EFFECT OF FUEL PRICES ON COST-EFFECTIVENESS OF HEATING SYSTEMS FOR BROILER POULTRY BARNS

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ABSTRACT

Recent advances in extraction have increased the supply of natural gas and increased the relative price difference between it and alternative fuels. However, natural gas is not available in many rural areas forcing poultry producers unable to access natural gas to use more expensive fuels. This paper determines the least cost appliance system and fuel source for heating a broiler chicken barn in Ontario, Canada. The empirical model estimates the amount of heat required for poultry production, selects appropriate heating appliances and fuel types, and calculates the final present value of costs over a 20-year period. Appliances examined include box heaters, radiant tube heaters and biomass boilers; fuels examined include natural gas, propane, heating oil and biomass. Natural gas is the least cost fuel for both box heaters and radiant tube heaters assuming there is an existing connection to a gas pipeline. However, natural gas heating systems become the most expensive approach if the poultry operator has to pay for a pipeline connection to the gas source. With no direct connection for natural gas, biomass boilers are the most cost efficient heating system, followed closely by radiant tube heaters fuelled by propane. Heating oil is the most expensive fuel examined and its costs are nearly double that for comparable box heaters and radiant tube heaters using propane.

KEYWORDS
Natural gas, fuel prices, biomass, heating systems, broiler barn

SUBJECT CLASSIFICATION
Q1;Q4

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Introduction

Advances in extraction technology have increased the supply of natural gas, which in turn has altered the relative prices of heating fuels. From 2006 prices, natural gas price fell by roughly 25%, while propane and heating oil prices increased 12% and 26% respectively (Ontario Energy Board. 2013a, Natural Resources Canada. 2014a, Natural Resources Canada. 2014b). These price changes can have significant impacts on production costs of energy intensive livestock operations including broiler chicken production. The changes could be significant enough to prompt a switch in either the type of fuel or the appliances used to generate the heat. In addition, the decline in natural gas price may be sufficient to warrant poultry operators to connect to a natural gas pipeline. In the midst of the changes in the relative costs of traditional heating systems, the emergence of biomass as a heating fuel has increased the uncertainty surrounding the cost-effective heating method and associated fuel source for broiler producers.

Previous studies have examined the potential for renewable energy to be used to supply heat in poultry barns. Choi *et al.* (2012) examined the use of a geothermal heat pump to supply heat to broiler chicken barns in Korea. Results indicated that heating fuel costs decreased with the use of a heat pump while electricity costs increased. Hughes (1981) identified alternative means of providing heat to poultry barns, including solar, methane, wind, coal and wood combustion. The author noted that most alternative forms of energy were quite expensive, although adoption of alternative heating methods could increase if improvements were made in heating efficiency or if traditional fuels increased in price.

The purpose of this paper is to determine the cost-effective heating system for broiler chicken barns under alternative barn and price conditions. The paper begins with a description of an empirical model that calculates the present value of purchase, installation, and fuel costs over a 20-year period for three heating systems (box heaters, radiant tube heaters, and a biomass boiler). The results of a base scenario for a representative poultry producer in Ontario Canada are presented followed by the results of several sensitivity analyses including altering the barn type, the costs of natural gas connection, the relative prices of fossil fuels, and the costs of biomass heating. While natural gas for radiant tube heaters are the least cost heating system, the analysis shows that this is only valid for operations with existing natural gas connections. The annual cost savings of lower fuel costs are not sufficient to warrant the capital costs of connecting to a nearby gas pipeline, depending on the connections costs.

Materials and Methods

The costs of alternative heating systems for a poultry barn are estimated through a spreadsheet model developed in MS Excel. The model consists of four sequential stages: (1) an estimate of the amount of heat needed by the poultry barn, (2) selection of heating appliances to provide that heat, (3) estimation of fuel use required by the chosen appliances, and (4) calculation of the present value of costs for each heating system. Three types of heating appliances are considered: box heaters, radiant tube heaters, and biomass boilers. The first two types of appliances can be fuelled by natural gas, propane, or heating oil, while only biomass is used for the boiler. As a result, the least cost for each of the seven heating systems can be estimated and comparisons made across systems.

Heating Requirements

The output of the first stage of the model is the total heat requirement for a given facility, expressed in terms of either GJ Hour $^{-1}$ or BTU Hour $^{-1}$ (or annually or area $^{-1}$). To arrive at this estimate, the initial step is to specify the dimensions of the poultry barn. Given the length, width, and height of the barn, the total volume of the barn that needs to be heated is calculated. The user must also specify the outside temperature, along with the desired inside and attic temperatures. The assumption that temperatures are constant over the course of a year is made to simplify model inputs. Attic temperatures are included within the model to account for heat lost through the roof. Poultry barn floors also represent a source of heat loss, but are not included within this model.

The amount of building heat gained and lost to the outside environment depends on the level of insulation. A poorly insulated building requires more energy to heat and higher ventilation rates than an appropriately insulated building, which can, on average, increase heating costs anywhere between 13% and 16% (OMAF 2010). The user can select between three potential levels of insulation: low insulation levels (R-4 in the walls and R-11 in the ceiling) for an older barn, moderate insulation levels (R-11 in the walls and R-19 in the ceiling) for a middle aged barn, and high insulation levels (R-20 in the walls and R-28 in the ceiling) for a new barn. The user can also select one of two air leakage levels: 'tight' barns are assumed to have an air leakage level of 1.0 x $10^{-3}m^3s^{-1}$ m^2 (0.2 cfm ft^{-2}) while more 'open' barns are considered to have an air leakage level of 1.5 x $10^{-3}m^3s^{-1}$ m^2 (0.3 cfm ft^{-2}).

Total heat requirement is based on the amount of heat lost through the ceiling and each wall of the barn. Heat loss is determined by the following equation from Czarick and Donald (N.D.)

$$\text{Building Heat Loss} = (\text{Area} \times (\text{Inside Temperature}-\text{Outside Temperature}))/(\text{R-Value}) \quad [1]$$

where heat loss is expressed in BTU $Hour^{-1}$ per area $feet^{-2}$, and temperature in Fahrenheit. Area refers to the size of the wall or ceiling through which heat may be lost. All units are then converted into metric units. Building heat loss calculations must be performed for every building component and summed together to determine the total building heat loss. Given the values specified by the user for the values on the right hand side of [1], the amount of heat that the system would have to replace to maintain a constant temperature in the barn is calculated.

In addition to heat loss from the walls and ceiling, heat loss can also result from ventilation. In the summer, the building ventilation must work to remove moisture and heat generated by the birds, and the heat gained by the building from its surroundings to reach an optimal temperature. In the winter, the ventilation system must create a balance between heat lost when moisture laden and ammonium contaminated air is exhausted from the barn, the heat loss from the building itself, and the heat generated by the birds. Heat loss from ventilation, also in terms of BTU/Hour, is calculated from the following equation from Czarick and Donald (N.D.)

Heat Loss from Ventilation =Air leakage x Area x (Inside Temperature-Outside Temperature) [2]

where air leakage, expressed in either m3s-1 m2 or cfm ft-2, is one of the two values specified by the user (0.2 or 0.3, as suggested by Czarick and Donald, N.D). Area refers to the heat in the building area lost through ventilation. The model calculates heating loss from each building element using equation [1] and heat loss through ventilation through equation [2] to determine the total heat loss for the entire building. The final tally of heat lost represents the amount of heat that must be added to the building to maintain the desired indoor temperature. If the user indicates that a heat exchanger is present, the model assumes a heat requirement savings of 40% (Zhang and Guo, 2010).

The heating requirement calculated on an hourly basis is converted into a yearly basis on the assumption that the heating system operates for approximately for 12 hours a day, for 7 days a week, for 6 months of the year. This is based on the assumption that a typical broiler chicken barn produces anywhere from 5 to 6 flocks a year, at 5 weeks a flock, resulting in 25 to 30 weeks of production per year, and a flock density of 1 bird ft^{-2} (approximately 10 birds m^{-2}) (Deen 2014). While heating demand decreases during the warmer months of the year and as the broiler chickens grow, the demand within this model is simplified to a constant level that reflects colder periods. This ensures that any heating appliance selected has enough excess capacity to handle colder temperatures.

Heating System

Given the heat required in the poultry barn from the first stage of the model, the next phase determines the size of appliance(s) necessary to supply this heat. The choice is based on the system that is able meet the energy requirements at least cost, which is the purchase and installation costs of all associated equipment such as boilers, furnaces, and storage tanks.

The model chooses the optimal size of appliance for three types of heating systems: box heaters (also known as forced air heaters), radiant tube heaters, and biomass boilers. For the first two heating systems, the user provides BTU output of the model, efficiency and purchase price of alternative models. The worksheet selects which model type and the number needed to meet the energy requirements of the barn at the lowest cost with the use of the constrained optimization tool Solver in MS Excel. Solver seeks to meet the heating requirement that has excess capacity built in to account for extreme cold temperatures based on numerous constraints. Only one size of appliance can be selected, which is typical of the choices made by most poultry operators. For example, energy requirements of 0.38 GJ hr^{-1} (360,000 BTU hr^{-1}) can be met by either four units of an appliance with a capacity of 0.11 GJ hr^{-1} (100,000 BTU hr^{-1}) six units of another model with a capacity of roughly 0.06 GJ hr^{-1} (60,000 BTU hr^{-1}) but not a combination of the two types of appliances. An additional constraint is that there must be three or more appliances of the appropriate size. This ensures minimally sufficient appliance spacing in a poultry barn for even heat distribution. Using three units allows for an appliance to be located in the middle and at each end of the poultry house, and reduces the space between appliances. If only two units were to be used, the distance between each unit would be greater, creating the potential for cold spots within the barn. For example, with an energy requirement of 0.38 GJ hr^{-1} (360,000 BTU hr^{-1}), two appliances with a capacity of 0.21 GJ hr^{-1} (200,000 BTU hr^{-1}) could supply the desired heat, but three appliances, each with a capacity of 0.13 GJ hr^{-1} (120,000 BTU hr^{-1}) is considered more optimal.

An additional constraint for radiant tube heaters is that the combined length of the tube heaters and spacing requirements between them do not exceed the length of the barn. Radiant tube heaters are sold in pre-determined lengths that may vary from 6 to 24 meters (20 to 80 ft.). They are typically installed end to end, running down the length of the building. This constraint ensures that the length of the heater and the clearance on either side of each heater does not exceed the length of the building. One and a half to three meters (5 to 10 ft.) on either end of each radiant tube heater is added to the total heater length. Multiple tubes run down the length of the barn to ensure even heat distribution and are given space to reduce the risk of fire. Industry suggestions for spacing distance between heaters range from 2.4 m (8 ft.) (Black 2013) to 8.8 m (29 ft.) (Czarick and Donald N.D.). The worksheet assumes a clearance of 4.2 m (14 ft.) between heaters, and 2.3 m (7.5 ft.) between heaters and end walls.

As with box heaters and radiant tube heaters, the choice of biomass furnace is based on the appliance size that can meet the heating requirement at least cost. However, biomass boilers are larger pieces of equipment than the other heating appliances and are installed outside of the barn. Additional costs for piping and ductwork to transport heat into the barn are not considered here. Because of differences in installation, operation and initial investment costs, the constraints imposed on box heaters and radiant tube heaters do not apply to biomass boilers. Different sized biomass boilers can be selected by the model at the same time to meet the heating demand and there are no restrictions on the number of boilers that may be selected. Biomass boiler industry experts suggest using multiple various sized boilers is common practice among boiler operators in an attempt to achieve heating demand while minimizing costs (Clarke 2013). The use of multiple boilers would also over some redundancy in the case of a non-operational unit.

Fuel Calculations

The next stage in the worksheet is the calculation of fuel costs to run the previously chosen heating system, which has been selected based on the heating requirements estimated in stage one. Fuel calculations are restricted based on appropriate appliances. Natural gas, propane, and heating oil may power the selected box heaters or radiant tube heaters, but biomass (woody or herbaceous) alone is used to fire the boiler. This restriction on appliance and fuel combinations reflects the current combinations used within the industry. The prices for these fuels are set to default values from 2013, but may be adjusted by the user. The fuel prices are multiplied by the amount of fuel needed to provide the necessary heat to determine fuel costs with each heating system. The required fuel volume is adjusted for the efficiency of the appliance system. An additional consideration for natural gas is the cost of connecting to a pipeline, which is assumed to be \$35,000 km^{-1} but can be varied by the user. Adjusting natural gas connection costs can also be used to account for variation in pipeline connection cost schemes.

Cost Calculations

The fourth portion of the model summarizes the cost information to allow users to make informed decisions regarding fuel/appliance combinations. The cost calculations begin with the purchase and installation costs for the least cost appliance selected in second stage of the model for each heating system. The fuel expenses for each heating system as calculated using the process described in the above sub-section, are incurred annually, except for natural gas pipeline connection costs. If connection costs are necessary, they are incurred in the first year of the period. The model determines the present value of the costs for capital, periodic maintenance, and fuel for the heating system specified by the user over a twenty year period. A twenty year period was selected for analysis based on the longest lifespan of the appliances investigated.

Base Model

While the worksheet can be used to determine the cost of heating under a variety of scenarios, we illustrate the approach using a base model in which the values of the parameters are typical for a commercial poultry farm in Ontario, Canada. The values used for the hypothetical farm are listed in Table 1.

The broiler chicken barn in the base case is assumed to be 14 m by 76 m (48 ft. by 250 ft.), identical to the standard poultry barn example used in Ventilation for Livestock and Poultry Facilities (2010). The height of this building is set at 3.6 m (12 ft.). The barn is assumed to be stocked at a density of one bird per square foot (roughly 10 birds per square metre) resulting in a flock of 12,000 birds (Ward 2014). The barn's indoor temperature is set to 26°C (80°F) and the attic temperature to -1°C (30°F). The outdoor temperature is assumed to be -12°C (10°F). Although not a yearly average temperature in Ontario, this outdoor value was selected to reflect heating demands of poultry producers in the colder winter months. Thus, the base case model makes significant simplifying assumptions, and estimates higher heating demands than would normally exist.

For the base case scenario, R-values are set to those used by Czarick and Donald (N.D.) who model a more modern poultry house with walls having an insulation level of R-11 and ceilings having an R-value of 19. It is assumed that the walls of the base case building do not contain any curtains based on the recent trend for buildings to have continuous walls, and rely on ventilation systems to move barn air instead of open walls (Czarick and Donald N.D.). Air leakage values are also based on Czarick and Donald (N.D.).

Table 1. Parameter Values for Barn, Heating Appliances and Fuel used in Base Model and Sensitivity Analysis

Parameter	Base	Low	High	Standard Deviation[a]	Distribution Type[a]
Flock Size	12,000	12,000	12,000		
Barn					
Length (ft)	250	250	250		
Width (ft)	48	48	48		
Height (ft)	12	12	12		
Air Leakage (cfm/ft^2)	0.3	0.2	0.3		
Insulation - Walls	R-11	R-4	R-20		
Insulation –Ceiling	R-19	R-11	R-28		
Heating Appliances					
Box Heaters					
Capacity (BTU)	100,000	100,000	100,000		
Efficiency	80%	80%	80%		
Number	4	4	4		
Purchase Cost	$4,240	$4,240	$4,240		
Installation Cost	$424	$424	$424		
Maintenance					
Lifetime (years)	10	10	10		
Radiant Tube Heaters					
Capacity (BTU)	125,000	125,000	125,000		
Efficiency	92%	92%	92%		
Number	3	3	3		
Purchase Cost	$4,500	$3,375	$5,625		
Installation Cost	$450	$337	$562		
Maintenance					
Lifetime (years)	10	10	10		
Biomass Boilers					
Capacity	100 kW	100 kW	100kW		
Efficiency	95%	95%	95%		
Number	1	1	1		
Purchase Cost	$55,000	$41,250	$68,750		
Installation Cost	$5,500	$4,125	$6,875		
Maintenance	20% of Purchase cost every five years				
Lifetime (years)	20	20	20		
Fuel Prices					
Natural Gas	$0.28/m^3	$0.08/m^3	$0.37/m^3	$0.09	Triangular
Hookup Costs	$35,000/km	$35,000/km	$35,000/km		
Hookup Distance	5 km	0 km	15 km		
Propane	$0.50/ltr	$0.61/ltr	$0.75/ltr	$0.03	Beta General
Heating Oil	$1.25/ltr	$0.87/ltr	$1.26/ltr	$0.12	Triangular
Biomass	$0.07/lbs.	$0.03/lbs.	$0.07/lbs.	$0.02	Pareto
Discount Rate	8%	4%	16%		

[a]- Standard deviation and distribution type information come from Ontario Energy Board and Natural Resources Canada (2013, 2014a, 2014b)

The purchase and installation costs for the appliances in the base case are based on the least cost system among commercially available models in Ontario. The prices for the box heaters and radiant tube heaters are from Black (2013) and JAD-Vent Distributors (2009) while information on biomass boilers is from Suave (2013). The appliances selected and the corresponding cost for the base model minimize purchase and installation costs while ensuring only one type of model is used, spacing requirements are met, and the required heat is produced. The base case price is $4,664 for a box heater, $4,950 for a radiant tube, and $60,500 for a biomass boiler. These costs include the cost of the appliance itself, and an assumed 10% labour and installation cost.

It is assumed that no maintenance or cleaning is conducted on either box heaters or radiant tube heaters over their lifetimes. These appliances are replaced every 10 years. Biomass boilers, usually located outside of the barn, last longer than the other two heating systems but require periodic maintenance due to the nature of biomass combustion residuals. Biomass boilers are expected to be replaced in year 20 with maintenance costs of 20% of the initial boiler cost incurred every 5 years (National Resource Canada. 2000, Suave 2013).

All fossil fuels can power both box heaters and radiant tube heaters. The prices of \$0.28 m^{-3} for natural gas (\$0.08 10,000 BTU^{-1}), \$0.50 L^{-1} for propane (\$0.20 10,000 BTU^{-1}), and \$1.25 L^{-1} for heating oil (\$0.34 10,000 BTU^{-1}) are based on Ontario market prices in the fall of 2013. There are two scenarios for natural gas use with box heaters and radiant tube heaters. One assumes that a natural gas pipeline connection to the barn exists and the other assumes that the connection is 5 km away and costs \$35,000 km^{-1} for a total of $175,000 to hook-up (Clarke et al. 2013).

Although it is unlikely that a single natural gas consumer would pay the full cost of installing 5 km of natural gas pipeline, this scenario is adopted to illustrate an extreme example of natural gas pipeline connection costs. There is a large range of variation in pricing of natural gas pipeline expansions.

Expansions may prove profitable to natural gas utilities and they may absorb the entire cost. Expansions may benefit numerous consumers along the pipeline, and a cost sharing system may be adopted. A single consumer may be beyond the reach of a pipeline, and may pay to have that pipeline connected. Any combination of the above scenarios may exist in regards to the expansion of a single pipeline. Given the variability associated with pipeline connection costs, the assumptions of 0 km and 5 km capture two extreme situations. The analysis of variation in pipeline distance presented below illustrates cost scenarios between these two extreme situations.

Unlike fossil fuels, there are no databases tracking the market prices for biomass. As a result, the price of biomass is based on Clarke et al. (2013), who assumes a biomass price of \$0.15 kg^{-1} (\$0.07 lbs^{-1} or \$0.09 per 10,000 BTU) in order to provide biomass producers with enough of an incentive to grow biomass, and to account for value-added processes such as off-farm transportation, drying or pelletization.

Sensitivity Analysis

The results of the base model are shocked in several ways to determine how sensitive the results are to changes in model parameters. First, the break-even fuel prices are calculated. The fuel price at which a poultry operator is indifferent between one fuel/appliance combination over another is determined using MS Excel Goal Seek. The present value of costs for the selected system was set to achieve an equal value to a comparison system by allowing only the selected system's fuel price to vary. If fuel prices are higher (lower) than the break-even price, the operator should prefer the comparison (selected) system.

In addition to running break-even analysis with respect to fuel prices, the model is run for alternative values of selected parameters. The low and high values for these parameters are listed in Table 1. For example, while the physical dimensions of the barn are kept constant, air leakage and insulation levels are allowed to vary to reflect older, poorly-insulated, leaky barns versus newer, better-insulated and tighter poultry barns. In addition, the natural gas pipeline connection distance is varied from the base value of zero (barn has access to natural gas currently) to a maximum of fifteen kilometers. The discount rate used in the present value of cost calculations is also varied to either 4% or 16% from the base of 8% to reflect different rates of time preference or cost of capital. A higher discount rate places more emphasis on earlier expenditures and less emphasis on expenditures that occur later on in the time period.

The final analysis examines the effect the distributions of fuel prices have on the present value of costs. The price distributions are estimated empirically based on historical prices taken from the Ontario Energy Board (2013a) and Natural Resources Canada (2014a, 2014b). Variation in biomass prices is based on conclusions from Clarke et al. (2013), De Laporte (2013) and Kelly et al. (2012). The resulting minimum, most likely, maximum, and standard deviation and type of distribution for fuel prices are listed in Table 1. The software @RISK, published by the Palisade Corporation (2013) is used to incorporate these fuel distributions into the present value of cost calculations for each fuel/appliance combination. The final analysis allows all variables, excluding barn insulation and air leakage, to vary based on the parameters in Table 1. In this case, appliances are allowed to vary plus or minus 25% from the original base case value.

RESULTS

Costs of Heating Systems under Base Model

The present value of costs for the seven heating systems over a 20 year period under the base model parameters are listed in Table 2.

Table 2. Present Value of Costs for Alternative Heating Systems under Base Model and Two Barn Types

Heating System	Base	Cost Per Bird	Old Barn	New Barn
Box Heaters				
Natural Gas (5 k)	$238,699	$0.20	$262,141 (10%)	$212,731 (-11%)
Natural Gas (0 k)	$76,662	$0.06	$100,104 (31%)	$50,694 (-34%)
Propane	$181,804	$0.15	$237,932 (31%)	$199,311 (-34%)
Heating Oil	$307,916	$0.26	$408,367 (31%)	$201,495 (-35%)
Radiant Tube Heaters				
Natural Gas (5 k)	$230,093	$0.20	$249,742 (9%)	$208,246 (-9%)
Natural Gas (0 k)	$68,056	$0.06	$87,705 (29%)	$46,209(-32%)
Propane	$159,507	$0.13	$207,567 (30%)	$105,912 (-34%)
Heating Oil	$269,170	$0.22	$351,423 (31%)	$177,377(-34%)
Biomass Boiler	$149,907	$0.12	$201,057 (34%)	$111,852(-25%)

Old Barn- Air leakage = 0.3 cfm/ft^2, wall insulation= R-4, ceiling insulation= R-11
New Barn- Air leakage = 0.2 cfm/ft^2, wall insulation = R-20, ceiling insulation = R-28
[a]- Percentage change from Base in parentheses

Appliance Choice

For a given fossil fuel, box heater systems are approximately 14% more expensive than radiant tube heater systems. The difference in costs is a result of difference in initial purchase price and/or appliance efficiency. The radiant tube heater system chosen for the base case is slightly more expensive than the box heater model ($4,500 vs. $4,240). The $260 difference incurred initially and upon replacement after 10 years, represents a small proportion of the difference in the overall costs of the two heating systems for a given fuel.

The cost savings with the radiant tube heaters is due to the difference in appliance efficiency. The box heater model selected in the base case is assumed to have an efficiency level of 80% while the radiant tube heater is rated at an efficiency level of 92%. Efficiency ratings are based on industry data (Black 2013, JAD-VENT Distributors. 2009). Consequently, the radiant tube heater uses less fuel over its lifetime to provide the same quantity of heat as the box heater. The difference in efficiency levels reflects a difference in annual heating requirements of approximately 100's of GJ or 100 million BTUs. Over the course of the twenty year time frame, the extra fuel needed to supply this heat for a box heater is significant, and explains the difference in radiant tube versus box heating systems. The extent of the difference will vary with the type of fuels as discussed further below.

These results support current trends in the industry. Poultry operators can reduce the amount of fuel used by switching to higher efficiency appliances, specifically radiant tube heaters (Government of Alberta 2014). Radiant tube heaters, with higher efficiency levels, are paying for themselves through long term cost savings. A broiler operator using natural gas could save $919 per year through fuel savings by switching to a radiant tube heater. Annual savings amount to $2,316 and $3,991 for propane and heating oil respectively. Savings for heating oil are greater than the calculated savings for natural gas and propane due to differences in fuel prices. Heating oil fuel costs are much higher, hence any savings in the amount of heating oil needed translates to larger cost savings.

The biomass boiler is the most expensive system to purchase and install ($55,000 vs. $4,500) but it is also assumed to operate at a higher efficiency and have a lifetime of 20 years with periodic maintenance. Its 95% efficiency results in approximately 27 GJ or 26 million BTUs less being required per year to heat the poultry barn than the radiant tube heater system. While more expensive than either of the natural gas systems with existing connections, the biomass boiler is less expensive than the other box heater and radiant tube heater combinations. A combination of low biomass fuel costs and the low heating requirements of using a biomass boiler are sufficient to outweigh the associated high investment costs under the assumptions in the base version of the model.

Fuel Choice

Natural gas systems, when a pipeline is already in place, are the cheapest options available, for both box heaters and radiant tube heaters. Without the extra costs of installing a pipeline, the present value of costs for a natural gas system range from $68,056 for radiant tube heating to $76,662 with a box heater for a building of 4,077 m^{-3} (144,000 ft^{-3}). Without a pipeline connection, costs are nearly a third of what they would be under the assumption of a poultry producer paying the full cost of a 5 km natural gas pipeline connection. Including pipeline connection costs results in natural gas going from the least expensive heating fuel to the most expensive option. Alternative system costs would have to be considerably higher before consumers would consider paying for the entire costs of a connection to a natural gas pipeline 5 km away. Biomass system costs would have to increase by 53% to 59% (from $80,185 to $88,893), and propane systems would have to increase by 31% to 44% (from $56,895 to $70,585), depending on the appliance type chosen, before poultry producers would consider using natural gas if a pipeline connection was necessary.

When natural gas is not easily accessible and pipeline construction is necessary, biomass is the most economical fuel choice, with system costs of $149,906 over the twenty year period. Propane is the second most economical fuel. Propane system costs are $159,507 for a radiant tube heater system and $181,804 for box heaters. Heating oil systems are the most expensive system in every situation, regardless of the state of natural gas accessibility. The costs for a heating oil system, over a twenty year period are $269,170 for radiant tube heaters to $307,916 for box heaters. These high prices are due largely to the high current costs associated with heating fuel.

The results of the base case analysis suggest that biomass, propane and natural gas should be the more common fuels used for heating in the poultry industry, and those operations using heating oil should be switching to alternate fuels. Currently, propane and natural gas are the more popular fuels in the Ontario industry (Ward 2013b). The analysis supports the use of natural gas when pipeline connection costs are low. In areas without natural gas, the analysis suggests that biomass might be an attractive option, although the cost of propane is only slightly higher. However, uncertainties and hidden costs associated with biomass are likely to make the perceived cost of biomass systems greater than the cost of propane systems. This would encourage the adoption of propane over biomass, despite the calculated cost savings. Industry data do support this conclusion, indicating that propane is the fuel of choice when natural gas is unavailable.

The lack of practical applications for biomass systems is likely due to a number of hidden costs associated with biomass that have not been incorporated into this analysis. Biomass, unlike natural gas and propane, cannot be quickly turned off and on to accommodate changing heat demand, nor can it be easily stored in storage tanks or underground pipelines. Additional labour costs may also be incurred if no automatic biomass boiler feeder system is used. Sourcing a stable supply of biomass may present challenges for biomass consumers, given the nature of the biomass industry in Ontario. Although the price assumed within the model aims to ensure a stable supply price, this might not always be the case. Lower prices may make biomass systems more attractive, but may also reflect instability in supply. There may also be issues associated with pioneering biomass as an industrial heating source for poultry operations, which may limit adoption.

Barn Type

The final two columns in Table 2 list the present value of costs for two barn types. An old barn, which assumes a high level of air leakage and low insulation levels, and a more modern barn with a low level of air leakage and high insulation levels are examined. As the rate of air leakage and the insulation level change, the heating requirement changes. The worksheet determined the appropriate model currently available for each appliance system and then determined the amount of fuel required.

The relative ranking of heating system does not change with the older barn compared to the base model. Assuming a connection, radiant tube heaters with natural gas are the cheapest heating system followed closely by box heaters fuelled with natural gas. The next cheapest options of biomass and propane are approximately double the costs of natural gas heating systems. The most expensive option for the older barn is heating oil. Across all heating systems, the costs are approximately 30% greater for the older barn compared to the base model assumptions. Greater costs for older barns are a result of higher heat requirements in poorly insulated barns. Higher heat requirements lead to larger appliance and fuel requirements.

The cost of heating an older barn with natural gas with and without pipeline connection costs ranges from $262,141 to $100,104 for box heaters (an increase of 10% and 31% over the base case), and $249,742 to $87,705 for radiant tube heaters (an increase of 11% and 34% over the base case). For propane, the cost of heating an older barn ranges from $237,931 to $207,566 for box heaters and radiant tube heaters respectively, and represents a 31% increase over the base case propane box heater scenario, and a 30% increase over the radiant tube heater scenario. For heating oil, costs for an older barn are $408,366 to $351,423 for box heaters and radiant tube heaters, illustrating 31% increases over the base case for both box heaters and radiant tube heaters. The cost of heating an old biomass boiler powered barn is $201,057, a 34% increase over the base case.

Available data on upgrading poultry barns suggests that in some circumstances, it is economical to improve insulation, and it is generally always economical to tighten barns. Insulation costs vary widely depending on barn size, desired insulation type and insulation level. Cost estimates range from roughly $5 to $10 per square metre ($0.50 to over $1.00 per square foot) (Homewyse 2014). Depending on barn size, upgrading insulation can present significant one-time costs to barn operators ($6,000 to $12,000 and upwards). Given the present value of cost savings between older barns and the base case, improving insulation is an economical choice. Tightening a barn involves identification of undesired air movement, and is usually easily remedied with foam or plastic. The costs of tightening a barn are considered to be minimal.

For the more modern barn, a new fuel ranking is generated, and is dependent on the type of appliance being used. Natural gas powered radiant tube heaters and box heaters are the cheapest options, followed by propane powered radiant tube heaters, biomass boilers, heating oil radiant tube heaters, propane and heating oil box heaters, and finally, natural gas for both appliances with a five kilometer pipeline connection distance. This ranking for the more modern barn suggests that if natural gas is accessible, it should be used regardless of the appliance, but any other fuel section should be dependent on appliance choice. These results are due to the changes in appropriate appliances that must be made when barn air leakage and insulation improve. Smaller, or fewer appliances are required, highlighting the cost difference between the two fossil fuel appliance options.

Sensitivity Analysis

Break-even Fuel Price

The fuel price at which a poultry farmer would be indifferent between two fuel/appliance systems is listed in Table 3. For example, the present value of costs is the same for a propane box heater and a heating oil powered box heater if propane rises 72% from the base price of \$0.50 L^{-1} to \$0.86 L^{-1} with heating oil kept at its base price of \$1.25 L^{-1}. If propane is less (greater) than \$0.86 L^{-1}, the propane (heating oil) box heater system is the preferred system. Alternatively, heating oil price could fall 42% from \$1.25 L^{-1} to \$0.73 L^{-1} with a constant propane price and the cost of heating with a box heater system would be the same for the two fuels.

The cost effectiveness of natural gas for heating broiler barns are highlighted by the break-even prices listed in Table 3. Provided a pipeline connection exists, the price of natural gas would have to more than double to \$0.58 L^{-1} before the producer would consider switching to the next lowest cost heating system which is a boiler fueled with biomass. Among traditional fossil fuels, natural gas prices would have to increase by 120% before it would be profitable to switch from natural gas fueled box heaters to propane with radiant tube heaters. Natural gas prices would have to nearly triple before heating oil would be preferred regardless of the heating appliance. Thus, natural gas as the preferred fuel choice is robust to a wide range of possible fuel price changes.

The conclusion surrounding natural gas depends critically on whether a connection to a natural gas pipeline exists. Assuming the producer is five kilometers from a pipeline and has to pay for the connections costs, natural gas price would need to be approximately one-fifth of the current price before a producer would consider switching from propane to natural gas. In contrast, if heating oil was the current fuel choice and propane or biomass were not available, natural gas prices could still double approximately and it would be worth it to incur the pipeline connection costs and make the switch to natural gas.

Table 3. Fuel Price for Heating System Chosen at Which Operator is Indifferent between two Heating Systems

Base Heating Systems for which Price is Changed[a]	**Base Fuel Price**	**Radiant Tube Heater**				**Biomass Boiler**
		Natural Gas (5 km)	Natural Gas (0 km)	Propane	Heating Oil	
Natural Gas (5 km)	$0.28	--	np [b]	-$0.05 (-118%) [c]	$0.46 (64%)	-$0.08 (-129%)
Natural Gas (0 km)	$0.28	np	--	$0.71 (154%)	$1.22 (336%)	$0.66 (136%)
Propane	$0.50	$0.73 (46%)	$0.20 (-60%)	--	$0.86 (72%)	$0.47 (-6%)
Heating Oil	$1.25	$1.06 (-15%)	$0.29 (-77%)	$0.73 (-42%)	--	$0.68 (-46%)
Biomass Boiler	$0.07	$0.17 (143%)	$0.00 (-102%)	$0.10 (43%)	$0.22 (214%)	--

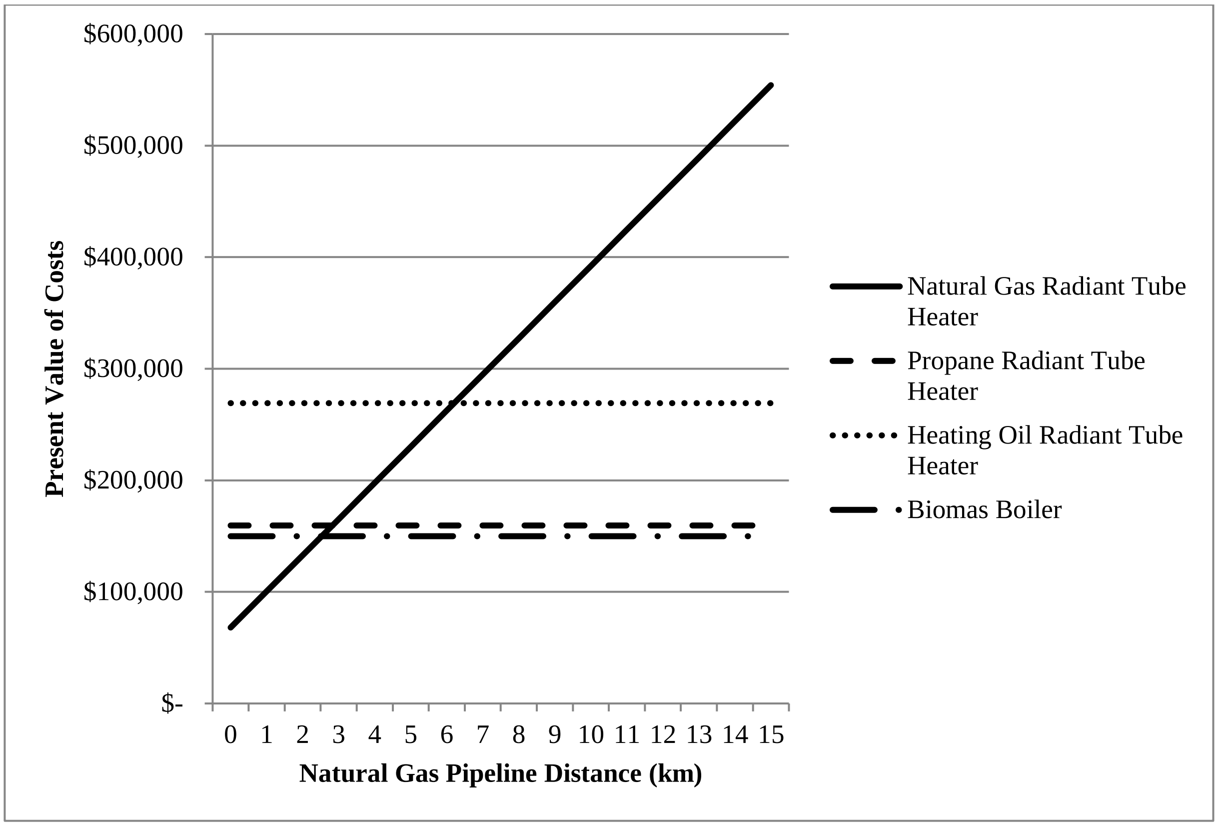
[a]- The break even fuel price is for the fuel used to power the heating system in the left most column
[b]- np (not possible) as the same fuel is used so a price change in the fuel can not result in changing relative costs of the heating systems
[c]- the percentage change in break-even fuel price from the base fuel price is in parenthesis.

While heating oil regardless of the heating appliance is the most expensive option unless there are dramatic changes in relative prices, producers using propane are more likely to switch between propane and alternatives depending on the price changes. For example, a 30% increase in propane prices with constant natural gas prices would result in a broiler producer considering installing a pipeline to allow conversion to natural gas. The systems that are most sensitive to price changes are those using propane versus biomass. Biomass boilers are the cheapest option and it would require an increase in the price of biomass from \$0.15 kg^{-1} (\$0.07 lbs^{-1}) to either \$0.22 kg^{-1} (\$0.10 lbs^{-1}) for propane fuelled radiant tube heaters and \$0.26 kg^{-1} (\$0.12 $lbs.^{-1}$) for propane fuelled box heaters before the latter heating systems become cost effective. Alternatively, propane prices would have to fall from \$0.50 L^{-1} to \$0.41 L^{-1} for box heaters or \$0.47 L^{-1} for radiant tube heaters before total heating costs would be the same for a propane and biomass heating systems. Given the lack of a liquid biomass market presently, the relatively small changes in relative propane and biomass prices, suggest that it is unlikely a broiler producer would be induced to switch from the use of propane to biomass under current market conditions. This could change if propane prices continue to increase (EIA 2014) and if biomass markets develop.

Natural Gas Pipeline Connection Cost

The conclusion surrounding the cost-effectiveness of natural gas heating systems depend critically on whether a connection exists between the broiler barn and a natural gas pipeline. The break-even distance between the barn and the pipeline is illustrated in Figure 1 for radiant tube and biomass boiler heating systems. Each kilometer of pipeline is assumed to cost \$35,000, regardless of how many kilometers of pipeline are being installed. At approximately two kilometers of pipeline, or \$70,000 in contribution to pipeline construction costs, the costs are similar between natural gas radiant tube heating (including the costs of pipeline connection) and the alternative propane and biomass heating systems. The distance increases to seven kilometers before a heating oil system would be the preferred option.

Figure 1. Present Value of Costs as Natural Gas Pipeline Distance is Increased



Discount Rate

The costs are incurred over a twenty year period so altering the discount rate alters the relative importance of purchase and installation costs, which occur initially, and fuel costs, which are borne annually (see Table 4). Lowering the discount rate to 4% increases the absolute value of the present value of costs but does not change the least cost ranking of heating systems from the base scenario. Radiant tube heaters and box heaters fueled by natural gas are the most cost effective systems with the same appliances fueled by heating oil the most expensive options. However, increasing the discount rate to 16% not only lowers the present value of costs but, more importantly, it changes the relative rankings. A higher discount rate places more emphasis on earlier expenditures and less emphasis on expenditures that occur later on in the time period, while a lower discount rate places more emphasis on expenditures that occur later in the time period, and less emphasis on earlier expenditures. Both heating oil systems become cheaper options than the natural gas systems due to the significant initial investment costs required for connecting to the natural gas pipeline.

Table 4. Present Value of Costs for Alternative Heating Systems under Base Model with Varying Discount Rates

		Discount Rate	
Heating System	Base (8%)	Low (4%)	High (16%)
Box Heaters			
Natural Gas (5 km)	$238,699	$273,797 (15%)[a]	$197,957 (-21%)
Natural Gas (0 km)	$76,662	$105,527 (38%)	$47,095 (-63%)
Propane	$181,804	$251,065 (38%)	$110,586 (-64%)
Heating Oil	$307,916	$425,630 (38%)	$186,741 (-65%)
Radiant Tube Heaters			
Natural Gas (5 km)	$230,093	$261,850 (14%)	$192,804 (-19%)
Natural Gas (0 km)	$68,056	$93,581 (38%)	$41,942 (-62%)
Propane	$159,507	$220,160 (38%)	$ 97,174 (-64%)
Heating Oil	$269,170	$371,956 (38%)	$163,396 (-65%)
Biomass Boiler	$149,907	$178,440 (19%)	$91,679 (-64%)

[a]-The percentage change in cost of heating system compared to the base.

Distribution of Costs

The software @RISK is used to conduct an analysis of the effects of changes in variables on the present value of cost calculations. The @RISK simulations calculated the present value of costs 10,000 times for every fuel/appliance combination using the distributions given in Table 1. The minimum, mean, and maximum present value of cost, as well as the 95% confidence interval for each of the nine fuel-appliance combinations are listed in Table 5. The distribution of the present value of costs for the natural gas and biomass heating systems are skewed leftwards indicating that costs are likely to be lower than the mean values. In contrast, the present value of cost distributions for propane and heating oil are both skewed rightwards suggesting that total costs are likely to be higher than the mean.

Variation in pipeline connection distance has the greatest effect on the present value of costs for natural gas heating systems, while changes in fuel price and discount rate have a roughly equal impact on costs. Appliance prices have a very small effect on the relative rankings among heating systems. Similarly, the present value of costs for propane and heating oil systems are affected largely by the discount rate and to a lesser extent by corresponding fuel prices. Again, changes in appliance prices appear to generate relatively little change in the final calculations. Fuel price have the largest impact on the cost of a biomass boiler system compared to any other variables examined, followed by the discount rate and appliance costs. For biomass systems, the cost of the appliance has a larger impact on the present value of costs than any other appliance examined.

Table 5. Present Value of Cost Calculations When All Variables are Allowed to Change Based on Their Specified Distributions

Heating System	Minimum Value	Mean Value	Maximum Value	95% Confidence Interval	Standard Deviation
Box Heaters					
Natural Gas[a]	$30,404	$264,102	$590,260	$107,344 - $446,243	$102,775
Propane	$136,620	$230,701	$357615	$168,173 - $301,532	$40,655
Heating Oil	$121,867	$245259	$403,994	$172,035 - $329,620	$47,989
Radiant Tube Heaters					
Natural Gas	$33,102	$259,730	$592,372	$105,385 - $440,803	$101,818
Propane	$124,336	$206,526	$321,930	$151,129 - $269,819	$36,196
Heating Oil	$113,339	$219,467	$360,683	$155,261 - $295,018	$42,571
Biomass Boiler	$67,273	$121,191	$1,807,223	$86,532 - $171,959	$42,566

[a]- Natural gas pipeline distance is considered a variable in this case, therefore there is no separate analysis of the 5 km and 0 km pipeline connection distance scenarios

CONCLUSIONS

Broiler chicken barns can be heated with a variety of appliances and fuels but the least cost option depends on a number of factors including fuel prices. Relative fuel prices have changed considerably with the increases in the supply of natural gas, the steady price increases for conventional fuels (propane and heating oil), and the development of biomass alternatives. However, natural gas pipeline infrastructure is limited in rural areas, and poultry producers not already located on the natural gas pipeline face high connection costs.

This paper estimated the present value of purchase, installation, and fuel costs over a twenty year period for nine heating systems. The empirical model determined heating requirements given barn size, insulation, and ventilation parameters and the least cost equipment choice to meet that heat demand. It then calculated the amount of fuel requirement for that appliance system and the resulting fuel cost. Base case results suggest that natural gas, when a pipeline is already in place, is the least cost, followed by biomass, propane, natural gas when a pipeline is not in place, and heating oil. These results are supported by the current trends in the poultry industry. Biomass was projected to be the least cost heating system if a natural gas connection does not exist, followed closely by propane fuelled appliances. However, the price difference between biomass and propane systems may not be enough to biomass use over propane use. Unacknowledged biomass costs may serve to make biomass systems more costly than reported here.

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