u'(x)} = -\frac{(du'/dx)}{u'} = -\frac{d}{dx}\log(u') = -\frac{(du'/u')}{dx}$$

When the risk parameter in this study was interpreted as the percentage change in marginal utility per income dollar as suggested by Cochran and Raskin, results showed different levels of risk aversion per dollar when comparing an annual income scale to an investment return scale. At an expected outcome of $1.62 million on an annual income scale, the marginal utility was decreasing at a rate equal to 1.014×10^{-6} per dollar. However, when the scale of the risk parameter was adjusted to the 15-year net present value of a dollar, the marginal utility per dollar increased to 4.236×10^{-6} which represented a higher rate of decrease in marginal utility. Therefore, the inclusion of the time dimension associated with project investment, increased the rate of decline in marginal utility per dollar as well as increased the maximum level of risk aversion permitted for feasibility on a 15-year investment scale. Unfortunately, further interpretation of size for the Arrow-Pratt coefficient in this project was not possible without more detailed information on the potential investors and their individual preference functions.

Part I, Chapter 5
Discussion and Conclusions

Rockingham County's abundant poultry operations have left the region with litter disposal problems. Currently, direct application to soil in the area results in nutrient runoff in the Chesapeake Bay watershed. Research is currently underway to analyze alternative litter disposal methods to direct land application.

One such method is the use of poultry litter as a fuel source. Methods used for accomplishing this task vary according to the fuel source replaced, location, funding, and the technology used for the combustion of poultry litter. The method that seems most appropriate for Rockingham County, VA is the partial replacement of coal at a neighboring county power plant through the attachment of an external staged litter combustion unit.

A feasibility model is developed in this paper which tests the plausibility of partially displacing coal with poultry litter at the Bremo Bluff power plant in Fluvanna County. Due to the model's dependency on a range of values for several of its benefit-cost variables, uncertainty is incorporated into the model through the estimation of probability distributions and the use of Monte Carlo simulations. Furthermore, feasibility is analyzed for both private and public investment scenarios, therefore, the model is estimated under risk neutral and risk averse preferences.

Discussion

Results from the Monte Carlo simulations show a project partially displacing coal with poultry litter to be feasible under both public (7 percent interest rate) and private (10 percent interest rate) investment scenarios with only a small probability of negative returns in both cases. When the private investment scenario includes a risk averse utility function, the project maintains feasibility for a range of risk preferences but eventually generates a negative expected utility as the risk parameter increases. Although expected returns are different for both investment cases, positive net returns occur after the fifth year in both situations. Statistics from scenario and sensitivity analysis confirm a strong dependency of the results on three variables: unit litter acquisition cost (ULAC), unit ash value (UAV), and annual ash production (AAP) with winter ash production being slightly more significant than summer ash production.

Unit Litter Acquisition Cost

According to the scenario and sensitivity analysis, unit litter acquisition cost (ULAC) is one of the most important variables influencing the outcome of the feasibility model. Litter acquisition costs had to be less than $9.98 per ton in the private investment case and less than $10.15 per ton in the case of a public investment, for feasibility. Due to the variable's uncertainty, its probability distribution is estimated from information provided in the three studies detailed in this paper as well as information from the Virginia Tech Cooperative Extension office in Harrisonburg, VA. Since a specific probability distribution can not be confirmed, a histogram distribution is used to represent ULAC probabilities.

Further research is needed for a more accurate estimation of the probability distribution for ULAC that would lower its level of uncertainty. Such research might include elicitation methods such as litter price surveys prepared for regional farmers coupled with a more detailed elicitation of subjective probabilities for litter prices from experts familiar with poultry litter. Moreover, statistical analysis may help in the forecasting of litter price movements due to either an increase in demand from litter's use as a fuel or from possible restrictions on direct land application. For example, growth in demand from its use as a fuel should increase the price of litter while a restriction on direct land application will leave farmers with a greater incentive to sell their litter, pushing litter prices down.

Unit Ash Value

Results from the feasibility model show that UAV is an important variable for offsetting litter acquisition costs. Without the possible sale of litter ash as a fertilizer, the sustainable litter acquisition cost would drop to an unfeasible level. The project would also incur additional costs from the disposal of litter ash. Simulation results found the minimum estimate of UAV, required for feasibility, to be $32.72 per ton for the public investment case and $33.71 per ton for the private investment case.

Since little research has been conducted on residual litter ash's use as a fertilizer, it should be assumed that uncertainty is greater for this variable. For this model, the probability distribution for UAV uses numbers from Antares *et al*. in the Monte Carlo simulations. A more detailed nutrient composition of residual ash could aid in reducing uncertainty in the feasibility model by providing a more accurate appraisal for the value of litter ash.

Annual Ash Production

Uncertainty in annual ash production (AAP) is positively correlated with the uncertainty in litter utilization capacity (LUC) which is estimated using a range of poultry litter heating values contingent on bedding material and moisture content. According to the Virginia Tech

Cooperative Extension office in Harrisonburg, bedding material in Rockingham County is generally a standard wood chip material. Consequently, bedding is unlikely to be the cause of heating value uncertainty. It can then be inferred that heating value fluctuations are due to the variability of moisture content, which is most volatile during winter months. Although winter months affect heating value uncertainty, regression analysis show there is no evidence to suggest their effect on the mean heating value is more influential than summer months. Implications are that first order heterogeneity may not be apparent for different seasons. Unfortunately, evidence against the null hypothesis of a normally distributed residual set suggest the OLS model is not statistically most adequate. Therefore, conclusions drawn from the model should be limited to standard correlations and not used for more in depth statistical inference.

Unit Litter Value and Coal Prices

Unit litter values (ULV) in the model drop annually when real coal prices follow the decreasing trend projected by the DOE. As a result, net revenues decrease during the future years of the project and eventually generate negative returns. Despite a decrease in future litter values, ULV does not drop below ULAC during the life of the project. Therefore, the window of opportunity for a project to replace litter with coal in Virginia is estimated at 26 years. If real coal prices follow this decreasing trend, poultry litter will eventually become too expensive to be used as a substitute fuel source. However, when coal prices increase, the opportunity for project feasibility increases beyond thirty years.

Transportation and Cleaning

Given the estimates for transportation and truck cleaning costs, feasibility will not be affected by fluctuations in these two variables. Transportation and cleaning are insignificant portions of total costs. However, an estimated 13 trucks a day would be needed to transport over 300 tons of poultry litter daily. The technical feasibility of utilizing 13 trucks a day to transport litter and the environmental risk associated with it, should be considered in future studies.

Efficiency Rates

It should be noted that the thermal efficiency of poultry litter and the power plant efficiency play an important role in the determination of feasibility. Lower efficiency rates in both cases would increase the poultry litter needed to replace coal and increase the utilization capacity (LUC). The effect on net revenues would be twofold, 1) a decrease in returns due to the increase in litter needed for production and 2) an increase in returns due to the enhanced production of residual ash. If the external combuster can not generate the 9 MW_e needed to replace 3.75 tons of coal per hour, then LUC would decrease and effects on net revenues would be the opposite of the increase in LUC described above. Transportation and cleaning costs would also be expected to change but the results are not discussed here due to the insignificant impact of the two costs.

Risk Aversion

When the proposed project is analyzed for feasibility using a constant absolute risk averse utility function, the investment decision is dependent on the Arrow-Pratt measure of absolute risk aversion. Compared to risk neutral investment preferences, the investor with risk preferences represented by the utility function described in the previous section, is willing to forgoe uncertain returns up to $1.62 million in order to ensure, with certainty, that the project does not incur a loss. As the level of risk aversion increases, the amount of income the investor is willing to give up or pay for positive returns, increases until it is greater than $1.62 million. At this point, the incentive for investment decreases until the investor eventually decides not to pursue the project. Another interpretation of the risk parameter, which leaves the decision maker indifferent to the investment, demonstrates that at the expected outcome the marginal utility per dollar invested on the project is decreasing at a rate of 4.236×10^{-6}.

Unfortunately, the size of the risk parameter used to measure the level of risk aversion in the preference function, varies according to each investor and, therefore, is difficult to determine. Conclusions on whether the Arrow-Pratt coefficient is more risk neutral or risk averse are not possible without more empirical information on the individual investor's interpretations of risk parameter values. According to a summary table of commonly used risk aversion coefficients on annual agricultural income provided by Cochran and Raskin (1986), the risk parameter or Arrow-Pratt coefficient in this study (4.236×10^{-6}) would be considered almost risk neutral. However, the risk averse coefficients used in Cochran and Raskin are based on annual income and not on a 15-year NPV scale. Results in this study show the risk coefficient increases when adjusted to a NPV scale. Furthermore, using these risk coefficient interpretations assumes the private investor has similar preferences to the investors listed on the Cochran and Raskin (1986) summary table. The study completed in this paper does not attempt to make an assumption on the preferences of the potential investor nor does it assume the agricultural sector would be the likely source of investment funds. Therefore, the conclusion that the project is feasible to a risk averse investor is constrained by the range of parameters used in the constant absolute risk averse utility function.

Concluding Remarks

The partial replacement of coal with poultry litter at an electrical generating unit is proven to be feasible under both private and public investment scenarios. Based on results in this study, an estimated 110 thousand tons of poultry litter per year of the approximately 271 thousand tons produced annually in Rockingham County could be used to partially replace coal during electricity generation. However, feasibility is constrained to the acquisition cost of poultry litter and the value of residual litter ash as a fertilizer. In addition, the DOE 20-year real coal price forecast leaves a 26-year window for feasibility before coal prices drop below poultry litter's replacement value.

Further studies should be conducted which would examine the possible benefits to the feasibility model from the inclusion of emission allowance trading, tax incentives directed to the use of Biomass fuels, and policy restrictions on the direct land application of poultry litter. The substitution of coal with poultry litter will likely lower the SO_2 emissions and increase the allowance permits for the Bremo Bluff power plant. These permits could then be sold at its market value to generate more revenues. Since poultry litter contains high levels of nitrogen, reduction of NO_x emission from the substitution of litter for coal is not guaranteed. Data for poultry litter NO_x emissions would be needed to complete a study of this type. Tax credits proposed by both federal and state governments for the adoption of alternative power plant production technologies intended to reduce NO_x and SO_2 emissions through the use of Biomass fuels could also increase net revenues for the project. Consequently, a thorough assessment of these tax credits might be an important aspect of future feasibility studies. Finally, policy restrictions on direct land application of poultry litter may not only generate greater net revenue through a decrease in the cost for litter acquisition but may also increase the viable term of the project.

Part II

The Addition of NOx and SO_2 Allowance Trading to the Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia's Chesapeake Bay Watershed

Background

Research on alternative disposal methods for poultry litter have been spurred by the environmental problems associated with nutrient runoff from excessive land application. Nutrient runoff from soils containing high levels of phosphorous and nitrogen has been established as a cause of pollution in the Chesapeake Bay Watershed (CBP 2001, Overview Page). Due to a high concentration of broiler operations in Rockingham County, VA, alternative poultry litter disposal research focuses on this region. Options suggested for poultry litter disposal range from using it as cattle feed to composting litter into fertilizer and transporting it to soils that do not contain excess phosphorous and nitrogen. Recently, studies have been conducted on the utilization of poultry litter as an energy source.

Although research on the feasibility of converting litter to energy vary according to the techniques proposed, results from certain studies appear promising. The Maryland Power Plant Research Program (PPRP) found, during a case study that entailed fueling the state's Eastern shore Correctional Institute with poultry litter, that under certain scenarios direct combustion of poultry litter could be a viable fuel source in wood fired boilers. Results suggested that poultry litter could power a 40,000-lb./hr boiler and eventually replace a wood fired cogeneration facility with two litter fired 2 MWe (megawatts of energy) cogeneration facilities. However, each scenario examined by PPRP had capital costs that exceeded $10 million. Antares Group Incorporated, T.R. Miles Technical Consulting Inc., and Foster Wheeler Development Corporation conducted an analysis for the Northeast Regional Biomass Program on the utilization of poultry litter as a fuel. They concluded litter could fire a medium scale cogeneration facility with the aid of government subsidies and/or tipping fees on litter delivery. However, capital costs in this facility also totaled close to $10 million. Hall Associates and Heuristic Engineering (HAHE) suggested a different approach when using litter as a fuel. Their method employed a poultry litter fired external combuster, which would be used to co-fire an existing boiler. Although initial investment depended on the size of the external combuster, costs were significantly lower than Antares *et al*. and PPRP. Their conclusions showed that co-firing a residual fuel oil or gas fueled boiler with poultry litter was feasible when residual ash from the combustion process could generate revenues from its sale as a fertilizer.

Potential emission reduction benefits from the combustion of poultry litter for electricity generation in place of coal is not thoroughly analyzed as a component of the feasibility studies described above. Although poultry litter combustion does produce NOx and SO_2 emissions, results from a study prepared by Alternative Resources Inc. (ARI) show, that under certain control techniques, emissions produced from the combustion of poultry litter are less than those of coal (Alternative Resources Inc., pg. 10). Therefore, the utilization of poultry litter as a fuel source would not only benefit the Chesapeake Bay by lowering the nutrient runoff from the watershed but could also lower emission reduction costs for coal fired power plants.

The Environmental Protection Agency (EPA) is currently attempting to reduce NOx and SO_2 emissions from coal-fired electrical generating facilities through the implementation of market based programs such as the Acid Rain Program, Ozone Transport Commission (OTC) NOx Budget Program, and the NOx State Implementation Plan (SIP Call) program (US EPA, Clean Air Markets Program Information Page). SO_2 emissions have been sited as a cause of acid rain while NOx emissions from coal combustion are known to carry ground level ozone over long distances (US EPA, Clean Air Markets Program Information Page). The EPA's current market based emission reduction programs are expected to reduce SO_2 and NOx emissions through a cap and trade system that allocates allowance permits per unit of emissions to electrical generating units (EGU). Polluting firms may purchase additional allowances if emissions are in excess of the budgeted allocation or generate additional revenue from the sale of unused allowances.

Acid Rain Program

Title IV of the 1990 Clean Air Act was implemented to reduce acid rain through reductions of SO_2 emissions totaling 10 million tons below 1980 levels by the year 2000 (Bailey *et al.*, pg. 6). In addition to a reduction in SO_2, Title IV also requires reduction in NOx emissions. The SO_2 and NOx emitting sources targeted by Title IV are mostly coal-fired power plants in the Northeastern United States. As a means to achieve their objective, the EPA established a market based cap and trade allowance policy. This policy leaves the polluting firms with greater flexibility in choosing the technology to be used to meet the required emission reduction. In the case of the SO_2 program, allowances are allocated annually according to historical fuel consumption and emissions rate from the polluting unit (Natsource, Environmental Division). One allowance permits an EGU to emit one ton of SO_2 emissions during a specific year (Natsource, Environmental Division). Once a ton of SO_2 is emitted, one allowance is retired from operation. Allowances can be freely purchased to meet a predetermined budget, sold if emission levels are below the assigned budget, or banked for future use.

As described by Ellerman *et al*. in *Markets for Clean Air*, the Clean Air Act requires SO_2 emission reduction in two-phases. The first phase was put in motion in 1995 with the purpose of reducing emissions in 263 facilities, located in 110 plants, from 21 states (Bailey *et al*., pg. 6). Allowances, under Phase I, were allocated by multiplying a baseline heat input with an emissions rate of 2.5 lbs. of SO_2 per million Btu. Several additions, extensions, and exceptions were added to the allocation method described under Phase I.

In 2000, the EPA began Phase II of the program, which is currently in operation. Under the second phase, a cap of 8.95 million annual allowances has been put into place. In addition, the firms that are allocated allowances include all electrical generating facilities that produced 25 MWe or greater. The number of allocated allowances is derived from a baseline that is determined using the 1985 emissions rate for a firm and its average heat input from 1985-87. Allowances are "equal to each unit's baseline heat input (fuel use) times the lesser of its actual 1985 emissions rate or 1.2 lb. of SO_2 per million Btu divided by 2000 lb." (Bailey *et al*., pg. 44).

Since the implementation of Phase II, more than 30 different allocation rules have been added to the original ordinance that runs from the year 2000 to 2009. These allocations are broken down into three categories: 1) variations in fuel type, age of the unit, and the utilization capacity of the unit, 2) rules which concentrate on special interest such as individual states or utilities, and 3) opportunities to earn bonus allowances for states which are in either "clean" or "dirty" camps. Similar to Phase I, excess allowances could be sold to firms that were unable to reduce emissions in a cost-effective manner.

NOx Cap and Trade Programs

Nitrogen Oxide (NOx) and volatile organic compounds (VOC) react under the presence of sunlight to form low-level atmospheric ozone also known as ground ozone (Natsource, Environmental Division). Low-level or ground ozone is not only a hazard to the human respiratory system and plant life but also causes an estimated $500 million dollars in lost crop production per year (US EPA, *Ozone, Good Up High Bad Nearby*). Since atmospheric ozone is formed under the presence of sunlight, ozone levels and its effects tend to be higher during summer months. Ground level ozone, once formed, is easily transported across states. As a part of the Clean Air Act amendment of 1990, Congress established a 12 state Ozone Transport Region (OTR) to deal with the problem of ozone transport. In order to alleviate the cross-state transport of ozone, the OTR states formed the Ozone Transport Commission (OTC) which introduced a cap and trade NOx market system similar to the one established in the Acid Rain Program. Currently, three different types of NOx markets exist throughout the country: Cap and Trade/Closed Markets, Permanent ERC/Offset Markets, and Open Markets (Natsource, Environmental Division).

Although, the EPA's NOx cap and trade program follows a similar format to the Acid Rain Program, they are not federally regulated. Instead, the NOx programs are regional, comprising a group of states and, therefore, are state regulated. An overview of the states included in the NOx programs is provided in Appendix F. The NOx State Implementation Plan (SIP Call) trading program developed in 1998, pertains to power plants in the state of Virginia, therefore, an overview of the SIP Call program is provided below.

Similar to other NOx programs, the NOx SIP Call is also expected to alleviate the long-range cross-state transport of ozone during the ozone season (May 1 – September 30) using a market system similar to the Acid Rain Program. Twenty-two states are included in the NOx SIP Call and are required to develop a cap and trade allowance system. The framework for the cap and trade system is in line with the OTC program, consequently, individual states regulate their NOx emissions program. According to the *Final Regulation Agency Background Document for the State of Virginia*, implementation will begin on May 31, 2004 and include all generators that have a 25 MWe capacity or greater. The NOx emission budget is to be implemented annually during the ozone season with one allowance permitting the holder to emit one ton of NOx emissions. For every ton of NOx emitted during a particular year, the polluting firm must have one allowance in its NOx Allowance Tracking System account (Natsource, Environmental Division). At the end of the year, one allowance from the NOx Allowance Tracking System (NATS) is retired for each ton emitted. Allowances in excess of actual emissions can then be sold at the market price, traded among other units within the 22 member states, or banked for future use. A re-estimation of the baseline heat input and reallocation is to be conducted every 5 years. By 2007, reductions in NOx emissions are expected to reach 1.1 million tons.

Problem Statement

This study is an extension of the previous paper *The Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia's Chesapeake Bay Watershed* (Rios 2003, Part I). The previous study incorporated risk and uncertainty in a feasibility analysis of the litter combustion technique proposed in HAHE. The coal-fired power plant proposed for the project was located 96.9 miles from Rockingham County, VA at Bremo Bluff in Fluvanna County. The conclusion of the previous study demonstrated that poultry litter was a viable option for co-firing coal under both risk averse and risk neutral preferences. Results were sensitive to the litter acquisition cost and litter ash value, requiring an acquisition cost of less than $10 per ton or an ash fertilizer value greater than $33 per ton. In addition, based on the Department of Energy's (DOE) 20-year price projection for coal per short ton for electrical power plants, an expected future decline in real coal prices (Base Year = 2000) would leave a small window of opportunity for a project of this type. Therefore, under the assumption this projection was correct, a project that proposed the partial replacement of coal with poultry litter combusted in a separate unit had a 26 year window of feasibility under a private investment scenario.

The initial study did not analyze the possibility of offsetting potential price increases in litter or decreasing ash value by generating additional benefits from the sale of unused emission allowances through EPA's market based cap and trade program. An expansion in demand for poultry litter as a fuel source could increase its price and raise costs in the feasibility model, while potential low levels of P_2O_5 and K_2O after combustion may decrease ash's competitiveness as a fertilizer. These potential shifts in values provide an incentive for the inclusion of allowance trading by significantly altering the revenue flow of the project.

The short life span of opportunity for project feasibility under the DOE projected declining real coal prices implies the project implementation would need to begin immediately or before coal prices drop to levels that can not be sustained by the unit litter value. Under this scenario, later years of the project could produce net income losses. If poultry litter is determined to produce a lower level of NO_x and SO_2 emissions, additional revenue generated from the sale of excess allowances could increase the span of opportunity for the project by providing it with greater annual returns for sustaining declining coal prices.

Objective

The fundamental objective of this paper is to analyze the effects on the feasibility of partially replacing coal with poultry litter when litter's benefits and costs from NOx and SO_2 emissions are included in the NPV equation. Prior to the determination of net present value, the total NOx and SO_2 emission tons produced from the combustion of poultry litter is estimated in order to determine if litter use will result in excess allowances. The distribution of expected Net Present Value and the accompanying sensitivity analysis will be estimated and analyzed after the incorporation of allowance transactions. The paper will determine the new minimum value of residual ash as well as the maximum litter acquisition cost possible for feasibility under the same conditions of uncertainty as the original study (*Rios 2003, Part I)*. The lifetime of opportunity for the project, under the DOE's 20-year projection of real coal prices, will be reevaluated to incorporate allowances from NOx and SO_2 emissions. This study will determine the range of risk parameter values required for feasibility under risk averse investor preference when emissions are included as a byproduct of litter combustion.

Part II, Chapter 2
Conceptual Framework

As aforementioned, this paper is an extension of the previous study, *The Economic Feasibility of Partially Replacing Coal with Poultry Litter during the Production of Energy in Virginia's Chesapeake Bay Watershed* (Rios 2003, Part I) with the inclusion of the potential monetary benefits from changes in NOx and SO_2 emissions. This section first presents the framework of the NPV model used in *Rios 2003, Part I* and details the derivation and probability distribution of the model variables. Secondly, a description of the methodology behind the calculations for allocation of NOx and SO_2 emissions is presented.

The Original Model

The original feasibility model analyzes a 15-year private investment scenario at a 10 percent social discount rate, and a 20-year public investment scenario at a 7 percent social discount rate. Monte Carlo simulations incorporate uncertainty using probability distributions on selected variables in the NPV equation. In the case of the private investor, net returns are inserted into a concave utility function in order to determine the degree of risk aversion that would deem the project unfeasible. Given a constant absolute risk averse (CARA) utility function, a utility value greater than zero results in a project feasible to risk averse preferences.

Components of the NPV Equation

Table 2.1 breaks down the revenue and cost variables of the feasibility model as well as the variables used in their calculation. Fixed values used in determining the Expected Net Present Value can be viewed in Table 2.2. Important model components derived using poultry litter heating value are available in Table 2.3 along with their range of values, while benefit-cost variables that have an assigned probability distribution not dependent on heating values, such as Unit Residual Ash Value (UAV), Unit Litter Acquisition Cost (ULAC), and Unit Litter Transportation Cost (ULTC), are listed in Table 2.4. The methodology behind the values for LUC, AAP, and ULV variables is available in Table 2.5. A brief description of these variables begins with the heating value of litter.

Table 2.1 Benefit-Cost Variables for the Feasibility Model

Benefits[1] ($): **TAR** = [(LUC*ULV) + (AAP*UAV)]

TAR: Total Annual Revenue

LUC: Litter Utilization Capacity (tons)

ULV: Unit Litter Value based on the unit energy cost of fuel replaced

AAP: Annual Ash Production (tons)

UAV: Unit Ash Value or disposal cost

Costs[1] ($): **TAOC** = [ALAC + ALTC + ALC + AUC + ACC + AMRC]

TOAC: Total Annual Operating Cost

ALAC: Annual Litter Acquisition Cost

ALTC: Annual Litter Transportation Cost

ALC: Annual Labor Cost

AUC: Annual Utilities Cost

ACC[2]: Annual Cleaning Cost

AMRC: Annual Maintenance and Repair Cost

Discounting:

Private: 10 % Discount Rate, 15 years.

Public: 7 % Discount Rate, 20 years

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[1] Information Source: HAHE

[2] ACC was not in HAHE but was added to the model in *Rios 2003, Part I*

Table 2.2 Feasibility Model Fixed Variables

Variable	Description	Value
CC*	**Cleaning Costs/Ton**	0.53
M*	**Distance (Miles)**	96.9
ULC	**Unit Labor Cost ($/yr./worker)**	35000
CHP	**Connected Horsepower**	500
HR	**Hours of Operation (Annual)**	8400
EC	**Electricity Cost ($/kWh)**	0.047
MRF	**Maintenance & Repair Cost**	0.05
UF	**Utilization Factor**	0.6
ALR	**Annual Labor Requirement**	2

Data Provided by Hall Associates and Heuristic Engineering
*Data Specific to Virginia and Bremo Power

Table 2.3 Range of Values for Variables Derived from Heating Value of Poultry Litter for the Incorporation of Feasibility Model Uncertainty

	LUC			**AAP**			**ULV**	
	Utilization capacity Tons/year			**Ash Quantity Tons/year**			**Unit Value of Litter ($/ton, year 1)**	
Statistics	Summer	Winter		Summer	Winter		Summer	Winter
	51,424.98	41,743.94		8,690.82	7,054.73		9.77	12.03
	54,436.35	49,426.87		9,199.74	8,353.14		9.23	10.16
	46,480.27	54,806.66		7,855.17	9,262.33		10.81	9.16
	47,114.50	81,379.59		7,962.35	13,753.15		10.66	6.17
	52,772.36	64,972.42		8,918.53	10,980.34		9.52	7.73
	55,562.62	66,400.38		9,390.08	11,221.66		9.04	7.56
	49,834.51	58,807.15		8,422.03	9,938.41		10.08	8.54
	48,827.75	64,281.22		8,251.89	10,863.53		10.29	7.81
	49,834.51	61,657.50		8,422.03	10,420.12		10.08	8.15
	56,603.60	87,889.96		9,566.01	14,853.40		8.87	5.71
	72,148.47	59,678.37		12,193.09	10,085.64		6.96	8.42
	47,206.52	58,381.01		7,977.90	9,866.39		10.64	8.60
	41,888.63	49,225.54		7,079.18	8,319.12		11.99	10.20
	46,659.73	42,627.41		7,885.49	7,204.03		10.76	11.78
	49,025.84	44,925.16		8,285.37	7,592.35		10.24	11.18
	49,225.54	47,206.52		8,319.12	7,977.90		10.20	10.64
	51,207.07	46,037.60		8,654.00	7,780.35		9.81	10.91
	58,100.33	70,879.00		9,818.96	11,978.55		8.64	7.09
	45,776.02	50,991.01		7,736.15	8,617.48		10.97	9.85
	64,624.97	53,710.53		10,921.62	9,077.08		7.77	9.35
	70,465.71	47,672.07		11,908.71	8,056.58		7.13	10.54
	54,436.35			9,199.74			9.23	
	50,458.74			8,527.53			9.95	
	58,100.33			9,818.96			8.64	
Mean	53,008.99	57,271.42		8,958.52	9,678.87		9.64	9.12
Min	41,888.63	41,743.94		7,079.18	7,054.73		6.96	5.71
Max	72,148.47	87,889.96		12,193.09	14,853.40		11.99	12.03
Variance	56,035,253.67	151,818,327.27		1,600,422.88	4,336,083.25		1.47	3.14
S.D.	7,485.67	12,321.46		1,265.08	2,082.33		1.21	1.77
Expected Value	57,344.16	64,103.22		9,691.16	10,833.44		9.43	8.96

Table 2.4 Range of Values for Feasibility Model Variables not Derived Using Heating Values

Statistics	UAV[1] Litter Ash Cost ($/Ton)	ULAC[2] Litter Acquisition Cost ($/Ton)	ULTC[3] Trans. Cost ($/Mile)	Price of SO_2 Allowances per Ton[4]	Price of NOx Allowances per Ton (2004-2015)[5]
	35	8	0.1	140	4741
	40	8	0.11	73	4741
	45	9	0.12	95	4087
	50	10		155	3433
		6		205	3433
		7		130	3433
		8		170	3433
				160	3433
					3433
					3433
					3433
					3433
Min	**35.00**	**6.00**	**0.10**	**73.00**	**3433**
Max	**50.00**	**10.00**	**0.12**	**205.00**	**4741**
Mean	**42.50**	**8.00**	**0.11**	**141.00**	**3705.5**
Expected Value	**42.50**	**8.49**	**0.11**	**144.70**	**4049.33**

Notes:

[1] Antares *et al.*

[2] Antares et al., PPRP, and Virginia Tech. Coop. Extension Office (Harrisonburg, VA)

[3] MTPP, PPRP, and Pelletier

[4] EPA, Clean Air Markets Division

[5] Cantor Fitzgerald provided price estimates through 2007. An assumption was added that prices would level off after 2007. Therefore, the value of $3433/ton was extended for the remaining years of the project.

Table 2.5 Methodology Behind Litter Utilization Capacity (LUC), Annual Ash Production (AAP), and Unit Litter Value (ULV)

1) General Energy Transfer Information

1 Btu/hr = .293 Watts

250 MW = 853,825,137.5 Btu/hr

Source: www.convert-me.com

75 million Btu/hr External Combuster generates 9MWe

Source: Malcolm Lefcourt, p. 5.

2) Coal to be Replaced

9MWe/250MWe = 0.036

2500 tons of coal/day generate 6000 MWe/day at Bremo Bluff Power Plant

104.16 tons/hr generate 250 MWe/hr

104.16*.036 = 3.75 tons of coal/hr. to be replaced.

3) Total Efficiency = Thermal Efficiency (Coal & Litter) * Boiler Efficiency

	Thermal Efficiency[1] (Fuel to Heat)	Boiler Efficiency[2] (Heat to Electricity)	Total Efficiency
Poultry Litter	0.7300	0.3410	0.2489
Coal	0.8810	0.3410	0.3004

[1] Lefcourt and Martin, p. 14.

[2] Robert H. Shannon, p. 25.

4) Amount of litter needed to replace 3.75 tons of coal per hour

Heating Value of Coal (HV_C) for Virginia = 12,715 Btu/lb.

Source: DOE, Energy Information Administration

Tons of litter needed to replace 3.75 tons of coal per hour.

(Note: The equation yields a range of values and a distribution in accordance to the values and distribution for poultry litter heating values HV_L.)

$$\left(\frac{3.75 tons/hr}{HV_L / HV_C}\right) \times \left(\frac{.3004 Therm.Effiency_{Coal}}{.2489 Therm.Efficiency_{Litter}}\right)$$

5) Variables Derived Using Heating Values (HAHE, pg. 15)

Annual Capacity Utilization of Poultry Litter

LUC = [Replacement Litter/hr (**Winter**) * 24 * 175] + [Replacement Litter/hr (**Summer**) * 24 * 175]

Annual Ash Production

$AAP = .169*LUC_W + .169*LUC_S$

Unit Litter Value

ULV =[Replaced Coal/Replacement Litter] * [Coal Price ($)/ton]

Heating Value

Poultry litter heating value is based on numbers from broiler operations in the Delmarva Peninsula (Delaware, and Eastern shore of Maryland and Virginia) that are available in a socioeconomic assessment prepared by Environmental Resource Management, Exeter Associates Inc. and McBurney Corp. (EEM). In accordance with a report prepared by the Maryland Power Plant Research Program (PPRP), the EEM study focuses on the use of poultry litter as an energy source at Maryland's Eastern Correctional Institute. The assessment provides heating values from numerous Delmarva poultry operations during both summer and winter months.

The amount of coal to be replaced and the quantity of litter needed for replacement are derived using the heating value of poultry litter and the total thermal efficiency (24.9 percent) determined in *Rios 2003, Part I*. Approximately 3.75 tons of coal per hour or 3.6 percent of coal consumption can be replaced with poultry litter (Table 2.2). Estimates of the quantity of poultry litter needed to replace coal average 12.62 tons per hr. during summer and 13.64 tons per hr. during the winter.

Monte Carlo simulations for variables dependent on poultry litter heating value are performed with @Risk using a histogram distribution determined to be the most appropriate probability distribution for heating value. This particular distribution requires minimum and maximum estimates of heating value as well as actual values or their probability. Since poultry litter heating value assumes a histogram distribution, variables derived from litter heating values also assume a histogram distribution. These variables include Annual Litter Utilization Capacity (LUC), Annual Ash Production (AAP), and Unit Litter Value (ULV).

Calculations for LUC, AAP, and ULV are as follows. LUC equals (daily replacement litter during summer * 175 summer days) + (daily replacement litter during winter * 175 winter days). According to HAHE, annual residual ash (AAP) is approximately 16.9 percent of LUC. Unit Litter Value (ULV) is equal to the amount of coal tons replaced per hour multiplied by the projected price of coal per short ton divided by the hourly total of replacement litter tons.

Unit Residual Ash Value

Currently, residual ash is not sold as a fertilizer in the United States, therefore, historical price information is unavailable and an accurate determination of the market value for Unit Ash Value (UAV) proves difficult. After considering several estimates, *Rios 2003, Part I* uses estimates from Antares *et al.* due to the vicinity of the Delmarva Peninsula's poultry operations to Rockingham County. A uniform distribution is utilized to represent the probability distribution of UAV with a minimum value of $35 per ton and a maximum value of $50 per ton.

Unit Litter Acquisition and Transportation Cost

Much like the values for residual ash, three different estimates are available for both Unit Litter Acquisition Cost (ULAC) and Unit Litter Transportation Cost (ULTC). The difference between both these variables and that of residual ash value is in the source considered for their estimates. Estimates for ULAC and ULTC are determined by employing information collected or generated within the Chesapeake Bay watershed region. Antares *et al.*, PPRP, and the Virginia Tech Cooperative Extension office in Harrisonburg, VA provided price ranges for ULAC, therefore, all three ranges are included in the Monte Carlo simulations with a histogram distribution. In the case of ULTC, single value estimates are obtained from Pelletier 1999, PPRP, and survey results provided by the Maryland Transportation Pilot Project (MTPP). As a result, a triangular distribution is adopted to represent the probability distribution of Unit Litter Transportation Cost.

Coal Prices

In order to test the project's sensitivity to the value of coal, *Rios 2003, Part I* examines the NPV using three different sets of coal price forecasts derived from an initial price of $31.89 per short ton for the year 2000 in the state of Virginia. The first set of projected Virginia coal prices follows the pattern of price changes from a forecast of national real coal prices per short ton (Base Year = 2000) estimated by the DOE. Two other sets of coal prices are estimated taking into account a 2.5 percent inflation rate. In one case, the inflation rate is added to a set of coal prices that follow the trend of real coal prices generated by the DOE. In another scenario, a nominal set of coal prices is estimated that increase by 2.5 percent annually beginning with $31.89 per ton in 2000. Net Present Value is compared using each of the three sets of coal prices.

Allowance Allocations

NOx SIP Call

As previously mentioned, the objective of the NOx SIP Call is to reduce the long-range transport of ozone caused by Nitrous Oxide emissions. The cap and trade system implemented by the EPA involves 22 states and is scheduled to begin on May 31, 2004. An allowance budget for each Electrical Generating Unit (EGU) is set on emissions during the ozone season (May, 1 – September, 30) with the NOx SIP Call giving each polluter the flexibility of deciding how best to reduce emissions. As detailed in the Introduction, one allowance permits the holder to emit one ton of NOx emissions. For every ton of NOx emitted during a particular year, the polluting firm must have one allowance in its NOx Allowance Tracking System account (Natsource, Environmental Division). At the end of the year, allowances from the NOx Allowance Tracking System (NATS) are retired according to the tons emitted.

Each state's allowance budget reduces NOx emissions from every large stationary EGU by 85 percent from 1990 levels to a core emission rate of 0.15 lb./MMBtu (Million Btu) (Natsource, Environmental Division). In order to achieve this standard, allowance allocation follows a standard formula set by the EPA. "Initial allocations for core source categories are based on the baseline heat input multiplied by the core emission rate normalized over the state budget" (Virginia State Air Pollution Control Board, *Background Document*, pg. 5). Multiplying the total NOx emissions by 0.908 adjusts total allocation to the state budget. According to the Virginia Department of Environmental Quality (DEQ), the rate of 0.908 is determined by subtracting the NOx budget, set aside for new source growth, from Virginia's EPA determined NOx emission budget. The normalized rate (0.908) is derived by dividing the EPA adjusted emission amount assigned to Virginia by the state's estimate of total NOx emissions calculated using the commonwealth's total heat input. The baseline heat input is determined by averaging the two highest annual heat input levels from the most recent 5 years. For non-electrical generating units the core emission rate is revised to 0.17 lb./MMBtu (Virginia State Air Pollution Control Board, *Background Document*, pg. 5). A reallocation of allowances is evaluated every 5 years based on changes in the baseline heat input.

It should be noted that proponents of permanent allocations do not consider the EPA's policy of reallocation optimal. According to an Economic Impact Analysis prepared by the Virginia Department of Planning and Budget (VDPB) on regulations for emission trading, reallocation in the short term is expected to change the number of allowances when an alternative fuel such as poultry litter is incorporated into total heat input. Continuous changes in allowance numbers is expected to increase the level of uncertainty associated with allowance trade contracts when compared to permanent allowance allocations. The increased uncertainty in future contracts associated with changes in allowance numbers occur as a result of firms continuously adjusting their production technology between reallocation periods in order to "chase" more allowances (VDBP, *Economic Impact Analysis*, pg. 10). As VDBP conclude, under a continuous reallocation policy firms do not know beforehand how many allowances trade partners will hold in the future or after reallocation, therefore, uncertainty in future contracts will lead to a preference for short term contracts. In addition, reallocation could stifle future production improvements due to technological change's effect on heat input and the possible reduction in the allocated allowances.

SO_2

As previously mentioned, the objective of the 1990 Clean Air Act is to reduce SO_2 and NOx emissions in two phases from northeastern U.S. fossil fuel power plants through an allowance trade system. The first phase involves NOx and SO_2 emission reduction in 263 power facilities. The second phase adds a ceiling of 8.95 million emission tons per year and includes all electrical generating units of 25 MWe or greater. Maximum allowance amounts accredited to each EGU, including Bremo Bluff, are provided in the *Code of Federal Regulations (CFR), Chapter 40, Part 73, Section 73.10 (Sulfur Dioxide Allowance System).*

Poultry Litter Emissions

Combustion of poultry litter is expected to produce changes in the NOx and SO_2 emissions due to the difference in emission rates between litter and coal. According to Alternative Resources Inc., the NOx emission rate from the direct combustion of poultry litter, assuming a 90 percent control efficiency for selective catalytic reduction (Appendix G) during combustion, is equal to 0.03 lb./MMBtu while SO_2 emission rates using a spray-dry absorber equal 0.07 lb./MMBtu. Both of these emission rates are lower than the maximum rates permitted under the allowance trade programs. Emission data on direct combustion of poultry litter in the UK show that urea in litter can play a part in the reduction of NOx emissions (EEM, Section 5-2). Although Antares *et al.* suggest that gasification through staged combustion has had some success in controlling NOx emissions, data on the NOx output from poultry litter test burns during staged combustion is not readily available. However, test burns performed by Heuristic Engineering on sawmill wood residue, which is material similar to the wood chips used in poultry litter, result in a NOx emission rate equal to 0.04 lb./MMBtu (Lefcourt and Martin, pg. 2). This rate is close to the rates on poultry litter NOx emissions estimated by ARI during direct combustion.

Part II, Chapter 3
Methods

The methods employed in this section include benefits and costs from allowance trading to total returns in the private investment NPV model from *Rios 2003, Part I.* The calculations for the quantity of NOx and SO_2 allowance and total emissions using poultry litter in boiler 3 at Bremo Bluff are also presented in this section. The market value for NOx and SO_2 allowances was based on the expected prices from Monte Carlo simulations using probability distributions for each set of prices. The range of market values for both types of emissions used in the Monte Carlo simulations can be viewed in Table 2.4. Before presenting the methodology behind the NPV model and the tradable allowance determination, a brief description of the Monte Carlo simulation used to derive Expected Net Present Value (ENPV) as well as the sensitivity analyses tests is provided below.

Monte Carlo Simulation

Monte Carlo simulation is an uncertainty propagation sampling method used on input variables of varying distributions in order to estimate an expected value and probability distribution for an output variable. A value is randomly selected from each input probability distribution and used in a specific model for the computation of the expected value for the output variable (Henrion and Morgan, pg. 199). The procedure is repeated until convergence and calculates an equal number of output values which "constitute a random sample from the probability distribution over the output induced by the probability distribution over the inputs" (Henrion and Morgan, pg. 199).

In this particular study, Monte Carlo simulations were run on @Risk using Latin Hypercube sampling and a random seed equal to one.[11] @Risk selected values for variables randomly from a predetermined probability distribution for use in the computation of net benefits in the NPV equation. As aforementioned, this procedure was repeated until convergence or until the mean and distribution of net benefits were derived with precision. Precision was determined when mean and descriptive statistics changed less than 1.5 percent from the previous iteration. Probability distributions were determined by matching the characteristics specific to the data of the uncertain variables with the most appropriate distribution available in *@RISK*. Statistical

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[11] Latin Hypercube Sampling: A stratified sampling technique in which "input values are obtained by sampling separately from within each stratum instead of from the distribution as a whole."(Henrion & Morgan). This generally results in a faster convergence than under Monte Carlo sampling.

techniques were then used to determine rank correlation and sensitivity analysis between the input variables, and the output variable (net revenue).

Input Scenario Analysis

Scenario analysis in @Risk provides a combination of input variables which significantly contribute to an output target (Palisade pg. 48). For example, if the target is a high level of NPV, possibly in the 90th percentile, then @Risk lists the combination of input variables that most influence the target outcome as well as the input percentiles required to achieve the target. It determines the significant input variables by taking the subset of iterations of the simulation that achieved the output target then compares the median value of the input variables in that subset to the median values for the input variables in the entire set of iterations. If the subset median for the input variable differs by at least one-half of a standard deviation from the overall median of the input variable then the input variable is deemed significant. @Risk demonstrates the significance by dividing the difference between the subset median and the overall median by the standard deviation of the input variable in the entire simulation (Palisade, pg. 148).

Rank Correlation and Regression Sensitivity Coefficient

Rank order correlation is conducted by assigning a different rank to each data point of a variable, generated through the number of MC iterations, in accordance to the data point's position within the minimum-maximum range of possible sample values for the variable (Palisade, pg. 146). For example, the 5th lowest data point in a sample receives the 5th lowest rank while the 5th highest data point receives the 5th highest rank. Once this is completed, the rank values are correlated in order to determine the relationship between values of different variables. @Risk ranks each input variable and correlates the rankings with rankings assigned to the output variable ENPV. In addition, @Risk provides a multivariate stepwise regression coefficient or sensitivity value for each input variable in the model.[12]

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[12] Multivariate Stepwise Regression: A technique for calculating regression values with multiple input values. Coefficients for each input value are normalized. A regression value or coefficient equal to 0 means no significance exists with the output variable while an absolute value of 1 means a significant 1 unit standard deviation change in the output variable exists due to a 1unit standard deviation change in the input variable. (Palisade, Guide to @Risk. P. 145).

NOx Allowance and Emissions

The number of allowances allocated to Bremo Bluff would generally be calculated using the formula described in the previous section [Example provided on Table 3.1 using 1998 data], however, since a five-year data set was not available, the highest two heat input years could not be averaged to verify the emission totals assigned to each boiler. According to the Virginia Department of Environmental Quality (DEQ), the actual allocations assigned to the 80 MWe unit (boiler 3) and the 170 MWe unit (boiler 4) at Bremo during the ozone season equaled 138 and 348 allowances, respectively. Since boiler 3 was the boiler chosen to be co-fired with poultry litter, calculations of total emissions were based on the coal and litter used in the 80 MWe boiler.

As previously mentioned, total NOx emissions for Bremo Bluff's boiler 3 were estimated based on values that included poultry litter as a partial source of fuel. According to estimates from *Rios 2003, Part I*, under the assumption that an external combuster could generate 9 MWe using poultry litter, approximately 3.75 tons of coal per hour would be replaced with litter. Therefore, heat input and NOx emissions were estimated for each fuel source under this substitution rate in order to take into account coal's partial replacement with poultry litter. Since the ozone season runs from May 1 to September 30, only litter utilization capacity (LUC) for summer months was used for the estimation of poultry litter and coal heat input. Re-allocation of allowances was calculated after 5 years with the total heat input from using both coal and litter.

Calculations of the allowances utilized by Bremo Bluff from the coal and poultry litter-fired boiler can be viewed in Tables 3.2 and 3.3 for 153 ozone days. Heat input (HI) for both fuel sources during the ozone season was calculated by multiplying each fuel's heating value with the number of pounds utilized during the ozone season. A NOx emission rate of 0.03 lb./MMBtu was assumed for the combustion of poultry litter based on estimates provided by Alternative Resources Inc. (ARI, pg. 7) on the use of a control technique (Selective Catalytic Reduction) which reduces NOx from flue gas by attaching a reduction device to the furnace (Appendix G). In the case of coal, the 90 tons per day of coal replaced by poultry litter was subtracted from the daily coal tonnage and multiplied by the number of ozone season days. Expected poultry litter utilization capacity (LUC) during the ozone season was estimated by multiplying the daily LUC during summer with 153 days. Total emissions (TE_{cl}) equaled [(0.908 * HI_{coal} * 0.15 NOx core emission rate) + (0.908 * HI_{litter} * 0.03 litter NOx emission rate)]. These emissions equaled the allowance allocations used by Bremo Bluff during the ozone season, therefore, they were subtracted from the NOx SIP Call assigned allowance allocations in order to determine the number of surplus or deficit allowances. Beginning in 2004, the difference in allowances was then multiplied by the expected NOx allowance price, added to the feasibility model on an annual basis, and discounted at a social rate of 10 percent. After 2010, total allowance allocations were re-estimated according to the average total coal and poultry litter heat input from 2004-2009.

Similar to the original study, probability distributions were incorporated into the model to represent the uncertainty associated with allowance prices and variables dependent on LUC. A histogram distribution was used to represent the probabilities associated with different values of LUC, HI_{litter}, HI_{total}, $NOx_{(litter)}$, TE_{cl}, and the number of allowances after reallocation. The expected price for NOx allowances was also determined using a histogram distribution along with estimates of OTC NOx allowance market prices.

Table 3.1 Methodology Behind Allowance Allocation at Bremo Bluff

Allocation Adjustment Rate = 0.908

Required Core Emission Rate = 0.15 lb./MMBtu

1998 Total Heat Input at Bremo Bluff = 6,256,335 MMBtu

Virginia Total Allowances = 0.908(Emission Rate * Heat Input)

Total Allowances = [0.908 * 0.15(lb./MMBtu) * 6,256,335 (MMBtu)]/2000 = 426 tons

Data Source: VA, Department of Environmental Quality

Table 3.2 Ozone Season Heat Input and Daily Utilization of Coal and Litter (Boiler 3)

Given[1]

NOx Allowance Allocations (AN) = 138 tons
Heating Value of Coal (HV_c) = 12,715 Btu/lb.[2]
Required NOx Emission Rate of Coal ($NOXER_c$)= 0.15 lb./MMBtu
Ozone Season = 153 Summer Days (May 1 - September 30)

Then

Total tons of NOx Emissions without state adjustment = AN/0.908 = **152**
Heat Input Coal (HI_c) = (2000 lb. *AN)/($NOXER_c$ * 0.908) = **2,026,431.72 MMBtu**
Ave. Ozone Daily Coal Use = **[**[1,000,000 Btu * (HI_c/HV_c)]/2000 lb.**]/**153 days = **520.83 tons**

Heat Input Litter (HI_l) = [(LUC/hr. * 24 * 153 days) * 2000 lb. * HV_l]/1,000,000 Btu = **455,020 MMBtu**

[1] Source: VA, Department of Environmental Quality
[2] Source: U.S. Department of Energy, Energy Information Administration

Table 3.3 Total Heat Input and NOx Emissions During Ozone Season (Boiler 3)

Given

Poultry Litter replaces 3.75 tons of coal per hour or 90 tons per day.
Emission Rate for Litter (ER_l) = 0.03 lb./MMBtu[1]

Then

HI Coal net litter (HI_{c-l}) = [(Daily coal tons – 90 tons) * 153 * HVc] = **1,676,260.62 MMBtu**
Total Heat Input (HI_t) = HI_{c-l} + HI_l = **2,131,280.60 MMBtu**
Total Emissions (TE_{cl}) = [(0.908 * HI_{c-l} * 0.15)/2000 + (0.908 * HI_l * 0.03)/2000] = **120.35 tons**
Surplus Allocations (SA_n) = AN - TE_{cl} = **17.65 tons**

Re-allocation = (0.15 * 0.908 * HI_t)/2000 = **145 tons**

[1] Source: Alternative Resources Inc.

SO_2 Allowance and Emissions

Allocations for Bremo Bluff’s two operating boilers, which were included in phase II of the Clean Air Act, equaled 2,028 allowances (tons) per year for boiler 3 and 5,158 allowances per year for boiler 4 from 2000-2009 (*Code of Federal Regulations, Chapter 40, Part 73*). For years 2010 and beyond, boiler 3 allowances would be reduced to 1,768 while boiler 4 allowances would be reduced to 5,170. Since poultry litter was proposed as a partial substitute for boiler 3, the maximum emissions permitted in the feasibility model were 2,028 tons of SO_2 per year through 2009 and 1,768 tons after 2009.

Similar to NOx emissions, SO_2 emissions were estimated based on values that included poultry litter as a partial source of fuel. Heat input and SO_2 emissions were computed for each fuel source under the assumption that poultry litter replaced 3.75 tons per hour of coal. However, since SO_2 emission monitors were not restricted to the ozone season, emissions using a combination of both fuel sources were estimated on an annual basis (350 days).

Tables 3.4 and 3.5 provide equations and values used in the derivation of total SO_2 allowances. Annual heat input for coal was estimated using the same daily coal use numbers provided above, while annual HI for litter used the expected LUC from *Rios 2003, Part I.* An SO_2 emission rate of 0.88 lb./MMBtu for boiler 3 was derived by dividing the boiler’s 1996 total SO_2 emission tons from coal, provided by the EPA, by its 1996 heat input. An SO_2 emission rate of 0.07 lb./MMBtu, after using a spray dry adsorber (scrubber) with a fabric filter to reduce SO_2 emissions, was based on estimates from Alternative Resources Inc. (ARI, pg. 7). Similar to the formula for NOx emissions, 90 tons per day of coal were subtracted from the total coal use before calculating its annual heat input net of poultry litter. Annual LUC was then used to calculate HI_{litter} and added to HI_{coal} to determine the total annual heat input (HIA_t) for Bremo Bluff. Total SO_2 emissions equaled [(0.88 * HI_{coal}) + (0.07 * HI_{litter})]. The estimated total SO_2 emission tons were then subtracted from the 2,028 allowances assigned to Bremo's boiler 3 through 2009. After 2009, estimated SO_2 emissions were subtracted from the unit's 1,768 allowances. Allowance differences during each year of the project were multiplied by the expected SO_2 prices and added to the model under a 15-year private investment scenario. According to the EPA, 1996 SO_2 emission averages for boiler 3 were 2,044 tons for the year. Therefore, under the assumption this annual total will not change during the life of the project, cost savings from no longer needing to purchase additional SO_2 allowances would also be added to the NPV equation if an excess of allowances exists.

Uncertainty was incorporated into revenue generated from the sale of SO_2 allowances as follows. A histogram probability distribution was used to represent uncertainty for LUC, HI_{litter}, HI_{total}, $SO_{2(litter)}$, and TE_{cl}. SO_2 allowance prices were available from Natsource with probabilities also represented by a histogram distribution using @Risk.

Table 3.4 SO_2 Annual Heat Input and Utilization of Coal and Litter (Boiler 3)

Given

Days per Year = 350
SO_2 Allowances Allocations (AS)[1] = 2,028 tons
1996 SO_2 emission average[2] = 2,044 tons

Then

HI_{coal} = (Daily Coal (tons) * 350 * 2000 lb.) * HVc = **4,635,628 MMBtu**
Emission Rate of Coal (ER_{coal}) = (2000 lb. * 2044)/HI_{coal} = **0.88 lb./MMBtu**
HI_{litter} (MMBtu) = 2000 lb. *Annual LUC * HV_l = **1,074,614.08 MMBtu**

[1] Source: Code of Federal Regulations
[2] Source: US, Environmental Protection Agency

Table 3.5 Annual Heat Input and SO_2 Emissions (Boiler 3)

Given

SO_2 Emission Rate for litter (ER_{litter}) = 0.07 lb./MMBtu[1]

Then

Annual HI_{coal} net litter (HIA_{c-l}) = [(Daily coal – 90 tons) * 350 * HVc] = **3,834,583.12 MMBtu**
Total Annual Heat Input (HIA_t) = HIA_{c-l} + HI_{litter} = **4,909,197.20 MMBtu**
Total Emissions (ETS_{cl}) = [[(ER_{coal} * HIA_{c-l})/2000] + [(ER_{litter} * HI_{litter})/2000]] = **1,728.40 tons**
Surplus Allowances (SA_s) = AS - ETS_{cl} = **299.6 tons**

[1] Source: Alternative Resources Inc

Expected Net Present Value

As previously mentioned the Expected Net Present Value from *Rios 2003, Part I* was recalculated with the incorporation of allowance trading for a 15-year term at a 10 percent discount rate.[13] The expected change in net revenue from the inclusion of emissions was estimated by determining the NPV exclusively from allowance trades. Sensitivity and input scenario analysis as well as rank correlations were re-applied to examine the changes in the significance of variables deemed important in *Rios 2003, Part I*. Net returns were also used to determine how much potential revenue from allowance transactions, in the case where a surplus of allowances was realized, would offset the negative influence on project worth caused by the DOE projected decrease in real coal prices and, therefore, increase the lifetime of opportunity for the project. Finally, the expected NPV estimated in this study, was inserted into the constant absolute risk averse (CARA) utility function[14] below to determine the change in the magnitude of the risk parameter and change in risk premium.

$$u(y) = -e^{-cy}$$

y = *Net Returns (Income)*
c = *Risk Parameter*

Similar to the model on Table 2.1, setup of the feasibility model with the incorporation of allowance trading was as follows:

Benefits: TAR (\$) = $[(LUC*ULV) + (AAP*UAV) + (SA_n*Price_{NOx}) + (SA_s*Price_{SO_2})]$

TAR: Total Annual Revenue
LUC: Litter Utilization Capacity (tons)
ULV: Unit Litter Value based on the unit energy cost of fuel replaced
AAP: Annual Ash Production (tons)
UAV: Unit Ash Value or disposal cost
SA_n: Surplus NOx Allowances
SA_s: Surplus SO_2 Allowances

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[13] Details on model variables are presented in Tables 2.3 and 2.4.

[14] Constant Absolute Risk Aversion: The condition in which the risk premium of a utility function remains unchanged despite changes in income. (Chambers & Quiggen).

Costs: TAOC ($) = [ALAC + ALTC + ALC + AUC + ACC + AMRC]

TOAC: Total Annual Operating Cost
ALAC: Annual Litter Acquisition Cost
ALTC: Annual Litter Transportation Cost
ALC: Annual Labor Cost
AUC: Annual Utilities Cost
ACC: Annual Cleaning Cost
AMRC: Annual Maintenance and Repair Cost

Part II, Chapter 4
Results

The following section details the results for the derivation of heat input and total emissions from the combustion of coal and poultry litter as well as NPV results from Monte Carlo simulations that include potential revenue generated from allowance trading. Heat input and emission numbers were used to estimate benefits or costs from allowances for NOx and SO_2 emissions attributed to the use of poultry litter. The new feasibility model added these components to the original model, which estimated the value of partially replacing coal with poultry litter at the electrical generating unit in Bremo Bluff, VA. The allowance-induced net present value was compared to the expected net present value of the private investment scenario in *Rios 2003, Part I*. Once again, risk and uncertainty were incorporated using Monte Carlo simulations while expected net present value, input scenario analysis, and sensitivity analysis were re-calculated. Similar to the original study, the sensitivity of ULAC to the range of ash values was re-evaluated as well as ULAC and UAV sensitivity to declining coal prices. A measurement of the degree of risk aversion was re-estimated to include costs or benefits due to emission changes.

Heat Input and Emission Values

NOx Emission Reduction Additions

Tables 3.2 and 3.3 display results on heat input and total emissions from the litter co-fired boiler at Bremo Bluff during the ozone season (153 days). Based on the approximated daily use of coal (520.83 tons) minus 90 tons of coal replaced per day, its heat input equaled 1.68×10^6 MMBtu (Table 3.2). With an expected summer heating value of 4,509.21 Btu/lb., the ozone season values for poultry litter utilization capacity and heat input were 50,186.94 tons and 4.55×10^5 MMBtu, respectively.

According to the NOx emission allocation formula set by the EPA, emission allocation for Bremo's co-fired boiler 3, based on its use of coal, equaled 114.15 tons while total emission from the combustion of litter, using a 0.03 lb./MMBtu NOx emission rate (Alternative Resources Inc., pg. 10), equaled 6.20 tons. This meant total NOx allowances during the ozone season were 120 tons, a surplus of 18 tons compared to the 138 tons allocated by the EPA (Table 3.3). When reallocations were calculated after year 2009 using the same formula but with the total heat input of litter and coal, the number of allocated allowances equaled 145 leaving a surplus of 25 tons. A comparison of Tables 3.2 and 3.3 shows the higher number of allocated allowances after reallocation were the result of a poultry litter's higher heat input per MW_e compared to coal. Poultry litter's elevated heat input was due to the large quantity of litter utilization capacity needed to replace coal which has a higher heating value and thermal efficiency than poultry litter. Consequently, litter's heat input would be expected to generate additional revenue after 2009. In both cases net revenues from NOx emission reduction equaled the annual surplus allowances multiplied by the expected NOx allowance price of $4,036.22 per permit. Therefore, expected revenue gains equaled $71,468 annually, for years 2004-2009, and $100,381 per year thereafter.

SO_2 Emission Reduction Additions

Heat input and total SO_2 emissions were calculated on an annual basis (350 days). Expected annual heat input for poultry litter totaled 1.07×10^6 MMBtu while annual heat input for coal after subtracting 90 tons per day equaled 3.83×10^6 MMBtu (Table 3.5). At an SO_2 emission rate of 0.88 lb./MMBtu from coal (Table 3.4) and an emission rate for poultry litter of 0.07 lb./MMBtu (Alternative Resources Inc, pg. 10), the total annual SO_2 emissions from both fuel sources was 1,728.40 tons, almost 300 tons below the maximum 2,028 tons of emissions set by the EPA for Bremo's boiler 3. The surplus allowances when multiplied by the expected price of SO_2 emissions ($144.70 per allowance) yielded an allowance revenue of $43,352. Furthermore, since 1996 data demonstrated Bremo's annual SO_2 emissions averaged 2,044 tons, 16 tons of surplus allowances at $144.70 each were added to total revenues to make up an expected revenue of $45,668 per year generated from the reduction of SO_2 emissions.

Monte Carlo Simulation Results

Expected Net Present Value

The Expected Net Present Value (ENPV) of the project, once emission reduction revenue was added, totaled $2.48 million which was $850 thousand greater than the $1.63 million ENPV of the project under the private investment scenario in *Rios 2003, Part I* (Table 4.1). The minimum ENPV equaled $-3.09 million while the maximum value was $8.90 million. Table 4.1 demonstrates that, when compared to the private investment case in the previous study, although potential maximum monetary benefit of the project increased significantly, minimum expected values were only slightly higher. Positive returns would be expected in the 5th year of the project or one year earlier than under the private investment case. The probability of breaking even also increased from just under 80 percent to nearly 95 percent in the allowance added ENPV.

Expected net present values for the new model approached returns achieved under a public investment scenario in the preceding study (Table 4.1). Under the allowance scenario ENPV was only $23 thousand below values obtained under a publicly funded project. When examined as a probability of occurrence, net returns had a 50 percent probability of equaling $2.32 million in the emission/allowance case and $2.54 million in the public investment case, while private investment was expected to earn only $1.50 million with the same probability. Obtaining high returns at 25 percent probability yielded an expected value of $3.90 million, which was $82 thousand less than the publicly funded scenario and $92 thousand more than the privately funded project. Although the potential maximum returns with the inclusion of emission revenues was greater than the private investment scenario and less than the public investment scenario, expected minimum returns were higher in this particular study than both private and public investment cases. At a 75 percent probability, the inclusion of allowance trading yielded an ENPV of $980 thousand while private and government funded projects achieved returns of $200 and $539 thousand, respectively**.**

Table 4.1 Expected Net Present Value of the Feasibility of Partially Replacing Coal with Poultry Litter ($)

	Investment Scenario		
	Private (Rios 2003, Part I)	**Public (Rios 2003, Part I)**	**Allowance Trading Included**
	15 yr., 10%	**20 yr., 7%**	**15 yr., 10%**
Statistics			
Minimum	-3,198,495.00	-4,386,203.00	-3,093,736.00
Mean	1,633,602.00	2,711,758.00	2,480,255.00
Maximum	6,975,324.00	10,098,600.00	8,901,421.00
Standard Deviation	1,899,871.00	2,783,945.00	1,973,584.00

Input Scenario Analysis

Similar to the previous paper, input scenario analysis was conducted at NPV percentile targets of less than 25 percent, greater than 75 percent, and greater than 90 percent (Table 4.2). Results of these experiments showed the combination of inputs more important to achieving a desired NPV target were unit litter acquisition cost, unit ash value, winter ash production, and summer ash production (ULAC, UAV, AAPW, and AAPS).

At a target NPV in the 75th percentile, the input combination included a low value of ULAC coupled with high levels of UAV and AAPW, however, unlike the private investment scenario, this combination did not include AAPS. ULAC was the most significant input variable with the highest ratio of median differential to standard deviation (–1.66) and an expected value in the 17th percentile. The negative coefficient signifies the subset median for the input variable was less then the overall simulation median. The least significant input variable was UAV with an expected value in the 69th percentile and a median differential to standard deviation ratio of 0.70 while AAPW had an expected value in the 70th percentile and a ratio value equal to 0.75.

Table 4.2 Input Combination Scenario Analysis for Expected Net Present Value Targets from the Feasibility Model With Allowance Revenue Included

	15 yr., 10%	
	Percentile	**Ratio Median to Std. Deviation**
Target > 75%		
Winter Ash Production (AAPW)	70.45%	0.75
Unit Ash Value (UAV)	69.32%	0.70
Unit Litter Acquisition Cost (ULAC)	17.25%	-1.66
Target < 25%		
Summer Ash Production (AAPS)	31.70%	-0.57
AAPW	30.10%	-0.63
UAV	28.90%	-0.72
ULAC	79.50%	0.66
Target > 90%		
AAPS	71.44%	0.84
AAPW	74.69%	0.94
UAV	74.87%	0.87
ULAC	11.84%	-1.83

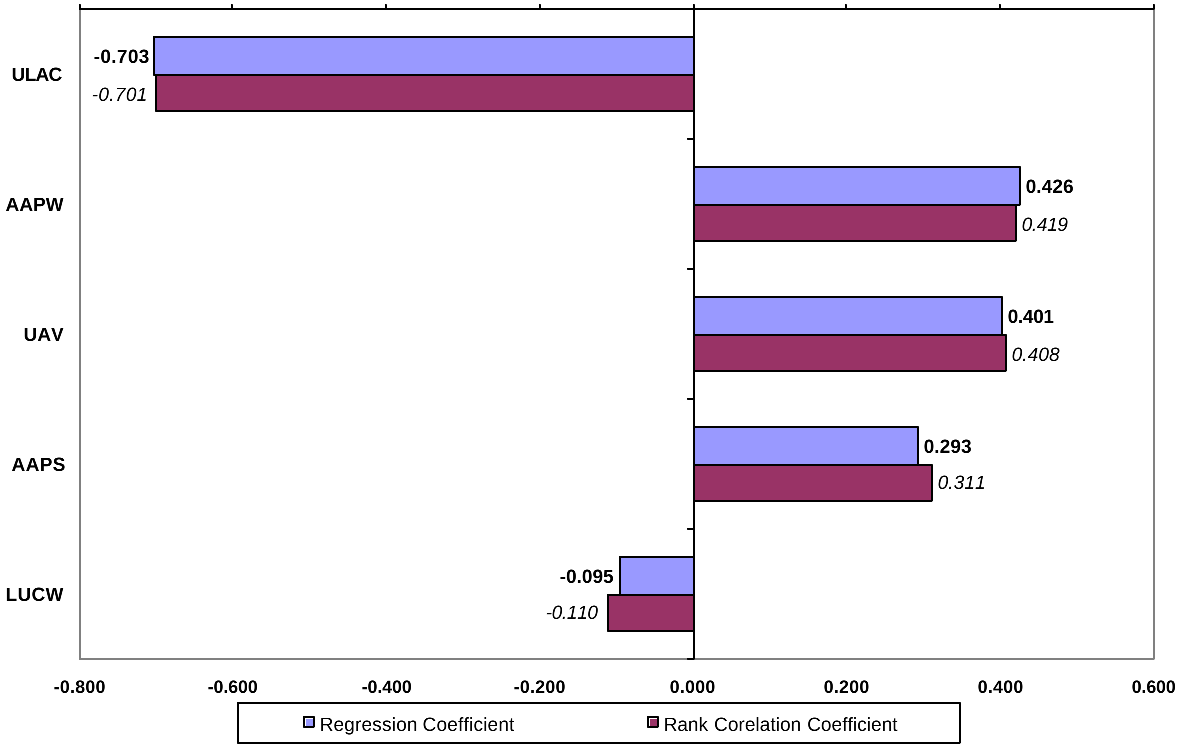
When the NPV target increased to the 90th percentile, AAPS entered the input combination scenario along with ULAC, UAV, and AAPW. AAPS, AAPW, and UAV each required an expected value in the 71st percentile or higher and had similar ratio coefficients (Table 4.2). As was anticipated, a low ULAC value (11th percentile) was the most significant variable with a negative coefficient of –1.83.

At a target for NPV inside the 25th percentile, there was little difference in significance between the variables with UAV having the highest significance at a ratio value of –0.72 and AAPS having the lowest ratio at –0.57. As expected, achievement of this target required an input combination with a high ULAC (79th percentile) and low levels of AAPS and AAPW with percentiles of 31 and 30, respectively. The median differential to standard deviation ratios for these variables were ULAC= 0.66, AAPW= -0.63, and AAPS= -0.57. The expected value of UAV was inside its 28th percentile and had a ratio coefficient equal to –0.72.

Table 4.3 Sensitivity Analysis and Rank Correlation for the Feasibility Model

	Investment (15 yr., 10%)	
Variable	**Sensitivity**	**Rank Corr. Coeff.**
ULAC	-0.703	-0.701
AAPW	0.426	0.419
UAV	0.401	0.408
AAPS	0.293	0.311
LUCW	-0.095	-0.110

Figure 4.1 Regression Sensitivity and Rank Correlation Coefficients from Sensitivity Analysis of Feasibility Model



Rank Correlation and Regression Sensitivity Coefficients

As described in the previous chapter, rank order correlation provides a measure of the correlation existing between the input and output variables through the assignment of different ranks to the data points of each variable. In this case, input variables were correlated with ENPV. A comparison of rank correlation coefficients in Table 4.3 for this study with private investment rank coefficients in Table 4.3 of the previous study (Rios 2003, Part I) exhibited no change in the order of importance among the input variables.

According to Figure 4.1, the variable with the highest importance was ULAC with a correlation and regression sensitivity coefficient equaling –0.70. The next highest rank correlation values were AAPW (0.42) and UAV (0.41) each with a sensitivity coefficient of 0.43 and 0.41, respectively. Ash production in winter proved more important than summer production with a correlation coefficient of 0.31 and sensitivity coefficient of 0.29. Winter litter utilization capacity had the 5th highest correlation coefficient at –0.11 and a sensitivity value of –0.09 while summer utilization capacity did not prove to have a significant correlation or regression coefficient with ENPV. It should be noted that neither SO_2 nor NOx prices demonstrated a significant effect on ENPV compared to ULAC, AAPW, UAV, AAPS, and LUCW with SO_2 price correlation and stepwise regression coefficients equal to 0.04 and 0.05, respectively. Similar in significance to SO_2 prices, the NOx price correlation coefficient equaled 0.04 while its regression coefficient equaled 0.02.

Unit Ash Value with Unit Litter Acquisition Cost

ULAC sensitivity to different fixed ash values provided different restrictions to litter acquisition costs resulting from the inclusion of potential emission revenues to the NPV model (Table 4.4). In each case, the emission reduction revenue added an average of $0.74 per ton to the maximum allowable litter acquisition cost when compared to the private investment scenario in *Rios 2003, Part I*. At an expected ash value of $42.50 per ton, limits on ULAC increased to $10.71 while an increase in ash value to a maximum of $50 per ton, resulted in a rise in the maximum allowable ULAC to $11.97 per ton compared to $11.24 for private investment in the previous study. A minimum ash value of $35 per ton permitted a ULAC up to $9.44 per ton in this particular study compared to the $8.70 per ton permitted under the case without allowance revenue. As expected, under the scenario that litter ash could not be used as a fertilizer, the maximum allowable ULAC fell to $3.53 per ton. Once again, ULAC values when UAV equaled zero did not take into account a possible ash disposal cost to the project. It should be noted that when ULAC equaled its expected value of $8.49 per ton, ash value was constrained to greater than or equal to $29.35 per ton.

Table 4.4 Effect of Ash Value on Required Litter Acquisition Cost ($)

Investment (15 yr., 10%)		
ULAC	NPV	Ash Value (UAV)
10.71	2,758.86	42.50
11.97	11,106.83	50.00
9.44	5,541.52	35.00
3.52	11,106.83	0.00

Declining Poultry Litter Replacement Values

Implications from the previous paper were that a decrease in the price of coal coupled with a stable price of litter could eventually result in future poultry litter costs growing too expensive to be used as a replacement for coal. Since litter was proposed as a partial replacement of coal, declining projected real coal prices resulted in a decreasing future replacement value of litter. With the inclusion of emission allowance trading and under real coal prices (Base = 2000), extending the life of the project to 30 years still generated positive returns. This suggested the opportunity for feasibility under an allowance trading scenario was greater than 30 years compared to 26 years for the private investment case in *Rios 2003, Part I*. It was determined in *Rios 2003, Part I* that, under the DOE real coal price projections, an increase in ULAC to a rate greater than $11 per ton or a drop in UAV below $30 per ton not only produced a negative NPV but also resulted in negative future net returns for both investment scenarios. Emission allowance reduction revenues increased the life of the project by increasing the potential of positive net returns on ULAC values to greater than $11 per ton and UAV values to less than $30 per ton. Negative returns were not realized until ULAC increased to values greater than $11.25 per ton or UAV dropped below $26 per ton.

Added Value of NOx and SO_2 Emissions

Table 4.5 provides results for the expected added value to the NPV model due solely to the sale of surplus NOx and SO_2 emission allowances. Monte Carlo simulations were run on emission revenues and showed the expected net value of allowance sales for the project was $855 thousand with a minimum of $562 thousand and a potential maximum of $1.13 million. Allowance sales were expected to generate $859 thousand with a 50 percent probability, $932 thousand with a 25 percent probability, and $778 thousand with a 75 percent probability. Despite higher allowance prices and total sales revenue for NOx emissions ($1.06 million) compared to SO_2 allowance revenues of $685 thousand, prices of SO_2 allowances, with a sensitivity coefficient of 0.90 and a rank correlation of 0.86, proved more important to total allowance revenue than NOx prices.

Table 4.5 Expected Added Return to the Feasibility Model from Emission Allowance Trading

Statistics	**Revenue ($)**
Minimum	561,975.30
Mean	855,216.80
Maximum	1,128,570.00
Sensitivity	**Coefficient**
SO2 Prices	0.90
NOx Prices	0.42
LUC (Ozone)	0.24
Litter HV (Summer/Ozone)	0.23
Rank Correlation	**Coefficient**
SO2 Prices	0.86
NOx Prices	0.31
LUC (Ozone)	0.19
Litter HV (Summer/Ozone)	0.17

Risk Aversion

Numbers for expected value and expected utility are presented in Table 4.6 while feasibility results from changes in the risk parameter are discussed below. Note the expected net present value based on the sum of expected values for each outcome at 5 percent probability intervals equaled $2.47 million and the expected net present value from the Monte Carlo simulations equaled $2.48 million. Inserting the ENPV into the utility function described in the previous section presented the value of the project's expected utility to the private investor. At an expected NPV of $2.47 million, an Arrow-Pratt absolute risk averse coefficient[15] equal to

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[15] Arrow-Pratt Coefficient: A measure of the absolute risk aversion of a utility function whereby the second derivative of the utility function is divided by the first derivative and multiplied by negative one. As the value of the coefficient increase, the level of absolute risk aversion increases (Varian, Microeconomic Analysis, pg. 178). Arrow-Pratt = $-u''(x)/u'(x)$

1.3267×10^{-6} represented the level of risk aversion which resulted in a certainty equivalent slightly greater than zero at $39.79 and still left a private investor favoring the project. The risk premium at this level of risk aversion approached $2.47 million (Table 4.6). Implications from the level of risk aversion described above, showed the private investor would be willing to give up $2.47 million under uncertainty conditions in exchange for a return on investment greater than zero with certainty. This exhibited an $850 thousand increase in risk premium compared to the private investment scenario under real coal prices in *Rios 2003, Part I*. A risk neutral investor, on the other hand, would always favor the higher expected value despite the level of risk associated with it. When adjusted to a 15-year NPV investment scale, the risk parameter per dollar increased to 5.542×10^{-6}. This meant that the marginal utility at $2.47 million was decreasing at a rate of 5.542×10^{-6} per dollar. The growth in the risk parameter on investment from 4.236×10^{-6} per dollar in the previous feasibility assessment (Rios 2003, Part I) demonstrated that the addition of emission reduction revenues lessened the risk associated with the project and increased the switch over parameter value for model feasibility by 1.306×10^{-6} units. Therefore, the probability of funding the project through non-government sources increased.

Table 4.6 Expected Income Values and Values for Expected Utility When Feasibility Model is Measured Under Constant Absolute Risk Averse Preferences

Income Outcome ($)	Probability	Expected Value ($)
-3,093,736.00	0.01	-30,937.36
-1,782,313.50	0.015	-26,734.70
-470,891.00	0.05	-23,544.55
34,944.08	0.05	1,747.20
399,563.40	0.05	19,978.17
707,774.10	0.05	35,388.71
979,965.00	0.05	48,998.25
1,286,329.00	0.05	64,316.45
1,526,547.00	0.05	76,327.35
1,762,620.00	0.05	88,131.00
2,051,699.00	0.05	102,584.95
2,325,493.00	0.05	116,274.65
2,589,528.00	0.05	129,476.40
2,909,624.00	0.05	145,481.20
3,246,471.00	0.05	162,323.55
3,509,631.00	0.05	175,481.55
3,902,492.00	0.05	195,124.60
4,281,243.00	0.05	214,062.15
4,624,549.00	0.05	231,227.45
5,073,187.00	0.05	253,659.35
5,791,475.00	0.05	289,573.75
7,346,448.00	0.015	110,196.72
8,901,421.00	0.01	89,014.21
Totals:	**1.00**	**2,468,151.05**
Certainty Equivalent ($):	**39.79**	
Risk Premium ($):	**2,468,111.25**	

Part II, Chapter 5
Discussion and Conclusions

Research on litter disposal methods in areas with a high concentration of poultry operations has led to studies analyzing the feasibility of using poultry litter as a source of fuel. However, the inclusion of NOx and SO_2 emissions from poultry litter has seldom been a part of these feasibility assessments. The NPV model described in *Rios 2003, Part I* analyzes the possibility of partially replacing coal with poultry litter at an electrical generating unit in Bremo Bluff, VA.

The NOx SIP Call market system and Phase II of the Acid Rain Program (Title IV of the 1990 Clean Air Act) have established an emission market that alters the feasibility of the model by making it possible to trade emission allowances in order to meet a cap determined by the EPA. Under this cap and trade system, polluting firms are granted the right to emit NOx and SO_2 pollutants equal in tonnage to an assigned number of allowances. Any excess allowances can be traded with other firms whose production level exceed the assigned emission amounts and, accordingly, must purchase additional allowances to meet its emission constraint. Given poultry litter's heat input and emission rates for NOx and SO_2, the substitution of coal with poultry litter at an EGU results in a decrease in total SO_2 and NOx emissions and, therefore, generates additional revenue from the sale of excess allowances at the market rate.

Revenue from the reduction in NOx and SO_2 emissions has been added to the NPV model in *Rios 2003, Part I.* The new assessment of Expected Net Present Value under conditions of uncertainty, along with input scenario and sensitivity and rank correlation analysis all include returns from allowance sales. Market prices for NOx and SO_2 allowances are determined through a histogram probability distribution. This study also reexamines ULAC sensitivity to different values of UAV, changes in the risk parameter for private investment, as well as the added value and increase in years of opportunity to the project from the inclusion of emission reduction revenues.

Discussion

NOx and SO_2 Allowances Uncertainty

Although results from Monte Carlo simulation demonstrate the feasibility of the project under a private investment scenario, three important factors, which introduce further uncertainty, need to be addressed. The NOx State Implementation Plan (SIP Call) is still in its early stages and not expected to replace the Ozone Transport Commission (OTC) market until 2003, therefore, accurate forecasts for NOx allowance prices will be difficult to obtain. Continuous 5-year reallocation of allowances increases the uncertainty of future allowance trade contracts. Finally, the NOx emission rate from poultry litter combustion is dependent on the control technique applied to the furnace, therefore, if control techniques prove technically unfeasible then the proposed project may be rejected based on a failure to constrain its NOx emission rate below the EPA's 0.15 lb./MMBtu requirement.

The 15-year revenue flow that is added to the NPV model once allowance trading is included is dependent on a combination of historical pricing data for SO_2 emissions and forecast prices for NOx emissions. In the case of SO_2 emissions, the availability of historical allowance pricing data makes price fluctuations less difficult to model, therefore, uncertainty associated with its revenue stream is reduced. Historical prices for the NOx SIP Call market are not available since the market is not due to phase out the OTC market until 2003. Although, forecasts for NOx allowance prices by environmental brokerage firms have been projected up to 2007, this information is not available to the public. Consequently, prices in the model are based on annual OTC prices through 2007. Potential price volatility in the early stage of the NOx SIP Call or the possibility of prices leveling off at a rate lower than the model's expected $4,036 per ton in the later years of the proposed litter replacement project, could significantly reduce the added value of emission reduction.

The contention of the Virginia Department of Planning and Budget is that reallocation will not only change the number of allocated allowances once poultry litter heat input is taken into account but also increase the level of uncertainty associated with allowance trade contracts when compared to permanent allocations. In the case of SO_2 emissions, the EPA, under Phase II of the Acid Rain Program, sets the number of allowances for the long term based on past emission numbers. Therefore, reallocation does not occur and is not a cause for concern. However, NOx allowances are recalculated every five years based on the firm's heat input level, consequently, changes in technology such as the use of poultry litter as a fuel source will affect the number of allocated allowances. Not only will future allowance trade contracts be affected by short term reallocations but technological improvements may be delayed as heat input changes are taken into account prior to a decision on production methods (VDPB, pg. 8). In this particular project, if selective catalytic reduction is determined to be successful at controlling NOx emissions, then the firm may have more incentive to pursue a litter co-fired technology due to the potential revenue gain from an increase in heat input and litter's lower NOx emission rate of 0.03 lb./MMBtu.

Emission rates for NOx and SO_2 emissions from poultry litter were difficult to obtain and appear to be sensitive to the combustion process and the control technique applied during combustion. In addition, since poultry litter moisture content and bedding material affect heating value, it is possible these two factors could also alter NOx and SO_2 emissions from litter. This study follows the assumption that a fuel which produces a NOx emission rate greater than 0.15 lb./MMBtu would be rejected as a partial replacement of coal. Therefore, the study assumes selective catalytic reduction (SCR) as a NOx emission control technique for poultry litter would be successful with a control efficiency up to 90 percent (Appendix G). However, according to Alternative Resources Inc. (ARI), selective catalytic reduction is still being tested for technical feasibility. If SCR is not technically feasible then further research must be conducted on the potential of achieving maximum control efficiency (50 percent) from nonselective catalytic reduction in order to reduce the emission rate from litter to 0.15 lb./MMBtu.

Conclusion of Model Results

Under conditions of uncertainty, results from the NPV equation that include allowance transactions show an improvement in feasibility, when compared to the private investment scenario in *Rios 2003, Part I*, with an expected value of $2.48 million. This represents a 52 percent enhancement in expected profit. Positive returns are expected in the fifth year or one year earlier than under the private investment scenario. When compared to both private and public scenarios in *Rios 2003, Part I*, potential maximum returns in this particular study are greater than the private investment case and less than the public investment case, however, expected minimum returns are higher for this particular study than under both private and public investments. This implies the project is less likely to incur losses even when compared to a publicly funded project with a 20-year life and a 7 percent discount rate. NPV simulations run exclusively on the allowance revenue yield an expected addition of $855 thousand to the original model.

The inclusion of allowance revenue does not alter the variables deemed important by input scenario analysis nor does it change the order of significance in rank correlation or sensitivity analysis. Input scenario analysis illustrates that ULAC, UAV, AAPW, and AAPS are the most important variables for ENPV targeting with litter utilization capacity and ash production having a higher significance in winter than summer. This is likely the result of a greater range of outcomes associated with the higher level of uncertainty in winter heating value data when compared to summer heating value data.[16] When compared to the private investment case in *Rios 2003, Part I,* regression sensitivity and rank correlation coefficients maintain ULAC as the most significant variable followed by AAPW, UAV, AAPS, and LUCW. Sensitivity analysis on the NPV of allowance revenue, demonstrate prices for SO_2 are more significant than NOx prices despite SO_2 allowances yielding an overall lower revenue compared to NOx allowances.

As expected, the inclusion of allowance revenues, provides variables such as UAV and ULAC with more room to sustain price fluctuations. When UAV is fixed, price constraints on ULAC in the feasibility model increase by an average of $0.74 per ton. This could offset a litter price increase due to a growth in demand from litter utilization at Bremo Bluff. However, a litter ash disposal cost is not taken into account when UAV has zero value. The value of minimum UAV for feasibility also drops by $3.65 per ton when ULAC is fixed at its expected value. With more room for sustaining price changes, the potential for negative returns on the project decreases.

Once allowance revenue is incorporated, the risk associated with the investment decreases and permits a higher level of risk aversion to the project from a private investment standpoint. The risk parameter value per dollar that leaves the investor almost indifferent to the project increases by 1.306×10^{-6} units to 5.542×10^{-6}. This change in the break even level of risk aversion results in an increased risk premium for the private investor. Compared to a risk neutral investor, the risk averse investor, whose preferences are represented by a constant absolute risk averse (CARA) expected utility function, is willing to forego $2.47 million under uncertainty conditions in exchange for returns that are certain but slightly greater than zero. This is an $850 thousand increase over the private investment scenario in *Rios 2003, Part I.* Thus, with the project more attractive to private investment, it is less likely to need public funding. However, feasibility to a risk averse private investor is conditional on the investor's interpretation of the size of the risk parameter in the CARA utility function.

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[16] Note: *Rios 2003, Part I* found annual heating values were no more dependent on the winter season than the summer season.

In conclusion, the incorporation of emission allowances into the NPV study in *Rios 2003, Part I* suggests that the partial replacement of coal with poultry using an external combuster is feasible under a private investment scenario without the need for government subsidies, tax credits, or tipping fees on litter delivery. The project is expected to utilize or dispose of an average of 110 thousand tons of poultry litter annually. Poultry litter's lower emission rate and higher heat input value, improve the feasibility of the model, leaving more room for sustaining uncertainty in variables deemed important for feasibility under private investment, and reduce the project's level of risk to an investor with risk averse preferences. The inclusion of allowance revenue increases the span of opportunity for the project from 26 years to beyond 30 years when using real coal prices (Base Year = 2000) to represent the value of coal per short ton. It not only provides the Chesapeake Bay watershed with more than a 30 year litter disposal alternative to land application but also meets the EPA's emission guidelines.

Thesis Conclusion

The feasibility model, developed in this paper, suggests that the use of poultry litter for energy production is feasible under both private and public investment scenarios without the need for government subsidies or tipping fees. An estimated 110 thousand tons per year of poultry litter from the approximately 271 thousand tons produced annually in Rockingham County can be used to partially replace coal at Bremo Power in Fluvanna County, VA. Results demonstrate that poultry litter combustion not only provides Virginia with a 30-year alternative to direct land application but also meets the EPA's emission requirements.

Due to the model's dependency on a range of values for several of its benefit-cost variables, uncertainty is incorporated into the model through the estimation of probability distributions on important variables and the use of Monte Carlo simulations to determine ENPV. Expected net present values under both a private and public investment scenarios equal $1.63 million and $2.71 million, respectively. When measuring ENPV under constant absolute risk averse investor preferences, the private investor is willing to pass up an expected but uncertain $1.62 million in revenue for positive returns with certainty.

The model is sensitive to the acquisition cost of poultry litter and the value of residual ash as a fertilizer. These variables are dependent on the annual amounts of litter utilization capacity and ash production, which are derived using summer and winter estimates of poultry litter heating value. Feasibility is constrained to unit litter acquisition costs that are less than or equal to $9.97 per ton for the private investment scenario and $10.14 per ton for the public investment scenario at the expected ash value of $42.50 per ton. When unit litter acquisition cost equals its expected value, unit litter ash value must be greater than or equal to $32.72 per ton for feasibility in the public investment case and $33.71 per ton for the private investment case.

The feasibility model is also analyzed for sensitivity to litter's replacement value for coal, which depended on the price of coal per short ton. Therefore, ENPV is calculated for three different coal price forecasts. Under real coal prices (Base year = 2000), projected by DOE, the project has a 26-year opportunity for feasibility before generating negative returns. However, when coal prices are adjusted for inflation or follow an inflationary trend, the opportunity for feasibility expands to over 30 years.

An estimation of NOx and SO_2 emission rates demonstrates that poultry litter combustion has lower NOx and SO_2 emission rates when compared to coal combustion. Thus, poultry litter not only generates lower levels of NOx and SO_2 emissions than coal but it also generates emission levels below the totals allocated to Bremo Power by the EPA. Under the EPA Cap and Trade Emission Allowance system, excess allowances can be sold to firms whose emission levels exceed the amount allocated to them by the EPA.

When emission allowance trading is included in the feasibility model, the reduction in total SO_2 and NOx emissions results in an $855 thousand increase in expected net present value ($2.48 million) when compared to the private investment scenario. Price constraints on unit litter acquisition cost increase by an average of $0.74 per ton while unit litter ash value constraints when sold as fertilizer decrease by $3.65 per ton. As expected, higher expected revenue results in a project that is more feasible to a risk averse private investor. The additional revenue from allowance trading also increases the opportunity for feasibility beyond 30 years, improving the incentive for private funding.

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Appendix A. Hall Associates & Heuristic Engineering: Litter Utilization Capacity and the Monetary Manure Value per Ton when Replacing Residual Fuel Oil

1) Amount of Residual Fuel Oil Replaced

Residual Fuel Oil to be replaced

$$\frac{10\,MillionBtu/hr}{(152{,}400\,Btu/gal)*.87} = 75.4\,gal/hr$$

Notes: (HAHE, pg. 7)

1. 1 ton poultry litter = 152,400 Btu/gal of Residual Fuel Oil.
2. 75.4 gal/hr of residual fuel oil = 2,970 lb./hr of poultry litter
3. Thermal Efficiency: Residual Fuel Oil = 87%; Poultry Litter = 73%.
4. HV_L = Heating Value of poultry litter (Btu/lb.)
5. HV_O = Heating Value of residual fuel oil (Btu/lb.)

Amount of litter (tons) needed to replace 75.4 gallons of fuel oil per hour.

$$\frac{75.4}{\left(\dfrac{HV_L/HV_O}{.73/.87}\right)}$$

2) Variables Derived Using Heating Value of 4613 Btu/lb. of Poultry Litter

Annual Capacity Utilization of Poultry Litter tons (HAHE, pg. 15)

LUC = [Replacement Litter/hr * 24 * 350 days]

Annual Ash Production in tons (HAHE, pg. 15)

AAP = .169*LUC

Unit Litter Value $ (HAHE, pg. 15)

ULV = [(2000lb/2970lb)*75.4 gal* (0.66/gal)]

Appendix B. Bremo Bluff Power Plant

Net Generating Capacity: 250 MWe/hr.

Electrical Generating Units:
Unit 1: Not Active
Unit 2: Not Active
Unit 3: 80 MWe (Operating since 1950)
Unit 4: 170 MWe (Operating since 1958)

Estimated Average Coal Consumption: 2,500 tons/day

Source: Bremo Power Station Website

Appendix C. Histogram Probability Distribution[1]

Applications: Grouped Data as well as data requiring probability distribution approximations and graphic estimations of distributions.

Parameters: *[min, max,(p_1,...,p_n)]*

Distribution:

$$F(x) = F(x_i) + p_i \frac{x - x_i}{x_{i+1} - x_i}$$

$$if$$

$$x_i < x \leq x_{i+1}$$

Mean:

$$\sum_{i=0}^{n} \frac{1}{2}(x_{i+1} + x_i) p_i$$

Variance:

$$\sum_{i=0}^{n} (\frac{1}{2}(x_{i+1} + x_i) - \overline{x})^2 p_i$$

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[1] Source: Palisade, @Risk Guide

Appendix D. Fertilizer Value of Poultry Litter Ash

The Tennessee Valley Authority (TVA) Environmental Research Center evaluated litter ash's value as a replacement to fertilizer in the Lower Delmarva Peninsula in a study prepared for Antares *et al*. entitled "Fertilizer Nutrient Value of Broiler Litter Ash" (B.R. Bock). In this study, examples of derived ash values as a replacement to fertilizer were based on the available P_2O_5 and soluble K_2O in litter ash after combustion (Bock, pg. 4). Data on the percentage of available P_2O_5 and soluble K_2O in litter after combustion were provided by FibroPhos, which is owned by Fibrowatt and market poultry litter ash in the UK, as well as test burns from Primenergy Inc. in the United States. Given a percent of the nutrient's plant availability, calculation of litter's fertilizer value after combustion was as follows.

(% Nutrient/100) x (2000 lb./ton) x (Wholesale Fertilizer Nutrient Value/ton) = Ash Fertilizer Value

Wholesale fertilizer prices were based on prices for superphosphate and potassium chloride in the Delmarva Peninsula.

According to the TVA, residual ash would likely need to be granulated or co-granulated with materials in conventional fertilizer before being applied to land. The cost of granulation was estimated at $20 per ton. An additional cost of $15 per ton was added to ash in order to cover the costs of transporting litter ash to land areas that do not contain excess nutrients. In the Delmarva region, this meant transporting litter 120 miles north to the upper areas of the Delmarva Peninsula. Once these costs were subtracted, this left a litter ash value that ranged between $35 per ton and $50 per ton. These values were determined under the assumption that P_2O_5 had a wholesale value, per pound of nutrient, equal to $0.22 while K_2O had a value of $0.12.

Appendix D. Fertilizer Value of Poultry Litter Ash (continued)

Estimated Wholesale Fertilizer Replacement Value of Phosphate and Potash in Broiler Litter Ash after Combustion

			Wholesale Value of Fertilizer Replacement		Granulation and Transportation Costs/ton ($)		
	Total Available after Combustion	Available and/or Soluble at Plant	$/lb. of Nutrient	$/ton of Ash	Granulation	Transportation	Total Value ($)
Fibrophos							
(0% carbon)							
P_2O_5	24.40%	12.20%	0.22	53.68			
K_2O	16.30%	8.20%	0.12	19.92			
Total				73.64	20.00	15.00	**38.64**
Primenergy							
(14.4% carbon)							
P_2O_5	20.90%	16.00%	0.22	70.4			
K_2O		5.60%	0.12	13.44			
Total				83.84	20.00	15.00	**48.84**

Information Source: Tennessee Valley Authority (TVA) Environmental Research Center, *Fertilizer Nutrient Value of Broiler Litter Ash.*

Using the nutrient availability percentages from both FibroPhos and Primenergy on the wholesale fertilizer value per pound of nutrient assumed in the HAHE study (P_2O_5 = \$0.23; K_2O = \$0.10), litter ash values ranged from \$72.52 per ton to \$84.80 per ton. Once granulation and transportation costs were subtracted, the total ash values fell within the range estimated by the TVA (\$35 to \$50 per ton). It should be noted that these values also assumed equal carbon percentages to both Primenergy and FibroPhos.

Appendix E. Mispecification Tests on OLS Model Regressing Heating Value on Moisture Content

	Dep. Variable	Indep. Variables	Indep. Variables	Null Hypothesis	Test Statistic	Critical Value	Conclusion
TESTS		**(Restricted)**	**(Unrestricted)**	**(Ho:)**		**P-Value**	
Model*	Y		C + X	B** = 0			(See *Rios 2003, Part 1,* Chapter 3)
Assumption							
Normality							
Skewness	U				-0.8318		
Kurtosis	U				4.3264		
Skewness-Kurtosis	U			Normality	8.2987	0.0158	R
					F-Test Statistic	**P-Value**	
Static Homo-skedasticity	U^2	C	C + Yhat^2	a1=0	0.8803	0.3538	FR
Linearity (Reset 3)	U	C+X	C + X + Yhat^2 + Yhat^3	a1=a2=0	0.5706	0.5698	FR
Linearity (KG 2)	U	C+X	C + X + X^2	a1=0	0.6816	0.5117	

X = Moisture + Summer
Y = Heating Value (HV)
U = Residual
C = Constant
R = Evidence against the Null Hypothesis (Ho:)
FR = Lack of evidence against the Null Hypothesis (Ho:)
T = Total number of observations in the regression.
K = Total number of variables in the unrestricted regression.
**Since HV data was from individual poultry houses and seasonal dummy variables were included in the model, tests on spatial dependence were not conducted.*
***B= the Coefficient of the regressor X; a = coefficient of the additional variables in the unrestricted model.*

Appendix F. NOx Trading Programs and the Participating States

	Ozone Transport Commission (OTC) NOx Budget Program	Section 126 Federal Nox Budget Training Program	NOx State Implementation Plan (SIP) Call
Participating States	CT,DC,DE,MA,MD,ME, NH,NJ,NY,PA,RI,VT	DC,DE,IN,KY,MD,MI, NC,NJ,NY,OH,PA,VA, WV	AL,CT,DC,DE,GA,IL,IN, KY,MA,MD,MO,NC,NJ, NY,OH,PA,RI,SC,TN,VA, WV

Information Source: US, Environmental Protection Agency, Clean Air Markets Program

Appendix G. Poultry Litter NOx and SO_2 Emission Rates

Alternative Resources Inc. analyzed different emission control techniques when preparing *A Review of the Expected Air Emissions for the Proposed Fibroshore 40-MW Power Plant to be Fueled with Poultry Litter and Wood* for the Maryland Environmental Service. In the case of NOx emissions, the control techniques proposed were Nonselective Catalytic Reduction and Selective Catalytic Reduction. Estimates on the expected rate of emission reduction varied according to which technique was implemented, however, only the selective catalytic reduction method resulted in an expected NOx emission rate that was within the Environmental Protection Agency's limit of 0.15 lb./MMBtu. A dry adsorber was proposed as an emission reducing technique for SO_2 emissions. Details of these emission control techniques are provided below.

NOx

1) Nonselective Catalytic Reduction (SNCR)

- Injects Urea or Ammonia into the furnace to reduce NOx emissions.
- NOx Control Efficiency ranging from 25 – 50%.
- NOx emission rate = 0.25 lb./MMBtu
- Note: At maximum control efficiency, emission rate approaches 0.15 lb./MMBtu

2) Selective Catalytic Reduction (SCR)

- Adds a device to the furnace that reduces NOx in the flue gas.
- NOx Control Efficiency up to 90% (theoretical)
- NOx emission rate = 0.03 lb./MMBtu
- Note: The technical feasibility requires further study.

SO_2

Spray-Dry Adsorber (scrubber) coupled with a Fabric Filter: A scrubbing system that has an SO_2 removal efficiency of up to 80%. The expected SO_2 emission rate is 0.07 lb./MMBtu.

ARTURO D. RIOS 13400 Copper Croft Run, Apt. J, Blacksburg VA. (540) 449 -1017

OBJECTIVES:

- To conduct economic cost-benefit analysis with the incorporation of risk and uncertainty.
- To conduct market research using empirical analysis and/or linear programming.

EDUCATION:

Master of Science, Agricultural and Applied Economics
Field of Specialization: Environmental and Natural Resource Economics, Thesis Option
Virginia Tech University, Blacksburg VA (August 2000 – January 2003)

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EXPERIENCE:

University of Maryland, Center for Environmental Science, *Economic Consultant* (August 2002 – September 2002)

1. Analyzed the Economic Impact for Baltimore, MD area industries of moving a major shipping port to Norfolk, VA. Used IMPLAN (Input/Output Model Software) to determine total and marginal industry effects from changes in imports and exports.

2. Prepared a Hedonic Price model to do a statistical comparison of waterfront property values in the vicinity of an existing dredge site in the Chesapeake Bay (Baltimore County). Used GIS to arrange data and prepared cross-section regressions on SAS and Eviews.

Virginia Polytechnic Institute and State University, *Research Assistant/Graduate Student* (August 2000 – August 2002)

Prepared a literature review on methods of poultry litter disposal as an alternative to land application.

International Monetary Fund (IMF), Washington DC, *Research Assistant* (July 1997 – August 2000):

1. Provided research work for workshops, working papers, and other research papers at the IMF Institute.
   Research work included: Data gathering, updating, and maintaining databases; Preparing time series, cross-section, panel-data, and simultaneous equation regressions; Performing tests on data such as rank correlation, autocorrelation, granger-causality, chow tests, unit-root, and cointegreation; Organizing extracted data into tables and charts. The packages used in the manipulation of data and application of econometrics included: Aremos, PcGive, TSP, Eviews, Microfit, and PcFiml.

2. Provided input and preliminary analysis on regression results for workshops, working papers, and other research papers.

3. Trained and taught foreign central bank representatives on the basics of using excel for data management and regressions as well as basics of running empirical tests and statistical analysis on PcGive and Eviews.

4. Prepared PowerPoint presentations for other Institute workshops.

Automotive Parts & Accessories Association (APAA), Bethesda MD, *Economic Research Analyst* (April 1997-July 1997).

Prepared and published an update to a previous publication on the Mexican automotive industry which included an analysis of the economic situation following the 1994 crisis. Used excel to track the auto parts industry along side the Dow Jones Industrial Average. Updated, on a quarterly basis, a financial monitor of manufacturers and retailers in the industry for the APAA web site. Before I left, I was preparing to work on the development of an empirical model that would have provided forecasts on the automotive parts industry for the association's quarterly publication.

Advanced Solutions International (Association Management Software Developer), Alexandria VA, *Regional Business Coordinator* (April 1996- March 1997).

Aided in coordinating of iMIS association software through resellers for the mid-Atlantic region. Developed marketing strategies and organized seminars/ trade shows for the mid-Atlantic and southeast region of the United States. Used spreadsheets to track orders and tabulate incoming payments.

Mr. Arthur Heyman (Consultant and former employee of the OAS), *Research/Consultant* (March 1996 - December 1996).

Performed an opportunity and pre-feasibility study as well as researched the production of an alternative crop to the coca leaf in the Chaparre region of Cochabamba, Bolivia. The study consisted of all aspects of a development project including market, institutional, environmental, social, financial, and economic cost-benefit analysis.

KCI Communications (Financial Publishing Co.), Alexandria VA, *Research Intern* (September 1994 - December 1994).

Researched the market conditions for the launching of a Spanish financial newsletter. Responsibilities included contacting Hispanic brokers for the insight and editorial assistance on the project. Gathered marketing information from companies that targeted the Hispanic population.

LANGUAGE SKILLS: Fluent in English and Spanish.

COMPUTER SKILLS:

Operating System: Windows and Macintosh
Econometric/Statistics Software: Aremos, Eviews, Limdep, Matlab, Microfit, PcFiml, PcGive, Rats, SAS, SPSS, TSP, and Micro TSP.

Economic Input-Output Software: IMPLAN
Math Software: GAMS, Lindo, Lingo, Mathematica, QM, @Risk.
Geographical Software: GIS
Office and Data Management Software: Microsoft Word, Excel, PowerPoint, Access, WordPerfect, Adobe Acrobat, Lotus 123, Harvard Graphics, and Freelance Graphics.
Languages: Basic and Pascal.

PUBLICATIONS AND RESEARCH WORK:

1. The Mexican Market for U.S. Automotive Products – 1997 Update

2. Thesis: “The Economic Feasibility of Partially Replacing Coal with Poultry Litter During the Production of Energy in Virginia’s Chesapeake Bay Watershed”

PERSONAL: spouse Souk K. Rios