Feasibility of Reducing a Dairy Farm's Manure Enterprise Costs Using a Wet Gasification Technology

Peter Wright and Curt Gooch
Cornell PRO-DAIRY Dairy Environmental Systems Program

October 2018

Executive Summary: Manure management is a major system on dairy farms and there is a goal to minimize costs and maximize benefits. Adding a wet gasification system to reduce spreading costs and possibly increase byproduct sales was evaluated on a central New York farm that was considering expanding but would need additional crop fields to recycle the additional manure at a further distance from the farmstead. There are many variables to consider. On the example farm the economics of the system would only be favorable if some optimistic values were assumed such as higher prices for the ash byproduct and/or higher prices for the excess energy produced. Dairy manure as produced moisture content is too high for efficient gasification. Wet gasification is better suited to operations where the raw manure is drier or can be separated into a low concentration liquid stream (that can be spray irrigated) and a high total solid content (25 to 30% solids) solid stream that could be processed by gasification into a salable ash.

Background: A successful manure management system on dairy farms is one of the major operations a modern sustainable dairy farm must have in place. Manure has value as a nutrient source, soil amendment, and with treatment it can also be an energy source. The challenges with raw dairy manure are the low density of nutrients (so hauling costs are comparatively high when compared to conventional fertilizers) and high moisture content so most energy extraction is costly (anaerobic digestion is an exception but that process only very marginally reduces the mass of manure to be hauled). A gasification technology that extracts energy from the manure solids and reduce the mass was evaluated to determine the potential as an improvement to a farm's existing manure management system. This technology was investigated on an example farm to see what the possible applications might be. Current and projected farm data along with cost and performance data from the supplier of the gasification system were used to perform an annual economic cost benefit analysis to determine the value of the system to the farm's manure handling enterprise.

Farm: The farm used for the analysis was a 1,500 milking cow dairy farm located in central NY and was selected because the farm is representative of dairy farms that are striving to be more sustainable and have some goals to grow the farm. They have capacity in their existing milking system to expand to 2,500 milking cows. Each cow produces an average of 150 lbs. of raw manure (urine and feces) per day. Manure exiting the barn contained bedding, wastewater, and other fluids and solids added by the cows, machinery, and people. Therefore, 1,500 cows will produce about 113 tons of manure per day and 2,500 cows will produce about 188 tons of manure per day. One aspect to consider in the potential to expand includes handling the additional manure that would be produced. In 2016 they used 1,591 acres to recycle manure on their owned and rented cropland. This operation involved 1,760 loads of long-term storage effluent at a cost of approximately $217,000 (some manure was pumped to a drag hose system directly). If they expanded to 2,500 milking cows, based on a projection of the manure amounts, hauling costs and field locations they would need an additional 1,400 acres and have an estimated total manure spreading cost of $332,000 per year (assuming the average distance hauled to the new fields was 6 miles one way).

Dairy farms use a land base to both grow and harvest forage as well as to recycle the nutrients from manure as fertilizer for the growing crop. This farm averaged 1.4 acres of cropland per cow; however, there are farms with both more and less acres per cow. The area surrounding the farm is intensively farmed and competition for land may mean they have to go much further from the farmstead to rent or purchase enough land for an expansion. A technology to reduce the manure handling cost could be a factor in the economic decision to expand to 2,500 milking cows. This farm has their high producing cows on sand bedding. Sand-laden dairy manure would present problems both for the required pre-gasification treatment system using mechanical solid-liquid separation (SLS) as well as the wet gasification unit itself. Switching stall bedding to a material other than sand bedding could have a detrimental impact on milk production, milk quality, cow comfort, and overall herd health.

Technology: The proposed treatment system is a wet gasification system which would reduce the total mass of manure required to be hauled to cropland. In wet gasification, organic streams including manure are thermally converted to a syngas in two stages. The first stage, called devolatilization, converts the manure slurry to a char slurry under saturated liquid water conditions. The second stage, called gasification, converts the previously prepared heated char mixture into gaseous synfuel, steam, and ash. After conversion, the stream is cooled to both recycle energy and extract the beneficial heat for reuse. The processing conditions are such that high-moisture waste streams can be treated without the substantial energy penalty associated with vaporizing the water. The projected mass and energy flows are shown in Figure 1. One potential benefit of this process is that it may reduce the manure hauling cost associated with additional cows and a more distant land base to recycle the nutrients from the expansion and mitigate those costs through possible byproduct sales. The wet gasification technology required an influent dry matter content (DM) of at least a 25% total solid (TS) to have a positive energy balance. Since barn effluent from a modern dairy farm is approximately 10% TS a SLS system would be needed for pre-treatment before gasification. Current screw-press technology (typically used on dairy farms) can produce a separated solids stream with a 30% TS. This 30% TS stream would then be fed to the wet gasification system. After wet gasification the resulting outputs would include a liquid portion containing the silicon, phosphorous and potassium ash, syngas, high temperature steam, and low temperature heat. Organic matter and nitrogen would be consumed in the gasification process.

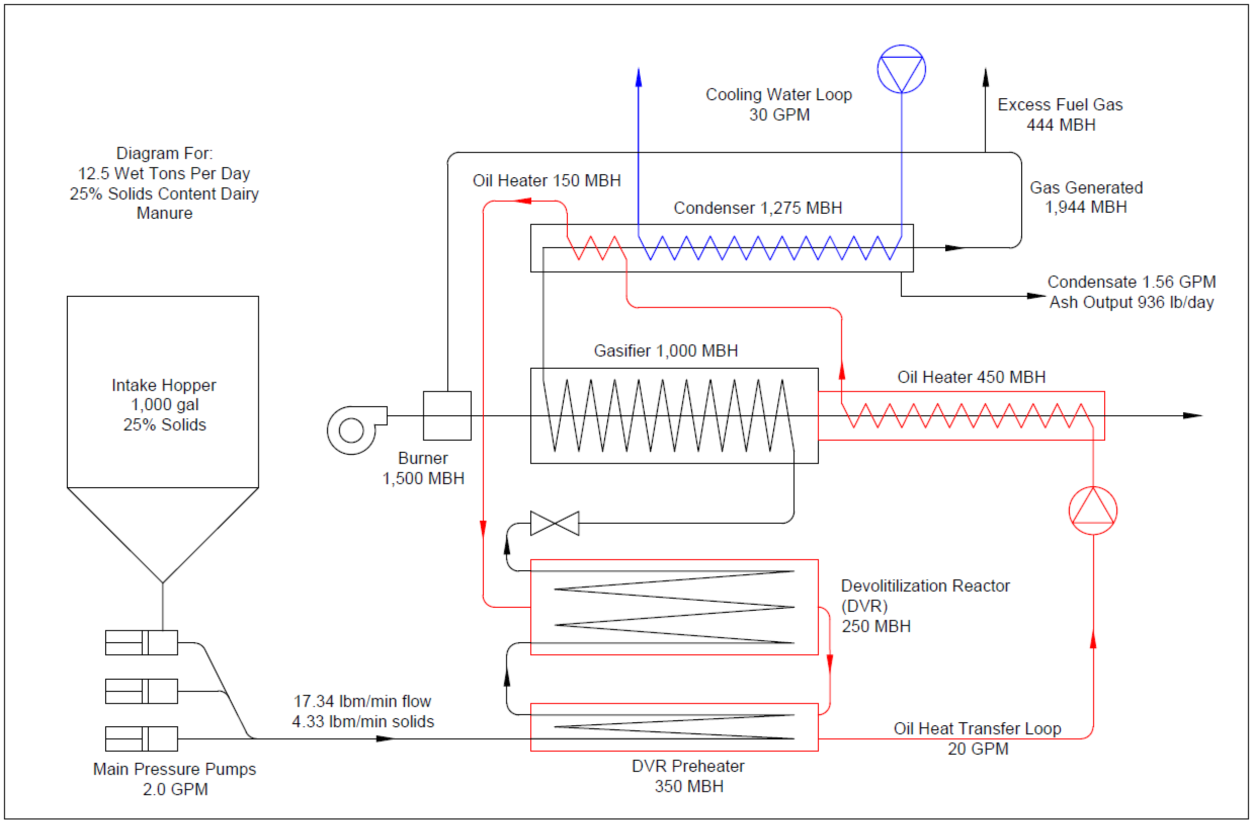

Figure 1. Example mass and energy flows for a wet gasification system.

Thermal energy produced on a dairy farm has little value. Although a minimum amount of heat as hot water could be utilized this lower temperature heat value was not included in this analysis. Using the heat as a driver for cooling was not considered in this analysis as dairies already have plate coolers utilizing a temperature exchange with ground water and commercial absorption chillers do not achieve temperatures low enough for proper milk storage (< 38°F). The energy from the syngas and steam produced from this technology was assumed to be used to produce electricity using a steam driven generator and a syngas fueled engine-generator and exported from the farm. At this time, a syngas fueled engine-generator is not readily available.

Economics: An initial look at the system's economics was made by calculating the annual economic costs minus benefits of the system. This was done using an excel spreadsheet using actual manure spreading costs from the farm for the crop year 2016 (September 2015 to August 2016). The actual amount of manure, as recorded in the farm's Concentrated Animal Farm Operation (CAFO) permit documentation, was used to obtain the number of tractor and spreader or truck loads delivered per field, pumping costs to the fields, and spreading methods (either directly from the tractor and spreaders or trucks, from a pumped drag hose system, or a combination of delivery by trucks and then spreading through the drag hose system). Both capital costs, and annual operation and maintenance costs were included in the manure hauling operation to determine an hourly rate ($120/hour for the trucks and tractor spreaders, and $520/hour for the pumping/drag hose system). The travel distances to and from each field (0.08 miles to 19.02 miles roundtrip) and spreading rates (8,260 gallons/acre to 19,610 gallons/acre) were determined for each field and used to determine the total cost of applying the manure to each individual field. Costs ranged from $36/acre for close fields with a low amount of manure spread, to $256/acre for further fields spread at a high amount of manure. Travel speeds were assumed to be an average 20 miles per hour on the road with trucks, 15 miles per hour with tractors, and five miles per hour in the field.

The annual benefits minus the annual costs of the technology applied to the farm's manure handling enterprise was determined by including the capital costs for the technology as well as the additional appurtenances (SLS, steam and syngas combustion engine-generators) including lost opportunity, the operating costs, (parasitic energy cost, O&M cost) losses to the farm in potential milk production (from shifting away from sand for bedding) nutrients (nitrogen) loss, organic matter lost, and the potential benefits to the farm in reduced hauling costs, electricity production, and potential sales of the nutrients in ash. A 30% TS content for the solid stream from the SLS was assumed.

Zero economic benefit prices: The prices needed to have a zero economic benefit for the system (net benefits minus costs) are shown in Table 1. This analysis assumes that there are no ash sales, no sand bedding (no loss income from milk), and lost opportunity rate is 10%. Each of the variables are considered alone. A combination of more optimistic (lower) costs and/or (higher) benefits could be achieved to provide this system with a positive economic benefit.

Table 1. Prices to obtain a zero economic benefit (net benefits minus costs equal $0) for the expanded 2,500-cow dairy in central NY for each variable alone.

Variable	Break Even Price	Comments
Capital costs ($/Unit)	$0 Wet Gasification $0 for SLS $1,750/kW for steam gen-set	- Assuming grants are available - Assuming a separator already exists - Steam gen-set is $1,750/kW
Electric Price ($/kWh)	$0.156/kWh 5 million kWh/yr. produced	Includes $0.03/kWh maintenance cost on engine-generators. (This is renewable energy but only ~50% reduction in GHG.)
Hauling cost ($/load)	$2,530/load 159 loads/yr. reduced	8,400 gallons/load (approximately a 420-mile round trip)
Ash Sales ($/ton)	$374/ton 898 tons/yr. produced	This price includes the reduced hauling costs as the water separated from the ash can be spray irrigated without hauling.

Variables used: There are a number of variables that would determine the feasibility of using the gasification system to benefit the farm. On-farm changes to use the technology include adding a screw-press separator, changing bedding for high producing cows from sand bedding to paper or other organic bedding material, and additional N fertilizer to replace that lost in the gasification system. Constraints are that the moisture content (MC) of the manure fed to the gasifier would need to be 75% MC or less for a net positive energy balance. After SLS the solid stream is only 20% of original cow manure mass plus the bedded pack manure from the heifer operation (approximately equivalent to 60 cows, at a herd size of 1,500 and 100 cows at a herd size of 2,500) would be able to be processed with the wet gasification technology. Running the system with a negative energy balance (wetter than 75% MC) eliminates any energy benefit, increases the energy cost of the system, increases the nitrogen loss, and increases the capital costs. These costs are more than the benefit of reducing the manure hauling costs.

Table 2 and Table 3 show most of the variables. Variables not included in the tables but included in the analysis are loss of organic matter at $2/ton, insurance at $5,175/unit-year, propane used for startup 4 times per year at $1,200/unit-year, parasitic electricity, averaging 6 kWh/hr. at $0.08/kWh totaling $4,205/unit-year. A 95% capacity factor was assumed for both the steam engine (62 kW/unit) generator and the combustion engine (141 kW/unit) generators. These and other factors were included in the economic calculation shown in the tables. Each individual farm may have variations in all these values. These variables will also change over time. Changes in the values will affect the economic calculation and the overall results. Farms with a number of optimistic values may find that the benefits are greater than the costs. Most dairy farms operating as a freestall in the humid northeast with current prices would have costs greater than the economic benefits.

The capital costs of the wet gasification system were provided by the manufacturer. The optimistic amount could occur with economies of scale. Another consideration is the possibility of grant funding for the technology to encourage innovative technology and allow for third-party performance monitoring and verification and to assist the farm to provide better nutrient control (phosphorous could be exported in the ash as a result of this technology). The capital costs for this technology are significant.

Modern dairying is a capital-intensive business. Farms have a number of opportunities to invest in their business that will provide a return on investment and reduce operating costs. A 10% opportunity cost was selected assuming there are opportunities on most farms for capital spending that would achieve that rate. Highly capitalized farms may have the more optimistic value of 3%. Some farms already have a SLS so this cost would not be included in evaluating the system. The capital costs for the steam and combustion engine generators are estimated as there is not a large market for steam generators and the combustion engines on the market at this time do not run on syngas. Again, the optimistic costs could occur in the future if the technology were produced on a larger scale. As farms decide which investment to make, they need to consider the cost of the investment, the rate of lost capital they are forgoing with each investment, and the return on investment.

The installation cost of $50,025 includes site preparation (land grading, gravel), crane to unload and place each unit, utility connection including electric, water and propane, and then connection of components and the control panel. It is assumed that a difficult site and or multiple units would have a larger cost of $100,000.

The manufacturer estimated the life of the project to be 20 years. As the actual life increases or decreases it changes the impact of the capital costs by spreading the costs over more or less years. An optimistic life span of 25 years was used. The manufacturer also calculated the processing capacity per unit at 30% TS to be between 14 to 17.1 wet tons per day. The more manure that is processed the more ash is produced, the more the hauling costs are reduced, and the more nitrogen is lost. The manufacturer will provide the preventive maintenance of the equipment for a set fee of $25,000 per unit per year. The optimistic rate of $20,000 per unit per year would again come from economies of scale. Over the life of the project the labor costs for this maintenance may increase.

The calculation results shown in the tables make it clear that if shifting from sand for bedding causes a loss in milk production and quality, then the application of this technology would not be beneficial. Sand is an excellent bedding, keeping cows comfortable and reducing mastitis incidents. Some farms experience as much as a 7 lbs. per cow per day milk production increase when switching to sand bedding. There are a number of farms that use sand for bedding but there are also a number of farms using organic bedding so this variable would not need to be considered on those farms. Some farms do use the separated solids from the SLS and so an alternative bedding may need to be found in that case.

The wet gasification process converts all the nitrogen in the manure to a gaseous form that is not recovered to be recycled for fertilizer. A farm that is utilizing all the manure to provide the nitrogen for their crop production would experience a cost to replace this nitrogen. A cost of $0.30 per pound of nitrogen fertilizer was assumed. However, some farms have a nitrogen excess and so the optimistic impact of the wet gasification process would not be a cost and in some cases might be a benefit.

Wet gasification produces both steam and a syngas. The most fungible use of the steam and syngas on a dairy farm is to turn it into electricity for offsite sale. Renewable energy should get a premium price in the market. The optimistic price of this renewable energy was set at $0.07/kWh. An operating cost of the engine gen-set was already subtracted out of this cost. There would also be a greenhouse gas reduction with the combustion of some of the manure and reduction of methane emissions from storage with SLS. It may be possible to get renewable energy credits and carbon credits. Verification and certification for these credits may add an additional cost.

The amount of electricity produced depends on the efficiency of the steam and combustion engine generators. Presently there is a steam engine available with an efficiency of 14 %. It may be possible to optimistically increase this efficiency to 30%. Combustion engines do exist with efficiencies in the 40% range for biogas. However smaller engines that may not be sized specifically for the system and would be fueled by the syngas may have a lower efficiency.

The value of the ash would depend on its intended use. If the ash would be disposed of on the farm it likely would remain mixed in the effluent and need to be hauled and spread on fields meeting the nutrient management plan in the farm’s CAFO permit. However, the value of the phosphorus in the ash as a feed supplement for swine has been estimated as high as $600/ton. Conditioning the ash, finding the market, and delivery may reduce this amount to the $300/ton value used as the optimistic range.

Sensitivity: An economic sensitivity analysis was performed by calculating the difference between the annual economic benefit and the annual economic costs using the individual most optimistic range given and then dividing by the base case and then calculating the percentage reduced (or increased). The larger the percentage the more that factor will influence the resulting annual economic analysis. The results of the sensitivity analysis show that the variables that influence the outcome of the total annual economic cost/benefit analysis are the ones least under the control of the technology provider or farm (capital cost, lost capital rate, milk production change with bedding use change, nitrogen value of fertilizer, price of electricity, and value of the ash).

Table 2. Major cost and benefit components for a 1,500 cows dairy farm using a 2 unit wet gasification process comparing realistic case annual benefits minus costs of a net cost to the farm of -$261,300 (for 2 units) and no loss of production with various operating variables. Each individual variable is evaluated alone.

Item	Value	Range	Sensitivity	Comments	Annual Benefits – Cost using best[1] or worse[2] value
Capital costs/unit	$1,000,000	$1,000,000 - $750,000	23%	Wet gasification $1M - $1.5M but grants could reduce capital costs	−$200,600
Capital Cost Solid Liquid Separator		$100,000 - $200,000	−5%	Costs increase if modification needed	−$273,900
Capital Cost/kW For Steam generator	$2,000	$2,000 - $500	9%	More efficient production?	−$238,900
Capital Cost/kW For combustion eng-generator	$500	$500 - $800	−4%	Engine gen-set may not be standard size	−$271,600
Installation Cost total	$50,025	$50,025 - $100,000	−2%	Little change with additional units	−$267,200
Life	20 years	20 - 25 years	7%	With maintenance life may increase	−$242,800
Lost Opportunity Cost	10%	10% - 3%	49%	Investment return	−$133,800
Through Put Wet	17.1	17.1 - 14 tons/day-unit	2%	w/o ash sales N and OM loss is reduced	−$256,100
Preventive Maintenance/year-unit	$25,000	$25,000 - $20,000	4%		−$251,300
On-Farm					
Change in Milk production from sand as bedding to organic	0	7 lbs./cow-day - 0 lbs./cow-day	−250%	$17/CWT for milk	−$912,900
Loss of N available to recycled	13.2 lbs. N/wet ton	0 - 13.2 lbs. N/wet ton	19%	1 lb. N/cow/day and $0.30/N lb.	−$211,900
Benefits					
Electric Price	$.05	$0.05 - $0.07/kWh	26%	Get renewable Energy and GHG value	−$193,900
Efficiency of Steam generator	14%	14 - 30%	9%	Availability in future?	−$237,000
Efficiency of engine - gen	30%	30 - 40%	−10%	Combustion engine efficiency varies with size of engine	−$286,400
Hauling cost per load	$128	$128/load - $150/load	1%	Future?	−$259,000
Value of Ash	$0	$0/ton - $300/ton	81%	Buyer? Sale of ash would also reduce hauling costs	−$50,700

[1]Best value case give the most optimistic value and is highlighted in the range.

[2]Worse value case is used to show sensitivity on some items and is highlighted in the range.

Table 3. Major cost and benefit components for a 2,500 cows dairy farm using a 3 unit wet gasification process comparing realistic case annual benefits minus costs of a net cost to the farm of -$382,700 (for 3 units) and no loss of production with various operating variables. Each individual variable is evaluated alone.

Item	Value	Range	Sensitivity	Comments	Annual Benefits – Cost using best[1] or worse[2] value
Capital costs/unit	$1,000,000	$1,000,000 - $750,000	24%	Wet gasification but grants could reduce capital costs	−$291,600
Capital Cost Solid Liquid Separator		$100,000 - $200,000	−3%	Costs increase if modification needed	−$395,700
Capital Cost/kW For Steam generator	$2,000	$2,000 - $500	9%	More efficient production?	−$349,100
Capital Cost/kW For combustion eng-generator	$500	$500 - $800	−4%	Eng-gen-set may not be standard size	−$398,200
Installation Cost total	$50,025	$50,025 - $100,000	−2%	Little change with additional units	−$388,600
Life	20 years	20 - 25 years	9%	With maintenance life may increase	−$355,500
Lost Opportunity Cost	10%	10% - 3%	49%	Investment return	−$195,300
Through Put Wet	17.1	17.1 - 14 tons/day-unit	2%	w/o ash sales N and OM loss is reduced	−$375,200
Preventive Maintenance/year-unit	$25,000	$25,000 - $20,000	4%		−$367,700
On-Farm					
Change in Milk production from sand as bedding to organic	0	7 lbs./cow-day – 0 lbs./cow-day	−283%	$17/CWT for milk	−$1,468,600
Loss of N available to recycled	13.2 lbs. N/wet ton	0 - 13.2 lbs. N/wet ton	19%	1 lb. N/cow/day and $0.30/N lb.	−$308,600
Benefits					
Electric Price	$.05	$0.05 - $0.07/kWh	26%	Get renewable Energy and GHG value	−$281,500
Efficiency of Steam generator	14%	14 - 30%	10%	Availability in future?	−$346,200
Efficiency of engine - gen	30%	30 - 40%	−10%	Combustion engine efficiency varies with size of engine	−$420,400
Hauling cost per load	$128	$130/load - $155/load	1%	Future?	−$378,800
Value of Ash	$0	$0/ton - $300/ton	83%	Buyer? Sale of ash would also reduce hauling costs	−$63,700

[1]Best value case give the most optimistic value and is highlighted in the range.

[2]Worse value case is used to show sensitivity on some items and is highlighted in the range.

Discussion: The annual manure hauling cost savings with the technology (and no ash sales) is approximately 106 loads/year (only 6% of the loads) or $13,554/year with 1,500 cows and approximately 159 loads/year (also only 6%of the loads) for the 2,500-cow operation for a savings of $20,331 per year at the present manure hauling costs. Best (most optimistic) case using all the best ranges in Table 2 and none of the worst yields annual benefits minus costs of $356,000 per year! Best (most optimistic) case using all the best ranges in Table 3 yields an annual benefit minus costs of $541,000 per year!

Certainly a combination of the some of the optimistic values could result in a positive net economic benefit. Each farm will have both opportunities and challenges that will make their application unique. Farms with a land constraint may use this technology to meet the demands (lower application rates) of their nutrient management plans despite a net economic cost of this system when taken as part of the whole farm management system.

The wet gasification system as well as the engine generators will produce a large amount of low-grade heat. The 1,500-cow example will produce an average of 4 million BTU/hour from the two engine-generators and 3 million BTU/hour from the two wet gasification units in the system. The 2,500-cow example would have three units so there would be the opportunity for a total of 10.5 million BTU/hour of available heat. Unfortunately there are no simple ways to utilize this potential benefit without adding another enterprise to the farm.

Ash sales as a feed supplement or as fertilizer have the potential to turn the wet gasification technology into a positive return. Ash is produced at a calculated rate of 0.82 tons per unit per day. The effluent of the wet gasification is ash mixed with water. The ash can be settled and then dried (using some of the excess heat from the system). The main constituents of value are phosphorous at 6% and potassium at 6.6%. If the TS from the effluent from the wet technology are removed for sale the remaining liquid could be spray irrigated at a low cost close to the farm. This decreases the hauling costs as well. For the 2,500-cow operation it reduces the yearly loads from 53/unit without ash sales to 178 loads per unit reduced with the sale of the ash and irrigation of the remaining liquid. Dairy farms in the humid northeast produce manure at approximately 10% TS. Although the wet gasification technology can be utilized at this moisture content it requires much more energy input and the energy balance is negative. This would also increase the capital costs as the throughput of all the manure would require a larger processing system. Even eliminating all the hauling costs on the example farm would not justify this high capital cost.

Technology advantages: A farm that was not using sand for bedding would be a better candidate for this technology. Dairy farms in drier climates might benefit from the wet gasification technology as the manure in those climates would be drier after deposition and collection. Swine farms (often separated from a land base so hauling costs are higher) that can use the heat generated for the swine housing, heat treatment to separate the solids, and more potential for a higher value of the ash (as a feed supplement) may create an opportunity for this technology. Certainly poultry farms that are notoriously separated from a land base, use the heat in the poultry barns, and produce an as excreted higher TS manure would find this technology much more favorable. Farms with a combination of animal production systems such that mixing a drier manure (poultry litter) with a wetter manure (dairy) to get a higher TS product for the wet gasifier might also benefit.

There may be synergies in using the wet gasification system in conjunction with an anaerobic digestion system (ADS). The ADS system uses biology to produce biogas (approximately 60% methane) still leaving much of the carbon available for gasification. The biogas could be combined with syngas to more easily run an engine-generator set. The waste heat from both the engine-generator set and the wet gasification could be used to dry the effluent from the ADS to enable a positive energy balance from the wet gasification system. In any case synergies with other enterprises that could utilize the waste heat (such as greenhouses, grain and wood drying, adsorption chillers, etc.) would help to increase the benefit side of the annual benefit/cost analysis.

Conclusions: There are many variables to consider when evaluating the impact of a manure treatment system on an individual dairy farm. Dairy manure, with an as produced total solids of 10% is too wet to efficiently utilize wet gasification technology as energy costs to remove the moisture is too high. The values for byproducts, energy, and nutrients from manure need to be large enough to support a manure treatment system. Dairy farms need to consider the impact of a manure treatment technology on the whole farm system.