A Review of Biomass Furnaces for Heating Poultry Houses in the Northwest Arkansas Region

Prepared for

Winrock International

by

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Executive Summary

Recent rises in propane prices have led to increased interest in bioenergy systems for heating poultry houses. For a typical curtain-wall broiler house located in the northwest Arkansas region, a target displacement rate of 85% of current propane consumption would require approximately 474,000,000 Btu/year, or a biomass-furnace system with a maximum output of 420,000 Btu/hour. At $2.20/gallon, the value of the displaced propane would equal $11,200 per year (averaging $12,300 per year over ten years at an annual escalation rate of 2.0%). This amount represents the maximum annual owning and operating costs a bioenergy system could incur and still achieve breakeven economic performance.

Five types of bioenergy systems were considered and evaluated in this assessment:

- A cordwood-fired furnace in which the fuel is manually loaded and ash is manually removed. Such furnaces have been commercially available for many years.
- A corn-fired furnace system with automated fuel storage, handling, and in-feed with manual ash removal. Such furnace systems are commercially available, and over 30 units have been installed at poultry farms in the region during the past two heating seasons.
- A wood pellet-fired furnace system with automated fuel storage, handling, and in-feed with manual ash removal. Several such units have been demonstrated in the past, and most of the commercially available corn-fired furnace systems can be modified to use premium grade wood pellets.
- A raw litter-fired furnace system. Despite numerous efforts and investments during the past twenty-five years, no such units are commercially available (although some development efforts are still underway). Nonetheless, such a system was evaluated here, given the significant attractiveness and potential benefits of such a system.
- A pelletized litter-fired furnace system. Although no commercial units are available specifically for use with pelletized litter, it is expected that some of the commercially available corn-fired furnace systems could be modified to use litter-derived pellets (although the rate of ash production would be significantly higher with litter-derived pellets than with corn or wood pellets).

The economic analyses utilize a Net Present Value (NPV) approach, reflecting both owning and operating costs over an assumed service life of each system.

- Owning costs reflect financed capital costs, including all primary system components:
  - fuel storage, handling, and in-feed;
  - the combustion furnace;
  - the heat distribution sub-system;
  - ash management (if applicable); and
  - instrumentation and controls.
- Operating costs include biomass fuel, electricity, and maintenance; no labor costs were considered.

Based on the various assumptions noted, these analyses indicate that:

- Cordwood systems are economically attractive but labor-intensive.
- Corn-fired systems are only attractive if cull corn (or on-farm-produced corn) can be obtained well below current market prices.
- Wood pellet-fired systems are attractive, provided that assumed system efficiencies and service life are achieved.
- Raw litter-fired systems would be very attractive, if such systems can be designed and fabricated to meet all of the fundamental criteria set forth in Section E.
- Pelletized litter-fired systems are not attractive under the assumed conditions.

Sensitivity analyses were performed for each of the five systems, with results presented in the appendices. Key factors affecting the economic performance of the various bioenergy systems include:

- price of propane,
- annual propane consumption (prior to installation of the bioenergy system),
- target fraction of propane to be displaced,
- price of biomass fuel,
- system efficiency,
- system service life, and
- capital cost of the system.

Environmental considerations associated with use of biomass-fired furnace systems include:

- Displacement of a fossil fuel (propane) with a renewable fuel (biomass).
- Production of ash, which for raw and pelletized litter-fired systems would require subsequent management since essentially all of the phosphorus and other mineral nutrients contained in the litter would still be contained in the litter-derived ash.
- Air emissions from the biomass furnace systems would be far below regulated levels.
- There appear to be numerous environmental and economic benefits associated with the dry heat nature of biomass-fired furnaces. These benefits need to be validated and quantified.

This review is focused primarily on the poultry industry in the northwest Arkansas region, which includes southwest Missouri and northeast Oklahoma, and was undertaken during the period December 2007~April 2008. Analyses performed and comments presented reflect discussions with and information obtained from various growers, integrators, equipment vendors, and public agencies (federal and state). This report was prepared for Winrock International by Jim Wimberly, BioEnergy Systems LLC, based in Fayetteville, Arkansas. The analyses and views presented herein are by the author and are not necessarily endorsed by Winrock International.

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A. Introduction

This report is a review of biomass-fired furnace systems in use or being considered for heating poultry houses (primarily broiler houses). This review was undertaken during the period December 2007~April 2008. This review is focused primarily on the poultry industry in the northwest Arkansas region, which includes southwest Missouri and northeast Oklahoma. The analyses in this report reflect a "typical" poultry barn in the region—a 40' x 400' broiler house with curtain sidewalls heated with propane. Accordingly, various adjustments would need to be made in order to apply the report's discussions and results to other types and/or sizes of poultry production facilities.

This report is intended to help growers better understand issues and options regarding biomass heating systems. This report should also be of value to the integrators, equipment manufacturers and vendors, state and federal agencies and private consultants that provide technical and other assistance to the poultry industry, lenders and other financial entities that support poultry operations, and the research and extension community.

Analyses performed and comments presented reflect discussions with and information obtained from various growers, integrators, equipment vendors, and public agencies (Federal and State). This report was prepared for Winrock International by Jim Wimberly, BioEnergy Systems LLC, based in Fayetteville, Arkansas. The analyses and views presented herein are by the author and are not necessarily endorsed by Winrock International.

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Winrock International and BioEnergy Systems LLC would like to express their gratitude to the following people for their assistance during development of this report:

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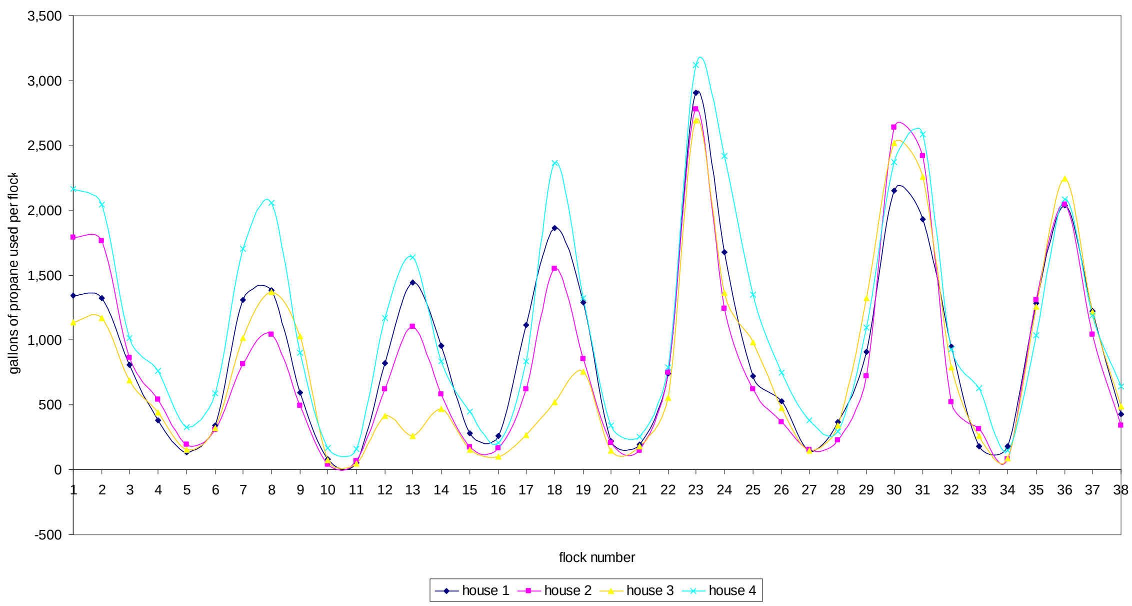
B. Displacing Propane

1. Background

The vast majority of growers in the region use propane as fuel for space heating.[2] For these growers, propane has been their single greatest operating expense. Typical consumption varies from about 4,000 to about 7,000 gallons/house/year, depending on the size of house, type of house, ventilation design and operation, amounts of insulation and sealants used number of flocks per year, timing of flocks vis-à-vis season, meteorological conditions, etc. Figure 1 depicts propane consumption (in gallons per flock) during a six-year period by the four broiler houses at the University of Arkansas' (UA) Broiler Research Facility near Savoy, Arkansas.[3]

Figure 1: Propane Consumption by Flock for Four Houses over a 6-year Period



The primary factor driving increased interest in reducing propane consumption has been the rapidly rising price of propane. It was purported that during the '07~'08 heating season some growers in the region simply elected to <u>not</u> accept chicks and to skip a flock of mid-winter production rather than incur the high cost of energy for space heating.[4] While this decision might work for some growers on a limited basis, it does not constitute a long-term sustainable strategy for the region's poultry industry in terms of addressing rising energy costs.

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[2] Only a small fraction of poultry farms in Arkansas and the region are located near natural gas lines.

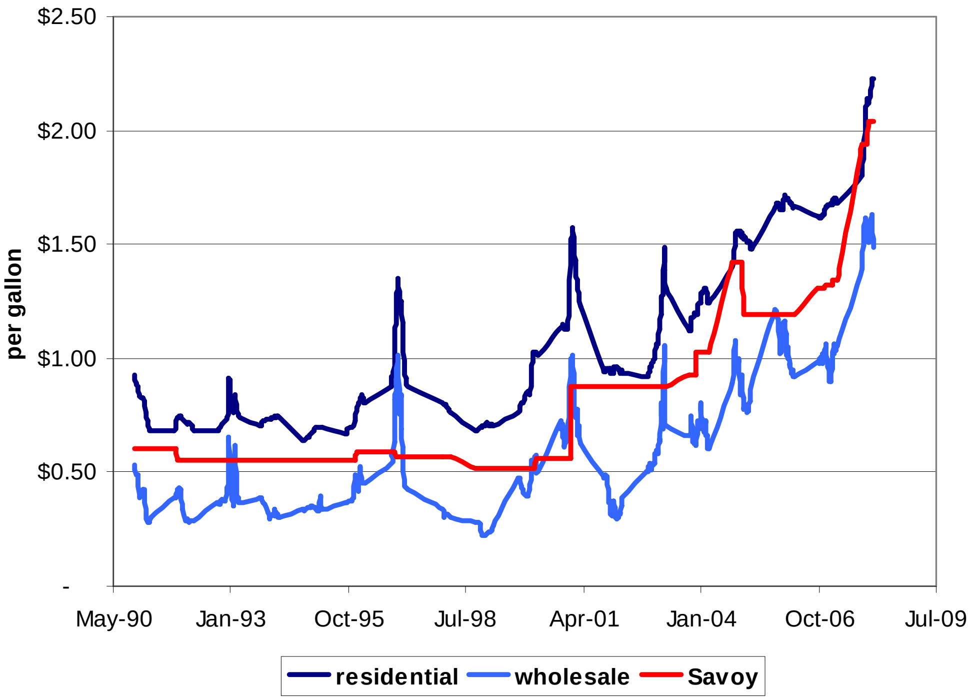
[3] In addition to being a research facility, the UA's "Savoy" facility is operated as a commercial enterprise; as such the facility's propane prices are reasonably representative of those paid by other growers in the region.

[4] Methods of compensating growers for fuel costs vary by integrator; but apparently some of those compensation strategies have not kept pace with the rising costs of propane.

Propane costs from 1990 through 2007 are set forth in Figure 2; the red curve reflects propane prices paid by the UA's Savoy facility. The wholesale and residential prices are from the U.S. Department of Energy's Energy Information Administration for this region of the United States.

As shown in Figure 2, the price of propane for poultry growers has almost doubled during the past three years. Accordingly, growers throughout the region are seeking ways to reduce propane consumption, either through energy efficiency improvements, alternative heating systems, or modifications to production methods.[5] While there are numerous options for decreasing propane consumption through energy efficiency improvements (e.g., optimal ventilation practices, better insulation and/or sealing of walls and ceilings, etc.) and many of those options appear to be economically attractive, the focus of this report is on the use of biomass-fired furnace systems to off-set propane fuel consumption.

Figure 2: Propane Prices, 1990~2007



2. Target displacement of propane

In discussion with academic researchers, several growers, and others, and based on past efforts to develop/evaluate biomass-fired furnace systems, it has been concluded that a reasonable and realistic target displacement level by such systems is 80% ~ 90% of propane consumption.[6] For the economic analyses performed herein, a target displacement

[5] For example, some growers have elected to reduce in-house temperatures, including during brooding; however, such actions can lead to significant reductions in bird growth performance.

[6] This level would likely change due to energy efficiency improvements introduced to a given house, with changes reflecting the type, extent, and effectiveness of any such improvements. In particular it should be noted that in such

level of 85% is used (the remaining 15% of annual load would continue to be met by existing propane heaters, which would be operated in conjunction with the biomass furnace during extremely cold weather and operated exclusively during extremely mild weather). It is further assumed that the average propane consumption rate in the region is 6,000 gallons per house per year, the energy content of propane is ~91,000 Btu per gallon[7], and that propane-fired heating systems (e.g., brooders, radiant heaters, forced-air furnaces) achieve ~98% system efficiency.[8]

Accordingly, total propane fuel energy required for space heating is estimated to average approximately 557 million (MM) Btu per house per year. The target displacement level of 85% of propane consumption would be equivalent to 5,100 gallons per year of propane, or 475 MM Btu. Both calculations reflect 98% propane system efficiency.

3. Design capacity of a biomass-fired heating system

Determination of the design size of a biomass-fired furnace system to achieve 85% propane displacement is not simple, since minute-to-minute space heating requirements (and, therefore, heating system output levels) are so variable. Figure 3 illustrates the variability in propane consumption by hour during two winter flocks at Savoy (the first flock is shown in purple; the second in dark blue).[9]

Historically, integrators have required growers to have a heating system capacity of approximately 1 MM Btu/hour, equivalent to approximately 11 gallons/hour/house of propane.[10] However, analysis of the Savoy data indicates that such a level provides for a "worst-case scenario" heating capacity, and that 85% of the propane is consumed at levels of ~205,000 Btu/hour (2.25 gallons/hour) or less[11] – refer to Figure 4.[12]

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instances the total amount of propane to be displaced would drop (even if the level of propane displacement does not drop), which could significantly affect the overall economics of the biomass-fired furnace system.

[7] refer to: http://www.eia.doe.gov/kids/energyfacts/science/energy_calculator.html

[8] Propane-fired systems are considered to have such high efficiencies because all of the products of combustion (primarily water vapor and carbon dioxide) are retained within the poultry house (i.e., the furnaces are not vented so there are no "stacks" and therefore no heat loss through the stacks).

[9] Hourly propane consumption data was collected for sixteen consecutive flocks for each of Savoy's four curtain-wall houses during the period November 1990 through November 1993; the consumption data shown in Figure 2 is for flocks 1 and 11 for House #1 only, and is provided to illustrate the variability in hourly consumption. The typical grow-out duration during this period was 55 days per flock, with between-flock durations of 4~20 days (averaging around 14 days). Average annual propane consumption during the 3-year period was 4,649 gallons/year.

[10] Specific requirements vary by integrator.

[11] This analysis is for flock #1 for Savoy house #1; flock #1 consumed 306% more fuel than the average flock during the 16-flock period and was 26% higher than the second-highest flock during that period.

[12] This data applies to a broiler house having construction/size/location similar to the Savoy houses during the 2000~2003 period (i.e., a 40' x 400' well-insulated conventional curtain-sided house in Northwest Arkansas).

Figure 3: Propane Consumption by Hour for Two Flocks at Savoy

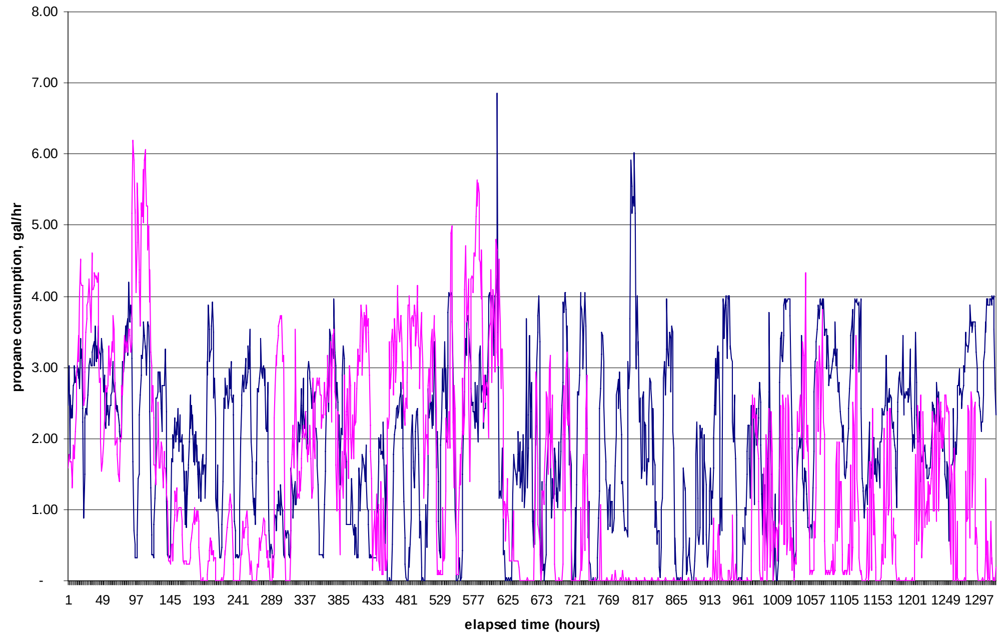
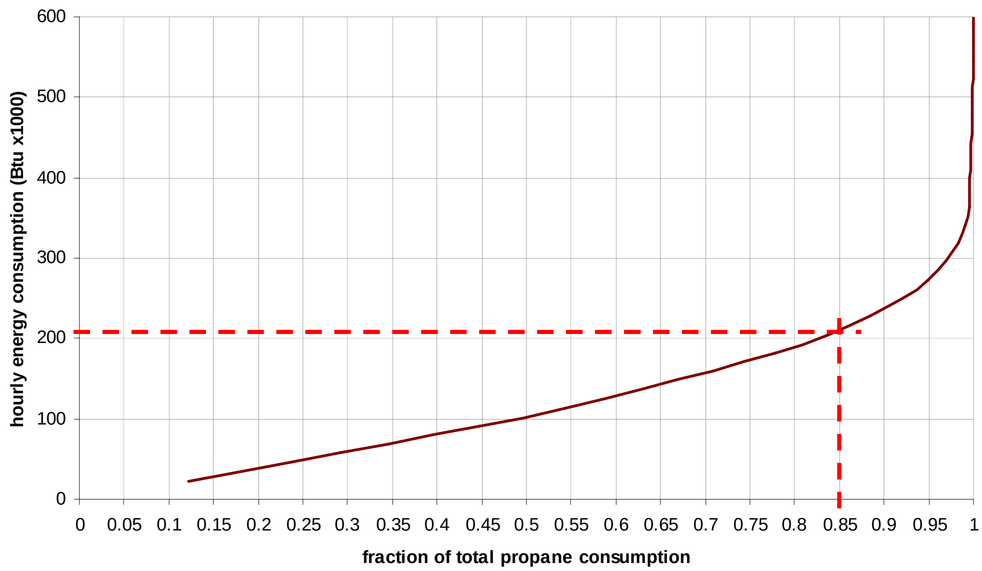


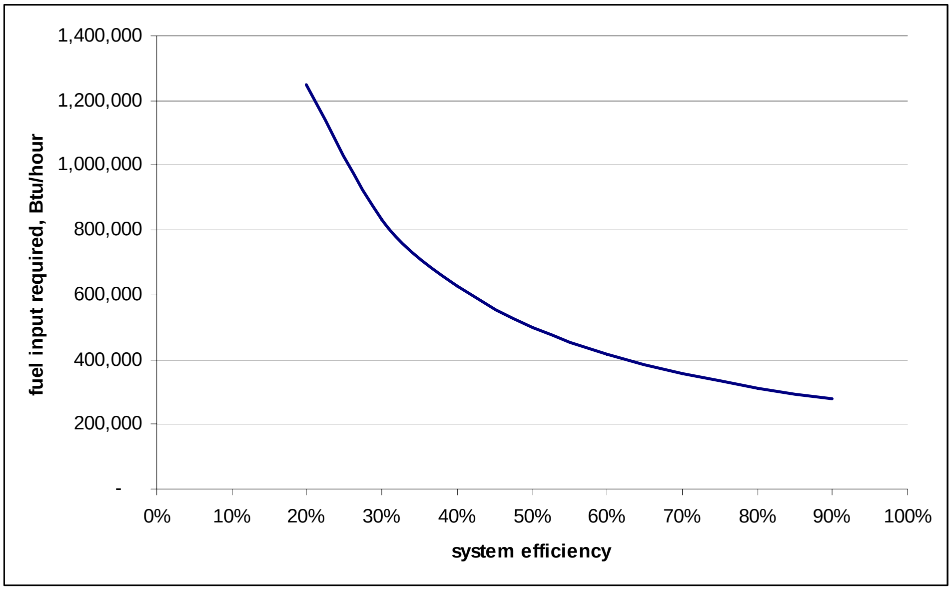
Figure 4: Hourly Energy Requirements vs. Fraction of Total Propane Consumed



Providing a ~25% margin to allow for more severe winters and greater heating demand than those at Savoy during 2000~2003, a design biomass-fired furnace system output would be 250,000 Btu/hour (for 85% propane displacement).[13] The corresponding fuel input size of the furnace depends on overall system efficiency, as depicted in Figure 5. Thus, a biomass-fired system with an Annual Fuel Utilization Efficiency of 60% would entail a design fuel input capacity of ~420,000 Btu/hour to achieve 250,000 Btu/ hour output and the target 85% propane displacement. On the same heat-energy-per-square-foot basis, a 50x500 house would require ~650,000 Btu fuel energy input capacity.

[13] The required furnace size would depend on many factors, e.g., house size/design, extent of insulation/sealing, etc.

Figure 5: Required Furnace Size vs. System Efficiency for 250,000 Btu/hour Output



4. Secondary heating system

Poultry (particularly chicks) have low tolerance to cold temperatures, and failure of a poultry house space heating system can be catastrophic. Thus, until such time as a biomass-fired furnace system can be demonstrated to be as reliable as a propane-fired system, the biomass systems will be considered secondary or supplemental systems (even when target propane displacement is 85% or greater). Some growers are reluctant to use space heating to even partially displace brooders, in which case the role of a biomass system would be even more limited.

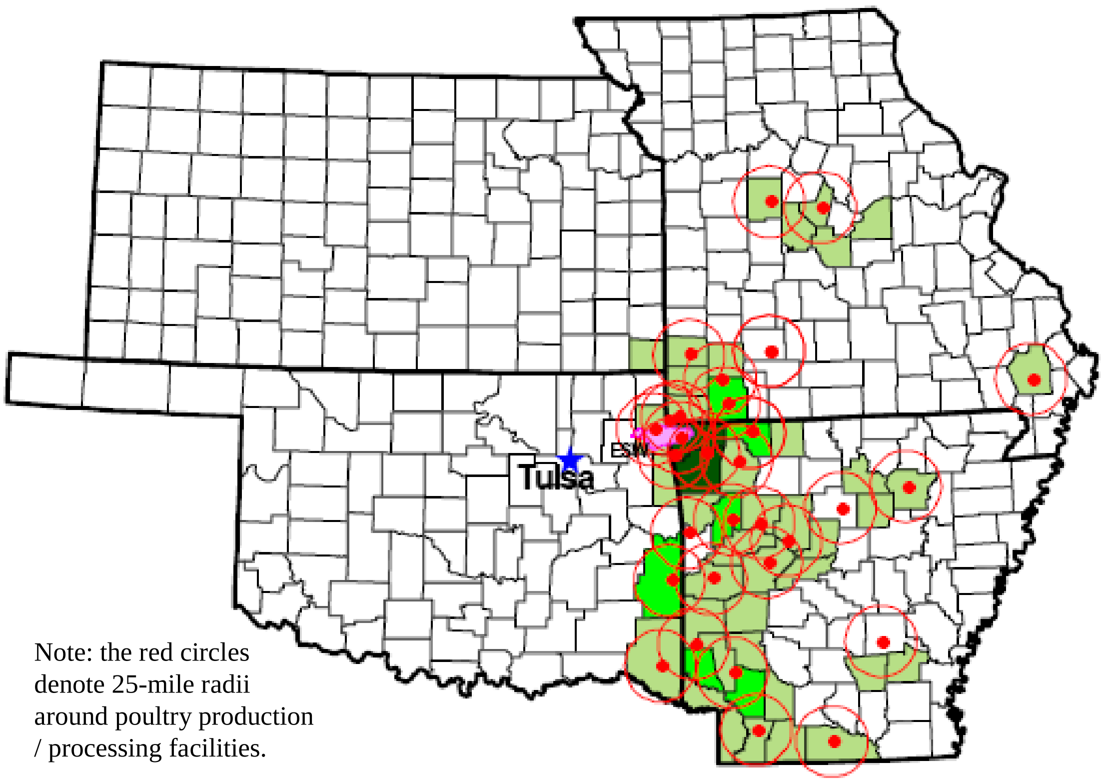
For retrofit applications (i.e., installing a biomass system in an existing house), a grower should expect to continue to use the existing propane system as necessary (i.e., at 15% of space heating energy requirements, based on an 85% target displacement by biomass) and for 100% of heating energy requirements in the event the biomass system fails. The same approach should also be used for new house applications, even if the design displacement of propane approaches 100%.

Relatively low levels of heating are often required during mild weather. It is anticipated that, during such situations, a grower would rely exclusively on the existing propane system for space heating and that the biomass heating system would be turned off (or perhaps operated at idle), given the relatively high convenience factor and system efficiency of propane furnaces compared to biomass furnaces at low output levels.

C. Regional Energy Perspectives

Assuming there are approximately 17,000 poultry houses in the study region, then total average propane consumption is ~102,000,000 gallons/year, which equates to ~9.3 trillion Btu/year.[14] Displacing 85% of this propane with biomass would require ~1.28 million tons/year of wood pellets (or ~1.41 million tons/year of corn) at 60% biomass furnace system efficiency. The geographic base of the region's poultry industry is shown in Figure 6 (taken from a November 2000 report, so the information may now be somewhat out of date).

Figure 6: Poultry Operations in the 4-state Region[15]



Assuming that wood pellet-fired furnace systems have a zero net atmospheric carbon contribution (because the carbon released during combustion was originally captured from the atmosphere via photosynthesis during timber growth) and assuming that propane emits 12.7 pounds of CO_2 per gallon,[16] the displacement of 85% of the region's propane consumption by wood pellets for poultry house heating would avoid approximately 551,000 tons of CO_2 per year from propane.

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[14] Assuming an average of 6,000 gallons/house/year.

[15] Source: *Alternative Poultry Litter Management in the Eucha/Spavinaw Watershed*, Foundation for Organic Resources Management; November 2000.

[16] refer to: http://www.earthlab.com/carbon-calculator.html

D. Feedstock (biomass fuel) options

Primary biomass fuel options for furnaces for heating poultry houses include:

- Cordwood
- Corn
- Wood pellets
- Raw litter
- Pelletized litter
- Other possible biomass fuels
    - Straw
    - Pelletized grasses
    - Densified waste paper

A discussion of each biomass fuel follows. A table of energy-related values including prices and costs is set forth in Appendix 1. A table comparing key energy-related characteristics of the primary biomass fuels considered is shown in Figure 7.

Figure 7: Comparison of Key Energy-related Characteristics of Biomass Fuels

fuel	energy content (HHV)	moisture content (wet basis)	system efficiency	typical ash content (% by weight)	ash-to-energy content (LHV) ratio	ash-to-energy ratio compared to wood pellets
cord wood	8,200	20%	45%	5.0%	7.6	6
corn	7,000	15%	60%	1.5%	2.5	2
pelletized litter	5,400	10%	60%	20.0%	41.2	31
raw litter	5,400	24%	50%	20.0%	48.7	37
wood pellets	8,400	9%	65%	1.0%	1.3	1

1. Cordwood

Cordwood ("chunk wood") is still being used to heat a few poultry houses in the region.[17] Cordwood prices vary considerably, depending on quality (e.g., seasoned oak vs. mixed hardwoods, amount of bark, etc.) and location (e.g., distance from the source). A typical price for cordwood in northern Arkansas is $200 per cord,[18] which equates to ~$63/ton (at roughly 20% moisture content for seasoned wood and assuming a bulk density of about 50 pounds/cubic foot). As shown in Attachment 1, the cost of cordwood is low compared to most other fuel options; however, the inconvenience is high.

2. Corn

Corn is a "natural pellet" which facilitates fuel storage, handling and in-feed. Corn has a higher heating value (HHV) of 6,900~7,000 Btu/pound, which equates to a lower heating value (LHV) of ~6,000 Btu/lb at 15% moisture content (wet basis). Under certain circumstances, corn could be produced as a carbon-neutral fuel. Cull corn, priced well below feed corn when available, can be used as fuel when not acceptable as feed. During the past two heating seasons interest in corn-fired furnaces for heating poultry houses in the region has increased substantially. However, the price of corn has also risen sharply (over $6/bushel in April 2008, compared to less than $3/bushel in 2006). Several furnace manufacturers have promoted their furnaces for poultry house applications, with over thirty such units installed at poultry houses in the region during the '06~'07 and '07~'08 heating seasons. These units were originally designed for heating shops and other small buildings, although one manufacturer has completely redesigned and fabricated a unit specifically for poultry house applications (which is a severe and challenging operating environment).[19]

The corn-fired units being promoted reflect relatively simple design and fabrication regarding fuel handling and combustion components; as such they achieve relatively low capital cost, albeit with reduced operating efficiencies compared to more sophisticated designs. However, the shop-style furnace systems are not specifically designed to withstand the harsh operating conditions of poultry houses; as a result, such units used in poultry houses would likely have high maintenance costs and/or limited service life.

Most of the corn-fired furnaces could also use pelletized fuel (e.g., wood pellets or pelletized litter), although some adjustments to combustion airflow would likely be required to optimize system operating efficiencies. In some instances, minor modifications or adjustments may also be required to the fuel handling components. And, as noted in Section D.5 below, use of high-ash-content litter-derived pellets would require frequent clean-out of the relatively small ash pots typically used by these corn-fired burners (there are no [known] units available with a mechanical ash removal component).

[17] According to the Energy Information Agency, per capita cordwood consumption in Arkansas has dropped from 1,500 pounds per year in 1960 to 135 pounds per year in 2004.

[18] A cord is 4 feet x 4 feet x 8 feet.

[19] Refer to SAR Biomass Energy Systems LLC at www.sarbiomass.com.

3. Wood pellets

Wood pellet-fired stoves were developed in the early 1980s, primarily for residential applications. By the early 1990s, wood pellet production in North America had exceeded 1 million tons per year, and pellet-fired furnace systems were being developed for light commercial applications. Premium grade wood pellets have less than one percent ash[20] (by weight) and are typically less than 10% moisture content.[21] Most wood pellets are made from kiln-dried hardwood sawdust and are 0.25 inch diameter and roughly an inch long.

During the 1995~1996 and 1996~1997 heating seasons two such wood pellet-fired furnace systems[22] were installed at broiler houses in Arkansas.[23] Although no performance data was collected during the demonstration projects, the participating growers observed significant benefits attributed to the "dry heat" aspects of the bioenergy systems (compared to propane-fired systems, for which a primary product of combustion is water vapor) – refer to §H.4.

In 1999 a pellet-fired furnace system was installed at House #3 at the UA-Savoy facility.[24] The custom unit[25] successfully demonstrated the technical feasibility of using wood pellets to heat a broiler house. An economic analysis of that system, performed in 2003, concluded that the wood pellet-fired system would be economically feasible at $1.53 per gallon of propane.[26]

Like corn, a key benefit of wood pellets is that the material can utilize low-cost, and readily available fuel storage and handling equipment, i.e., the same types of silos and augers currently being used on poultry farms for poultry feed.

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[20] Many pellets are available with less than 0.5% ash.

[21] For more information refer to the Pellet Fuels Institute, the industry trade association, at www.pelletheat.org. A list of pellet producers is available from the website, including producers located in Arkansas and the Missouri.

[22] Made by Traeger Industries, the units had a 500,000 Btu/hour rated output capacity.

[23] One unit was located near Prim (north-central Arkansas) and was installed inside the poultry house; the second unit was located near Durham (northwest Arkansas) and was installed in a custom-fabricated shed located adjacent to (but outside of) the poultry house. The project, implemented by Winrock International in cooperation with the Northwest Arkansas and Ozark Foothills Resource Conservation and Development Councils (with funding support by the Arkansas Energy Office and the U.S. Department of Energy), demonstrated the basic technical viability of wood pellet-fired systems for heating poultry houses; the units used jet tubes for hot air distribution.

[24] As part of a project managed by the Foundation for Organic Resources Management in cooperation with the University of Arkansas Department of Biological and Agricultural Engineering and supported by the Arkansas Energy Office and the U.S. Department of Energy; the focus of the project was development of biomass-fired furnace systems for heating poultry houses.

[25] The 600,000 Btu/hour unit was designed and fabricated by Pyro Industries, the firm that successfully commercialized pellet stove technology, which were invented by Dr. Jerry Whitfield.

[26] Source: *Final Report: Commercialization of Biomass Direct-fired Heating Systems*, Foundation for Organic Resources Management, June 2003

4. Raw litter

The physical and fuel characteristics of raw litter are highly variable, and the material is considered a low quality fuel, relative to the other biomass fuels discussed herein. Nonetheless, the material can be used as a fuel, and the material is very attractive as such, given that the fuel is already produced and available at the poultry farm, the cost per unit of energy contained within the biomass is very low (refer to §G.2), and many poultry farms have "surplus" litter.[27]

Over the past 25 years, numerous resources have been invested in attempting to develop farm-scale litter-fired energy systems. Despite these efforts, no systems have been demonstrated to date to meet all four of the fundamental criteria required for successful commercial deployment (refer to §E).[28] Nonetheless, a few such efforts are still underway, given the undeniable attractiveness of such a system.

The primary challenge in developing a raw litter-fired farm-scale system reflects the highly variable and challenging physical and fuel characteristics of raw litter. The material is difficult to store and handle—simple off-the-shelf equipment such as tube augers cannot be effectively used, which means that more expensive materials handling equipment is required to accommodate raw litter.

In addition, the variability in quality of litter makes it significantly more challenging to control in-feed and combustion parameters, and there are some concerns regarding emissions from litter combustion, particularly at low thermal efficiencies. Thus, relatively simple furnace systems (e.g., the corn-fired burners currently being promoted) cannot be effectively used with raw litter as fuel. These factors, including the significant variability in litter characteristics that exist from farm to farm (and occasionally, from flock to flock, etc.), should be addressed during design and operation of any farm-scale litter-fired energy system.

Another concern with regard to litter as a potential fuel is subsequent management of the mineral nutrients, essentially all of which would be captured during combustion in the form of ash. Given the environmental concerns regarding these nutrients (particularly phosphorus), the litter-derived ash would need to be managed effectively, since the amount of litter-derived phosphorus is not reduced as a result of the combustion process. This would likely entail collection and on-farm storage of the ash material, some of which could be land-applied on the farm (subject to the specific nutrient management plans for that farm). The balance of the phosphorus-rich ash material would need to transported off-site, presumably through some regionally-coordinated ash management program (i.e., aggregation and subsequent transport to some distant location where the material can be beneficially re-used without environmental concerns).

[27] The amount of litter considered to be "surplus" will vary widely and may be determined by watershed- or farm-specific factors other than environmental or ecological based considerations.

[28] In contrast, large-scale centralized (off-farm) litter-fired energy facilities have been proven to be technically viable, with several systems operating in the U.K. since the early 1990s; the first such facility in the United States began operation in 2007; for more information, refer to: www.fibrowattusa.com.

5. Pelletized litter

Pelletizing raw litter results in a more consistent quality fuel (e.g., moisture content, Btu/pound) and can effectively overcome the storage and handling challenges associated with raw litter, enabling use of off-the-shelf storage and handling equipment (e.g., hopper-bottom silos and tube augers) and use of less complex furnace systems.[29]

However, litter pelletizing is expensive (significantly aggravated by the high ash content of litter), and does not address concerns regarding emissions from the constituents in litter (which are still contained in the litter-derived pellets). Moreover, the pelletized litter still has very high ash content, requiring frequent removal of ash from a furnace. Finally, pelletizing the litter does not diminish the need for post-combustion management of the litter-derived phosphorus, all of which is contained in the pelletized litter (refer to the discussion in §D.7).

6. Other possible biomass fuels

a) **Straw**: As a loose biomass feedstock, straw has significant physical handling and furnace in-feed challenges. Use of baled straw with a farm furnace would likely require some method of size reduction (e.g., a bale buster, shredder, or hammer mill). Whether in loose or sized form, off-the-shelf equipment (e.g., corn silos and tube augers) cannot be effectively used to store and convey this material. No technical or economic analyses were undertaken for straw for this report.

b) **Grass pellets**: There is increasing interest in the production of densified biomass fuels from perennial herbaceous energy crops (e.g., switchgrass) and even from certain biomass waste sources. These pellets would perform essentially the same as wood pellets and could utilize the same off-the-shelf storage and handling equipment. However, the energy content of the grass-derived pellets would likely be lower than that of wood-derived pellets, reflecting expected higher ash content and expected lower bulk density of the grass pellets. As of April 2008, interest in such feedstocks has been expressed by some of the region's wood pellet producers.[30] No technical or economic analyses were undertaken for grass pellets for this report.

c) **Paper pellets and other densified waste fuels**: Another possible fuel that could be used in farm-scale furnaces could be pellets or small briquettes made from waste paper or other waste materials. For more information about such fuels, contact Balcones Resources in Little Rock.[31] No technical or economic analyses were undertaken for paper pellets or similar fuels for this report.

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[29] Pelletizing the litter would entail transport of the raw litter to a centralized pelletizing facility where it would be dried and densified. The litter pellets (including all of the phosphorus originally contained within the raw litter that is now contained within the litter pellets) would then be transported *back* to the poultry farm for use as fuel.

[30] Also, a recently constructed cooperative in Missouri is producing biomass pellets from various feedstocks; dedicated grasses will be a target feedstock: Show Me Energy Cooperative in Centerview; www.goshowmeenergy.com

[31] http://www.balconesresources.com/pages/fuel_tech.html

d) **Sawdust**: The poultry industry and the forest products industry are often co-located geographically. As a result, many growers are near a source of sawdust, and the material has often been considered a target feedstock for heating poultry houses.

   The nature and quality of woody residue varies significantly. Some mills produce softwood residues and others produce hardwood residues, whereas most produce a mixed stream of hardwood- and softwood-derived sawdust, off-cuts, slabs, etc. The moisture content of sawdust from primary milling operations is typically 50% (wet basis) or greater (i.e., half the weight of the material is water), whereas the moisture content of sawdust from secondary wood manufacturing operations is kiln-dried (typically in the range of 8~15% moisture content, wet basis). Also, residues from secondary operations typically contain no bark, in contrast to residues from primary operations which generally has high bark content (which equates to high ash content and relatively high abrasiveness as a fuel).

   However, like raw litter, sawdust (particularly high moisture-content material from primary mills) is difficult to store, handle, and feed into a furnace. While mechanical systems exist to handle sawdust at many sawmills and other forest products processing facilities, it has not been economically feasible to scale down such equipment for use on a poultry farm. Again, as has been the case with raw litter, numerous efforts have been made over the years to develop sawdust-fired farm-scale furnace systems, but no such systems have yet been developed that are commercially available and meet all four criteria set forth in §E.

E. Key criteria for selecting a furnace system

There are four key criteria that should be used to evaluate a farm-scale biomass furnace system for heating poultry houses:

- **Technically viable**

  The entire system should be functional, reliable, and serviceable.

- **Economically feasible**

  The capital and operating costs associated with the system should be exceeded (or at least equaled) by the monetary benefits that accrue from the system. In other words, an investment in the bioenergy system should make economic sense.

- **Environmentally acceptable**

  On balance, the environmental aspects of the system should be positive. Using biomass to displace propane provides an inherently positive environmental benefit (displacement of a fossil fuel with a renewable fuel).

- **User friendly**

  The "hassle factor" should be considered acceptable by the grower/operator—most producers do not have the time (or the inclination, or perhaps the aptitude) to "baby sit" a system that is difficult to operate or is labor-intensive.

To be commercially successful, it is likely that a furnace system would have to meet all four of the above criteria.

F. Furnace system components

1. Fuel storage, handling, and in-feed

For raw litter, fuel storage, handling, and in-feed has been the Achilles Heel of many attempts to develop a bioenergy system. Raw litter can be difficult to manage. It can heat up through composting and generate significant odors; it invites bugs, rats, and other vermin; it readily bridges when handled, which creates numerous materials handling challenges; and it can be highly variable in quality (i.e., physical and chemical characteristics). For example, ash content can vary from 17% to 24% by weight.

In contrast, corn is easy to store (using conventional hopper bottom silos) and handle (using typical conveyance equipment, including tube augers common on poultry farms). The same is essentially true for pelletized biomass (wood, litter, other), although repeated or excessive handling will increase the fines content.

Feeding biomass fuel into a furnace is a critical step, and the difficulties should not be under-appreciated. Densified fuels (e.g., wood pellets) readily flow and can be essentially metered into the furnace. In contrast, raw/loose fuels (litter, sawdust) will readily bridge, even with vertical sidewalls in a gravity-based in-feed chamber.

2. Furnace system

a) Processing technology options

Four basic conversion technologies could be used to convert biomass fuels into thermal energy for poultry house space heating:

- **Gasification:** The concept of converting poultry litter into a synthesis gas and using the gas as fuel in off-the-shelf gas furnaces is very attractive, and at least two companies have seriously looked into this approach. However, to date, no such systems have been successfully demonstrated, and commercially deployable biomass gasification remains an elusive technology (regardless of feedstock or scale).
- **Pyrolysis:** Conceptually, pyrolysis is even more attractive than gasification. The intermediate energy product, biocrude, could be readily stored and piped to and used in a slightly modified off-the-shelf gas-fired (or diesel-fired) furnace, and at least one company has been trying to develop a pyrolysis system for poultry applications using litter fuel. However, to date, no such systems have been successfully demonstrated, and biomass pyrolysis systems are not yet available on a commercial basis (regardless of feedstock or scale).
- **Anaerobic digestion:** Anaerobic digestion—the only biological (i.e., not thermochemical) conversion technology discussed here—seems counter-intuitive for a relatively dry feedstock such as poultry litter. Nonetheless, this process could provide a gaseous intermediate fuel which can be used in conventional gas-fired furnaces or used as a fuel for generating electricity. Several efforts outside of Arkansas have focused on anaerobic digestion of litter feedstocks, including a project in Mississippi.[32]
- **Combustion:** This traditional approach is the one most commonly used for biomass feedstocks and is the technology used for all of the biomass-fired systems currently being used or considered in the northwest Arkansas region (including corn, wood pellets, and pelletized litter).

b) Design considerations

Furnaces should use outside combustion air and exhaust the products of combustion to the outside in order to avoid impacting the static pressure in the house (a parameter of increasing concern by the poultry industry). Furnaces require some type of heat exchanger to capture the heat from the combustion gases and deliver the heat to the interior of the poultry house for space heating. Furnaces can be located inside the house or within an attached shed that is open or ducted to the house. Locating the unit inside captures the radiant heat from the unit and avoids the cost of the shed, but could interfere with clean-out activities. An in-house location could also improve access to the furnace unit for maintenance activities.

[32] Refer to: http://www.technologyalliance.ms/images/admin/spotedit/attach/32/poultry_litter_biorefinery.pdf

c) Furnace system efficiency

The efficiency of a furnace system is a measure of its ability to convert the calorific value of the fuel into usable energy, i.e., space heating in a poultry house. The amount of heat actually delivered compared to the amount of fuel consumed is fundamental to the economic performance of the system. The efficiency of residential heating systems is reflected in the system's Annual Fuel Utilization Efficiency (AFUE), a measure of thermal efficiency established by the U.S. Department of Energy.[33]

For biomass-fired furnaces used to heat poultry houses, system efficiency should be measured over a long period (e.g., a year). Short-term measurements, particularly if limited to steady-state operating conditions, may not adequately reflect start-ups and shut-downs[34] and could be substantially higher (and, therefore, misleading) than long-term measurements.

Well-designed and fabricated biomass furnaces using high-quality meter-able fuel (e.g., premium wood pellets) may be able to achieve an AFUE of 65% or greater. However, good furnace maintenance is essential to maintaining system efficiency and, as discussed in §G.5, system efficiency is a key variable affecting the economics of a biomass-fired furnace system for heating poultry houses, and growers should request substantiating data from furnace manufacturers to support their efficiency claims. For the economic analyses undertaken for this study, assumptions for system efficiencies are shown in Figure 7.

d) Heat exchangers

All of the current furnace designs being deployed in the northwest Arkansas region employ air-to-air heat exchangers, although systems utilizing hot water loops have also been considered over the years. Key aspects to consider in evaluating heat exchangers include:

- **Design:** Is there sufficient surface area for effective thermal energy transfer? Can the components be accessed for maintenance? Does it require filters?[35]
- **Fabrication:** Will the materials hold up over the projected life of the furnace? Is the metal sufficiently thick to be field-welded if necessary?
- **Service-ability:** Are all components readily accessible for inspection and for maintenance (both routine and major)?

[33] For more information, refer to: http://en.wikipedia.org/wiki/Annual_fuel_utilization_efficiency

[34] Start-up and shut-down activities are relatively inefficient, particularly for systems that do not have variable output levels (i.e., are either on or off).

[35] Poultry houses are dusty operating environments, and conventional air filters require substantial additional maintenance—daily or even more frequently cleaning or changing. Clogged filters reduce system efficiency and increase fire risks.

e) Turn-down

The most simple furnace designs entail operating modes of either on or off, with no intermediate options. However, such systems are far less efficient than those that utilize stepped or continuously variable modes, which require simultaneous adjustments of both fuel flow and air flow.[36] The more sophisticated systems cost more, but the additional cost would be warranted if there are sufficient improvements in overall system efficiency. At least one biomass furnace manufacturer has developed a multi-fuel continuously-variable furnace system for poultry house applications.

3. Heat distribution

The hot air output from the furnace heat exchanger is typically directed towards the center of the house where it can be picked up and distributed by the in-house heat distribution system. The jet tubes with axial fans on the intake ends used in earlier distribution systems are effective but accumulate dust, which can be a bird health hazard (particularly in production houses employing low-to-no antibiotics practices). Plus, cleaning and disinfecting is labor-intensive. Instead, stirring fans have been demonstrated to be effective, low cost, and easy to install and maintain.

4. Ash management

There are significant variations in the ash content of biomass feedstocks. For example, raw litter-fired systems will generate over 50 times the amount of ash as systems using premium wood pellets. Ash production is also directly affected by furnace system operating efficiency and maintenance (unburned fuel, as a component of ash, will likely increase as system efficiency decreases). All of the systems currently being promoted in the northwest Arkansas region use simple ash pots that are emptied manually (automated ash removal is possible but would require some re-design of the furnaces and would add considerable capital and operating costs). The frequency of clean-out is directly correlated to the size of the ash pot, fuel consumption, and system efficiency.

As discussed in §G.4 and §H.2, systems using raw or pelletized litter will also need to employ effective management of the ash, given the high levels of phosphorus in the fuel that end up as ash. Such nutrient-rich ash can be an asset. For example, Fibrowatt has been further processing and marketing its litter-derived ash for over 15 years.[37]

5. Instrumentation & controls

Effective instrumentation and controls are an essential component of the overall system. In addition to responding to demand sensors (thermostats, humidity controls, etc), modern controls should integrate the heating system with the house's ventilation system, as well as provide step- or continuously-variable thermal output.

[36] A desirable turn-down ratio would be an idle mode with less than 10 percent of the fuel consumption of full output under steady-state operating conditions.

[37] For more information, refer to: http://www.fibrophos.co.uk/

G. Economic considerations

1. Capital costs

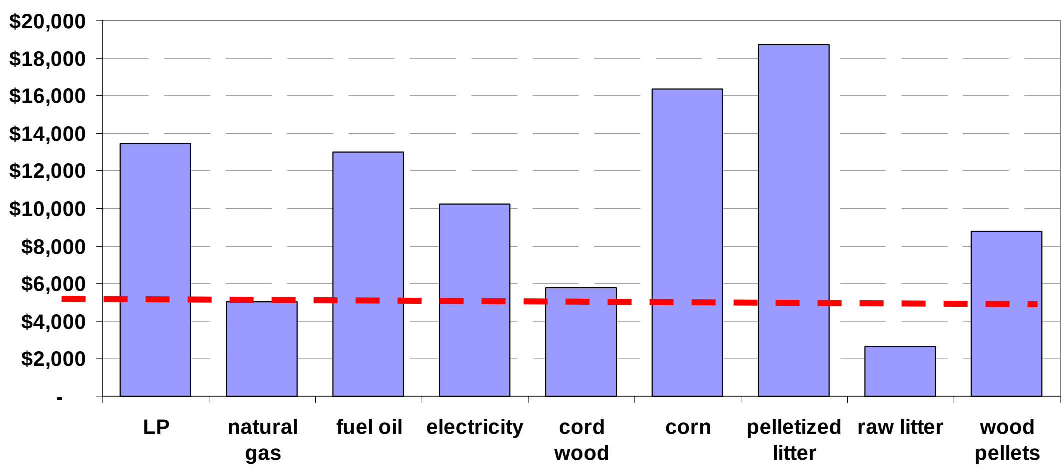
The capital cost of a furnace system includes all key components—fuel storage and handling; the furnace system (including, possibly, automated ash removal[38]); heat distribution; and installation and start-up. Estimates for the various biomass-fired furnace systems considered in this report are set forth in Appendix 2; all costs are on a per-house basis. These costs range from $16,500 for a cordwood-fired system with manual loading to $34,000 for a raw litter-fired system with mechanical in-feed—assuming such a system can be designed and fabricated that meets all of the selection criteria set forth in §E. Capital costs are captured within owning costs, which also includes financing costs.

2. Operating costs – fuel is the primary expense

Operating costs include fuel (the primary expense), electricity (for the various motors and fans required for fuel conveyance, furnace operations, and heat distribution[39]); and maintenance. No labor costs were considered in this assessment. Operating costs are analyzed in detail for each system assessed in §G.3 below.

As the primary operating expense, the cost of the biomass fuel is critical to the economic performance of the furnace system. A comparative analysis of fuel expenses is shown in Figure 8, which shows that, if only considering fuel expenses (with each assumed to provide 100% of the required heat energy output), raw litter appears to be the most attractive biomass option, whereas pelletized litter appears to be the most expensive option. The red line in the graphic provides a reference against natural gas (still the least expensive option, even at $9 per thousand cubic feet (MCF).

Figure 8: Comparison of Annual Fuel Costs

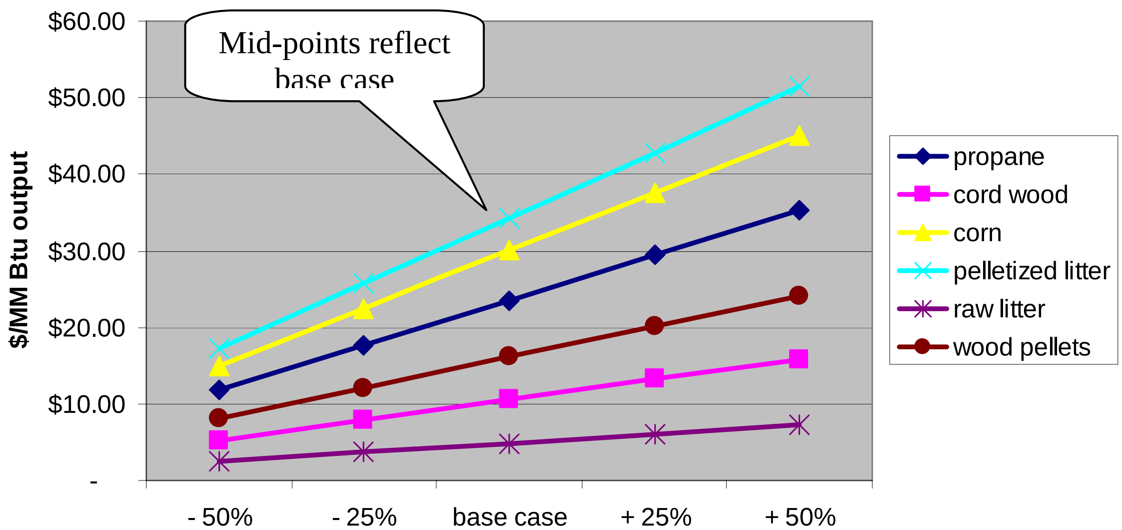


[38] None of the capital costs shown in Appendix 2 include mechanical/automatic ash removal.

[39] For this analysis, net annual electricity costs are assumed to be zero.

An alternate comparison of fuel costs is shown in Figure 9, in which the supplied fuel cost (again, at 100% of required capacity) for the five biomass options are compared to propane. For each fuel, a curve depicts variations in supplied fuel cost (in $ per million Btu) based on 50% variation in feedstock costs.

Figure 9: Comparison of Fuel Costs



3. Common assumptions

Assumptions common to each of the five systems analyzed are shown in Figure 10.

Figure 10: Common Assumptions

average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
service life of furnace system	10.0	years
furnace down payment rate	20%	of capex
financing period	5	years
furnace system financing interest rate	7%	APR
discount rate for NPV calcs	5%	
current fuel cost reimbursement from integrator	$0	per house per year
grant funds available to offset capital cost	0%	of total capex
annual escalation of LP prices above CPI	2.0%	
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	

4. Economic analyses

Economic analyses were performed on five systems (details of the included components are shown in the Capital Costs spreadsheet shown in Appendix 2).

- **Cord wood:** This analysis assumes use of a simple design (relatively inefficient), manually-loaded combustion furnace. The detailed analysis is shown in Appendix 3.
- **Corn:** This analysis assumes use of a simple combustion system such as those that have been promoted in the northwest Arkansas region during the past two heating seasons. The detailed analysis is shown in Appendix 4.
- **Raw Litter:** This analysis assumes use of a hypothetical system capable of using raw litter (hypothetical, since no such system is commercially available). The detailed analysis is shown in Appendix 5.
- **Pelletized Litter:** This analysis assumes use of the corn-fired system described above, but using pelletized litter. The detailed analysis is shown in Appendix 6.
- **Wood Pellets:** This analysis assumes use of the corn-fired system described above, but using premium grade wood pellets. The detailed analysis is shown in Appendix 7.

For each analysis, assumptions are shown in blue font (with cash outflows or negative results shown, where appropriate, in red font). All analyses are on a per-house basis. The economic performance of each bioenergy system was analyzed using a Net Present Value (NPV) analysis; simple payback (in years) is also shown, but should be used cautiously, as this is not considered an accurate portrayal of an investment.

A detailed summary of key assumptions and results of the analyses is shown in Appendix 8; a high-level summary of key assumptions and results of the analyses is shown in Figure 11; a discussion of the economics of each furnace system follows.

Figure 11: Summary of Economic Performance of Biomass Furnace Systems

Average annual expenses	cord wood	corn	pelletized litter	raw litter	wood pellets
over the projected service life					
Total benefits (from displaced propane)	$12,300	$12,300	$12,300	$12,300	$12,300
Owning costs	-$1,900	-$2,400	-$2,300	-$4,000	-$2,300
Operating costs					
Biomass fuel	-$5,100	-$14,200	-$16,200	-$2,300	-$7,100
Maintenance & electricity	-$600	-$600	-$600	-$600	-$600
total Owning & Operating Costs	-$7,600	-$17,200	-$19,100	-$6,900	-$10,000
Net benefit (loss)	$4,700	-$4,900	-$6,800	$5,400	$2,300

5. Sensitivities of key factors affecting the economics

Key factors affecting the economics of the furnace systems include:

- price of propane
- annual propane consumption (prior to installation of the bioenergy system)
- target fraction of propane to be displaced
- price of biomass fuel
- system efficiency
- system service life
- capital cost of the system

For each of the furnaces evaluations shown in Appendices 3 through 7, sensitivity analyses are provided in both tabular and graphical formats. Each analysis also includes a tornado chart depicting the relative sensitivity of the key factors.

6. Observations regarding the economic analyses

a) Overview

A fundamental figure in the analyses is **current propane consumption** – assumed in these analyses to be 6,000 gallons per year. This amount is based on empirical consumption data compiled from several growers in the region, which range from 4,000 to 7,000 gallons/year per house (for broilers). Unfortunately, no known public domain data set exists that quantifies this important assumption.[40] The economics of each of the bioenergy systems are less favorable with a reduced annual propane consumption level. For example, the NPV for a wood pellet system is positive at 6,000 gallons/year but is negative at 4,000 gallons/year. Thus, there is a need to understand a specific farm's propane consumption levels prior to analyzing the economics of an investment in a bioenergy system for displacing propane.

Annual propane consumption can also be reduced through various **energy efficiency practices** (e.g., insulation and/or sealing of the sidewalls in a curtain house). Again, the economics of displacing propane with biomass fuel will be different if a farm's annual propane consumption is reduced from such practices.[41]

The target **propane displacement level** of 85% was discussed in §B.2. A lower displacement level will result in less attractive economics for a bioenergy system. Furnace systems with a high turndown ratio (e.g., with continuously variable output downwardly adjustable to, say, 10% of maximum output) may be able to increase actual displacement beyond 90 percent.

[40] A grower survey would be extremely useful, providing this and much more information related to the energy aspects of poultry production in the northwest Arkansas region.

[41] For more information about energy efficiencies refer to: http://www.ag-tite.com/support-files/auburnfinal.pdf

The results of each of the five analyses are highly sensitive to the **price of propane**. Thus, investments in such systems should reflect a high confidence level that propane prices over the assumed system service life will not significantly drop below the base case assumed price of $2.20/gallon.

The results of each analysis (with the exception of raw litter-fired systems) are also highly sensitive to **furnace system efficiency** and, to a lesser degree, **system service life**. Factors affecting system service life and efficiency include: system design (e.g., effective combustion and thermal transfer), equipment components (e.g., sealed motors), system fabrication (e.g., heavy gauge metal), design from a maintenance perspective (e.g., accessibility of wear points), and routine maintenance practices.

b) **Cordwood**

While the NPV results are attractive (NPV = $34,000), it is important to realize that this reflects a simple system (with relatively low system efficiency) that requires manual loading of the fuel and removal of the ash, thereby constituting a labor-intensive system—which probably does not satisfy criterion #4 set forth in §E.

c) **Raw litter**

The economics of a raw litter-fired furnace system appear very attractive—provided that such a system can be designed, manufactured, sold, and operated within the assumptions set forth in Section E (which, as discussed previously, has not been the case). Again, system efficiency and service life are important. For example, NPV drops to zero if efficiency drops to 45% and service life drops to 4.2 years.

Note that total annual consumption of raw litter for fuel is estimated to be 116 tons per year per house (@ 50% system efficiency). This amount is roughly equivalent to the total amount of litter produced per house per year for a typical broiler operation with annual clean-out.[42]

d) **Pelletized litter**

Based on the assumptions used in this analysis, pelletized litter-fired systems are <u>not</u> economically attractive. To achieve a breakeven NPV, the price of litter pellets would need to drop from $200/ton to $110/ton (delivered). If system efficiency drops from 60% to 55% and service drops from 10 to 6 years, then the price of litter pellets would need to drop to $82/ton to achieve breakeven NPV.

e) **Corn**

Based on the assumptions used in this analysis, corn-fired systems are <u>not</u> economically attractive. However, using low-cost cull corn as fuel could significantly im-

[42] Total annual production of litter per house is affected by numerous factors such as quantity and type of initially bedding material, bird production management practices, heating/ventilation practices, frequency of clean-out, etc.

prove the economic—if cull corn could be obtained for $3.00/bushel ($107/ton), then the NPV would increase to $14,700.

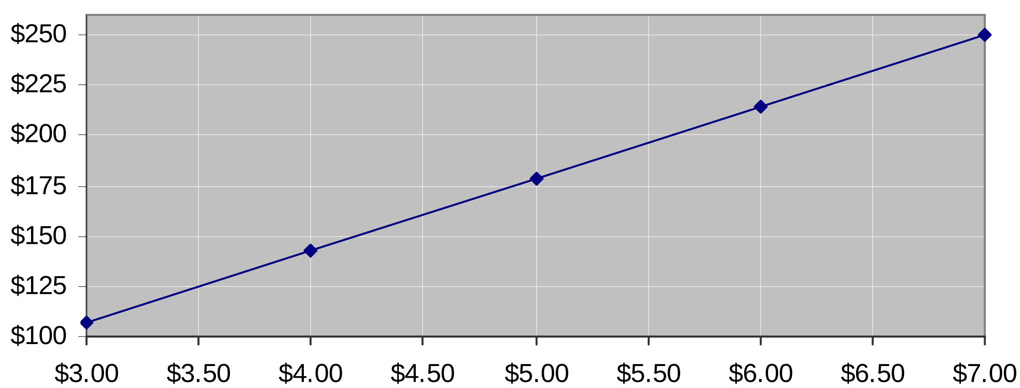
Another option in some instances may be production of corn on or near the poultry farm—by eliminating transportation costs (and, possibly, other cost components) a grower may be able to produce corn fuel at costs significantly lower than the $6.00/bushel base case assumption.

For the scenario in which corn as fuel costs $3.00/bushel and an NPV of $14,700 is achieved, the economics are still sensitive to furnace system efficiency…NPV would be zero at about 48% system efficiency.

At $3/bushel corn, a 25% decrease in capital cost (i.e., from $20,000 to $15,000) would result in a 35% improvement in NPV (from $14,700 to $19,800).

A chart for comparing cost per bushel to cost per ton for corn is shown in Figure 12.

Figure 12: Cost per Bushel vs. Cost per Ton (for Corn)



f) **Wood pellets**

Based on the assumptions used in this analysis, wood pellet-fired systems are economically attractive. The assumed price of wood pellets—$160/ton, delivered—is based on data from pellet producers in the region that have expressed interest in bulk pellet sales to growers in the region. The economics are highly sensitive to the cost of pellets, the cost of propane, the base gas consumption rate (gallons/year), and furnace system efficiency.

If the price of pellet fuel is $130/ton (e.g., for a grower located closer to pellet mill in which the transport costs would be less), then NPV rises from $10,600 to $21,700. If system efficiency increases from 65% to 70% (note: many pellet stove manufacturers claim a system efficiency of 85%, although the operating conditions in a residence are significantly better than in a broiler house), then NPV rises to $14,800.

H. Environmental considerations

1. Reduced fossil fuel consumption

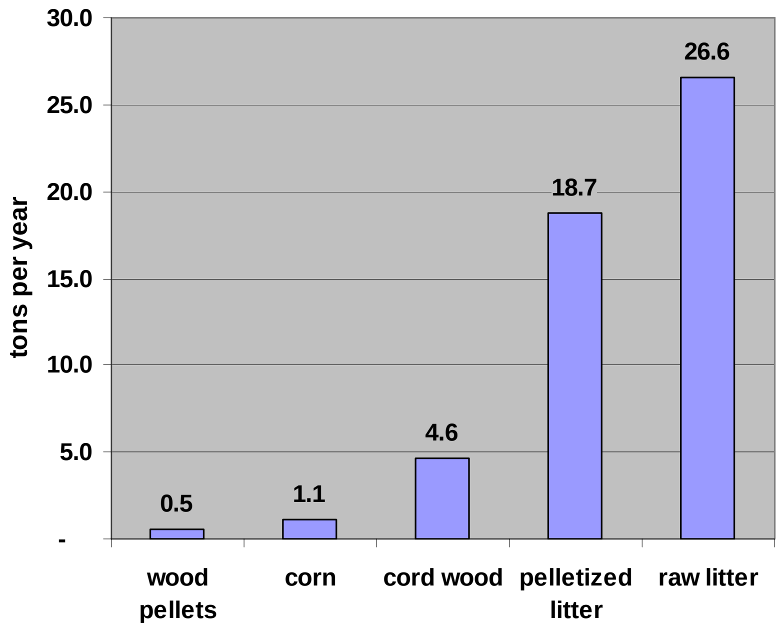
The primary benefit associated with such systems is displacement of a fossil fuel (propane) with a renewable fuel (biomass). If 1,000 poultry farms used biomass furnace systems for space heating, total avoided CO_2 emissions would be ~33,000 tons/year.[43]

If litter-fired systems can be successfully developed and deployed, then use of litter as fuel would avoid land application of said litter and lead to potential water quality benefits on/near those farms.[44] If 1,000 litter-fired systems were deployed, a total of 116,000 tons per year of litter would not be land-applied.

2. Ash

Total annual ash production (based on the ash content levels shown in Figure 7) for the various systems considered in this assessment are shown in Figure 13. As discussed in §F.4, systems using raw or pelletized litter will need to effectively manage the nutrient-rich ash from the furnaces (which will likely entail some type of regionally coordinated aggregation, further processing, and sales program).

Figure 13: Annual Ash Production from Bioenergy Furnaces



Note that ash production from raw litter combustion would be over 50 times greater per ton of litter (as received) than the ash per ton of wood pellets.

[43] At the base case assumptions of 6,000 gallons/year propane consumption, 85% displacement by biomass, and 12.7 pounds CO_2 per gallon of propane; this calculation also assumes that the biomass fuels have zero net CO_2 emissions.

[44] This assumes that all of the nutrient-rich ash is managed effectively.

3. Air emissions

According to the Arkansas Department of Environmental Quality regulation #18, Section 301, biomass furnaces would fall under existing regulations only if air emissions exceeded the following criteria:

- CO_2 > 40 tons/year
- NO_X > 25 tons/year
- SO_X > 25 tons/year
- VOCs > 25 tons/year
- Particulates > 15 tons/year.

The bioenergy systems considered here—with total fuel consumption ranging from 44 tons/year of wood pellets to 81 tons/year of raw litter—would emit only a small fraction of these levels. However, it is possible that such furnaces could become regulated if sufficient biomass-fired furnaces are deployed in areas of concentrated poultry production.

4. Benefits of dry heat

Producers who have used biomass furnaces have noticed an overall improvement in ambient air quality within the house. The improved air quality has been attributed to the "dry heat" associated with the biomass furnaces, whose products of combustion are vented. In contrast, the products of combustion of propane-fired systems are not vented, which substantially increases moisture levels within the houses (about 6.8 pounds of water vapor are released into a poultry house for every gallon of propane consumed).

The dry in-house environment achieved by the dry heat bioenergy systems is thought to have three significant results: reduced in-house ammonia levels, reduced ventilation requirements, and increased litter quality. In turn, reduced in-house ammonia levels should provide a healthier environment for the human operators and for the birds, potentially leading to reduced mortality, improved feed conversion, and/or shorter grow-out periods.

Reduced in-house water vapor and/or ammonia levels may also result in reduced ventilation requirements, thereby reducing exhaust fan run time, which would result in reduced space heating loads (and fuel consumption) and reduced electric consumption.

In turn, reduced ammonia levels should result in more nitrogen retained in the litter which would increase the fertilizer value of the litter.

These are important potential environmental and economic benefits that are associated with the dry heat nature of bioenergy furnace systems compared to propane heating systems. Although growers that have used bioenergy furnaces have enthusiastically described and endorsed these various benefits, limited scientific data exists to validate or quantify the benefits. Given the range and potential significance of these benefits, rigorous data collection and analyses focused on the benefits of dry heat systems should be a priority research focus for the integrators and the supporting academic community.

I. Observations and Conclusions

- Propane consumption at a "typical" broiler house in the northwest Arkansas region has been 4,000~7,000 gallons per year; an average of 6,000 gallons/year/house was assumed in this study. Propane prices for the region's growers have risen dramatically in recent years, with prices in early 2008 over $2.00 per gallon (up ~ 100% in three years).

- A reasonable target displacement level of propane by biomass is 85% of annual consumption, equating to a target displacement of 5,100 gallons/year of propane. At $2.20 per gallon for propane, the value of the displaced propane is $11,200 per year.

- Based on propane consumption data from the University of Arkansas' Savoy facility and the assumptions set forth herein, a design furnace input capacity of 420,000 Btu/hour (i.e., to achieve an output of 250,000 Btu/hour at 60% system efficiency) was determined.

- Any commercially successful biomass furnace system should meet four criteria:
  - Technically viable.
  - Economically feasible.
  - Environmentally acceptable.
  - User friendly.

- Four basic conversion technologies could be used to convert biomass into thermal energy for space heating: gasification, pyrolysis, anaerobic digestion, and combustion. Of these, only combustion furnaces are currently available for commercial deployment.

- Each biomass-fired thermal energy system contains the following principal components: fuel storage, handling, and in-feed; the processing unit; heat exchanger; ash management; heat distribution system; and instrumentation and controls.

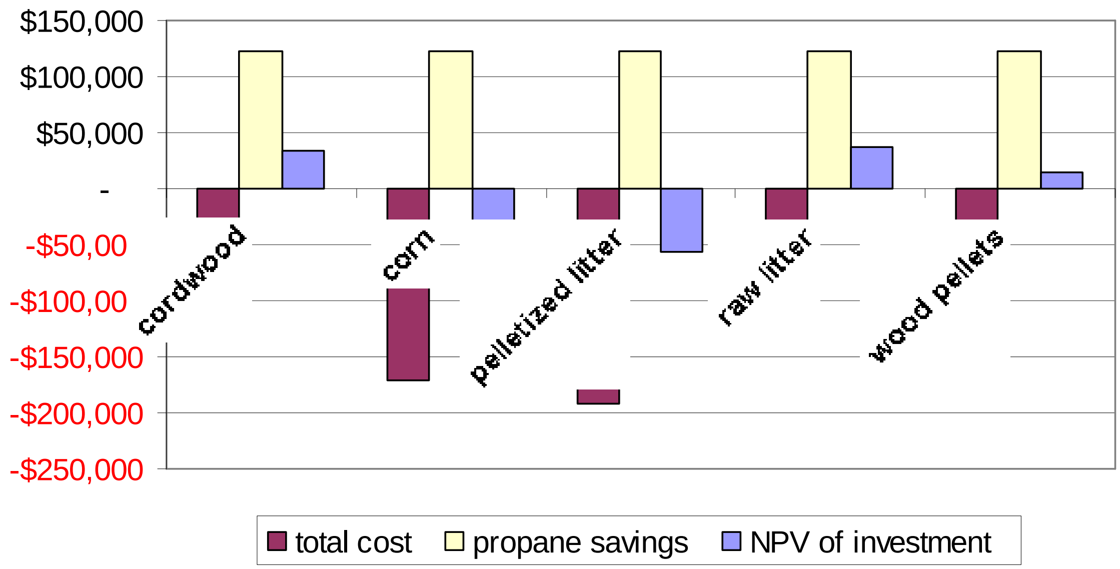
- Key factors affecting the economics of any biomass-fired furnace system include system efficiency and system service life. Both of these factors are significantly affected by equipment design, fabrication, and service-ability.

- The challenges of biomass fuel handling, storage, and in-feed are often under-appreciated and have proven fatal to many biomass energy projects, including on-farm furnaces.

- All of the systems analyzed in this study entail manual ash removal. Automated (mechanical) ash removal subsystems could be incorporated but at significant additional cost. The amount of ash to be managed from a raw litter-fired system would be over 50 times the amount of ash to be managed from a wood pellet-fired system.

- In the combustion systems considered in this study, all of the phosphorus and other minerals contained within poultry litter would end up as ash. Thus, all of the ash from a raw litter-fired furnace or a pelletized litter-fired furnace would need to be effectively managed at both farm and regional scales. The nutrient-rich ash from a centralized litter-to-energy system has been shown to have significant agronomic and economic value.

- The economics of five biomass-fired furnace systems were analyzed using a Net Present Value method and the assumptions set forth herein for cordwood, corn, wood pellets, raw litter, and pelletized litter. The summary economic results for the assumed base case system service life are shown below.



- The economics of a simple design cordwood-fired furnace system are attractive, but such a system is labor-intensive (labor costs were not included in the economic analyses).

- The economics of a corn-fired furnace system do not appear attractive unless fuel corn is available at rates substantially below feed corn market prices.

- The economics of a wood pellet-fired furnace system appear favorable.

- The economics of a raw litter-fired furnace system appear attractive, but no such system is commercially available. Moreover, none of the numerous efforts to develop such a system in the past few years have resulted in any system demonstrated to meet all four deployment criteria set forth above.

- The economics of a pelletized litter-fired furnace system do not appear attractive.

- **For each biomass-fired furnace system considered, the economics are highly sensitive to a number of variables, many of which are site-specific. Thus, any grower interested in a biomass-fired furnace system should undertake or obtain an economic analysis specific to that farm in order to better understand and quantify the potential benefits and risks associated with the various furnace options.**

- The potential economic and environmental benefits associated with the "dry heat" nature of biomass furnaces are significant and have been demonstrated, but have not yet been quantified and therefore have not been incorporated in these analyses.

Appendix 1: Comparison of Fuel Characteristics and Economics

target energy output = 546,000,000 Btu/yr

fuel	energy content (HHV)	units	energy content (LHV)	moisture content (wet basis)	bulk density (lbs / cu ft)	typical ash content (% by weight)	units required per year	approximate cost per unit, delivered (Spring 2008)	est. delivered cost per ton	extended cost for target output	gross $ per MM Btu	system effi-ciency	$ / year	net $ / MM Btu
LP	91,000	Btu/gallon	91,000	n/a	n/a	n/a	6,000 gal	$2.20 / gal	n/a	$13,200	$24.18	98%	$13,469	$24.67
natural gas	1,000	Btu/cu ft	1,000	n/a	n/a	n/a	546,000 cf	$9.00 / mcf	n/a	$4,914	$9.00	98%	$5,014	$9.18
fuel oil	140,000	Btu/gallon	140,000	n/a	n/a	n/a	3,900 gal	$2.00 / gal	n/a	$7,800	$14.29	60%	$13,000	$23.81
electricity	3,413	Btu/kWh	3,413	n/a	n/a	n/a	159,977 kWh	$0.064 / kWh	n/a	$10,238	$18.75	100%	$10,238	$18.75
cord wood	8,200	Btu/lb	6,560	20%	50.0	5.0%	83,232 lb	$200.00 / cord	$63	$2,601	$4.76	45%	$5,780	$10.59
corn	7,000	Btu/lb	5,950	15%	44.8	1.5%	91,765 lb	$6.00 / bu	$214	$9,832	$18.01	60%	$16,387	$30.01
pelletized litter	5,400	Btu/lb	4,860	10%	40.0	20.0%	112,346 lb	$200.00 / ton	$200	$11,235	$20.58	60%	$18,724	$34.29
raw litter	5,400	Btu/lb	4,104	24%	25.0	20.0%	133,041 lb	$20.00 / ton	$20	$1,330	$2.44	50%	$2,661	$4.87
wood pellets	8,400	Btu/lb	7,644	9%	44.0	1.0%	71,429 lb	$160.00 / ton	$160	$5,714	$10.47	65%	$8,791	$16.10

note: for each fuel above, the calculations assume 100% of the target heat energy is provided by each respective fuel.

Appendix 2: Assumed Capital Costs

note: these rough cost estimates for the purpose of this overview analysis;
more detailed assessments should be performed for any specific site and installation.

	cord wood	corn	raw litter	pelletized litter	wood pellets	
fuel storage & handling						
silos						
required capacity		66		88	48	tons
contingency on capacity		15%		15%	15%	
design capacity		76		101	55	tons
design capacity		23		31	17	cu ft
capacity per silo		750		800	750	cu ft
total # of silos required		0.0		0.0	0.0	units
design # of silos used		1		1	1	units
cost per silo		$3,000		$3,000	$3,000	per unit
total cost for silo(s)		$3,000		$3,000	$3,000	
materials handling		$500		$500	$500	
foundations		$500		$500	$500	
other (1) (2)	$500		$15,000			
subtotal cost	$500	$4,000	$15,000	$4,000	$4,000	
furnace system						
combustor unit	$7,500	$7,500	$7,500	$7,500	$7,500	
ash management (3)	-	-	$4,000	$4,000	-	
instrumentation & controls	$1,000	$1,000	$1,000	$1,000	$1,000	
shed	$1,000	$1,000	$1,000	$1,000	$1,000	
subtotal cost	$9,500	$9,500	$13,500	$13,500	$9,500	
heat distribution						
fans / ducts	$2,000	$2,000	$2,000	$2,000	$2,000	
other	-	-	-	-	-	
subtotal cost	$2,000	$2,000	$2,000	$2,000	$2,000	
installation & start-up						
labor	$2,000	$2,000	$2,000	$2,000	$2,000	
contractor's margin	$2,000	$2,000	$2,000	$2,000	$2,000	
	12%	10%	6%	8%	10%	
subtotal cost	$4,000	$4,000	$4,000	$4,000	$4,000	
shed sealing & insulation	$500	$500	$500	$500	$500	
summary						
fuel storage & handling	$500	$4,000	$15,000	$4,000	$4,000	
furnace system	$9,500	$9,500	$13,500	$13,500	$9,500	
heat distribution	$2,000	$2,000	$2,000	$2,000	$2,000	
installation & start-up	$4,000	$4,000	$4,000	$4,000	$4,000	
sealing & insulation	$500	$500	$500	$500	$500	
	$16,500	$20,000	$35,000	$24,000	$20,000	

notes:
1. cordwood: assumes that the fuel is stored outside and handled with existing farm bucket loader.
2. raw litter: assumes that the fuel is stored in an existing stacking shed and transported with existing farm bucket loader, then fed into a custom fuel surge storage & handling system with outfeed conveyors for feeding into the furnace.
3. raw litter and pelletized litter: ash management costs reflect the need to remove from the furnace and aggragate the relatively high volume of litter-derived ash on the farm, then have the high-nutrient-content material exported from the farm for (beneficial) use elsewhere.

Appendix 3.A: Detailed Economic Analyses of a Cordwood-fired System

Single-house furnace system calcs:		cord wood
base case key assumptions		
average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
biomass furnace fuel	cord wood	
energy content of biomass fuel, LHV	6,560	Btu/lb
biomass system energy efficiency	45%	
cost of biomass fuel (delivered to farm storage)	$63	per ton
bulk density of biomass fuel	50	lbs/cu ft
estimated capital cost, complete & installed	$16,500	
service life of furnace system	10.0	years
furnace down payment rate	20%	of capex
furnace system financing interest rate	7%	APR
current fuel cost reimbursement from integrator	-	per house per year
grant funds available to offset capital cost	0%	of total capex

Summary economics (over system service life):			cord wood
target propane displacement			
historic propane consumption =	6,000	gallons / year	
propane displaced by biomass system =	5,100	gallons / year	
starting cost of propane =	$2.20	per gallon	
value of displace propane =	$11,220	per year	
fuel consumption over life of furnace			
total biomass fuel consumption	802	tons	
total biomass fuel consumption	1,604,000	lbs	
total biomass fuel consumption	28,643	bushels	
total propane displaced	51,000	gallons	
system economics (over furnace service life)			
	entire system	per ton	
capital cost	$16,500	$20.60	
maintenance & electricity	$5,795	$7.20	
financing	$2,483	$3.10	
subtotal	$24,777	$30.90	
biomass fuel	$50,533	$63.00	
total	$75,311	$93.90	
propane savings	$122,856	$153.20	
net income (loss) to grower =	$47,545	$59.30	
resulting NPV of investment =	$34,030	$42.40	
simple payback, years =	2.4		

cash flow							cord wood
year	propane savings	capital outlay	biomass fuel	electricity	maintenance	financing	total
1	$11,220	-$3,300	-$5,053	-	-$400	-$3,137	-$670
2	$11,444		-$5,053	-	-$432	-$3,137	$2,823
3	$11,673		-$5,053	-	-$467	-$3,137	$3,017
4	$11,907		-$5,053	-	-$504	-$3,137	$3,213
5	$12,145		-$5,053	-	-$544	-$3,137	$3,411
6	$12,388		-$5,053	-	-$588	-	$6,747
7	$12,636		-$5,053	-	-$635	-	$6,947
8	$12,888		-$5,053	-	-$686	-	$7,149
9	$13,146		-$5,053	-	-$740	-	$7,352
10	$13,409		-$5,053	-	-$800	-	$7,556
11	-		-	-	-	-	-
12	-		-	-	-	-	-
13	-		-	-	-	-	-
14	-		-	-	-	-	-
15	-		-	-	-	-	-
totals:	$122,856	-$3,300	-$50,533	-	-$5,795	-$15,683	$47,545

Appendix 3.B: Detailed Economic Analyses of a Cordwood-fired System

calculations and other assumptions (in blue font)		cord wood
reductions in fuel consumption from other practices		
reduction from insulation & sealing	0%	
reduction from conversion to tunnel	0%	
reduction from dry heat (vs wet)	0%	
net estimated fuel consumption	6,000	gal/year, propane
average fuel cost	$2.20	per gal, propane
annual escalation of LP prices	2.0%	
typ annual fuel expenses	$13,200	per house/yr
target displacement of propane	5,100	gal/year, propane
propane cost savings (average over service life)	$12,286	per year
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
net energy to be displaced	473,571,000	Btu/yr
biomass fuel required (@100% efficiency)	36	tons/yr
total biomass fuel required @ design efficiency	80	tons/yr
cost of biomass fuel (delivered to farm storage)	$63	per ton
total cost of biomass fuel	$5,053	per year
subtotal annual fuel cost savings	$7,232	per year
less fuel cost reimbursement from integrator	$0	per year
net annual fuel cost savings	$7,232	per year
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	
litter export/utilization subsidy	$0	per ton
litter export/utilization subsidy	$0	per system per year
direct economic benefits from dry heat	$0	per house / yr to grower
net savings in propane from bioenergy system	$6,832	per year
equilavent value of biomass as fuel	$85.18	per ton
furnace capital cost, complete & installed	$16,500	capex
grant support (e.g., from USDA)		
amount of grant	$0	
cost of energy audit required to get grant	$300	
net furnace capital cost	$16,500	net capex
simple payback period	2.4	years
service life of furnace system	10.0	years
furnace financing: down payment rate	20%	of capex
furnace financing: down payment amount	$3,300	
amount financed	$13,200	
financing period	5	years
discount rate for NPV calcs	5%	
annual interest rate	7%	APR
monthly payments	$261	per month
annual payments	$3,137	per year

Appendix 3.C: Detailed Economic Analyses of a Cordwood-fired System

sensitivity analyses of NPV vs key variables — **cord wood**

base fuel consumption

gal/yr	
3,000	$6,490
4,000	$15,670
5,000	$24,850
6,000	$34,030
7,000	$43,220

energy value of fuel

Btu/lb	
5,500	$26,510
6,000	$30,390
6,500	$33,670
7,000	$36,490
7,500	$38,920

propane cost

per gal	
$1.00	-$17,300
$1.50	$4,090
$2.00	$25,480
$2.50	$46,870
$3.00	$68,260

propane displacement

% of historical	
75%	$27,550
80%	$30,790
85%	$34,030
90%	$37,270
95%	$40,510

capex

turnkey	
$12,500	$38,090
$14,500	$36,060
$16,500	$34,030
$18,500	$32,010
$20,500	$29,980

fuel cost

per ton	
$43	$46,420
$53	$40,230
$63	$34,030
$73	$27,840
$83	$21,650

furnace system efficiency

35%	$22,880
40%	$29,160
45%	$34,030
50%	$37,940
55%	$41,130

furnace system service life

yrs	
8	$24,650
9	$29,390
10	$34,030
11	$38,570
12	$43,010

annual maintenance

per yr	
$200	$36,200
$300	$35,120
$400	$34,030
$500	$32,950
$600	$31,860

financing duration

yrs	
3	$34,290
4	$34,160
5	$34,030
6	$33,910
7	$33,780

financing interest rate

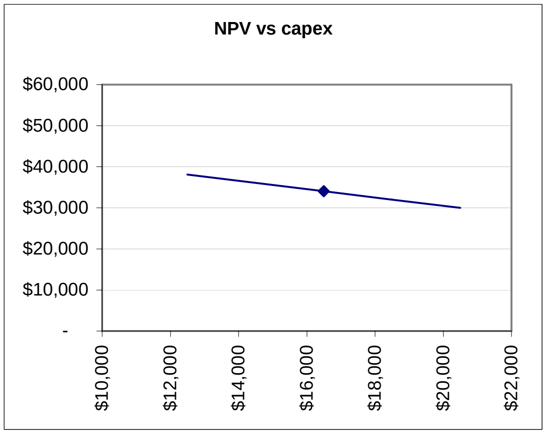
APR	
5%	$34,670
6%	$34,350
7%	$34,030
8%	$33,710
9%	$33,380

grant amount

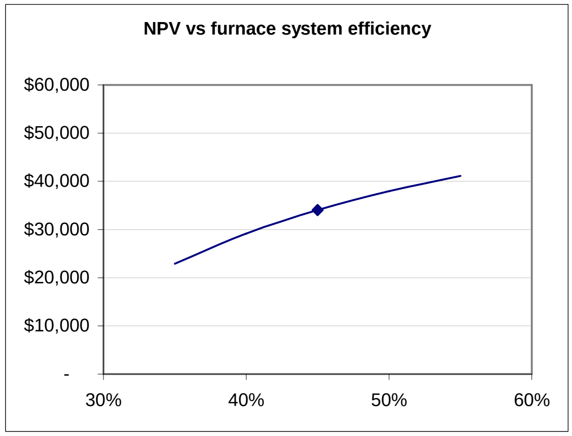
% of capex	
0%	$34,030
25%	$37,910
50%	$42,090

Appendix 3.D: Detailed Economic Analyses of a Cordwood-fired System

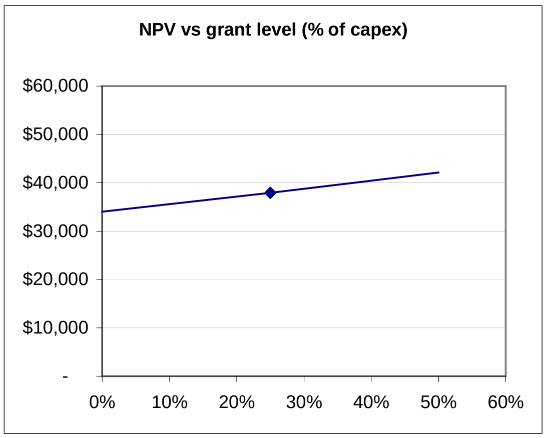
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **cord wood**



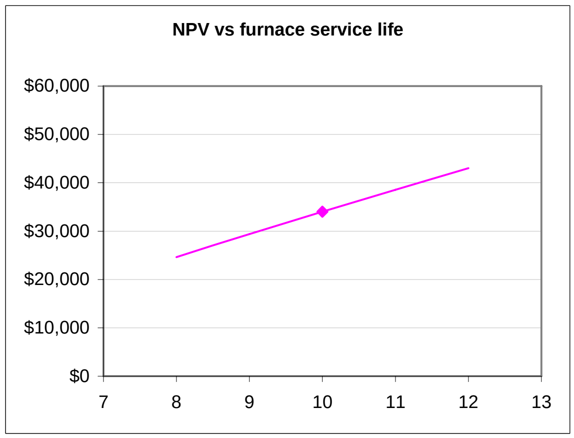
capex = $16,500



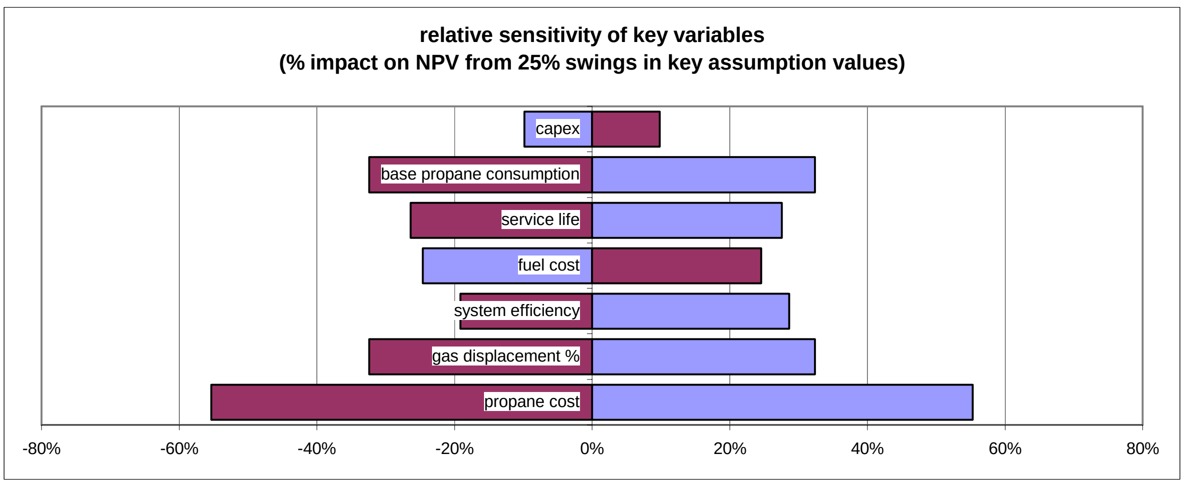
furnace system efficiency = 45%



grant level = 0%

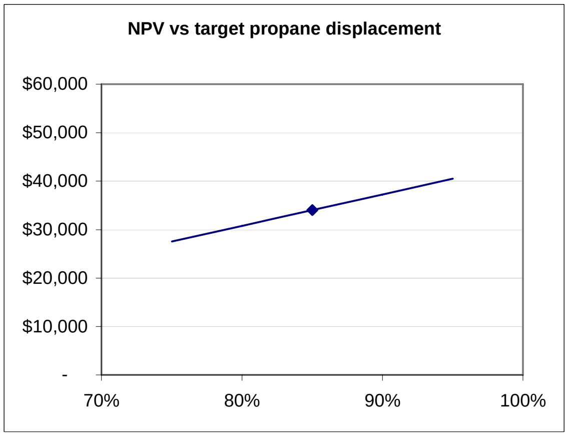


service life = 10.0 years

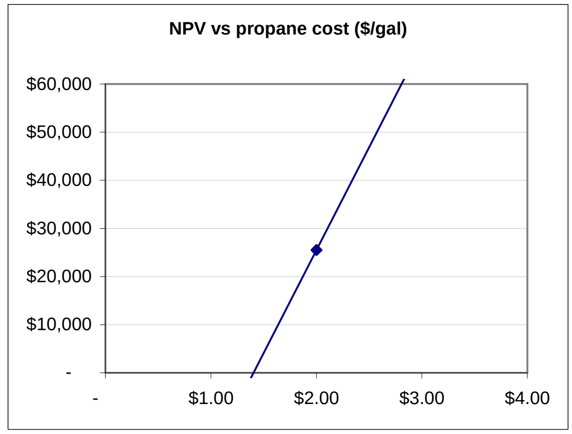


Appendix 3.E: Detailed Economic Analyses of a Cordwood-fired System

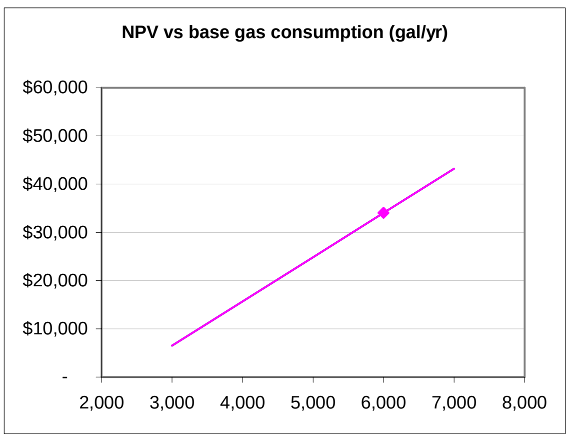
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **cord wood**



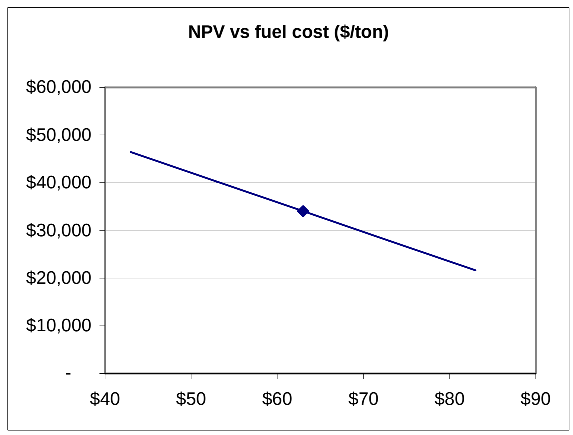
propane displacement level = 85%



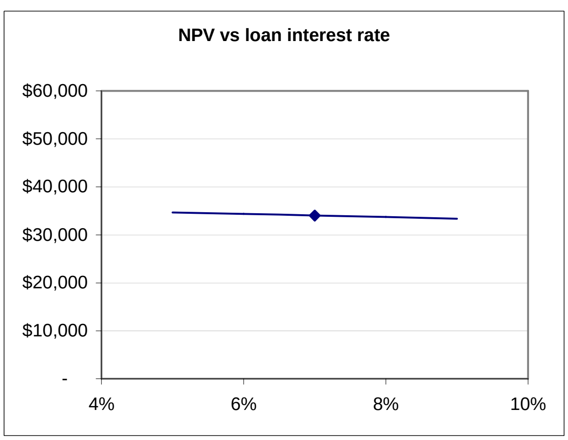
propane cost = $2.20 per gal



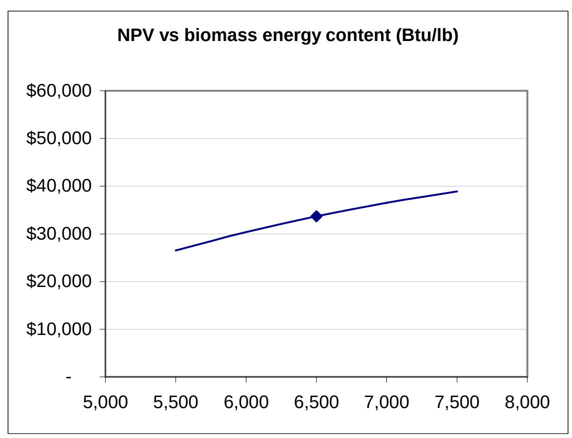
average propane consumption = 6,000 gal/yr



fuel corn cost = $63.00 per ton



loan interest rate = 7%



energy content of corn = 6,560 Btu/lb

Appendix 4.A: Detailed Economic Analyses of a Corn-fired System

Single-house furnace system calcs:		**corn**
base case key assumptions		
average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
biomass furnace fuel	corn	
energy content of biomass fuel, LHV	5,950	Btu/lb
biomass system energy efficiency	60%	
cost of biomass fuel (delivered to farm storage)	$214	per ton
bulk density of biomass fuel	45	lbs/cu ft
estimated capital cost, complete & installed	$20,000	
service life of furnace system	10.0	years
furnace down payment rate	0%	of capex
furnace system financing interest rate	7%	APR
current fuel cost reimbursement from integrator	-	per house per year
grant funds available to offset capital cost	0%	of total capex

Summary economics (over system service life):		**corn**
target propane displacement		
historic propane consumption =	6,000	gallons / year
propane displaced by biomass system =	5,100	gallons / year
starting cost of propane =	$2.20	per gallon
value of displace propane =	$11,220	per year
fuel consumption over life of furnace		
total biomass fuel consumption	663	tons
total biomass fuel consumption	1,326,000	lbs
total biomass fuel consumption	23,679	bushels
total propane displaced	51,000	gallons

system economics (over furnace service life)

	entire system	per ton
capital cost	$20,000	$30.20
maintenance & electricity	$5,795	$8.70
financing	$3,761	$5.70
subtotal	$29,556	$44.60
biomass fuel	$141,939	$214.10
total	$171,495	$258.70
propane savings	$122,856	$185.30
net income (loss) to grower =	-$48,639	-$73.40
resulting NPV of investment =	-$40,400	-$60.90
simple payback, years =	n/a	

cash flow — **corn**

year	propane savings	capital outlay	biomass fuel	electricity	maintenance	financing	total
1	$11,220	-	-$14,194	-	-$400	-$4,752	-$8,126
2	$11,444		-$14,194	-	-$432	-$4,752	-$7,934
3	$11,673		-$14,194	-	-$467	-$4,752	-$7,739
4	$11,907		-$14,194	-	-$504	-$4,752	-$7,543
5	$12,145		-$14,194	-	-$544	-$4,752	-$7,345
6	$12,388		-$14,194	-	-$588	-	-$2,394
7	$12,636		-$14,194	-	-$635	-	-$2,193
8	$12,888		-$14,194	-	-$686	-	-$1,991
9	$13,146		-$14,194	-	-$740	-	-$1,788
10	$13,409		-$14,194	-	-$800	-	-$1,585
11	-		-	-	-	-	-
12	-		-	-	-	-	-
13	-		-	-	-	-	-
14	-		-	-	-	-	-
15	-		-	-	-	-	-
totals:	$122,856	-	-$141,939	-	-$5,795	-$23,761	-$48,639

Appendix 4.B: Detailed Economic Analyses of a Corn-fired System

calculations and other assumptions (in blue font)		corn
reductions in fuel consumption from other practices		
reduction from insulation & sealing	0%	
reduction from conversion to tunnel	0%	
reduction from dry heat (vs wet)	0%	
net estimated fuel consumption	6,000	gal/year, propane
average fuel cost	$2.20	per gal, propane
annual escalation of LP prices above CPI	2.0%	
typ annual fuel expenses	$13,200	per house/yr
target displacement of propane	5,100	gal/year, propane
propane cost savings (average over service life)	$12,286	per year
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
net energy to be displaced	473,571,000	Btu/yr
biomass fuel required (@100% efficiency)	40	tons/yr
total biomass fuel required @ design efficiency	66	tons/yr
cost of biomass fuel (delivered to farm storage)	$214	per ton
total cost of biomass fuel	$14,194	per year
subtotal annual fuel cost savings	-$1,908	per year
less fuel cost reimbursement from integrator	$0	per year
net annual fuel cost savings	-$1,908	per year
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	
litter export/utilization subsidy	$0	per ton
litter export/utilization subsidy	$0	per system per year
direct economic benefits from dry heat	$0	per house / yr to grower
net savings in propane from bioenergy system	-$2,308	per year
equilavent value of biomass as fuel	-$34.80	per ton
furnace capital cost, complete & installed	$20,000	capex
grant support (e.g., from USDA)		
amount of grant	$0	
cost of energy audit required to get grant	$300	
net furnace capital cost	$20,000	net capex
simple payback period	n/a	years
service life of furnace system	10.0	years
furnace financing: down payment rate	0%	of capex
furnace financing: down payment amount	$0	
amount financed	$20,000	
financing period	5	years
discount rate for NPV calcs	5%	
annual interest rate	7%	APR
monthly payments	$396	per month
annual payments	$4,752	per year

Appendix 4.C: Detailed Economic Analyses of a Corn-fired System

sensitivity analyses of NPV vs key variables — **corn**

base fuel consumption

gal/yr	-$40,400
3,000	-$32,660
4,000	-$35,240
5,000	-$37,820
6,000	-$40,400
7,000	-$42,980

energy value of fuel

Btu/lb	-$40,400
5,000	-$61,220
5,500	-$49,370
6,000	-$39,490
6,500	-$31,130
7,000	-$23,960

propane cost

per gal	-$40,400
$1.50	-$70,350
$2.00	-$48,960
$2.50	-$27,570
$3.00	-$6,180
$3.50	$15,210

propane displacement

% of historical	-$40,400
75%	-$38,580
80%	-$39,490
85%	-$40,400
90%	-$41,310
95%	-$42,220

capex

turnkey	-$40,400
$16,000	-$36,290
$18,000	-$38,340
$20,000	-$40,400
$22,000	-$42,460
$24,000	-$44,520

fuel cost

per ton	-$40,400
$107	$14,400
$143	-$4,040
$179	-$22,470
$215	-$40,910
$251	-$59,350

furnace system efficiency

	-$40,400
50%	-$62,320
55%	-$50,360
60%	-$40,400
65%	-$31,970
70%	-$24,740

furnace system service life

yrs	-$40,400
8	-$38,270
9	-$39,430
10	-$40,400
11	-$41,210
12	-$41,860

annual maintenance

per yr	-$40,400
$200	-$38,230
$300	-$39,320
$400	-$40,400
$500	-$41,480
$600	-$42,570

financing duration

yrs	-$40,400
3	-$40,010
4	-$40,200
5	-$40,400
6	-$40,590
7	-$40,780

financing interest rate

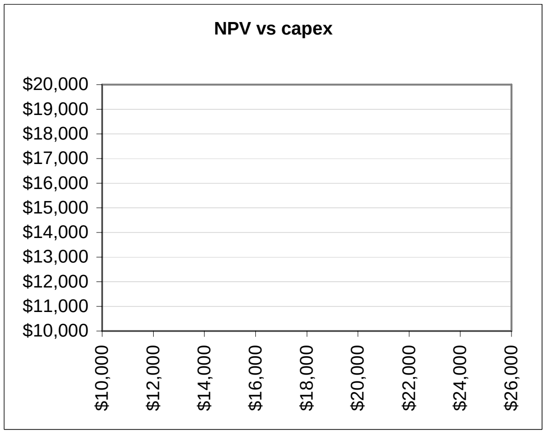
APR	-$40,400
5%	-$39,430
6%	-$39,910
7%	-$40,400
8%	-$40,890
9%	-$41,390

grant amount

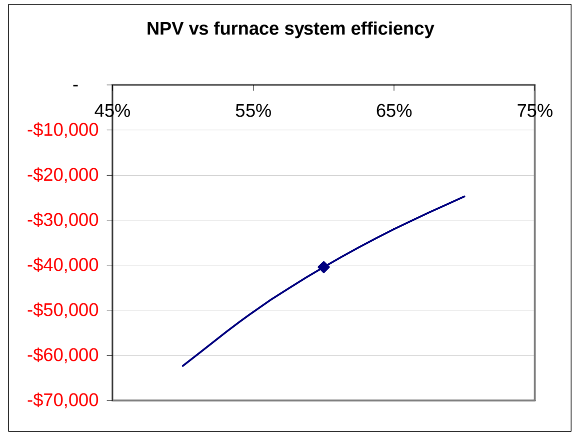
% of capex	-$40,400
0%	-$40,400
25%	-$35,570
50%	-$30,420

Appendix 4.D: Detailed Economic Analyses of a Corn-fired System

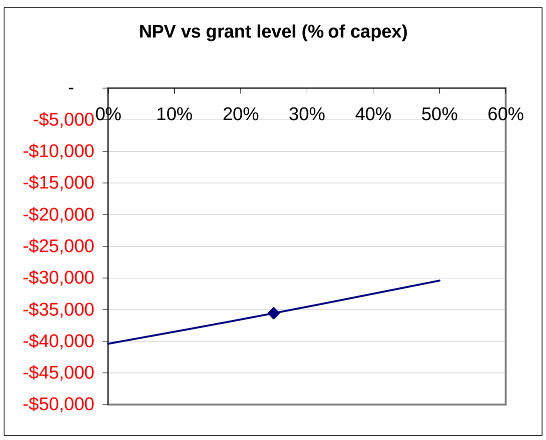
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **corn**



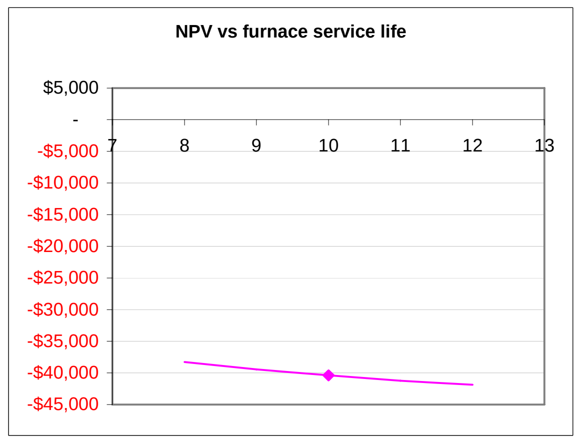
capex = $20,000



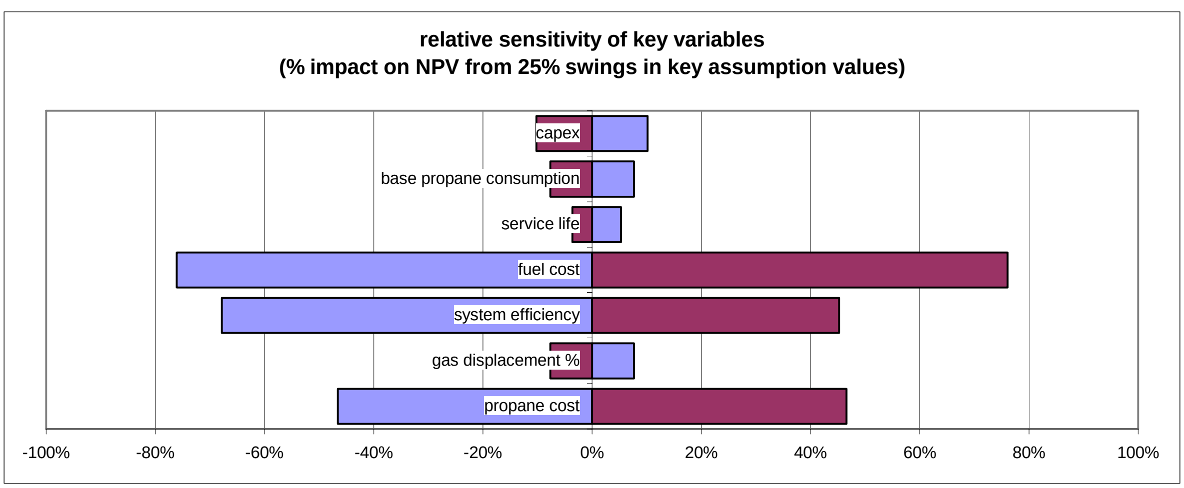
furnace system efficiency = 60%



grant level = 0%

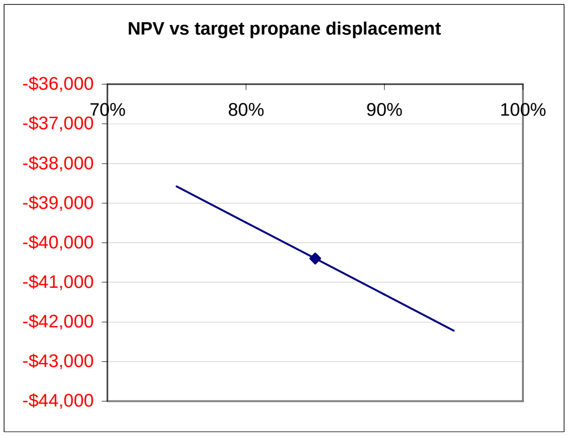


service life = 10.0 years

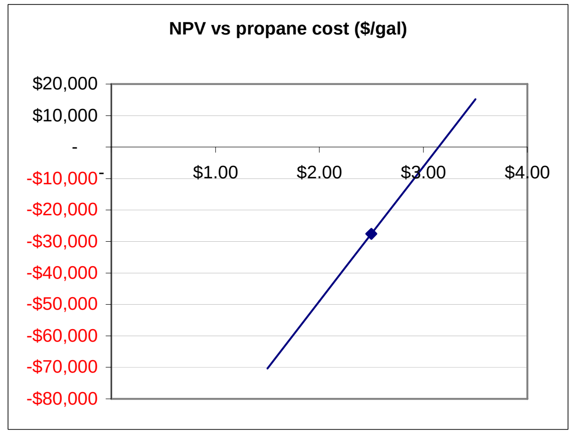


Appendix 4.E: Detailed Economic Analyses of a Corn-fired System

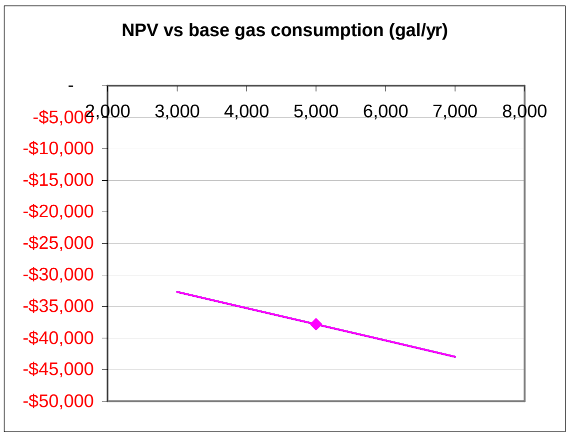
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **corn**



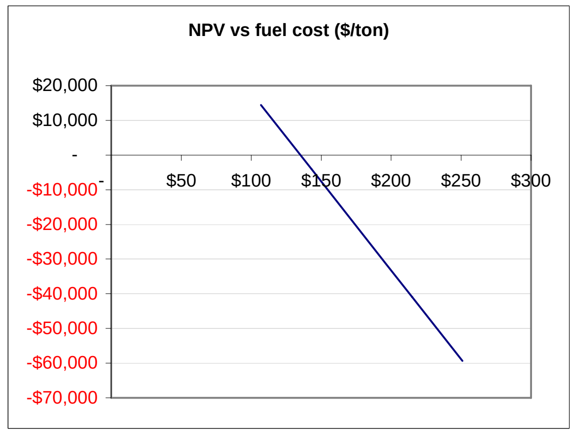
propane displacement level = 85%



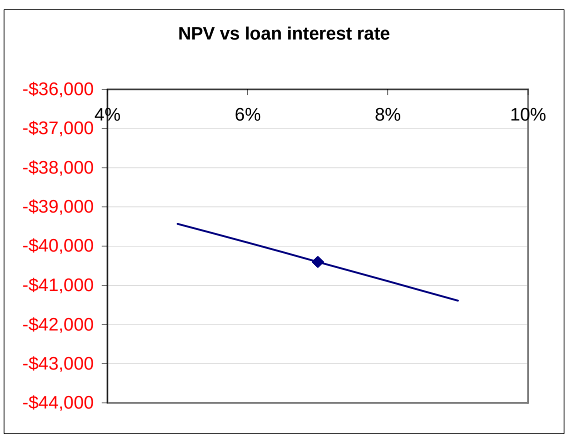
propane cost = $2.20 per gal



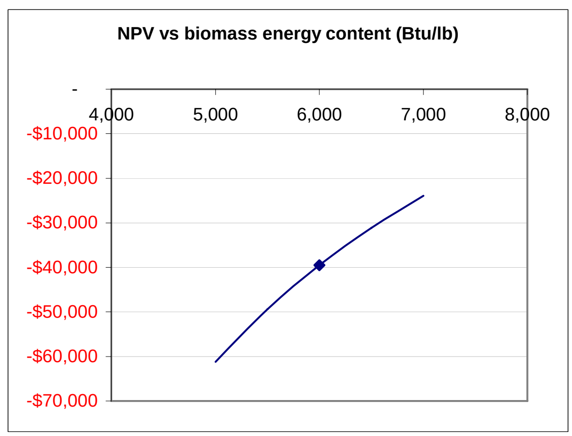
average propane consumption = 6,000 gal/yr



fuel corn cost = $214.00 per ton



loan interest rate = 7%



energy content of corn = 5,950 Btu/lb

Appendix 5.A: Detailed Economic Analyses of a Raw Litter-fired System

Single-house furnace system calcs:		raw litter
base case key assumptions		
average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
biomass furnace fuel	raw litter	
energy content of biomass fuel, LHV	4,100	Btu/lb
biomass system energy efficiency	50%	
cost of biomass fuel (delivered to farm storage)	$20	per ton
bulk density of biomass fuel	25	lbs/cu ft
estimated capital cost, complete & installed	$35,000	
service life of furnace system	10.0	years
furnace down payment rate	20%	of capex
furnace system financing interest rate	7%	APR
current fuel cost reimbursement from integrator	-	per house per year
grant funds available to offset capital cost	0%	of total capex

Summary economics (over system service life):			raw litter
target propane displacement			
historic propane consumption =	6,000	gallons / year	
propane displaced by biomass system =	5,100	gallons / year	
starting cost of propane =	$2.20	per gallon	
value of displace propane =	$11,220	per year	
fuel consumption over life of furnace			
total biomass fuel consumption	1,155	tons	
total biomass fuel consumption	2,310,000	lbs	
total biomass fuel consumption	41,250	bushels	
total propane displaced	51,000	gallons	
system economics (over furnace service life)			
	entire system	per ton	
capital cost	$35,000	$30.30	
maintenance & electricity	$5,795	$5.00	
financing	$5,266	$4.60	
subtotal	$46,061	$39.90	
biomass fuel	$23,101	$20.00	
total	$69,162	$59.90	
propane savings	$122,856	$106.40	
net income (loss) to grower =	$53,694	$46.50	
resulting NPV of investment =	$36,470	$31.60	
simple payback, years =	3.7		

cash flow — raw litter

year	propane savings	capital outlay	biomass fuel	electricity	maintenance	financing	total
1	$11,220	-$7,000	-$2,310	-	-$400	-$6,653	-$5,143
2	$11,444		-$2,310	-	-$432	-$6,653	$2,049
3	$11,673		-$2,310	-	-$467	-$6,653	$2,243
4	$11,907		-$2,310	-	-$504	-$6,653	$2,440
5	$12,145		-$2,310	-	-$544	-$6,653	$2,637
6	$12,388		-$2,310	-	-$588	-	$9,490
7	$12,636		-$2,310	-	-$635	-	$9,691
8	$12,888		-$2,310	-	-$686	-	$9,893
9	$13,146		-$2,310	-	-$740	-	$10,096
10	$13,409		-$2,310	-	-$800	-	$10,299
11	-		-	-	-	-	-
12	-		-	-	-	-	-
13	-		-	-	-	-	-
14	-		-	-	-	-	-
15	-		-	-	-	-	-
totals:	$122,856	-$7,000	-$23,101	-	-$5,795	-$33,266	$53,694

Appendix 5.B: Detailed Economic Analyses of a Raw Litter-fired System

calculations and other assumptions (in blue font)		raw litter
reductions in fuel consumption from other practices		
reduction from insulation & sealing	0%	
reduction from conversion to tunnel	0%	
reduction from dry heat (vs wet)	0%	
net estimated fuel consumption	6,000	gal/year, propane
average fuel cost	$2.20	per gal, propane
annual escalation of LP prices above CPI	2.0%	
typ annual fuel expenses	$13,200	per house/yr
target displacement of propane	5,100	gal/year, propane
propane cost savings (average over service life)	$12,286	per year
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
net energy to be displaced	473,571,000	Btu/yr
biomass fuel required (@100% efficiency)	58	tons/yr
total biomass fuel required @ design efficiency	116	tons/yr
cost of biomass fuel (delivered to farm storage)	$20	per ton
total cost of biomass fuel	$2,310	per year
subtotal annual fuel cost savings	$9,975	per year
less fuel cost reimbursement from integrator	$0	per year
net annual fuel cost savings	$9,975	per year
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	
litter export/utilization subsidy	$0	per ton
litter export/utilization subsidy	$0	per system per year
direct economic benefits from dry heat	$0	per house / yr to grower
net savings in propane from bioenergy system	$9,575	per year
equilavent value of biomass as fuel	$82.90	per ton
furnace capital cost, complete & installed	$35,000	capex
grant support (e.g., from USDA)		
amount of grant	$0	
cost of energy audit required to get grant	$300	
net furnace capital cost	$35,000	net capex
simple payback period	3.7	years
service life of furnace system	10.0	years
furnace financing: down payment rate	20%	of capex
furnace financing: down payment amount	$7,000	
amount financed	$28,000	
financing period	5	years
discount rate for NPV calcs	5%	
annual interest rate	7%	APR
monthly payments	$554	per month
annual payments	$6,653	per year

Appendix 5.C: Detailed Economic Analyses of a Raw Litter-fired System

sensitivity analyses of NPV vs key variables — **raw litter**

base fuel consumption

gal/yr	
3,000	-$1,670
4,000	$11,040
5,000	$23,750
6,000	$36,470
7,000	$49,180

energy value of fuel

Btu/lb	
3,000	$29,930
3,500	$33,410
4,000	$36,020
4,500	$38,050
5,000	$39,680

propane cost

per gal	
$1.00	-$14,870
$1.50	$6,520
$2.00	$27,910
$2.50	$49,300
$3.00	$70,690

propane displacement

% of historical	
75%	$27,490
80%	$31,980
85%	$36,470
90%	$40,950
95%	$45,440

capex

turnkey	
$28,000	$43,560
$30,000	$41,530
$32,000	$39,510
$34,000	$37,480
$36,000	$35,450

fuel cost

per ton	
$10	$45,390
$15	$40,930
$20	$36,470
$25	$32,010
$30	$27,550

furnace system efficiency

40%	$32,010
45%	$34,480
50%	$36,470
55%	$38,090
60%	$39,440

furnace system service life

yrs	
8	$23,640
9	$30,140
10	$36,470
11	$42,610
12	$48,570

annual maintenance

per yr	
$200	$38,640
$300	$37,550
$400	$36,470
$500	$35,380
$600	$34,300

financing duration

yrs	
3	$37,020
4	$36,740
5	$36,470
6	$36,200
7	$35,930

financing interest rate

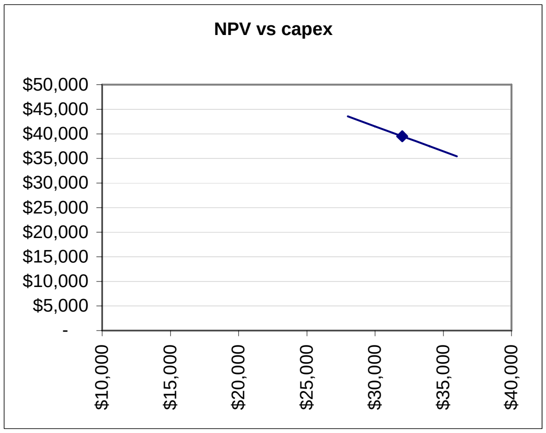
APR	
3%	$39,130
4%	$38,480
5%	$37,820
6%	$37,150
7%	$36,470

grant amount

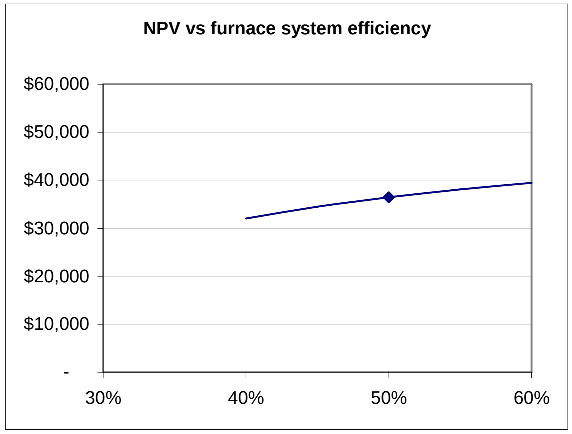
% of capex	
0%	$36,470
25%	$45,030
50%	$53,900

Appendix 5.D: Detailed Economic Analyses of a Raw Litter-fired System

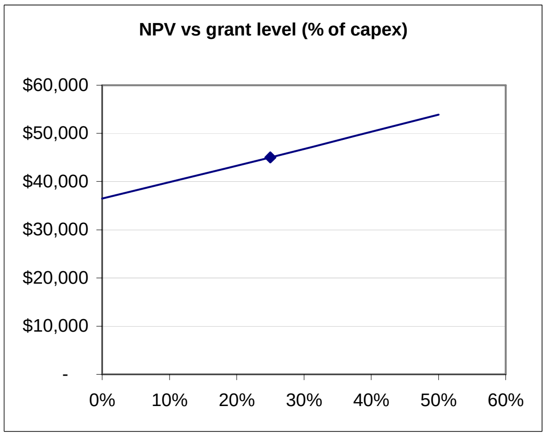
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **raw litter**



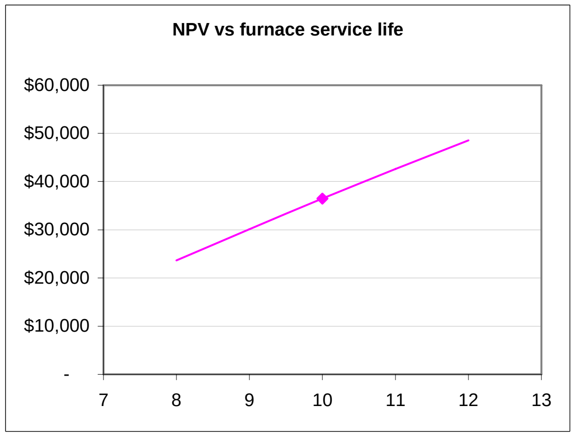
capex = $35,000



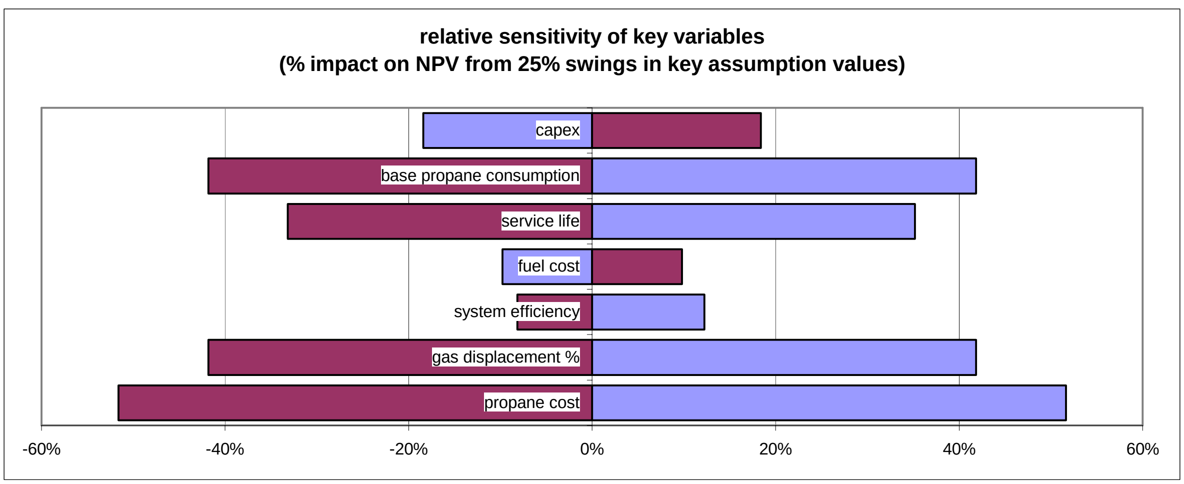
furnace system efficiency = 50%



grant level = 0%

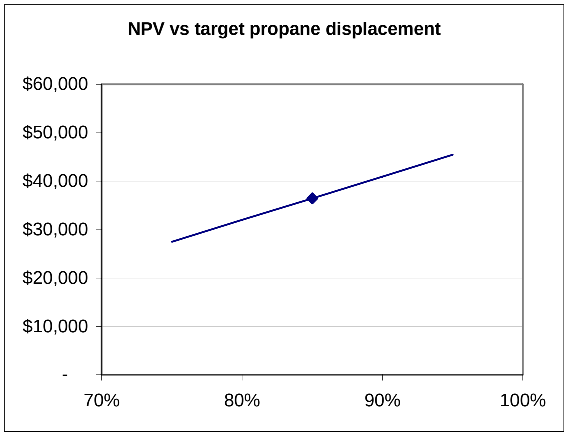


service life = 10.0 years

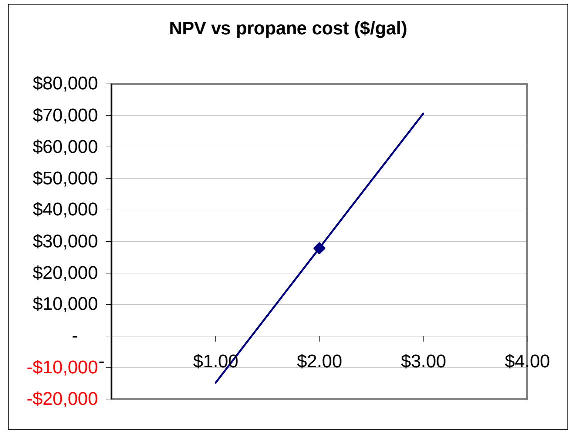


Appendix 5.E: Detailed Economic Analyses of a Raw Litter-fired System

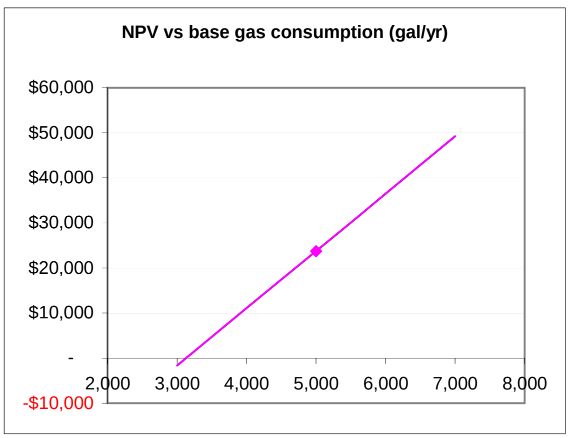
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **raw litter**



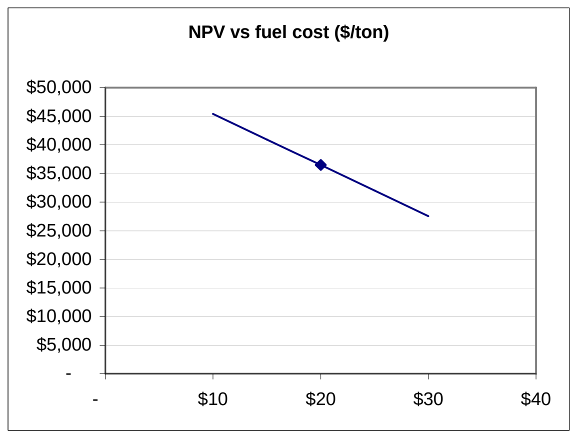
propane displacement level = 85%



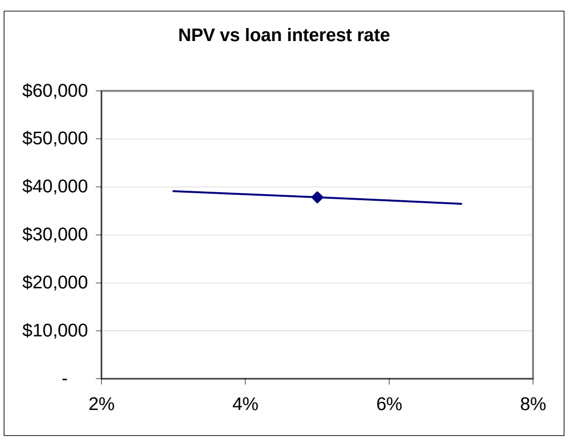
propane cost = $2.20 per gal



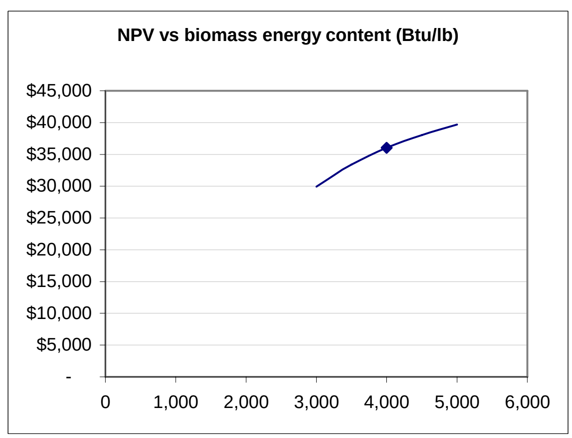
average propane consumption = 6,000 gal/yr



fuel corn cost = $20.00 per ton



loan interest rate = 7%



energy content of corn = 4,100 Btu/lb

Appendix 6.A: Detailed Economic Analyses of a Pelletized Litter-fired System

Single-house furnace system calcs:		pelletized litter
base case key assumptions		
average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
biomass furnace fuel	pelletized litter	
energy content of biomass fuel, LHV	4,860	Btu/lb
biomass system energy efficiency	60%	
cost of biomass fuel (delivered to farm storage)	$200	per ton
bulk density of biomass fuel	40	lbs/cu ft
estimated capital cost, complete & installed	$20,000	
service life of furnace system	10.0	years
furnace down payment rate	20%	of capex
furnace system financing interest rate	7%	APR
current fuel cost reimbursement from integrator	-	per house per year
grant funds available to offset capital cost	0%	of total capex

Summary economics (over system service life):			pelletized litter
target propane displacement			
historic propane consumption =	6,000	gallons / year	
propane displaced by biomass system =	5,100	gallons / year	
starting cost of propane =	$2.20	per gallon	
value of displace propane =	$11,220	per year	
fuel consumption over life of furnace			
total biomass fuel consumption	812	tons	
total biomass fuel consumption	1,624,000	lbs	
total biomass fuel consumption	29,000	bushels	
total propane displaced	51,000	gallons	
system economics (over furnace service life)			
	entire system	per ton	
capital cost	$20,000	$24.60	
maintenance & electricity	$5,795	$7.10	
financing	$3,009	$3.70	
subtotal	$28,804	$35.50	
biomass fuel	$162,404	$200.00	
total	$191,208	$235.50	
propane savings	$122,856	$151.30	
net income (loss) to grower =	-$68,352	-$84.20	
resulting NPV of investment =	-$55,900	-$68.80	
simple payback, years =	n/a		

cash flow							pelletized litter
year	propane savings	capital outlay	biomass fuel	electricity	maintenance	financing	total
1	$11,220	-$4,000	-$16,240	-	-$400	-$3,802	-$13,222
2	$11,444		-$16,240	-	-$432	-$3,802	-$9,030
3	$11,673		-$16,240	-	-$467	-$3,802	-$8,836
4	$11,907		-$16,240	-	-$504	-$3,802	-$8,639
5	$12,145		-$16,240	-	-$544	-$3,802	-$8,442
6	$12,388		-$16,240	-	-$588	-	-$4,440
7	$12,636		-$16,240	-	-$635	-	-$4,240
8	$12,888		-$16,240	-	-$686	-	-$4,038
9	$13,146		-$16,240	-	-$740	-	-$3,835
10	$13,409		-$16,240	-	-$800	-	-$3,631
11	-		-	-	-	-	-
12	-		-	-	-	-	-
13	-		-	-	-	-	-
14	-		-	-	-	-	-
15	-		-	-	-	-	-
totals:	$122,856	-$4,000	-$162,404	-	-$5,795	-$19,009	-$68,352

Appendix 6.B: Detailed Economic Analyses of a Pelletized Litter-fired System

calculations and other assumptions (in blue font)		pelletized litter
reductions in fuel consumption from other practices		
reduction from insulation & sealing	0%	
reduction from conversion to tunnel	0%	
reduction from dry heat (vs wet)	0%	
net estimated fuel consumption	6,000	gal/year, propane
average fuel cost	$2.20	per gal, propane
annual escalation of LP prices above CPI	2.0%	
typ annual fuel expenses	$13,200	per house/yr
target displacement of propane	5,100	gal/year, propane
propane cost savings (average over service life)	$12,286	per year
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
net energy to be displaced	473,571,000	Btu/yr
biomass fuel required (@100% efficiency)	49	tons/yr
total biomass fuel required @ design efficiency	81	tons/yr
cost of biomass fuel (delivered to farm storage)	$200	per ton
total cost of biomass fuel	$16,240	per year
subtotal annual fuel cost savings	-$3,955	per year
less fuel cost reimbursement from integrator	$0	per year
net annual fuel cost savings	-$3,955	per year
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	
litter export/utilization subsidy	$0	per ton
litter export/utilization subsidy	$0	per system per year
direct economic benefits from dry heat	$0	per house / yr to grower
net savings in propane from bioenergy system	-$4,355	per year
equilavent value of biomass as fuel	-$53.63	per ton
furnace capital cost, complete & installed	$20,000	capex
grant support (e.g., from USDA)		
amount of grant	$0	
cost of energy audit required to get grant	$300	
net furnace capital cost	$20,000	net capex
simple payback period	n/a	years
service life of furnace system	10.0	years
furnace financing: down payment rate	20%	of capex
furnace financing: down payment amount	$4,000	
amount financed	$16,000	
financing period	5	years
discount rate for NPV calcs	5%	
annual interest rate	7%	APR
monthly payments	$317	per month
annual payments	$3,802	per year

Appendix 6.C: Detailed Economic Analyses of a Pelletized Litter-fired System

sensitivity analyses of NPV vs key variables — **pelletized litter**

base fuel consumption

gal/yr	-$55,900
3,000	-$40,250
4,000	-$45,470
5,000	-$50,680
6,000	-$55,900
7,000	-$61,110

energy value of fuel

Btu/lb	-$55,900
4,000	-$82,860
4,500	-$65,930
5,000	-$52,390
5,500	-$41,310
6,000	-$32,070

propane cost

per gal	-$55,900
$1.00	-$107,230
$1.50	-$85,840
$2.00	-$64,450
$2.50	-$43,060
$3.00	-$21,670

propane displacement

% of historical	-$55,900
75%	-$52,220
80%	-$54,060
85%	-$55,900
90%	-$57,740
95%	-$59,580

capex

turnkey	-$55,900
$16,000	-$51,840
$18,000	-$53,870
$20,000	-$55,900
$22,000	-$57,920
$24,000	-$59,950

fuel cost

per ton	-$55,900
$180	-$43,360
$190	-$49,630
$200	-$55,900
$210	-$62,170
$220	-$68,440

furnace system efficiency

	-$55,900
50%	-$80,980
55%	-$67,300
60%	-$55,900
65%	-$46,250
70%	-$37,980

furnace system service life

yrs	-$55,900
8	-$51,200
9	-$53,670
10	-$55,900
11	-$57,900
12	-$59,700

annual maintenance

per yr	-$55,900
$200	-$53,730
$300	-$54,810
$400	-$55,900
$500	-$56,980
$600	-$58,070

financing duration

yrs	-$55,900
3	-$55,580
4	-$55,740
5	-$55,900
6	-$56,050
7	-$56,210

financing interest rate

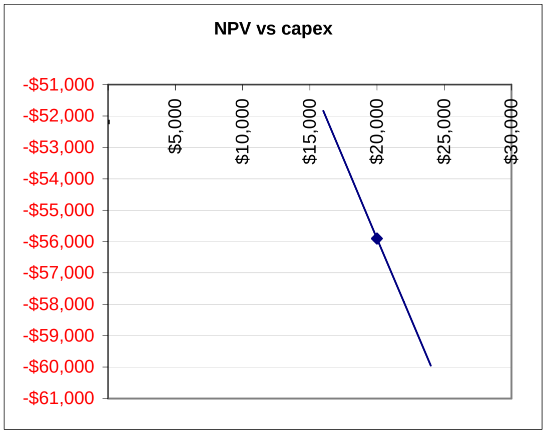
APR	-$55,900
5%	-$55,120
6%	-$55,510
7%	-$55,900
8%	-$56,290
9%	-$56,690

grant amount

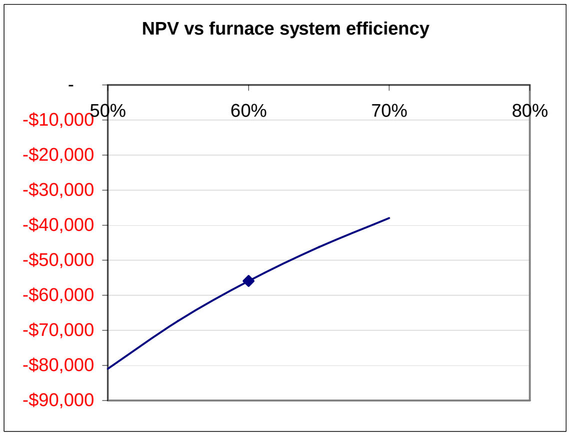
% of capex	-$55,900
0%	-$55,900
25%	-$51,130
50%	-$46,070

Appendix 6.D: Detailed Economic Analyses of a Pelletized Litter-fired System

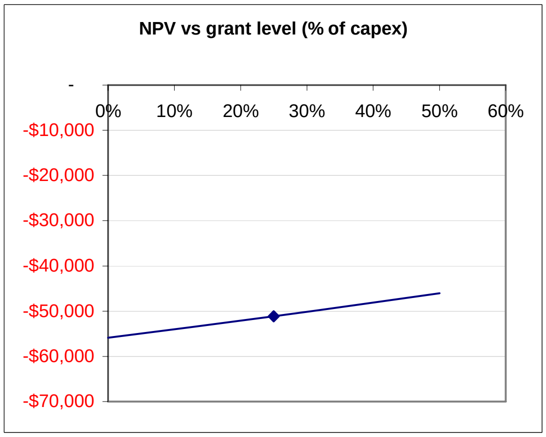
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **pelletized litter**



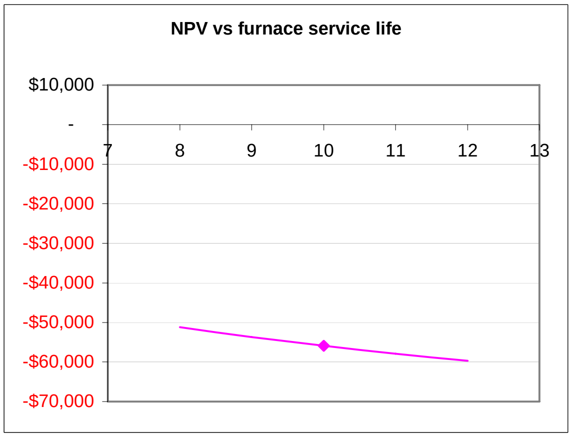
capex = $20,000



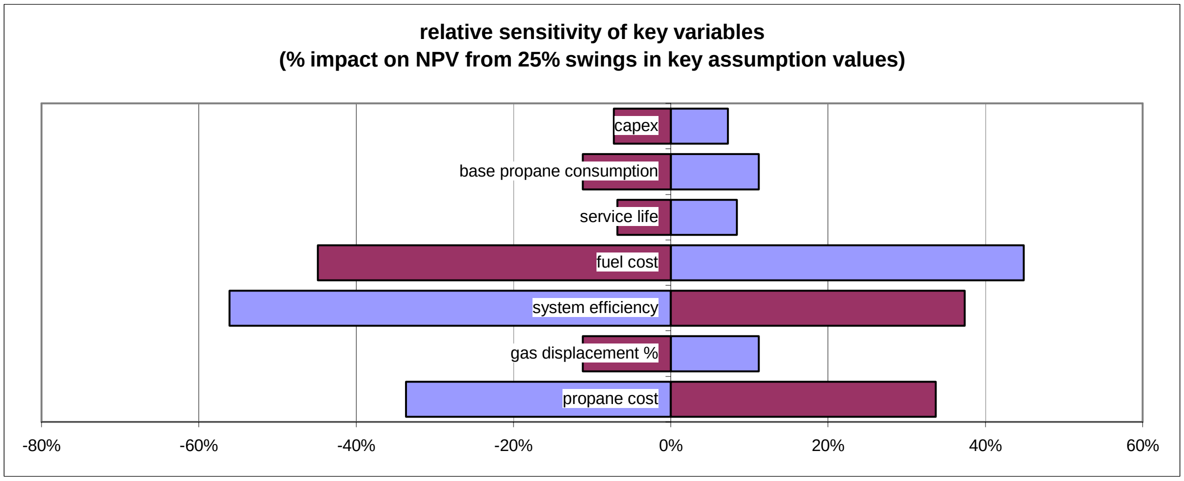
furnace system efficiency = 60%



grant level = 0%

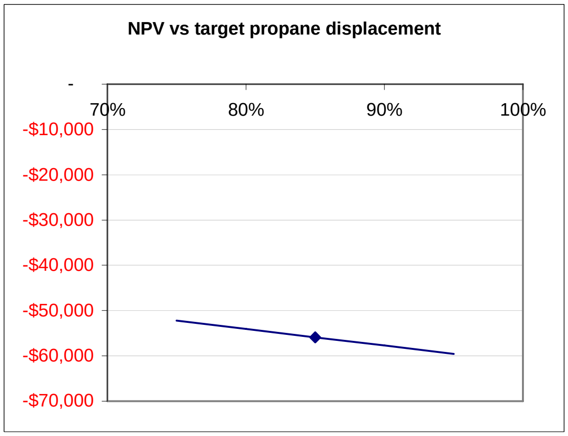


service life = 10.0 years

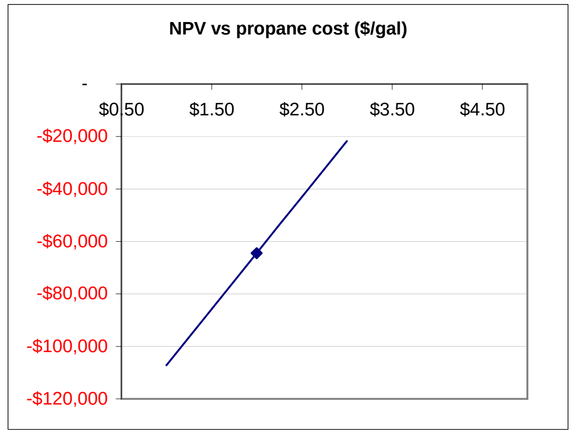


Appendix 6.E: Detailed Economic Analyses of a Pelletized Litter-fired System

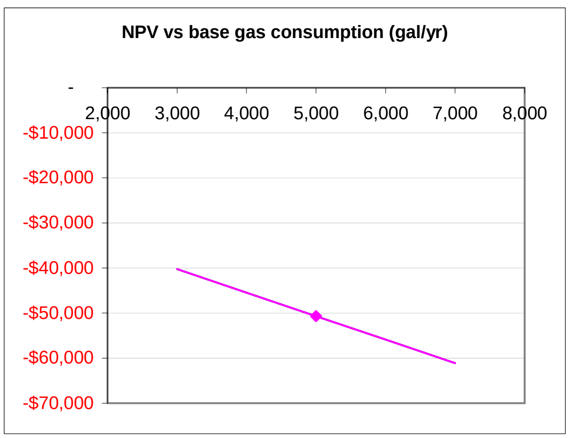
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **pelletized litter**



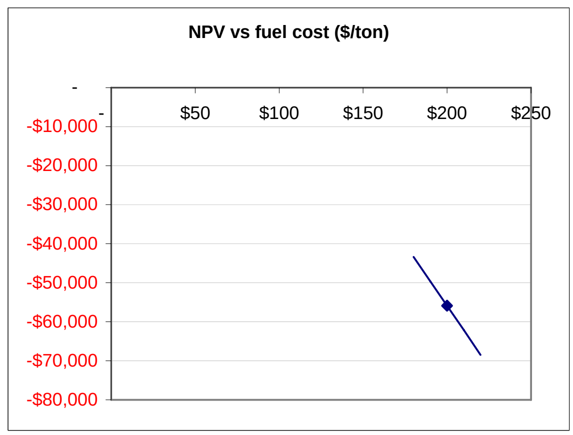
propane displacement level = 85%



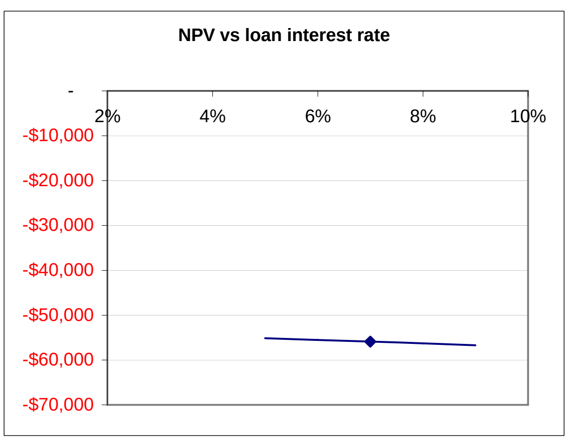
propane cost = $2.20 per gal



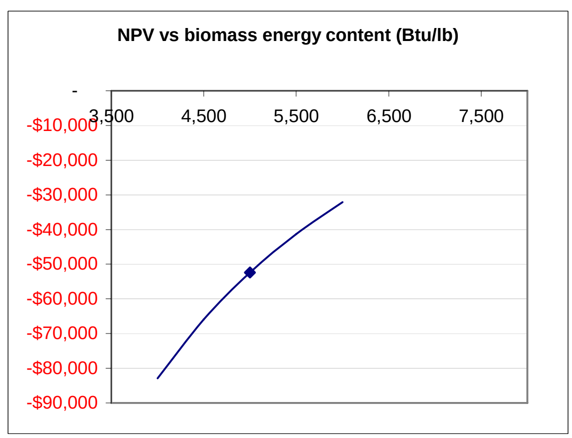
average propane consumption = 6,000 gal/yr



fuel corn cost = $200.00 per ton



loan interest rate = 7%



energy content of corn = 4,860 Btu/lb

Appendix 7.A: Detailed Economic Analyses of a Wood Pellet-fired System

Single-house furnace system calcs:		**wood pellets**
base case key assumptions		
average fuel consumption of propane	6,000	gal/year, propane
average propane cost	$2.20	per gallon
target displacement level of propane	85%	of annual consuption
biomass furnace fuel	wood pellets	
energy content of biomass fuel, LHV	7,644	Btu/lb
biomass system energy efficiency	70%	
cost of biomass fuel (delivered to farm storage)	$160	per ton
bulk density of biomass fuel	44	lbs/cu ft
estimated capital cost, complete & installed	$20,000	
service life of furnace system	10.0	years
furnace down payment rate	20%	of capex
furnace system financing interest rate	7%	APR
current fuel cost reimbursement from integrator	-	per house per year
grant funds available to offset capital cost	0%	of total capex

Summary economics (over system service life):			**wood pellets**
target propane displacement			
historic propane consumption =	6,000	gallons / year	
propane displaced by biomass system =	5,100	gallons / year	
starting cost of propane =	$2.20	per gallon	
value of displace propane =	$11,220	per year	
fuel consumption over life of furnace			
total biomass fuel consumption	443	tons	
total biomass fuel consumption	886,000	lbs	
total biomass fuel consumption	15,821	bushels	
total propane displaced	51,000	gallons	
system economics (over furnace service life)			
	entire system	per ton	
capital cost	$20,000	$45.10	
maintenance & electricity	$5,795	$13.10	
financing	$3,009	$6.80	
subtotal	$28,804	$65.00	
biomass fuel	$70,804	$159.80	
total	$99,608	$224.80	
propane savings	$122,856	$277.30	
net income (loss) to grower =	$23,248	$52.50	
resulting NPV of investment =	$14,830	$33.50	
simple payback, years =	4.2		

cash flow							**wood pellets**
year	propane savings	capital outlay	biomass fuel	electricity	maintenance	financing	total
1	$11,220	-$4,000	-$7,080	-	-$400	-$3,802	-$4,062
2	$11,444		-$7,080	-	-$432	-$3,802	$130
3	$11,673		-$7,080	-	-$467	-$3,802	$325
4	$11,907		-$7,080	-	-$504	-$3,802	$521
5	$12,145		-$7,080	-	-$544	-$3,802	$718
6	$12,388		-$7,080	-	-$588	-	$4,720
7	$12,636		-$7,080	-	-$635	-	$4,920
8	$12,888		-$7,080	-	-$686	-	$5,122
9	$13,146		-$7,080	-	-$740	-	$5,325
10	$13,409		-$7,080	-	-$800	-	$5,529
11	-		-	-	-	-	-
12	-		-	-	-	-	-
13	-		-	-	-	-	-
14	-		-	-	-	-	-
15	-		-	-	-	-	-
totals:	$122,856	-$4,000	-$70,804	-	-$5,795	-$19,009	$23,248

Appendix 7.B: Detailed Economic Analyses of a Wood Pellet-fired System

calculations and other assumptions (in blue font)		wood pellets
reductions in fuel consumption from other practices		
reduction from insulation & sealing	0%	
reduction from conversion to tunnel	0%	
reduction from dry heat (vs wet)	0%	
net estimated fuel consumption	6,000	gal/year, propane
average fuel cost	$2.20	per gal, propane
annual escalation of LP prices above CPI	2.0%	
typ annual fuel expenses	$13,200	per house/yr
target displacement of propane	5,100	gal/year, propane
propane cost savings (average over service life)	$12,286	per year
energy content of propane	91,000	Btu/gal
propane system efficiency	98%	
net energy to be displaced	473,571,000	Btu/yr
biomass fuel required (@100% efficiency)	31	tons/yr
total biomass fuel required @ design efficiency	44	tons/yr
cost of biomass fuel (delivered to farm storage)	$160	per ton
total cost of biomass fuel	$7,080	per year
subtotal annual fuel cost savings	$5,205	per year
less fuel cost reimbursement from integrator	$0	per year
net annual fuel cost savings	$5,205	per year
electricity costs for furnace system fans	$0	per year
average annual maintenance costs - furnace	$400	per year
annual maintance increase factor	8.0%	
litter export/utilization subsidy	$0	per ton
litter export/utilization subsidy	$0	per system per year
direct economic benefits from dry heat	$0	per house / yr to grower
net savings in propane from bioenergy system	$4,805	per year
equilavent value of biomass as fuel	$108.59	per ton
furnace capital cost, complete & installed	$20,000	capex
grant support (e.g., from USDA)		
amount of grant	$0	
cost of energy audit required to get grant	$300	
net furnace capital cost	$20,000	net capex
simple payback period	4.2	years
service life of furnace system	10.0	years
furnace financing: down payment rate	20%	of capex
furnace financing: down payment amount	$4,000	
amount financed	$16,000	
financing period	5	years
discount rate for NPV calcs	5%	
annual interest rate	7%	APR
monthly payments	$317	per month
annual payments	$3,802	per year

Appendix 7.C: Detailed Economic Analyses of a Wood Pellet-fired System

sensitivity analyses of NPV vs key variables — **wood pellets**

base fuel consumption

gal/yr	
3,000	-$4,890
4,000	$1,690
5,000	$8,260
6,000	$14,830
7,000	$21,410

energy value of fuel

Btu/lb	
6,500	$5,210
7,000	$9,800
7,500	$13,780
8,000	$17,270
8,500	$20,340

propane cost

per gal	
$1.00	-$36,500
$1.50	-$15,110
$2.00	$6,280
$2.50	$27,670
$3.00	$49,060

propane displacement

% of historical	
75%	$10,190
80%	$12,510
85%	$14,830
90%	$17,150
95%	$19,470

capex

turnkey	
$16,000	$18,890
$18,000	$16,860
$20,000	$14,830
$22,000	$12,810
$24,000	$10,780

fuel cost

per ton	
$150	$18,250
$160	$14,830
$170	$11,420
$180	$8,000
$190	$4,580

furnace system efficiency

55%	-$80
60%	$5,720
65%	$10,630
70%	$14,830
75%	$18,480

furnace system service life

yrs	
8	$8,010
9	$11,440
10	$14,830
11	$18,190
12	$21,490

annual maintenance

per yr	
$200	$17,000
$300	$15,920
$400	$14,830
$500	$13,750
$600	$12,660

financing duration

yrs	
3	$15,150
4	$14,990
5	$14,830
6	$14,680
7	$14,530

financing interest rate

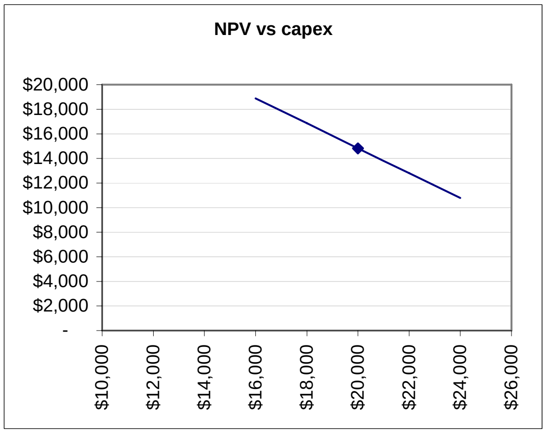
APR	
3%	$16,360
4%	$15,980
5%	$15,610
6%	$15,220
7%	$14,830

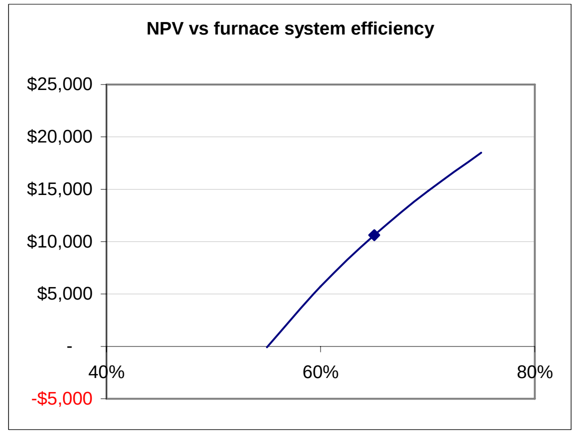
grant amount

% of capex	
0%	$14,830
25%	$19,600
50%	$24,660

Appendix 7.D: Detailed Economic Analyses of a Wood Pellet-fired System

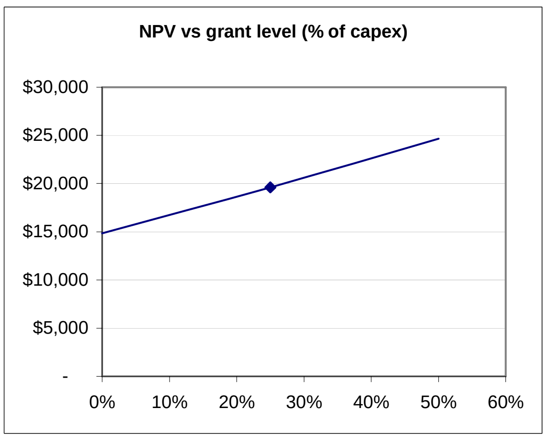
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **wood pellets**

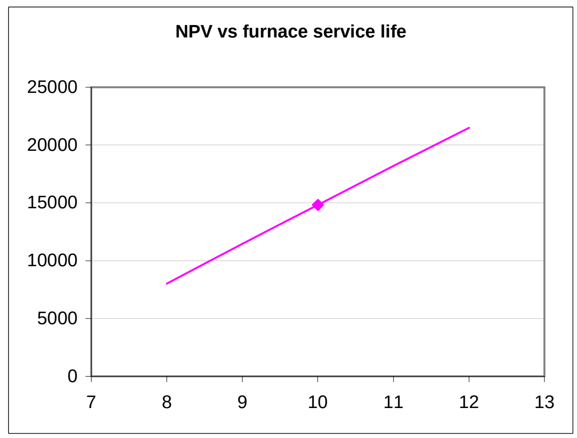




capex = $20,000

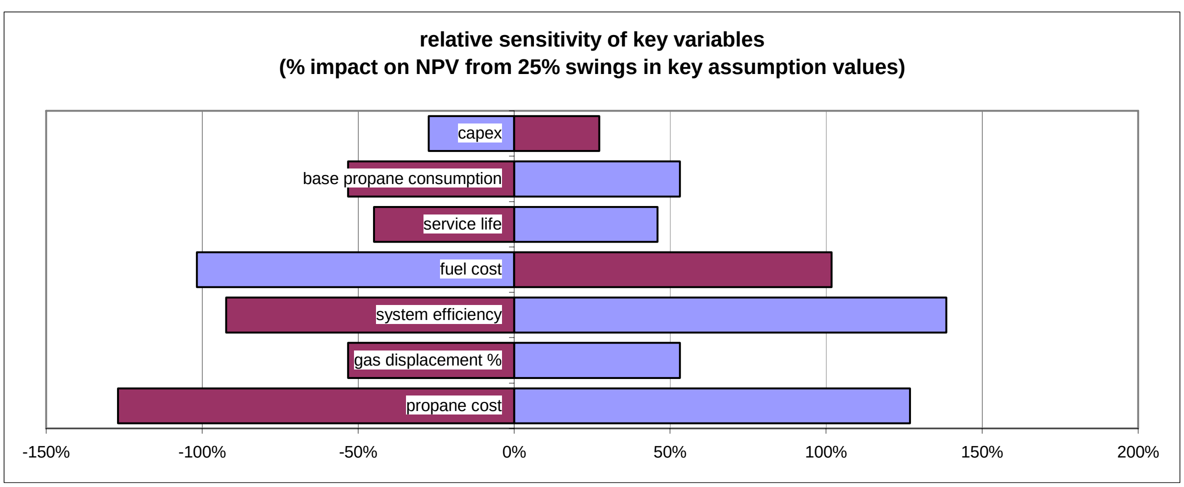
furnace system efficiency = 70%





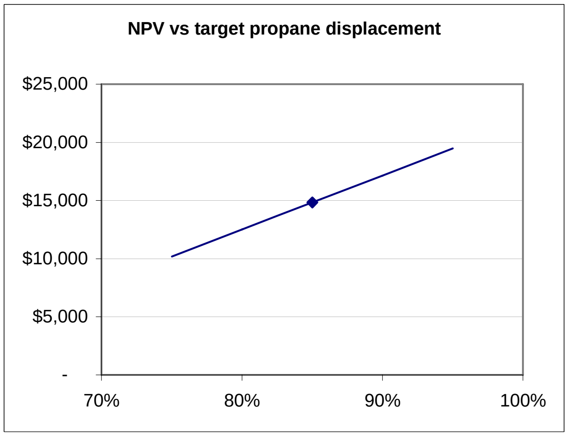
grant level = 0%

service life = 10.0 years

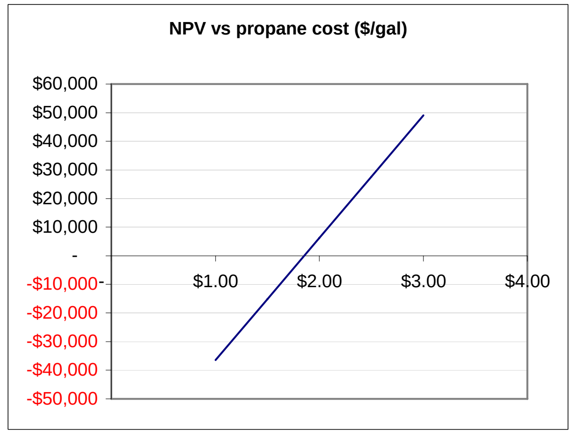


Appendix 7.E: Detailed Economic Analyses of a Wood Pellet-fired System

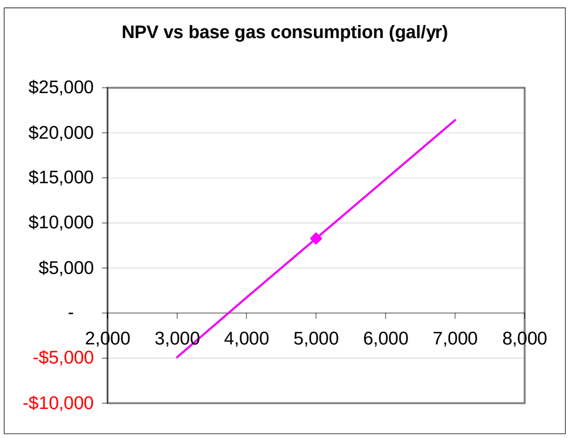
sensitivity analyses of NPV vs key variables (base case assumption shown below each graph) **wood pellets**



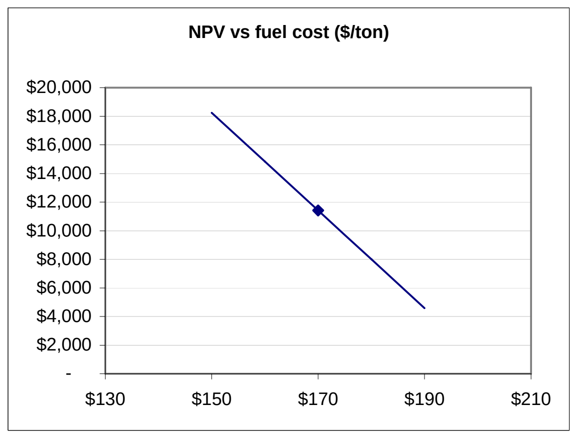
propane displacement level = 85%



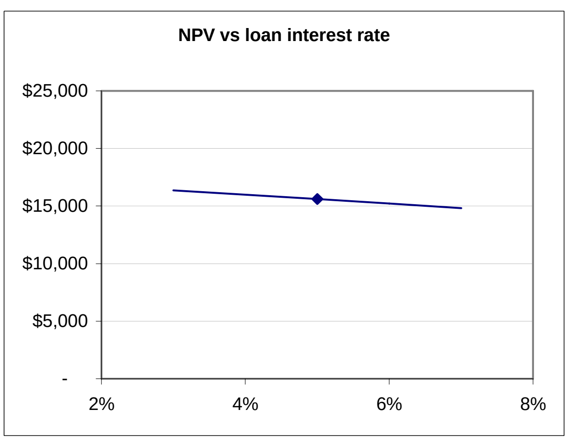
propane cost = $2.20 per gal



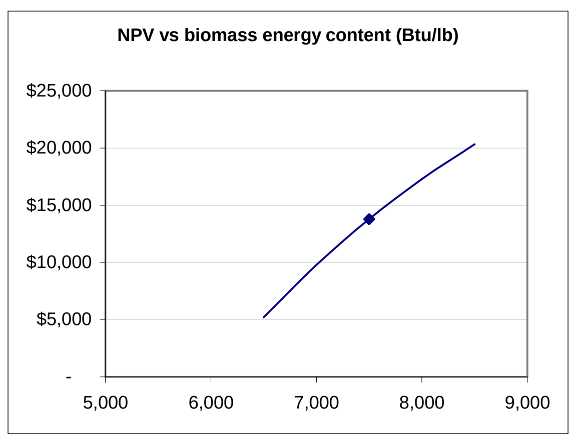
average propane consumption = 6,000 gal/yr



fuel corn cost = $160.00 per ton



loan interest rate = 7%



energy content of corn = 7,644 Btu/lb

Appendix 8: Summary Economic Analyses

comparative summary of economics of biomass furnace systems

	cord wood	corn	pelletized litter	raw litter	wood pellets	
Key Assumptions						
average fuel consumption of propane	6,000	6,000	6,000	6,000	6,000	*gal/year, propane*
average propane cost	$2.20	$2.20	$2.20	$2.20	$2.20	*per gallon*
target displacement level of propane	85%	85%	85%	85%	85%	*of annual consuption*
energy content of biomass fuel, LHV	6,560	5,950	4,860	4,100	7,644	*Btu/lb*
biomass system energy efficiency	45%	60%	60%	50%	70%	
cost of biomass fuel (delivered to farm storage)	$63	$214	$200	$20	$160	*per ton*
bulk density of biomass fuel	50	45	40	25	44	*lbs/cu ft*
estimated capital cost, complete & installed	$16,500	$20,000	$20,000	$35,000	$20,000	
grant funds available to offset capital cost	0%	0%	0%	0%	0%	*of total capex*
service life of furnace system	10.0	10.0	10.0	10.0	10.0	*years*
furnace down payment rate	20%	0%	20%	20%	20%	*of capex*
furnace system financing interest rate	7.0%	7.0%	7.0%	7.0%	7.0%	*APR*
current fuel cost reimbursement from integrator	$0	$0	$0	$0	$0	*per house per year*
Summary Results						
target propane displacement						
historic propane consumption =	6,000	6,000	6,000	6,000	6,000	*gallons / year*
propane displaced by biomass system =	5,100	5,100	5,100	5,100	5,100	*gallons / year*
starting cost of propane =	$2.20	$2.20	$2.20	$2.20	$2.20	*per gallon*
value of displace propane =	$11,220	$11,220	$11,220	$11,220	$11,220	*per year*
fuel consumption over life of furnace						
total biomass fuel consumption	802	663	812	1,155	443	*tons*
total biomass fuel consumption	1,604,000	1,326,000	1,624,000	2,310,000	886,000	*lbs*
total biomass fuel consumption	28,643	23,679	29,000	41,250	15,821	*bushels*
total propane displaced	51,000	51,000	51,000	51,000	51,000	*gallons*
system economics (over furnace service life)						
capital cost	$16,500	$20,000	$20,000	$35,000	$20,000	
maintenance & electricity expenses	$5,800	$5,800	$5,800	$5,800	$5,800	
financing costs	$2,500	$3,800	$3,000	$5,300	$3,000	
subtotal	$24,800	$29,600	$28,800	$46,100	$28,800	
biomass fuel expense	$50,500	$141,900	$162,400	$23,100	$70,800	
total	$75,300	$171,500	$191,200	$69,200	$99,600	
propane savings	$122,900	$122,900	$122,900	$122,900	$122,900	
net cash income (loss) to grower =	$47,600	-$48,600	-$68,300	$53,700	$23,300	
resulting NPV of investment =	$34,000	-$40,400	-$55,900	$36,500	$14,800	
simple payback, years =	2.4	n/a	n/a	3.7	4.2	