Renewable Energy and Environmental Sustainability Using Biomass from Dairy and Beef Animal Production Facilities

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Volume III of Three Volumes

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Submitted by
Dr. John M. Sweeten, Texas AgriLife Research-Amarillo[1]
Dr. Kalyan Annamalai, Texas Engineering Experiment Station (TEES)[2]
Dr. Brent Auvermann, Texas AgriLife Research & Extension Center, Amarillo[1]
Dr. Saqib Mukhtar, BAEN/Texas AgriLife Research, College Station[3]
Dr. Sergio C. Capareda, BAEN/Texas AgriLife Research, College Station[3]
Dr. Cady Engler, BAEN/Texas AgriLife Research, College Station[3]
Dr. Wyatte Harman, Texas AgriLife Research, Temple[4]
Dr. J.N. Reddy, Texas Engineering Experiment Station, College Station[2]
Dr. Robert DeOtte, West Texas A&M University, Canyon, TX[5]
Dr. David B. Parker, West Texas A&M University, Canyon, TX[5]
Dr. B.A. Stewart, West Texas A&M University, Canyon, TX[5]

1. Texas AgriLife Research (formerly Texas Agricultural Experiment Station), Texas A&M University System
Texas AgriLife Research & Extension Center-Amarillo
6500 Amarillo Blvd West, Amarillo, TX 79106-1796

2. Department of Mechanical Engineering
Texas Engineering Experiment Station (TEES)
Texas A&M University (TAMU), College Station, TX 77843-3123

3. TAMU Biological and Agricultural Engineering Department (BAEN) &
Texas AgriLife Research, Texas A&M University, 217 Scoates Hall,
College Station, TX 77843-2117

4. Blackland Research and Extension Center
Texas AgriLife Research (formerly Texas Agricultural Experiment Station)-Temple
720 E. Blackland Road, Temple, TX 76502

5. West Texas A&M University
Department of Agricultural Sciences & Engineering,
Canyon, TX 79016-0001

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Submitted to:
U.S. Department of Energy-Golden Field Office
MS1501, 1617 Cole Blvd, Golden, CO 80401-3393

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Volume III
Cattle Biomass Feedstocks: Properties, Preparation, Logistics and Economics

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Appendix C

Investigator Task Report on Task A.9. Characterization of Beef Cattle Manure Combustion Ash for Value-Added Uses

Dr. Robert DeOtte, Dr. David B. Parker, Dr. Bobby A. Stewart, Anthony J. Megel, WTAMU, Canyon, TX
&
Dr. John M. Sweeten, Texas AgriLife Research, Amarillo, TX

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Written by: **Robert E. DeOtte, Jr., Anthony J. Megel, David B. Parker, John M. Sweeten, and Bobby A. Stewart**

Program Manager: TEES – Randy Kurmrey

Principal Investigators: Kalyan Annamalai
John M. Sweeten

Co-Principal Investigator: Robert E. DeOtte, Jr.

Subcontractors: Texas Agricultural Experiment Station

Cost-Sharing Partners: Mechanical Engineering – TAMU

DOE Project Team
DOE-HQ contact: Sara Wilson; 303-275-4922
DOE Field Project Officer: Kevin Craig; 303-275-4955 Kevin.craig@go.doe.gov
DOE Contract Specialist: Michael A, Schledorn; 303-275-4993; Michael.schledorn@go.doe.gov
DOE Project Engineer

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Task A.9 Characterization of Manure Combustion Ash for Value-Added Uses

Executive Summary

The fundamental goal of this research effort was to identify and explore potential uses for ash produced by combustion of beef cattle manure. The mechanical properties of the ash were explored for engineering and construction applications. In a parallel study, funded by Panda Energy Corporation and led by Dr. Bobby A. Stewart at West Texas A&M University (Darapuneni et al., 2009), the agronomic properties of the ash were investigated.

In preliminary work Dr. David Parker, West Texas A&M University, characterized the physical and chemical properties of the ash. The original hypothesis was that the ash would have properties similar to those from lignite and sub bituminous coals allowing comparable applications. The chemical composition makes it more like a Class F than a Class C ash and the applications are consequently bound by the same limitations as Class F ash. A second objective of the chemical evaluation was to determine the hazard classification, if any, for the ash. The ash is essentially inert and is classified as a Nonhazardous Industrial Class 2 waste according to Texas state regulations.

The agronomic studies indicated there is no value for the ash as fertilizer or soil amendment, but it can be applied in low-level land applications for disposal without damaging crops. The key potential fertilizer nutrient is phosphorous but it is tightly bound and not easily released, even with reduction of pH.

The engineering analysis is less clear. The manure ash does not have the plasticity of Class C ashes produced through combustion of lignite and sub bituminous coals. Whereas those ashes can be applied directly as road base, the ash from beef cattle manure must have lime or Portland cement added to have adequate cohesion to provide structural stability. However, amendment with cement or lime improves the plasticity allowing the use of ash in several structural applications including road base, flowable fills, and surfacing material for feedlot pens. The ash is nonreactive and the cyclone fraction may be used as the fine aggregate component for concrete. Amended to soil it reduces shrink-swell capacity and provides a measure of structural strength. Perhaps the most promising application is as friction enhancing material on icy roads in lieu of salt or sand. An additional possible application surfaced after completion of this research project. Fly ash has been used successfully to sequester heavy metals from runoff. Because the manure ash has particularly low heavy metal concentrations, it may be particularly suited for this application.

Many proposed applications ultimately proved not feasible because complementary materials could not be found or the physical properties of the ash presented difficulties that could not be overcome. For instance, it was proposed initially to use the ash to develop fire resistant wallboard, but a suitable binding agent could not be identified.

Recommendations: Research on the ability of manure ash to sequester heavy metals in aqueous environments should be pursued. In bench top laboratory experiments, the bottom ash demonstrated promise as a treatment for icy roads. Field scale trials should be pursued in which finer fractions of ash are sintered and crushed and applied to icy roads. With proper amendment with lime or Portland cement, the ash can be used in road base and flowable fills. Care should be exercised in land applications of the ash as it provides no agronomic soil amendment capabilities and if applied too heavily could degrade agricultural properties of the soil.

Task A.9. Characterization of beef cattle manure combustion ash for value-added uses

ABSTRACT

Ethanol producers propose to use energy extracted from manure in a fluidized bed combustion (FBC) process to generate steam for distillation of ethanol from grain and crop residues. Unlike natural gas, coal, or petroleum products, manure is a renewable resource of which there is a substantial supply in the Texas Panhandle. Proposed steam plants would produce approximately 25,000 kg (28 tons) of ash per hour for every 91,000 kg (100 tons) of manure burned per hour.

Characterization and classification of the ash material was determined from physical and chemical testing. Researchers evaluated a number of potential uses of the ash in an effort to identify several alternatives that would create a value-added product. This included combining the ash with inexpensive, readily available materials.

Results of physical testing show that the ash is marginally suitable as a subgrade material for road construction. The ash is not self-cementing; however, because its composition is similar to that of Class F fly ash, an ash-cement or ash-lime product could be used for structural building projects. These include feedlot surfacing, road base, flowable fills, and concrete amendments. The ash may also be used to increase traction on icy roads, increase soil strength, and reduce shrink-swell characteristics of clay soils. Results from chemical analysis show that the ash is classified as a Nonhazardous Industrial Class 2 waste according to Texas state regulations.

Keywords: Manure, manure ash, fly ash, soil amendments, feedlot, cattle, animal waste

INTRODUCTION

With approximately 5.8 million cattle fed annually in Texas Panhandle feedlots (TCFA, 2009) producing 16 million metric tons of fresh manure (Parker et al., 1997), the Texas High Plains has an abundance of this potential biomass fuel. Cattle manure could be used as a replacement for natural gas or other non-renewable energy sources for the production of ethanol (Stewart et al., 2000). Beef cattle manure produces 28 Mg of ash for every 100 Mg combusted. Using the Unified Soil Classification System for the fly ash component, approximately 30 percent is classified as bag-house (silt (ML): 100 percent silt), and 70 percent as cyclone ash (silty sand (SM): 75 percent fine sand and 23 percent silty fines). The bottom ash is classified as a poorly graded sand (SP): 4 percent coarse sand, 75 percent medium sand, and 21 percent fine sand, with the coarser clinker rating as poorly graded gravel (GP): 5 percent coarse gravel and 95 percent fine gravel. Applications of each of these ash fractions were evaluated in an effort to find economically beneficial uses for what otherwise is a waste product.

The literature review suggested several possibilities:

1. mixing with gypsum, quick lime, and caliches to improve plasticity and suitability as a road base material,
2. use of ash in flowable fill mixtures,
3. use of ash as a soil amendment to reduce shrink swell capacity, and
4. use of bottom ash as a road treatment for icy roads.

BACKGROUND

Fly ash is a by-product of combustion, usually of coal, and may be pozzolanic if silica content is sufficiently high. Pozzolans are used to stabilize Portland cement by reacting with the lime in the presence of moisture (Troxell et al, 1968). Fly ash cement materials are often combined with soil or aggregate to stabilize soil or form concrete (Kalinski et al, 2003). In fact, 60 percent of coal ash used in construction-related projects was for cement production or concrete products. Seventeen percent was used for structural fills or embankments, while 14 percent was used for stabilizing waste materials (TFHRC, 1997). Greenlees et al. (1998) found that in general, soil stabilized with fly ash-cement is stronger than untreated soil.

The basic components of fly ash-cement are:

1. fly ash; may contain pozzolans that are the silicate sheets
2. cementing agent; contains lime that provides the alkaline
3. water

The fly ash used in concrete is typically rich in tri-calcium aluminate (3CaO Al_2O_3), with a relatively small amount of calcium oxide (CaO). Greenlees et al (1998) concluded that stabilizing soil with fly ash-concrete was significantly (up to ten times) more cost effective than concrete pavement.

Fly ash is characterized as either Class C, which is produced from the combustion of lignite and sub-bituminous coals mined mostly in the western United States, or Class F, which is produced from the combustion of bituminous and anthracite coals mined primarily from the eastern United States. The primary difference between Class C and Class F fly ash is the amount of lime (CaO) each contains. Class C fly ash typically contains over 20 percent lime by weight and is therefore considered self-cementing, while Class F fly ash generally contains less than 10 percent. Because Class F fly ash contains so little lime, an activator or cementing agent must be used to achieve cementation (FHWA, 1999; Kalinski et al, 2005). General chemical make-ups for different ash materials are presented in Table A.9.1.

In addition to cement materials, fly ash can also be used in the creation of geopolymers. Fly ash-geopolymers are lightweight materials made by utilizing the Si-Al components of ash and kaolinite (when available). The typical dry density of these geopolymers is about 1500-1650 kg/m^3 (Wu and Sun, 2004). Such lightweight materials can be used to build structures that reduce deadweight, provide better thermal insulation, and cost less to transport.

Table A.9.1. Typical composition of major chemical compounds in various ash products, by approximate percentage (Kalinski et al, 2003; Greenlees et al, 1998; HRI, 2005; Wu and Sun, 2004; Malhotra, 1998; TFHRC, 1997)

	Cement	Class C fly ash	Class F fly ash	Manure ash
SiO_2	>21	30-45	40-60	68
Al_2O_3	<6	15-25	20-30	9
Fe_2O_3	3	5-10	10-30	7.5
CaO	63	15-35	2-8	2.6

These geopolymers are constructed with lightweight aggregates, fly ash (and sometimes kaolinite), water, and an alkaline solution. The alkaline solution is needed to activate the fly ash, since it is typically low in CaO. The solution used by Wu and Sun (2004) was prepared by mixing NaOH and sodium silicate with water. The process is exothermic and the temperature of the solution rises rapidly to about 90 degrees Celsius. After it completely cools at room temperature, the solution is added to the dry-mixed aggregate, ash, and kaolinite. The specimen must cure for 24 hours before the mold can be removed. After discovering that using a reduced-alkaline solution compromised the compressive strength of geopolymer specimens, Wu and Sun (2004) concluded that there should be an optimum alkaline content, although the value was not quantified. However, they did determine that the amount of NaOH-sodium silicate activators is crucial for achieving maximum mechanical properties. An interesting finding was that specimens cured at 80 degrees Celsius for 24 hours had almost the same compressive strength as those cured at room temperature for 28 days.

When combining ash materials with Portland cement to form concrete, the key compositional differences are the amounts of aluminum oxide and calcium oxide. It appears that to form a strong bond with cement, materials low in CaO (<10-15 percent) should be high (~25 percent) in Al_2O_3; however, high alumina content is generally associated with high clay content which is generally undesirable for concrete. The addition of alumina or aluminates to manure ash should be investigated: 1) it may provide a suitable cementious material, or 2) it may be suitable as an amendment to Portland cement concrete.

Portland cement can be cured in its pure form. Since cement and manure ash are both high in SiO_2 and are both low in Al_2O_3 and Fe_2O_3, the addition of lime (CaO) to manure ash could give it chemical properties similar to Portland cement and should therefore be investigated. This might be achieved by adding CaO in the form of 11quivale (calcium carbonate) or gypsum (calcium sulfate).

If a low-cost material can be effectively added to manure ash for increased strength, the resulting product may provide both disposal of the manure ash waste and an economic alternative to standard concrete or ash based concretes. If such a product can be created, then manure ash may have uses as a building material in the following areas:

1. Concrete
2. Soil-stabilizer/roadbase
3. Geopolymers

Megel et al (2006) found the compressive strength of manure ash-cement at 15 percent cement (approximately the same proportion found in standard rock-cement concrete) to be approximately 1000 psi. Further investigation may be needed to determine the correct proportions of manure ash needed for concrete as compared to typical sand-based cement concrete.

Some consideration has been given to using the manure ashes as soil amendments. Sloan and Cawthon (2003) found that a mixture of coal ashes and dairy manure was effective in facilitating revegetation of acidic soils at surface mines. Darapuneni et al. (2009) found addition of ash to the soil does neither apparent agronomic harm nor good. The efficacy of combining the beef cattle manure with manure ash has not been explored. Further evaluation of the properties of both coal and manure ash and dairy and beef cattle manure may be warranted.

Additional possibilities are outlined by the Federal Highway Administration in Fly Ash Facts for Highway Engineers and are summarized with comparisons to manure ash properties.

Stabilized base course is typically comprised of 10-15 percent fly ash, 2-8 percent lime material (or Portland cement), and approximately 80 percent aggregate. If made from manure ash, the aggregate would be cyclone ash possibly mixed with bottom ash, while baghouse ash would replace the fly ash. Megel (2006) fabricated a similar material with approximately 27 percent baghouse ash, 64 percent cyclone ash, and 9 percent cement, which yielded a 28-day compressive strength of nearly 1000 psi. A reformulation refined to that of stabilized base course and prepared to ASTM C593 would likely meet the 400 psi requirement. This material would have a slow curing time – 28 days at ambient temperature or 7 days at 100 degree Fahrenheit. It would be essential to seal the layers quickly with high compaction (FHWA, 1999).

Flowable fill does not have to meet ASTM C618 specifications. A low fly ash content flowable fill contains a high percent of fine aggregate with just enough water to make it flow easily. Baghouse can serve as the fly ash component, and the fine aggregate could be replaced by cyclone ash. This would yield a mix criterion of 10.0 percent baghouse ash, 86.7 percent cyclone ash, 3.3 percent cement, and a moisture content of 17 percent (FHWA, 1999). Megel's experiment (2006) consisting of 28 percent baghouse ash, 67 percent cyclone ash, and 5 percent Portland cement yielded a 28-day compressive strength of 242 psi, which is workable given the typical 50-200 psi range. The design criteria will determine the desired strength. Generally, materials with a 50 psi strength can be removed by hand, while excavating equipment is required to remove strengths of 150-200 psi.

Fly ash has been shown to improve the performance of Portland cement concrete. Aluminosilicate compounds in the fly ash react with calcium hydroxide to form additional cement bonds. Typically, 15-30 percent of the cement is replaced with fly ash, which is added as 1.0 to 1.5 times the weight of the replaced cement. For such a replacement, baghouse ash would meet the generalized specification of particle size(more than 66 percent of the material should be finer than 44 µm). Fly ash cement generally requires less water than Portland cement concrete, but caution must be exercised as fly ash cement has a lower early strength.

According to the Federal Highway Administration (1999), Class C fly ash can be exclusively used in soil improvement, while Class F fly ash must be accompanied by a cementing material. An approximate water content of 35 percent is required. Fly ash can be used to improve soil strength at depths between 150 to 460 mm (6 to 18 inches). Typical ash additions are 8-16 percent dry soil weight. When implemented, it is advisable to complete compaction quickly, as longer compaction delay leads to lower strength. When fly ash is used to improve shrink/swell characteristics of soil, the typical addition ranges from 12-15 percent. When used effectively, ash additions can lower swell potential to less than 0.5 percent. To evaluate mixtures, soil-ash blends should be tested to ASTM D4829 or D1883 standards.

Asphalt pavements can also be constructed using fly ash, and the lower specific gravity of the ash allows use of less material than with soil aggregates. According to Megel et al. (2006), both baghouse and cyclone ashes meet the following requirements for use in asphalt pavements:

1. plasticity index < 1,
2. 100 percent finer than 600 µm,
3. 95-100 percent finer than 300 µm.

Additionally, baghouse ash meets the following specifications:

4. 70-100 percent finer than 75µm,
5. typically 40-70 percent finer than 20µm.

Therefore, baghouse ash can be used in asphalt filler.

Highway engineers may find use for manure ash in grouts for pavement subsealing. General strengths are: >1200 psi (8300 kPa) at 28 days, 600-800 psi (4100 – 5500 kPa) at 7 days. Fly ash has been used in grouts as follows: 25 percent cement, 75 percent ash, and 38-75 percent water. Restrictions should be placed on the application of ash grouts for pavement subsealing. If the air temperature is between 2° - 10° Celsius (36°- 50°F), an accelerator should be added to the mixture. If the temperature is below 2° C, the grout should not be applied (FHWA, 1999).

Sand and fly ash are used as abrasives to treat icy and snow-packed roads. The sand or ash increases the static coefficient of friction of the road surface, giving vehicles more traction and a shorting stopping distance. Comfort and Dinovitzer (1997) showed that applying sand to a snow-packed road at 300 kg/lane km (1064 lb_f/lane mile) at temperatures below -15° C (5° F) increased the friction coefficient from 0.18 to 0.40. However, increased traffic crushes and imbeds the treatment and the coefficient can drop to to 0.23. Therefore, abrasives are often added to brine solutions before they are applied, or salts are laid down instead where available. Borland and Blaisdell (1993) found that course sand increased friction coefficients better at lower temperatures, while find sand had a better effect at warmer temperatures close to the melting point of ice.

Several have reported on the efficacy of using fly ash to enhance heavy metals retention of soils (Ayala et al., 1998; Banerjee et al., 2003, 2004; Erol et al., 2005). In summarizing the work of the previously cited authors and others, Zhang et al. (2008) indicated that soil cation exchange capacity (CEC), clay content, and organic matter content correlated positively with retention of heavy metals. The high concentrations of oxides of iron, aluminum, and calcium were presumed to explain heavy metal retention. Apparently investigators were working with Class C ash originating from lignite to western sub bituminous coals, as Class F ash from eastern bituminous and and anthracite coals have low concentrations of calcium oxides. Zhang et al. (2008) amended Oklahoma soils with ash and were successful in reducing heavy metals concentrations from runoff. They further reported that Bayat (2002) had suggested adsorption by Al_2O_3 and Fe_2O_3 could predominate at ph less than 8.0. The manure baghouse ash studied herein has CaO levels comparable to the lower range for Class C ash and Fe_2O_3 levels only slightly lower. The use of ash to retain heavy metals was not explored in this study, but is recommended for future efforts.

RESULTS AND DISCUSSION

During the course of researching economically beneficial uses of manure ash, eight subtasks were identified, Table A.9.2, and six were completed. One uncompleted task was development of a fireproof building composites, which was not completed because a suitable binding agent could not be identified. The other uncompleted task involved third party fabrication of a light weight architectural faux stone which was not pursued further because the required additional funding through the state of Texas Emerging Technology Fund did not materialize. Near completion of the research two additional tasks were identified, but funding was not available to pursue: A.9.9 – test capacity of manure ash to capture and hold heavy metals and A.9.10 – develop field trials to confirm findings of bench tests to manure ash as road base, soil amendment, flowable fills, and road surface treatment.

Table A.9.2. **Task description and status**

Task Number	Description	Outcome
A.9.1	Characterize ash from combustion and gasification experiments. Literature review on economically beneficial uses of manure ash	Completed Presented in the Background section of this report
A.9.1.a	Evaluate properties as road base	Completed Discussed below and presented at ASABE annual meetings
A.9.1.b	Evaluate properties and a soil amendment and stabilizer	Completed Discussed below and presented at ASABE annual meeting
A.9.2	Mix with caliches, lime, and gypsum to improve plasticity and suitability as a road base material	Completed Discussed below and presented at ASABE annual meeting
A.9.2.a	Mix with caliches	Improved plasticity only very slightly Initial increase in cementation but could not withstand wetting cycle
A.9.2.b	Mix with lime	Did not improve plasticity Did provide significant improvement in compressive strength
A.9.2.c	Mix with gypsum	Did not improve plasticity Did not provide increase in cementing capacity
A.9.3	Characterize ash as flowable fill	Completed. Viable application. Field testing required. Discussed below and presented at ASABE annual meeting
A.9.4	Use ash as a structural soil amendment to reduce shrink-swell capacity of soil	Completed Discussed below and presented at ASABE annual meeting
A.9.4.a	Characterize two local soils – Randall Clay and Olton Clay Loam	Completed
A.9.4.b	Characterize cyclone ash amendment to reduce shrink-swell of expansive soils	Some improvement through four wetting cycles
A.9.4.c	Characterize baghouse ash amendment	Some improvement through four wetting cycles
A.9.5	Disseminate information	Four papers presented 2006 ASABE Annual Meeting 2007 ASABE Annual Meeting 2009 Texas Animal Manure

Task Number	Description	Outcome
		Management Issues Conf. 2010 ASABE International Symposium on Air Quality and Manure Management for Ag
A.9.6	Investigate use of bottom ash as surface application for roads covered with packed snow and ice	Completed Shows promise
A.9.7	Investigate use of ash in fireproof building materials	Unable to find suitable binding agents
A.9.8	Interact with Milestone, Inc. of Amarillo to use ash in light weight faux stone and concrete architectural features	Dependent upon funding from Texas Emerging Technology Fund with West Texas A&M University and Texas AgriLife Research as subcontractors Not funded
A.9.9	Design experiments to test capability of manure ash to capture and hold heavy metals from runoff and atmospheric CO_2	Proposed as part of request to DOE for continuation funding – Denied
A.9.10	Develop field trials to validate laboratory findings	Proposed as part of request to DOE for continuation funding – Denied

Characterization of Manure Combustion Ash

Fluidized bed combustion of manure will produce approximately 28 tons of ash for every 100 tons (dry basis) of feedlot manure. Approximately 70 percent of the fly ash is pre-separated in a cyclone and 30 percent captured in a bag-house. Heavier products are classified as bottom ash and clinker. The Unified Soil Classification System catalogs bag-house ash as fine silt (100 percent silt) and cyclone ash as silty sand (75 percent fine sand; 23 percent fine silt). Bottom ash is similar to coarse sand and clinker is comparable to small gravel (Megel et al., 2006).

Chemical Testing

Samples of bag-house, cyclone, and bottom ashes were chemically analyzed by ASK Laboratories, Inc. in Amarillo, Texas. The Texas Commission on Environmental Quality (**TCEQ**) designation of waste as hazardous or non-hazardous is determined using the toxicity characteristic leaching procedure (**TCLP**) (40 CFR Part 261). Of the 39 listed constituents of concern, only chromium exceeded the Class 3 (the most benign) limits of 0.100 mg/L and that only in the bag-house ash. Total dissolved solids also exceeded Class 3 acceptable levels of 500 mg/L for bag-house, cyclone, and bottom ashes.

Physical Testing

Tests for particle size were performed according the ASTM Standard D 422-63 (ASTM, 1996c) and classified according to the Unified Soil Classification System (ASTM D 2487-93; ASTM, 1996d). Atterberg limits were determined following ASTM Standard D 4318-95 (ASTM, 1996e). Bag-house ash had a plastic limit between 41 and 42 with the liquid limit ranging from 40 to 42, indicating a plasticity index in the range of 0 to 1. The bag-house ash is classified as a non-plastic, or cohesionless, soil. Cyclone ash had a plastic limit ranging from 56 to 62 and a liquid limit ranging from 50 to 56. The average plasticity index (**PI**) was calculated to be 6, so cyclone ash also has low plasticity and is comparable to a cohesionless soil.

Table A.9.3. Atterberg testing results of ashes mixed with calcium compounds show that virtually no plasticity is achieved.

Ash	Additive	Liquid Limit	Plastic Limit	Plasticity Index	Plasticity
Cyclone	20 % gypsum	41	46	-5	NP
Baghouse	20 % gypsum	37	40	-3	NP
Cyclone	20 % caliche	58	57	1	1
Baghouse	20 % caliche	38	39	-1	NP
Cyclone	20 % lime	41	44	-3	NP
Baghouse	20 % lime	38	39	-1	NP

Agronomic Applications of Fly Ash

The results of the agronomic applications of fly ash have been published in the American Society of Agricultural and Biological Engineers journal Applied Engineering in Agriculture (Darapuneni et al., 2009). A condensed version was presented at the Texas Agricultural Manure Management Issues conference in September 2009 (DeOtte et al., 2009) and will be presented at the ASABE Air and Waste Management Symposium in Dallas, TX on 12-14 September 2010 (DeOtte, et al., 2010). The agronomic evaluation was funded by Panda Energy, Inc. and the Dryland Agriculture Institute at West Texas A&M University through Texas state initiative funding.

Manure is a rich source of plant available nutrients (Whalen et al., 2000) that improve the chemical characteristics of many soils. Chemical analysis of the cattle manure fly ash (Hazen Research, Inc., Golden, CO performed all chemical and proximate analysis) confirms that most of the phosphorus present in the manure is retained in the ash after the completion of combustion process, suggesting potential availability in the ash. Mathers et al. (1972) found that manure P concentration ranged from 0.32 to 0.85 percent, and averaged 0.53 percent. Assuming that the dry weight of the ash produced after complete burning of manure is about 30 percent of the dry weight before burning, and further assuming that no P volatilized, the average P content of the resulting ashes would be 1.75 percent. According to the analysis conducted by HRI, P content of the bag-house ash and cyclone ashes were, respectively, 2.2 percent and 1.0 percent indicting little or no P volatilized during the burning process.

Previous work by others indicates some potential for various ashes to be used as a soil amendment or fertilizer (Darapuneni, 2008). Elemental analysis of ash obtained from burning 100 percent cattle manure showed the P content to be about 1.3 percent and the amounts of leachable P (dry basis) present in the bag-house and cyclone ashes were determined to be 200 mg/kg and 40 mg/kg, respectively (Megel et al., 2006). The pH, electrical conductivity (**EC**), and concentrations of Ca, Mg, Na, Fe, and Zn were also determined to understand the overall affects of the 2 ashes on plant growth and soil properties. The objective of this portion of the study was to determine the impacts of manure ash application on plant growth through plant available P present in the bag-house and cyclone ashes. The investigators did not explore other features of ash application such as impact upon cation exchange capacity, water field capacity, or pH.

Soil incubation study: As a precursor to greenhouse studies, and using the same soil and ash treatment, a soil incubation study was conducted in the laboratory to investigate the effects that temperature and length of incubation had on soils treated with various amounts of bag-house and cyclone ash. The test matrix consisted of 2 soils (Amarillo fine sandy loam and Olton clay loam), 2 ash types yielding 7 ash treatments (control, cyclone ash at concentrations of 0.5, 1.0, and 2.0 percent (w/w), and bag-house at the same concentrations with 3 replicates for each soil type, 3 temperatures (15, 25, and 35 ºC), and 3 durations of incubation (0, 60, 120 d). Soils were maintained at approximate field water capacity. All samples were processed and analyzed simultaneously after the final incubation time. Analyses were conducted for pH, EC, and Mehlich-3 (Frank et al., 1998) extractable P, Ca, Mg, Na, Fe, and Zn. All agronomic chemical analysis were performed by Servi-Tech Laboratories, Amarillo, TX.

The amounts of P, Ca, Zn, and Fe extracted from incubated soils by Mehlich-3 extracting solution (not shown, ref. Darapuneni, 2008) are very similar to quantities extracted from the soils in greenhouse pots following growth of grain sorghum (Darapuneni, 2008). There was no effect for either length of incubation or temperature, but there were differences due to type of ash and rate of ash addition. The bag-house ash had a larger effect than the cyclone ash. The P results indicate that approximately half of the total P in the ash was Mehlich-3 extractable. The kind and rate of ash application also significantly affected EC values for soil incubation, but not for the soil analyses following harvest of the grain sorghum plants in the greenhouse study (Darapuneni, 2008). The bag-house ash increased EC value more than cyclone ash, which supports the visual observations discussed for the greenhouse study that early growth of the grain sorghum plants was negatively affected by adding ash, particularly the bag-house ash at the 2 percent rate. The EC values were higher in the Olton clay loam than in the Amarillo fine sandy loam. The buffering capacity is higher for the Olton soil and the field capacity value is considerably higher, so the negative effect on plant growth for the Amarillo soil is not surprising. The pH values of the soils were not affected by kind or amount of ash, so no results are provided.

Sulfuric acid treatment study: Sixteen 108 cm^3 jars were partially filled with 50 g of ash (8 with cyclone and 8 with bag-house). Half the samples of each ash were treated with concentrated sulfuric acid, and the other half with water. Two extractants, water and Mehlich-3, were used to estimate the available P in the two ashes. In both procedures, 1:10 extraction ratios (sample:water or Mehlich-3 extracting solution) were used to extract available P. Available P was analyzed by Inductively Coupled Plasma (ICP) procedures. Almost no P from either the bag-house or the cyclone ash was extracted by water and only about 1 to 2.5 percent was extracted by Mehlich-3 solution when the ashes were treated with water (Table A.9.4). However, when the ashes were treated with sulfuric acid prior to extraction, about 50 percent of the P in bag-house and about 65 percent of the P in cyclone ash were extractable by either water or Mehlich-3 solution. These results indicate the sulfuric acid solubilized a portion of the phosphorus contained in the ashes. It is somewhat surprising, and the reason is not fully understood, why such a small amount of P was extractable by the Mehlich-3 solution, when the ashes were not treated with sulfuric acid; because in both the greenhouse study and the soil incubation study as much as half of the P was extracted by Mehlich-3 solution. In those studies, however, the ashes made up only 0.5 to 2 percent of the soil mass, so the ratio of extracting solution to ash was very large in comparison to extracting only ash. The solution to ash ratio was 10 to 1, so there was a quite small amount of extracting solution.

Table A.9.4. Amounts of P (mg kg^{-1}) extractable by either water or Mehlich-3 extracting solution from bag-house & cyclone ashes after treatment with either water or concentrated sulfuric acid.

Kind of ash	Water extracting solution		Mehlich-3 extracting solution	
	Acid treated ash (mg/kg)	Water treated ash (mg/kg)	Acid treated ash (mg/kg)	Water treated ash (mg/kg)
Bag-house (2.17 % total P)	10,400	<5	10,625	236
Cyclone (0.99 % total P)	6,675	<5	6,275	254

Greenhouse study: A greenhouse study was conducted using grain sorghum (*Sorghum bicolor* L. Moench) as the test crop, because it is well suited to the Southern High Plains. The study consisted of 2 soils (Amarillo fine sandy loam and Olton clay loam), 2 types of ash, 4 rates of ash application, and 3 replications. For each soil, there were 3 pots for each of 7 treatments: control, and 0.5, 1.0, and 2.0 percent additions by weight of cyclone and bag-house ash. Twenty-one pots were used for each soil for a total of 42 pots for the study. The soils were sieved through a 6-mm mesh screen to remove plant material. Each pot was filled with 17 kg of soil or soil and ash, and 2.8 g of urea (75 mg N kg^{-1} soil) was added as a basal application and thoroughly mixed with the soil. On 16 May, 2006, 9 seeds of sorghum variety NC+5C35 were planted in each pot by hand at a 2-cm depth. Water was added to approximate field capacity. Pots were weighed daily to determine water loss from evapotranspiration and water added periodically to maintain soil moisture near field capacity. Additional N as urea solution (15 mg N kg^{-1} soil) was added 30 and 60 d after planting. Thrip and greenbug infestations were observed during early and late growth stages, but were controlled.

Panicles and stalks from each pot were harvested separately and placed in bags. All samples were dried in an oven at approximately 50 ºC and dry weights determined. Samples were ground and analyzed for total N and P. Following harvesting of the plants, soil samples were collected from each pot, then dried, ground, and analyzed for pH, EC, and Mehlich-3 (Frank et al., 1998) extractable P, Ca, Mg, Na, Fe, and Zn.

There were no statistically significant differences ($p < 0.05$) due to kind or amount of ash on the panicle weights and stalk weights of grain sorghum plants. During the early growth stages, particularly for the Amarillo sandy loam, there were some visual signs indicating bag-house ash had a negative effect on the plants; however, as the plants matured, these signs dissipated. There were also no significant differences in the concentration of P in the panicles or in the stalks due to kind of ash or rate of application. There was, however, some indication that the P concentration of the panicles was greater for plants grown in the Amarillo soil because the concentration of P in the control treatment was lower than any of the other treatments; however, the difference was not significantly different at the 0.05 level. The P concentration of the panicles for all treatments, with the exception of the control treatment for the Amarillo soil, was about 0.35 percent or higher, which suggests that P was not limiting plant growth. Phosphorus concentration of sorghum grain is generally 0.33 or greater (Smith, 1995). Although the concentrations reported here are for panicles instead of grain, grain makes up about 80 percent of the weight of panicles. The P content of the control treatment for the Amarillo soil was only 0.25 percent, which indicates that plants from this treatment were possibly P deficient; but the P concentration of these plants were not statistically different at the 0.05 level.

The amounts of P, Ca, Zn, and Fe extracted from the greenhouse soils by Mehlich-3 extracting solution are shown in Table A.9.5. A considerable amount of the P added as ash was extracted by the Mehlich-3 solution. Using the 1 percent bag-house ash treatment for the Amarillo sandy loam as an example, approximately 217 mg P was theoretically added to each kg of soil because the P analysis of the ash was 2.17 percent. The extractable P from the 1 percent treated soil following harvest of the grain sorghum plants was about 150 mg kg^{-1} compared to about 25 for the control. This indicates that more than one-half of the total P added as bag-house ash was extracted by the Mehlich-3 solution. Similar extractable amounts were found for the other addition rates of bag-house ash and for the Olton clay loam as well. The P content of the cyclone ash was only 0.99 percent, so theoretically only 99 mg kg^{-1} P was added to the soil when 1 percent ash was added, but it appears from the data presented in Table A.9.5 that somewhat less than half of the P in the cyclone ash was extracted by the Mehlich-3 solution, but the amounts extracted were significant. It is not surprising that a higher percentage of the total P was extracted from the bag-house than from the cyclone ash, because bag-house ash is much finer in texture providing a greater surface area for reaction. The kind and amount of ash added to the soils had significant effects on the amounts of Ca, Zn, and Fe extracted by the Mehlich-3 solution. All three of the elements were increased more in soils treated with bag-house ash compared to cyclone ash. This parallels the data for P and likely for the same reason, which is that the bag-house ash is much finer in texture.

Table A.9.5. Analysis of soil from greenhouse pots following harvest of grain sorghum (values are averages of three replications)

Treatment							
Ash Type	Control	Bag-house			Cyclone		
Ash Rate, percentage	0	0.5	1.0	2.0	0.5	1.0	2.0
Soil	Amarillo sandy loam						
pH	8.6	8.6	8.7	8.6	8.6	8.6	8.6
EC, dS m^{-1}	0.41	0.29	0.37	0.48	0.44	0.34	0.30
P, mg kg^{-1}	27	76	150	248	46	61	107
Ca, mg kg^{-1}	1437	1657	1950	2370	1550	1657	1753
Mg, mg kg^{-1}	224	285	381	393	207	207	268
Na, mg kg^{-1}	197	158	213	223	227	186	184
Zn, mg kg^{-1}	1.7	3.4	5.2	7.7	2.0	2.5	3.5
Fe, mg kg^{-1}	49	66	109	169	85	70	86

Treatment							
Ash Type	Control	Bag-house			Cyclone		
Ash Rate, percentage	0	0.5	1.0	2.0	0.5	1.0	2.0
Soil	Olton clay loam						
pH	7.9	7.9	7.9	8.1	8.0	7.9	8.0
EC, dS m^{-1}	0.89	0.82	0.96	0.80	0.72	0.89	0.57
P, mg kg^{-1}	64	99	150	220	74	91	113
Ca, mg kg^{-1}	2257	2453	2637	3063	2263	2397	2433
Mg, mg kg^{-1}	424	454	513	575	443	441	497
Na, mg kg^{-1}	453	416	416	435	455	432	358
Zn, mg kg^{-1}	4.0	4.8	6.3	8.5	3.9	4.6	6.3
Fe, mg kg^{-1}	128	140	161	182	132	140	147

Electrical conductivity and Na measurements were also made on the extracts, but there were no measurable effects of the kind or rate of ash additions and the results are not shown. Soil pH values were also similar for all treatments and were about 8.6 for the Amarillo fine sandy loam and about 8.0 for the Olton clay loam. It was mentioned previously that early growth of the grain sorghum plants appeared somewhat stunted, particularly in pots of Amarillo fine sandy loam treated with 2 percent (w/w) added bag-house ash. The pH and sodium values do not indicate that salinity was a problem, but the buffering capacity of the Amarillo fine sandy loam is low and a small effect could have been enough to affect the small plants. Also, the soil samples were taken at the end of the study and considerable amounts of water had been added to the pots during the growing of the sorghum plants and the Ca and other elements added with the water could have caused some of the salts to precipitate.

The P concentration is about 2 percent for the bag-house ash and 1 percent for cyclone ash. Greenhouse and soil incubation studies indicated that some of the P in the ashes is plant available. However, the P content is so low that extremely large amounts would have to be added to soil to provide meaningful quantities. Soils incubated with different rates ashes also showed some increase in electrical conductivity, so ash should not be applied to soils at high rates without careful monitoring. Results suggest that these ashes can be applied to soils at rates of about 2 percent or less by weight without significant negative effects, but there will likely be no significant benefit. Adverse impacts could result at higher application rates.

Engineering Applications of Manure Combustion Ash

The physical and chemical characteristics discussed previously indicate that manure combustion fly ash does not have the characteristics expected of good road base and by FHWA requirements needs augmentation to provide the necessary plasticity and strength. Lime, caliches, gypsum, and Portland cement (discussed previously) were added with some success. The ability of the ash to reduce shrink-swell characteristics, for use as flowable fill, and for use as an abrasive for increasing friction on snow packed and icy roads were all explored.

Addition of 20 percent gypsum (calcium sulfate) or lime (calcium hydroxide) to bag-house and cyclone ashes yielded very low PI and are classified as non-plastic, Table A.9.2 above. Adding 20 percent caliches (calcium carbonate) to the bag-house ash yielded a low PI and the mix with cyclone ash has a PI of 1. All non-plastic mixes classify as inorganic silts, while the cyclone ash/caliches mix is considered elastic silt. Mixtures of 20 percent lime, caliches, or gypsum were added to bag-house ash with 31 percent water and cyclone ash with 34 percent water and then allowed to harden at room temperature. The mixtures were inspected at 24, 48, and 72 hr. All materials added cementing properties to the ashes; however, when rewetted the gypsum and caliches samples did not maintain strength and began to slake. The lime samples remained solid and after 7 d a metal putty knife could not penetrate the material. Lime was used in compression tests for evaluation as a possible cementing additive. Compression specimens were prepared according to ASTM (1996g) and tested per ASTM (1996h).

Based on Proctor testing of the ash, samples were prepared with appropriate moisture contents (cyclone ash at 35 percent, bag-house ash at 31 percent, and the 70 percent cyclone – 30 percent bag-house ashes at 34 percent moisture content). Four samples were made for each ash combination with 5, 10, 15, and 20 percent cement content and 5, 10, and 20 percent lime content – 48 total samples. Samples were cured in an air-tight, high-humidity environment for 28 d. Samples were compressed at a constant rate of 890 N/s (110 kPa/s) to a failure point 20 percent below the maximum load. The averages of maximum load and stress were calculated for each specimen type. At the optimum 10 percent ash content the 28-d compressive strength of the ash-cement mix is nearly 6900 kPa or about one-third the strength of traditional Portland cement concrete. The compressive strength of the ash-lime-cement combination with 10 percent lime is approximately 9300 kPa – close to one-half the strength of concrete. With the same proportion of cement, lime increases strength by 54.5 percent over samples without lime. Ash mixed with 5 percent lime at optimum moisture content yields suitable road base.

To examine the ability of the ash to improve shrink/swell in expansive soils, mixtures of ash and clay were made using Randall and Olton soils and tested in accordance with ASTM (1996e). Plasticity was verified according to ASTM (1996f). Randall clays are poorly drained soils found at the bottom of playas and are thermic Ustic Epiaquerts composed primarily of montmorillonite (Unger and Pringle, 1981). The liquid limit was 65, the plastic limit 31, and the plasticity index 34. Olton clays are thermic Aridic Paleustolls composed of montmorillonite and kaolinite (Unger and Pringle, 1998) and are found on gently sloping plains and upper side slopes of playas and draws. For the Olton clays the average liquid limit was 35, the plastic limit 16, and plasticity index 19. All values are consistent with the ranges provided by the USDA soil database.

To test the ash as a soil amendment, samples were prepared using a 20 percent ash concentration and evaluated by closely following ASTM (1996b). After being compacted, loaded, and saturated, samples were monitored for 24 hr until expansion had essentially ceased. Although initial results were promising, 50 percent reduction in soil expansion index, the soil-ash mixes tests were repeated to yield four wet/dry cycles after which the expansion index improvement was only 14–15 percent.

To test the ash for its ability to increase the friction of ice-covered roads, water was frozen (-10° C) in a metal tray at a depth of 1.27 cm. Using the apparatus shown in Figure 1, a flat plate loaded with a known mass was set on the treated ice and attached to a flask suspended over a pulley. Water was slowly added to the flask until the plate first began sliding at which point the weight of the water and the flask was measured. The following equation relates the coefficient of static friction to the known load and pulling force:

$$F = \mu_S N$$

where N is the normal force acting on the ice (weight of plate and known mass) and F is the pulling force (weight of the water and flask), and μ_S is the coefficient of static friction. Sand and a coal ash material typically used for traction control on ice were compared to the manure bottom ash for traction enhancement. Each treatment was applied at 300 kg/lane km (85 g/m^2) and at 600 kg/lane-km (170 g/m^2) with an assumed lane width of 3.6 m. The friction coefficients for all three treatments were comparable (Megel et al., 2007) indicating need for further study.

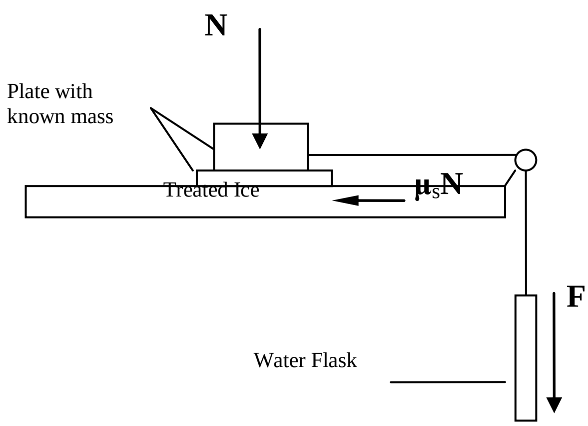

Figure 1. The setup for testing ice treatments satisfies the fundamentals of static friction coefficients. Friction is overcome by the weight of water added to the flask.

The engineering properties also presented little promise for use of the ash without amendment. The ash can be used in road base, but requires more Portland cement than would a Class C ash. In applications such as road base and flowable fills, the ash takes the place of the fine aggregates, but adds no plasticity. The addition of ash to expansive soils did improve the expansion index, but more testing is needed to see if the improvement continues to decline if the number of wet-dry cycles is increased beyond four. The use of bottom ash (tested) or fly ash after glazing and crushing (not tested) as a treatment for icy roads looks promising, but bears further investigation at field level.

ACCOMPLISHMENTS

Applications of a number of potential uses of manure ash were investigated resulting in a better understanding of the issues related to this product of combustion. From this work thus far one peer reviewed journal article has been published, two conference presentations made, one conference paper accepted for presentation in September 2010, and another journal paper is nearly ready for submission. One MS student completed a thesis and he and one undergraduate student both are coauthors on the above-mentioned publications and presentations.

Journal Publication

Darapuneni, M., B. A. Stewart, D. B. Parker, C. A. Robinson, A. J. Megel, R. E. DeOtte, Jr., 2009. *Agronomic Evaluation of Ashes Produced from Combusting Beef Cattle Manure for an Energy Source at an Ethanol Production Facility*, Applied Engineering in Agriculture, Vol. 25(6): 895-904, ISSN 0883-8542

Thesis

Darapuneni, M., 2008. Agronomic evaluation of ashes produced from combusting beef cattle manure for an energy source at an ethanol production facility. M.S. Thesis, West Texas A&M University, Canyon.

Conference Presentations

DeOtte, R. E., Jr., B. A. Stewart, A. J. Megel, M. Darapuneni, C. A. Robinson, and D. B. Parker, 2009. *Investigations into the Beneficial Uses of Ash from the Combustion of Manure from Beef Cattle Feedlots,* Texas Animal Manure Management Issues 2009 Conference*,* Round Rock, Texas, pp 181-192

DeOtte, R. E., Jr., B. A. Stewart, A. J. Megel, M. Darapuneni, C. A. Robinson, and D. B. Parker, 2010. *Investigations into the Beneficial Uses of Ash from the Combustion of Manure from Beef Cattle Feedlots*, ASABE International Symposium on Air Quality and Manure Management for Agriculture, Dallas, TX, 12 – 15 September 2010. Paper accepted for presentation.

Megel, A. J., D. B. Parker, R. Mitra, and J. M. Sweeten, 2006. *Assessment of chemical and physical characteristics of bottom, cyclone, and baghouse ashes from the combustion of manure*. ASABE Ann. Intern. Mtg. ASABE Paper No. 064043

Megel, A. J., R. D. DeOtte, Jr., and C. A. Robinson. 2007. Investigation of economically viable coproducts developed from ash from the combustion of manure. ASABE Ann. Intern. Mtg., Paper No. 074066. (Poster also entered into West Texas A&M University Student Research Conference – 1st Place)

Journal Publication Pending

Megel, A. J., R. E. DeOtte, Jr., D. B. Parker, C. A. Robinson, B. A. Stewart, and M. Darapuneni, 2010. *Assessment of Properties and Viable Coproducts of Ashes from the Combustion of Manure*, to be submitted to ASABE Applied Engineering in Agriculture.

CONCLUSIONS

Ash produced by the combustion of beef cattle manure has no suitable agronomic applications. It may be disposed as a surface treatment on cropland provided it is done at low application rates. The study concentrated on finding agronomic benefit so the amount that can be applied is not known.

The ash may have limited engineering uses including as an abrasive treatment for icy and snow packed roads, as a flowable fill, and as road base, though it behaves more like a Class F than a Class C ash and is subject to the same considerations and limitations. There is some possibility that the ash can be used as a soil amendment to minimize shrink-swell, but more work is needed. Class C ash from the Powder River Basin has been used to capture a sequester heavy metals in runoff. Because of the very low heavy metal content of the manure ash, this might provide a possible application; however, the oxides of aluminum and calcium suspected of providing potential for binding exchange are lower in concentration than in Class C ashes. It appears from the literature that the mechanism is not well understood, therefore further research may be warranted.

RECOMMENDATIONS

Consideration of using the ash for agronomic purposes should be abandoned as it shows no practical value. Further, there seems little point in disposing on crop land, although that may be done in relatively small quantities. If it seems desirable to pursue that disposal option, further studies on the carrying capacity of the land and crop should be conducted.

The engineering applications for beef cattle manure ash are more limited than for the Class C ash associated with combustion of western sub-bituminous coals and lignite. The ash may be used with lime or concrete amendment as a road base or flowable fill. There is promise that the ash may serve well as an abrasive for icy and snow packed roads, so two research avenues should be explored. First, the cyclone and baghouse ashes should be fused and crushed to provide an additional coarse material. The friction experiments conducted for the bottom ash should be repeated. Provided these experiments are successful, field trials applying this material to actual road surfaces should be conducted. Another avenue for investigation is use of the ash to sequester heavy metals and CO_2. Work of this nature for Class C ash has proved promising, but the physical and mineral properties of this ash are different, so the studies should begin with batch sorption and column leachate studies after the fashion of those conducted by Zhang et al. (2008).

The economic implications of these applications were not studied. Before adopting any particular strategy, a thorough economic evaluation should be performed.

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Additional Requested Information

Please include a section covering the following:

1) Names of graduate students, post-doc, research engineers, etc:

Anthony J. Megel, January 2006 – May 2007, B.S. Mechanical Engineering, May 2007

(2) Papers (journal, conference, thesis, dissertation, etc)
Student Presentation
Megel, A.J., R. E. DeOtte, Jr., C. A. Robinson, 2007. Investigation of Economically Viable Coproducts Developed from Ash from the Combustion of Manure, poster presentation at West Texas A&M University student research competition, April, 1st place poster.

Conference Presentation
Megel, Anthony J., Robert E. DeOtte, Jr., Clay Robinson, 2007. *Investigation of Economically Viable Coproducts Developed from Ash from the Combustion of Manure*, Poster presentation at ASABE Annual Meeting, June 2007, Paper No. 074066

Peer Reviewed – accepted pending minor revision

Darapuneni, Murali, B. A. Stewart, C. A. Robinson, D. B. Parker, A. J. Megel, **R. E. DeOtte, Jr.** *Agronomic Evaluation of Ashes Produced from Combusting Beef Cattle Manure for an Energy Source at an Ethanol Production Facility*, **Applied Engineering in Agriculture**, American Society of Agricultural and Biological Engineers, returned for minor modifications – June 2009.

Peer Reviewed – to be submitted
Megel, A. J., R. E. DeOtte, Jr., D. B. Parker, C. A. Robinson, B. A. Stewart, M. Darapuneni. *Assessment of Properties and Viable Coproducts of Ashes from the Combustion of Manure*, to be submitted to **Applied Engineering in Agriculture**, American Society of Agricultural and Biological Engineers.

Appendix D

Investigator Task Reports on Dairy Biomass Characterization, Inventory, and Utilization

Dr. Cady Engler, Dr. Saqib Mukhtar & Dr. Sergio Capareda, TAMU Biological & Agricultural Engineering Department

Task B.1.	**Engineering Analysis of a Commercial Digester (Engler & Mukhtar)**
Task C	**Biomass Characterization & Inventory (Mukhtar & Capareda)**
Task D	**Biomass Handling Methods (Capareda & Mukhtar)**
Task E	**Inventory Characterizations & Transport of Cattle Biomass (Capareda & Mukhtar)**
Task E.2.	**Dairy & Feedyard CAF) Systems Models (Auvermann, Sweeten, Mukhtar)**
Task F	**Sensitivity Analysis of CAFO Energy Systems (Capareda & Harman)**
Task I	**Energy Analysis of Dairy Farms & Feedyards (Engler, Mukhtar & Capareda)**

RENEWABLE ENERGY AND ENVIRONMENTAL SUSTAINABILITY USING BIOMASS FROM ANIMAL PRODUCTION SYSTEMS

Appendix D. Investigator Task Reports on Dairy Biomass Characterization, Inventory and Utilization (Tasks B.1., C, D, E, E.2., F and I)

Final Report

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**
Task Period: **06/01/2006 – 08/31/2009**

Dr. Cady Engler
Professor **Office:** 303 Scoates **Phone:** (979) 845-3685
E-mail: c-engler@tamu.edu

Dr. Saqib Mukhtar
Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: mukhtar@tamu.edu

Dr. Sergio C. Capareda
Assistant Professor
Office: 303D Scoates
Phone: (979) 458-3028
E-mail: scapareda@tamu.edu

Recipient organization
Texas Engineering Experiment Station, Texas A&M University System,
College Station, TX 77843

Date of Report: 02/28/2010

RENEWABLE ENERGY AND ENVIRONMENTAL SUSTAINABILITY USING BIOMASS FROM ANIMAL PRODUCTION SYSTEMS

Task B.1.: Engineering Analysis of a Commercial Digester

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**

Task Period: **06/01/2006 – 08/31/2009**

Dr. Cady Engler

Professor **Office:** 303I

Scoates **Phone:** (979)

845-3685

E-mail: c-engler@tamu.edu

Dr. Saqib Mukhtar

Associate Professor & Extension Specialist

Office: 207A Scoates

Phone: (979) 458-1019

E-mail: mukhtar@tamu.edu

Recipient organization

Texas Engineering Experiment Station, Texas A&M University System,

College Station, TX 77843

Date of Report: 08/31/2009

The purpose of this task was to assess the performance of a covered lagoon anaerobic digester installed on a 900-cow commercial dairy in Hamilton County, TX, in the Bosque River watershed. The digester was installed as one component of a phosphorus reduction manure management demonstration project at the dairy that involved several governmental agencies under the direction of the Brazos River Authority. The biogas produced by the digester was to fuel an electrical generator to provide power for the demonstration system. Our goal in this project was to monitor composition and flow rates on the inputs and outputs for the digester to determine its energy production efficiency under different operating conditions. The system was equipped for the demonstration project with flow meters to measure flow rates of the liquid manure stream fed to the digester and the biogas stream that was produced. However, there was no provision to measure the composition of the biogas stream or to collect data on a continuous basis for the operation.

The phosphorus reduction system, including the covered lagoon, began operation in early 2006. An instrument to continuously monitor the methane content of the biogas stream was purchased and installed at the dairy in June 2006 along with a data logger that was made available from another project to begin collecting data for this task. At that time the system had been shut down for about a month because of damage in another part of the system, but the system was expected to resume operation as soon as repairs were made. However, due to various issues related to the repairs, the system has never resumed operation. Consequently, it has not been possible to gather any data on performance of the covered lagoon anaerobic digestion system.

Sub-task B.1.a: Whole-farm Energy Analysis of Dairies.

The primary purpose of this sub-task was to conduct an analysis of all forms of energy usage throughout the dairy with the covered lagoon anaerobic digester to be able to evaluate the contribution of the digester and electrical generator to the overall energy balance. In addition, other dairies in the southwestern region of the U.S. were to be surveyed to develop a broad energy usage database for dairies within this region which could be used to help evaluate the feasibility of onsite energy conversion processes such as anaerobic digestion of manure to produce biogas or the benefit of various energy conservation practices.

Seven Texas dairies, including the dairy with the covered lagoon digester, were surveyed along with seven dairies in California. The survey gathered data on energy usage in the form of electricity, diesel fuel, gasoline, propane and natural gas which covered all direct energy inputs used for the dairy operations. Where possible, energy usage was quantified for different parts of the dairy operation such as milking, housing, and waste management. Since the covered lagoon digester and electrical generator did not operate after this project started, no data were collected to evaluate the contribution of biogas energy to the overall dairy operation. However, the energy usage survey was conducted, and those results are described in this report under Task I.

Renewable Energy and Environmental Sustainability Using Biomass from Animal Production Systems

Task C: Biomass characterization and inventory

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**
Task Period: 06/06 – 08/09

Dr. Saqib Mukhtar
Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: **mukhtar@tamu.edu**

Dr. Sergio C. Capareda
Assistant Professor
Office: 303D Scoates
Phone: (979) 458-3028
E-mail: **scapareda@tamu.edu**

Recipient organization

Texas Engineering Experiment Station, Texas A&M University System, College Station, TX 77843

Date of Report: 08/31/2009

Task C.1. Database Development for Dairy Biomass as Energy Feedstock

Introduction

As the need for cleaner, cheaper, more environmentally friendly fuels grows, Extension engineers, scientists and researchers at Texas A&M System are investigating ways of generating those fuels. One possibility is dairy waste.

Texas has a large concentration of dairy operations that, like other such operations, produce more than milk—they also generate, animal manure, carcasses and other biological material often called dairy biomass (DB). In the past, these products were considered waste, and disposing of it was a cost of doing business or, at best, revenue neutral for many facilities. But as researchers look for alternate fuel sources to replace fossil fuels, many are focusing on these dairy byproducts, specifically manure, as a renewable energy source.

Dairy biomass has been used as fertilizer, but because many of Texas' ever- growing operations are located close to each other and producing increasing amounts of DB, it is no longer possible to apply all of it to the land adjacent to these operations. In some areas of the state, such as the North Bosque watershed, the excessive application of dairy biomass to crop land has caused excess nutrients in the rainfall runoff.

Damage to the North Bosque watershed led to the development of a total maximum daily load (TMDL) program for phosphorus, which calls for removing 50% of the animal manure from the watershed. Transporting a low-value product such as manure over long distances is expensive; using the dairy byproduct as a fuel source instead of a fertilizer could save not only money but also the environment.

Dairies have a variety of methods for disposing of manure. To assist in evaluating these different methods, manure samples from 12 dairies in the three major dairy regions of the state—six in Central Texas, four in the Panhandle and two in Northeast Texas—have been characterized. Herd sizes of these dairies ranged from fewer than 300 cattle to more than 4,000.

Manure Management in Texas

Management methods vary in each region. In the Northeast, cattle are generally reared on pastures and the manure is not concentrated in one area so removal is not a large problem. Central Texas and Panhandle dairies employ two primary management styles—open lot dairies and hybrid facilities. Open lot dairies house the cattle in earthen corrals with minimal shade and paved feed lanes. In these facilities manure is removed through periodic scraping and piling. This method allows the manure to dry in the corral before transport; however, a large amount of soil is collected with the manure, so the material has higher ash (dirt) content. A hybrid facility houses some of the cattle in open lot corrals and the rest in free- stall structures, or large, open-air barns with concrete floors and loafing beds.

Free-stall dairies use several manure management techniques, including flushing the feed lanes with large volumes of water or vacuuming the manure into "slurry wagons." In the flushing method, water washes the manure to a liquid-solid separator. The liquid manure is returned to a water storage and treatment structure to be used for irrigation and as flush water. The vacuum process uses a slurry wagon equipped with a heavy-duty vacuum system to collect the manure several times each day. This system scrapes the manure to the center of the machine where it is vacuumed into a storage tank. Once collected, the manure is either taken to fields to be used as fertilizer or spread to dry in the sun. The vacuum method removes nearly all the manure in the corrals along with any bedding material that may have been moved from the free stalls. Table 1 shows the size and location of the facilities sampled, when were they sampled and type of manure management system used.

Table 1.Summary of facilities sampled for dairy biomass analysis.

Region	Dairy	Head Count	Winter Sampling Dates	Summer Sampling Dates	Facility Type	Feedlane Manure Removal
Central Texas	C1	2500	12/15/2005	6/19/2006	Free Stall Vacuum	Vacuum
	C2	2200	12/15/2005	6/19/2006	Hybrid	Scrape
	C3	2100	2/20/2006	6/19/2006	Open Lot	Flush
	C4	1500	2/20/2006	6/19/2006	Hybrid	Flush
	C5	1500	2/20/2006	6/19/2006	Hybrid Vacuum	Vacuum
	C6	1500	2/20/2006	6/19/2006	Open Lot	Scrape
Northeast	E1	299	2/8/2006	8/9/2006	Pasture	N/A
	E2	299	2/8/2006	8/9/2006	Pasture	N/A
Panhandle	P1	4000	2/22/2005	7/18/2006	Hybrid	Scrape
	P2	3000	2/22/2005	7/18/2006	Open Lot Flush	Flush
	P3	3500	2/22/2005	7/18/2006	Hybrid	Flush
	P4	4000	2/22/2005	7/18/2006	Open Lot	Scrape

The dairy biomass streams included open lot scrapings, feed, as-excreted manure, vacuumed manure, mechanically and gravitationally separated solids, open-lot scrapings and aged solids. Samples were collected in the winter seasons of 2005 and 2006 and summer season of 2006 to determine how the biomass varies seasonally.

Methodology

Sample Collection

The sampling scheme was designed to obtain the various streams of dairy biomass (DB) that represented the typical dairies in the state of Texas. Samples were collected from the three main dairy regions in the state of Texas, the Panhandle, Central Texas and Northeast Texas. A total of 12 dairies were selected for sample collection. The number and type of dairies in each region were selected as being representative of that region. Therefore, 6 dairies were selected from the Central Texas region, 4 dairies from the Panhandle region and 2 dairies from Northeast Texas. All dairies were categorized as either being large (>2000 cattle) or small (<2000 cattle).

The sampled dairies in the Central Texas region consisted of 4 hybrid (open-lots and free stalls) dairies and 2 open lot dairies. The Panhandle region dairy selection consisted of 2 hybrid facilities and 2 free stall facilities, all with more than 3000 head. The dairies in the Northeast region of the state were small pasture dairies with less than 300 head. The DB streams included open lot scrapings, free-stall flush water, vacuumed manure, aged solids, lagoon sludge, mechanically and gravitationally separated solids.

Representative samples were collected in triplicate from each source with each individual sample consisting of a composite of 10-15 sub-samples. The sub- samples were collected in a clean bucket and thoroughly mixed; a representative sample was then collected from the bucket. This entire process is repeated for each of the triplicate samples. The result was a total of approximately 360 samples collected over 2 seasons. Proximate analysis was conducted in house according to American Society for Testing and Materials (ASTM) standards, while ultimate analysis was conducted by Huffman Laboratories of Golden, Co. Some highly diluted samples (e.g., lagoon effluent) from the same source had to be combined to provide enough solids for analysis.

Laboratory Methods

Moisture content was determined for all samples by drying at 105°C to a constant weight according to ASTM method E1756-01. A modification was made to the procedure that allowed for larger samples sizes to compensate for the heterogeneous nature of dairy biomass in the various forms collected. For example, dairy feed is composed of many ingredients that have vastly different size characteristics, from various forms of hay to rolled corn. The dairy manure itself has significant variability in size as well due to the partially digested components of the feed passing through the animal while maintaining their general geometry. Concurrently, these materials contain significant amounts of moisture, up to 95% or more in some cases, which limits the ability to reduce the size of the various components of the sample prior to drying. The result of this work is that large sample sizes were used in the drying process. This benefitted the laboratory process in that it allowed for multiple different analyses to be conducted on the same laboratory sample. Once dried, the samples were ground. This produced more homogeneous samples for further analysis.

Ash content was determined using ASTM method E1755-01. Prior to the ashing analysis the samples were once again dried to a constant weight in order to account for the moisture absorbed by the sample during grinding. The absorbed moisture content during grinding and sample handling was calculated for each sample, and samples were determined to have a moisture content of up to 10% after grinding. This is due to the hydroscopic nature of animal manure. During analysis of large sample sizes it is imperative that the moisture absorbed during handling between analyses be quantified. The increased moisture content will correspond to errors in all other analyses conducted that rely on the dry basis mass of sample. Finally the high heating value (HHV) analysis using ASTM method E711-87 and the volatile matter content was conducted using ASTM method E872-82.

Results

The analyses of the collected samples focus on determining the properties of the DB pertinent for its use in a thermo-chemical conversion system. Each of the sampled DB stream was analyzed independently and their results compared across facilities, management type, region and location. Complete Proximate and Ultimate analyses were conducted on all the samples.

Task C.2. Dairy Biomass Characterization Survey

Biomass collected at the dairies was analyzed for nutrient content and thermo chemical properties. The nutrient content is critical to this research because of the common practice of using dairy biomass as fertilizer. When excessive dairy biomass is used in this way, runoff can pollute surface water. Nutrient analysis allows the value of dairy biomass as a fertilizer to be assessed and compared to its value as an energy source.

Two types of analyses are required:

• Ultimate analysis is the percentage of carbon, hydrogen, nitrogen, oxygen and sulfur in the fuel. These elements, the primary constituents of the fuel, can be used to calculate its energy content. All of these elements are reported on an as- received basis to reflect their nutrient content.

• Proximate analysis determines the moisture content, high heating value (HHV), ash content and volatile matter content of the fuel. The moisture content is the amount of moisture in the fuel when sampled. The high heating value of the fuel measures the total energy contained in the material in Kilojoules per Kilogram (KJ/Kg) of biomass. The ash content is the percentage of material remaining after complete combustion; this is the material that must be disposed of after the dairy biomass is used for energy conversion. Ash does not contribute to the heating value of the fuel and varies by source. Volatile matter is the non-moisture part of biomass that is liberated at high temperature in the absence of oxygen. This material is biodegradable.

Sampled Biomass Streams

For the research, several biomass streams were sampled at each facility. The samples were classified into these categories:

• **Feed.** Feed was collected as a composite sample (10-15 sub-samples were composited into one sample) from all feeding areas at each dairy in order to measure the raw source of the dairy manure.

• **As-excreted.** Freshly excreted manure was collected from several housing areas at each facility to determine the purest form of manure available. Moisture and soil may lower its thermo-chemical quality.

• **Vacuumed solids.** Vacuumed solids were collected from two facilities with different bedding types, sand and composted manure. This type of biomass has the least amount of soil or water mixed with the biomass during collection. An example of a vacuum collection apparatus is shown in Figure 1.

(Figure 1.Vacuum collection apparatus in use. The equipment is used while the cattle are away from their pens being milked. On the left are the stalls with sand bedding; at right is animal feed).

• **Separated solids.** Separated solids were collected from several facilities that use both mechanical and gravitational separation. Mechanical solids separation systems produce a pile of solids that is periodically removed. Gravitational separation systems slow the flow of water, allowing the solids to settle. These systems use parallel settling basins that are alternately shut off to allow for drying. Once a settling basin has dried out, the solids are removed for use. A picture of a mechanical solid separation system is shown in Figure 2 and the gravitational solids separation basin is illustrated in Figure 3.

(Figure 2. Mechanical solid separation system. Water flows across a sloped screen that collects the solids. The solids then fall to the bottom and are collected by an auger and stacked using the flighted-conveyor separator.)

(Figure 3. Gravitational solids separation basin during clean out. The liquid enters the basin in the foreground and slows to allow solids to separate from the water, which continues to flow through the basin and to the lagoon.)

• **Scraped solids.** This material is collected periodically from earthen pens by scraping the pen surface with a tractor and piling up the resulting material. This material, which is stored on site and then used as a fertilizer, constitutes a large portion of the total dairy biomass produced. Figure 4 shows the scraped solids piled for removal.

(Figure 4. Scraped solids piled for removal. The solids are scraped into piles before being moved to a storage area or loaded onto trucks for removal.)

• **Aged solids.** This material is aggregated from several biomass streams at each facility. Some facilities have active compost operations, while others stockpile it for later use. A large quantity of this material is available as a potential fuel or fertilizer.

Material Properties

Table2 shows the nutrient and trace metal analysis of the sampled dairy biomass streams on an as-received basis. The nutrient values can be used to determine the value of the biomass as a fertilizer. Commercial fertilizer is sold at different ratios of N, P and K, where P is in the form of phosphate (P_2O_5) and K is in the form of potash (K_2O). To convert the P and K values in Table 2 to equivalent fertilizer values, multiply them by 2.29 and 1.2 respectively. These values also can be used to calculate the quantity of nutrients exported from a region for specific sources of dairy biomass. The most nutrient-dense form of biomass, besides feed, is aged solids. This material is nutrient-rich because of its lower moisture content and the accumulation of non-volatile nutrients over time. For facilities that do not use vacuum equipment, it is the primary source of biomass for fertilizer and, because of its low moisture content, potentially for fuel. Facilities that use vacuum manure removal methods apply the removed biomass more continually. Table3 shows the proximate and ultimate analyses of the dairy biomass streams on an as-received basis. The data show large variations in moisture content for the materials (41% to 84% moisture). Note the variability in moisture content even within each biomass stream. The variation in moisture content illustrates one of the challenges in using biological materials as energy sources. Energy conversion facilities such as coal-fired power plants are designed for homogenous materials. Significant energy is available from dairy biomass as shown in the three high heating value numbers for each biomass source. The high heating value on a dry basis is the maximum amount of energy that can be extracted from the biomass, although it is not always possible to obtain this amount of energy because of difficulties in completely removing moisture. The dry, ash free (DAF) high heating value is the energy in the dry biomass assuming the ash is removed. This number is relatively constant since ash does not contribute to the high heating value of any material. The third value is the as-received (AR) high heating value, or the energy value of the biomass, with no changes to moisture content or ash, when collected from the facility. Compare these values with Powder River Basin coal that has a high heating value of 28,140 Kilojoules per Kilogram (KJ/Kg) on a dry basis, a dry ash-free high heating value of 30,233 KJ/Kg, and an as-received high heating value of 20,465 KJ/Kg.

Table 2.Nutrient characteristics of various dairy biomass streams on an as-received basis.

Nutrient (lb/ton)	Feed n = 69 Mean ± SD	As Excreted n = 26 Mean ± SD	Vacuumed w/ Sand Bedding n = 9 Mean ± SD	Vacuumed w/ Compost Bedding n = 6 Mean ± SD	Mechanically Separated n = 9 Mean ± SD	Gravitationally Separated Soilds n = 24 Mean ± SD	Scraped Solids n = 81 Mean ± SD	Aged Solids n = 18 Mean ± SD
Total N	33.8 ± 7.8	7.8 ± 1.3	5.6 ± 1.2	6.9 ± 1.2	5.3 ± 2.1	7.9 ± 7.6	21.9 ± 10.7	30.6 ± 13.3
P	4.6 ± 0.0	2.1 ± 0.0	1.5 ± 0.0	2.3 ± 0.0	1.1 ± 0.0	1.6 ± 0.0	6.4 ± 0.0	9.5 ± 0.0
K	17.8 ± 1.8	1.2 ± 0.5	4.8 ± 0.2	4.2 ± 0.7	1.9 ± 0.2	5.3 ± 2.0	22.9 ± 2.6	31.5 ± 5.1
Ca	14.1 ± 5.5	9.0 ± 0.5	8.1 ± 1.1	10.2 ± 1.5	9.0 ± 0.6	12.9 ± 8.4	38.9 ± 13.8	100.8 ± 15.5
Mg	4.9 ± 3.4	3.1 ± 1.5	2.6 ± 1.6	2.2 ± 2.1	1.7 ± 1.7	2.7 ± 15.0	8.9 ± 22.4	16.8 ± 74.7
Na	7.1 ± 1.1	1.2 ± 0.9	3.5 ± 0.3	2.2 ± 0.3	1.4 ± 0.4	3.0 ± 3.5	7.9 ± 3.9	10.3 ± 8.7
Zn	0.1 ± 4.6	0.1 ± 0.3	0.1 ± 0.5	0.1 ± 0.6	0.1 ± 0.3	0.2 ± 3.1	0.2 ± 3.9	1.6 ± 2.7
Fe	0.2 ± 0.0	0.8 ± 0.0	3.3 ± 0.0	0.9 ± 0.0	0.8 ± 0.0	2.5 ± 0.4	5.4 ± 0.1	16.1 ± 1.9
Cu	0.0 ± 0.3	0.0 ± 0.5	0.0 ± 0.5	0.0 ± 0.2	0.0 ± 0.2	0.1 ± 2.7	0.1 ± 3.8	0.1 ± 4.8
Mn	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.6 ± 0.0

Table 3.Proximate and ultimate analysis properties of various dairy biomass streams on an as-received basis.

Property		Feed n = 69 Mean ± SD	As Excreted n = 26 Mean ± SD	Vacuumed w/ Sand Bedding n = 9 Mean ± SD	Vacuumed w/ Compost Bedding n = 6 Mean ± SD	Mechanically Separated n = 9 Mean ± SD	Gravitationally Separated n = 24 Mean ± SD	Scraped Solids n = 81 Mean ± SD	Aged Solids n = 18 Mean ± SD
Moisture	%	41.42 ± 10.11	84.13 ± 1.79	51.98 ± 10.04	83.63 ± 2.44	83.20 ± 2.95	69.90 ± 20.09	40.77 ± 22.32	36.17 ± 18.01
Carbon	%	26.32 ± 3.57	42.55 ± 2.72	5.90 ± 0.74	6.80 ± 0.96	7.96 ± 1.50	12.03 ± 9.52	18.82 ± 6.92	11.12 ± 4.23
Hydrogen	%	3.23 ± 0.42	5.01 ± 0.71	0.73 ± 0.09	0.82 ± 0.12	0.92 ± 0.19	1.41 ± 1.08	2.22 ± 0.83	1.21 ± 0.41
Nitrogen	%	1.54 ± 0.25	2.48 ± 0.25	0.34 ± 0.04	0.42 ± 0.04	0.28 ± 0.04	0.45 ± 0.33	1.30 ± 0.57	0.97 ± 0.55
Oxygen	%	21.75 ± 3.25	29.89 ± 3.20	2.41 ± 1.04	4.67 ± 0.65	6.17 ± 1.30	8.21 ± 7.51	13.82 ± 5.54	8.58 ± 4.35
Sulfur	%	0.17 ± 0.03	0.30 ± 0.03	0.07 ± 0.02	0.07 ± 0.01	0.06 ± 0.01	0.07 ± 0.06	0.29 ± 0.13	0.25 ± 0.14
Ash	%	5.15 ± 4.75	19.77 ± 6.30	38.56 ± 12.03	3.59 ± 0.70	1.27 ± 0.18	12.43 ± 11.98	21.13 ± 12.12	41.69 ± 12.96
Volatile Matter	%	42.20 ± 4.87	67.13 ± 6.58	2.69 ± 4.13	7.16 ± 5.76	5.01 ± 6.98	9.20 ± 6.04	32.72 ± 9.79	21.40 ± 13.30
HHV_{dry}	KJ/Kg	15791 ± 1384	16568 ± 6228	4853 ± 933	14812 ± 270	15479 ± 521	11451 ± 4881	11360 ± 2237	4519 ± 2751
HHV DAF	KJ/Kg	16642 ± 1595	19843 ± 7552	23947 ± 4653	19128 ± 451	16786 ± 526	18253 ± 3735	17665 ± 1658	13044 ± 7614
HHV AR	KJ/Kg	9158 ± 1216	2629 ± 383	2258 ± 437	2740 ± 200	2553 ± 500	3777 ± 3337	6433 ± 2495	2809 ± 1888

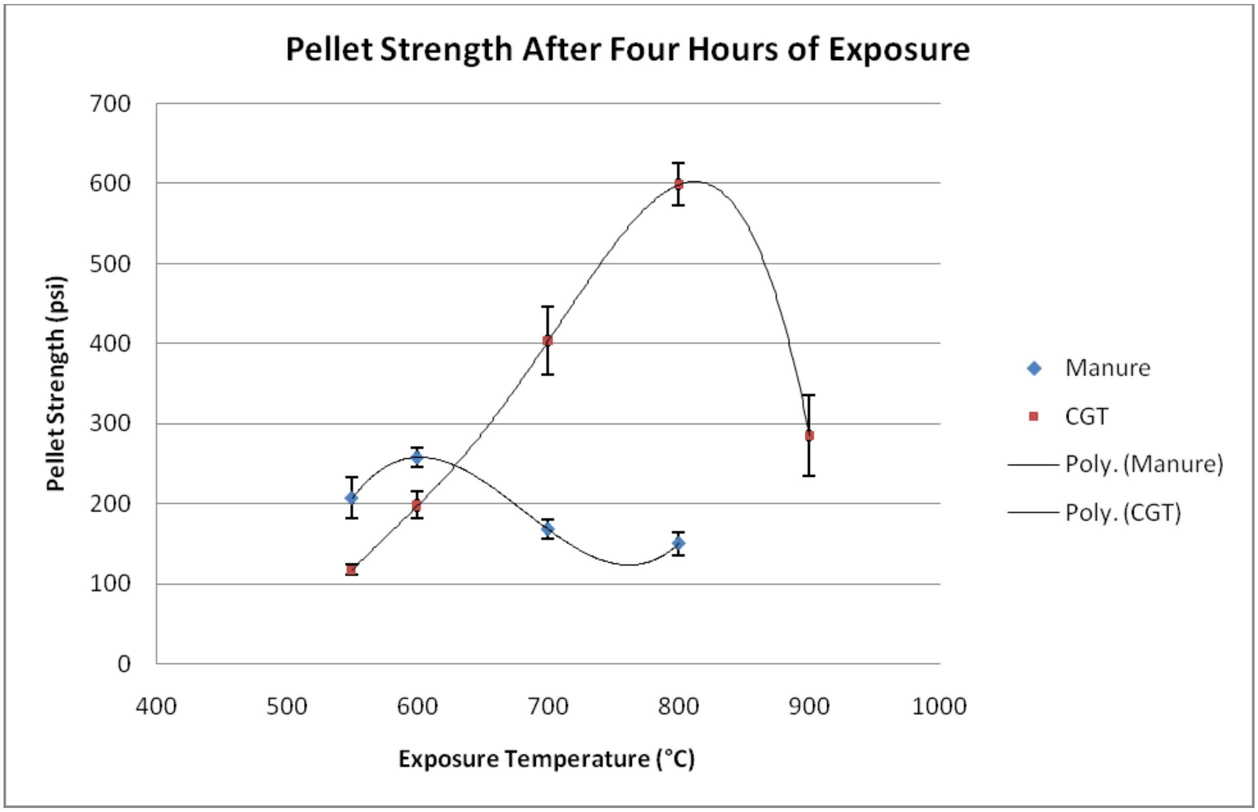
Summary

Dairy biomass could be an excellent feedstock for alternative energy systems to generate heat, power or fuel. Its high heating value of 19,843 KJ/Kg on a dry ash-free basis is comparable to as-received low grade coal. In addition, the use of dairy manure for alternative fuel could be an excellent mitigation measure to reduce excessive nutrient loading of land, groundwater and waterways. However, large variation in composition of different types of dairy biomass presents a unique challenge to use it for power generation. The successful use of animal manure for fuel depends upon its meeting the required physical and chemical characteristics that are ideal for thermal conversion systems. These include (a) low moisture, (b) low ash, (c) homogeneous in physical form and (d) low delivered cost. Producers who wish to use biomass resources such as animal manure as a feedstock for alternative energy production will need to implement best management practices to make such material is more suitable as a renewable fuel source.

Task C.3. Robust Analysis of the Ash Content in the DB and Related to Slagging Characteristics

The ash analysis of animal manure and its slagging and fouling potential resulted in the following conclusions:

a. The melting point for manure ash is approximately 600°C compared with common biomass at 800°C using mechanical strength as an indicator (figure C3.1). Thus, the ideal thermo-chemical process for animal manure is gasification rather than combustion.



(Figure 5. Slagging and fouling potential of manure compared with cotton gin trash using mechanical strength of ash pellet as indicator.)

b. The bed agglomeration index for animal manure was found to be 0.26 (compared with 0.04 for cotton gin trash ash (GCT)). Bed agglomeration occurs when index is less than 0.15. Thus, using this index, it is more likely for cotton gin trash biomass to enhance agglomeration in a fluidized bed compared with animal manure.

c. The alkali index for animal manure is 0.84 (compared with 2.23 for CGT). Slagging and fouling potential is certain to occur if the alkali index is greater than 0.34. Thus, for both biomass fuels, slagging and fouling potential is likely to occur during any thermal conversion processes.

d. The basis for the calculation are the ash analysis shown in Table 4.

Ash Component	**CGT Ash**	**Manure Ash**
% Aluminum Oxide Al_2O_3	3.46	3.115
% Calcium Oxide CaO	23.295	27.41
% Iron Oxide Fe_20_3	1.11	1.845
% Magnesium Oxide MgO	5.685	10.9
% Manganese Oxide	0.06	0.14
% Phosphate P_2O_5	2.245	4.98
% Potash K_2O	24.625	5.285
%Silica SiO_2	21.695	32.46
% Sodium Oxide Na_2O	0.76	1.815
% Sulfur Oxide SO_3	7.395	6.12
%Titanium Oxide TiO_2	0.245	0.22

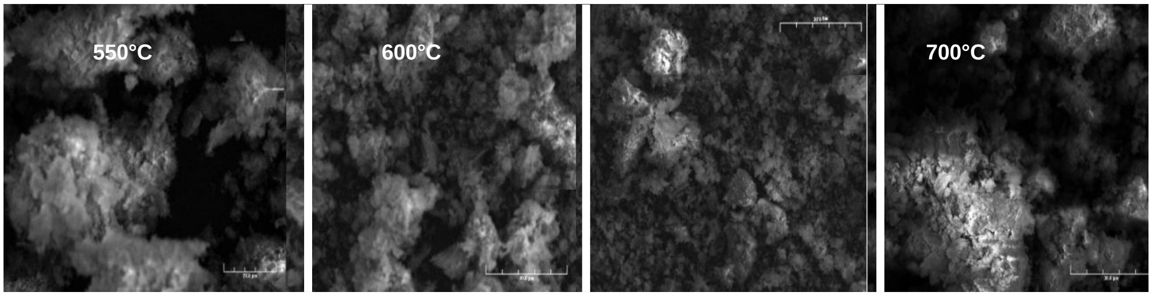
Table 4. Ash analysis of animal manure compared with Cotton Gin Trash (CGT) a common biomass residue in Texas

e. Two other slagging and fouling indexes are used. These are the slagging potential (Rs) and the fouling potential (Rf) commonly used for coal. The results showed that animal manure has an Rf of 0.02 and an Rs of 0.08. The degree of slagging is low if the value is less than 0.6 and the degree of fouling is also low if the value is lower than 0.2. This contradicts with the above indexes used for biomass wastes including the results of mechanical testing of animal manure pellets.

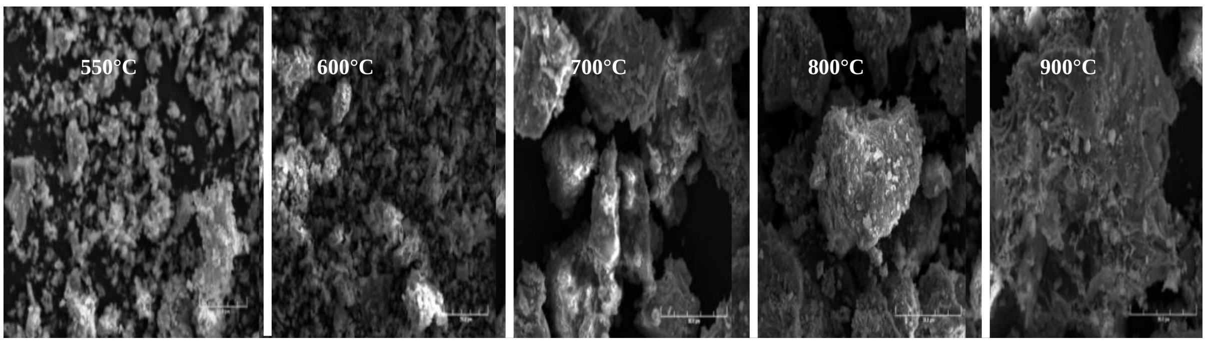
f. Coal materials also use alkali content as an indicator of fouling. The animal manure has an alkali content of 0.05. The degree of fouling is low if the alkali content is below 0.3, likewise contradicting with the indexes used for biomass wastes on alkali index.

g. Thus, we do not recommend the use of the coal indexes for evaluating slagging and fouling potential primarily due to the higher ash contents of most biomass residues.

h. Scanned Electron Microscope pictures (SEM) of animal manure pelleted ash and exposed under different thermal conversion temperature has been made.



(Figure 6. SEM pictures of manure ash at 1200x)



(Figure 7. SEM pictures of CGT ash at 1200x)

SCANNING ELECTRON MICROSCOPY (SEM) OF THE BIOMASS ASH SAMPLES

Ash samples of manure and Cotton Gin Trash (CGT) were heated at temperatures of 550, 600, 700 and 800°C for four hours. Additional ash samples of CGT were also heated at 900°C for the same length of time. Ten grams of the treated samples were sent to the Microscopy and Imaging Center at Texas A&M University, College Station, Texas for Scanning Electron Microscopy (SEM). SEM specimens were prepared by spreading sample particles of each batch on carbon tape and subsequent coating with amorphous carbon film of ~30 nm thickness. The carbon tape and film were used for fixation of particles and removal of accumulated charges. Micrographs were taken using a JEOL JSM 6400 scanning electron microscope equipped with a tungsten electron gun. It was operated at a 15 kV acceleration voltage with a 15 mm working distance. These images were analyzed to determine the effects of exposure temperature on the compressive strength of the ash pellets and consequently used to supplement and/or complement the evaluation of fouling and slagging behavior of the ash based on the calculated indices.

Fig 7 shows that agglomeration is evident for the CGT samples as temperature is increased. At a lower temperature of 550°C, materials are spread out and as

temperature is increased to 600°C, formation of small colonies of agglomerated slag is observed. There is one big agglomerated rock-like structure at a temperature of 800°C and a much bigger slag at 900°C. This is not so clear for animal manure samples.

Shown in the fig 6 at 550°C are materials that have started to fuse and becoming bigger lumps as temperature is increased. The images also indicated that even at lower temperature, the ash contained in animal manure will begin to form agglomerates and may lead to formation of even bigger slag at higher temperatures. Thus, it may be difficult to convert animal manure via thermal means if the conversion temperature is high. Even at the relatively lower gasification temperatures of 600°C (the maximum temperature where melting of ash was observed), some slagging and fouling may be expected. In the use of animal manure for thermal conversion work, there must be regular maintenance schedules to evaluate the formation of slag through hot conveying surfaces.

Manuscript Submitted for Publication and under review:

Maglinao, A. L. Jr. and S. C. Capareda. 2010. Predicting Fouling and Slagging Behavior of Dairy Manure and Cotton Gin Trash (CGT) During Combustion Manuscript under review for publication in the Transactions of the ASABE, St. Joseph, MI.

PROPERTIES DATA ON AS RECEIVED BASIS

Glossary

LN	:	Lagoon
OL	:	Open Lot Scrapings
CVS	:	Dewatered Vacuum Solids
VS	:	Vacuum Solids
FSV	:	Spread Vacuum Solids
FD	:	Feed
FF/FS	:	Free Stall Flush Water
SS/MS	:	Mechanically Separated Solids
GS	:	Gravitationally Separated Solids
CP	:	Compost
EP	:	Exercise Pen Scrapings
PL	:	Small Lagoon
ML	:	Large Lagoon
PS	:	Piled Open Lot Scrapings
LS	:	Lane Scrapings
LN1	:	First Lagoon
LN2	:	Second Lagoon
LN3	:	Third Lagoon
WW	:	Weeping Wall Influent
CP/CW	:	Aged Solids from Wall
WE	:	Wall Effluent
S	:	Samples Collected in Summer
W	:	Samples Collected in Winter.

- HHV AR : High Heating Value of As Received
- HHV dry : High Heating Value of Dry Sample
- HHV DAF : High Heating Value of Dry Ash Free Sample
- MC : Moisture Content in the Sample
- ASH : Ash Content in the Sample

- HHV dry = HHV AR / (1-MC)

- HHV DAF = HHV dry (1+ ASH)

---------- APPENDIX ----------

NUTRIENT ANALYSIS:

SAMPLES OF DAIRY C1 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4413	C1-S-LN-1		0.03		25.61	504.00	169.90	120.20	245.50	0.47	3.30	0.11	0.89
4414	C1-S-LN-2		0.03		25.11	468.60	167.30	113.10	231.00	0.53	3.19	0.14	0.90
4415	C1-S-LN-3		0.03		26.20	478.10	168.50	116.60	232.20	0.54	4.47	0.17	0.92
4416	C1-W-LN-1		0.13		156.40	401.00	972.00	176.10	229.30	14.37	6.16	2.65	11.23
4417	C1-W-LN-2		0.14		137.70	467.30	1212.00	163.40	166.50	13.27	7.31	3.02	17.01
4418	C1-W-LN-3		0.16		224.20	490.10	651.00	210.10	237.00	21.59	9.17	5.41	16.24
4521	C1-S-OL-1	44.53	1.02		2364.71	13263.02	28814.21	4188.03	2522.80	82.60	1577.58	12.75	114.49
4522	C1-S-OL-2	45.29	1.02		2455.61	13485.60	22266.80	4260.11	2662.98	85.57	1567.04	13.92	116.71
4523	C1-S-OL-3	42.74	1.08		2588.10	13840.02	22920.69	4496.53	2625.89	89.15	1633.59	13.39	121.33
4524	C1-S-CVS-1	39.58	0.36		914.09	3050.39	5527.44	1573.83	1965.93	41.99	1741.79	5.65	67.85
4525	C1-S-CVS-2	38.99	0.33		854.14	2364.76	4678.88	1455.71	1702.80	39.78	1857.15	5.40	66.20
4526	C1-S-CVS-3	39.74	0.32		861.11	2574.29	4665.29	1445.02	1981.33	39.71	2015.68	5.57	68.52
4527	C1-S-VS-1	50.33	0.29		694.44	1555.79	3772.74	1112.20	1437.57	31.24	1568.70	4.10	55.04
4528	C1-S-VS-2	48.09	0.30		733.51	1835.08	4161.24	1195.01	1479.48	34.42	1733.85	4.68	60.11
4529	C1-S-VS-3	49.09	0.32		762.63	1912.17	4159.83	1238.12	1494.71	33.45	1788.46	4.77	59.82
4530	C1-W-OL-1	29.96	0.84		2498.88	11459.97	55670.13	4189.55	3411.45	95.81	4416.46	18.71	203.73
4531	C1-W-OL-2	26.74	1.11		3415.19	16558.77	67221.12	5231.94	4533.08	122.34	4034.20	40.14	263.65
4532	C1-W-OL-3	16.27	0.94		3069.48	13280.98	41243.72	4507.93	4857.08	112.03	4184.74	21.20	212.25
4533	C1-W-FSV-1	69.37	0.22		666.90	2943.62	3354.12	1214.95	1849.68	33.64	1270.39	5.54	51.10
4534	C1-W-FSV-2	65.75	0.21		655.64	2911.67	3271.34	1169.12	2143.33	31.93	1378.07	8.91	52.10
4535	C1-W-FSV-3	66.87	0.20		575.85	2650.62	3012.43	1085.43	1868.02	29.59	1470.43	5.80	51.02
64990	C1-S-FD-1	52.50		1.25	1709.00	7002.11	5818.84	1979.46	1782.01	68.64	37.68	7.75	55.32
64991	C1-S-FD-2	50.33		1.40	1744.44	6817.59	5857.63	1982.20	1779.53	60.70	18.99	7.35	53.68
64992	C1-S-FD-3	50.71		1.30	1769.34	7227.85	5906.59	2021.47	1750.77	59.81	23.31	7.88	53.99
64993	C1-W-FD-1	45.80		1.52	2097.13	8046.95	7133.03	2449.96	3385.29	58.46	13.65	6.82	54.07
64994	C1-W-FD-2	48.48		1.54	1897.75	7992.89	8740.83	2501.37	3511.08	62.73	20.02	7.81	55.09
64995	C1-W-FD-3	48.01		1.59	1832.80	7527.16	8112.42	2351.14	3437.76	62.24	19.18	8.12	57.04

SAMPLES OF DAIRY C2 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4419	C2-W-LN-1		0.31		1005.00	1852.00	3828.00	1126.00	560.00	30.55	25.08	8.15	26.23
4420	C2-W-LN-2		0.32		993.00	1848.00	2884.00	1127.00	527.00	33.00	25.37	8.78	25.84
4421	C2-W-LN-3		0.30		982.00	1881.00	3628.00	1046.00	537.00	29.45	19.27	7.91	24.28
4422	C2-S-FF-1		0.11		155.00	1172.00	795.00	342.00	452.00	6.14	11.09	1.06	5.13
4423	C2-S-FF-2		0.11		136.00	1121.00	541.00	316.00	403.00	6.49	12.16	2.39	4.51
4424	C2-S-FF-3		0.11		147.00	1151.00	748.00	325.00	405.00	5.27	12.00	0.75	4.86
4425	C2-S-LN-1		0.19		603.00	1375.00	2434.00	675.00	464.00	20.04	11.66	4.05	16.72
4426	C2-S-LN-2		0.23		694.00	1223.00	2793.00	728.00	418.00	23.44	11.47	4.67	18.57
4427	C2-S-LN-3		0.16		440.00	1368.00	2165.00	556.00	462.00	15.29	10.27	3.08	12.86
4428	C2-W-FS-1		0.11		155.00	1206.00	616.00	327.00	441.00	6.21	9.70	1.52	4.73
4429	C2-W-FS-2		0.09		109.00	1282.00	763.00	269.00	464.00	6.89	9.05	4.66	3.48
4430	C2-W-FS-3		0.09		126.00	1219.00	830.00	281.00	476.00	4.74	6.06	1.15	3.54
4536	C2-W-SS-1	82.37	0.34		662.80	1521.51	4804.50	1119.84	911.07	28.62	564.06	7.27	28.92
4537	C2-W-SS-2	85.50	0.28		597.42	973.56	3836.83	915.12	684.42	22.53	352.22	6.06	22.45
4538	C2-W-SS-3	81.07	0.33		656.59	1251.29	4382.25	960.94	845.67	26.06	417.35	7.56	26.71
4539	C2-W-GS-1	72.29	0.29		1102.45	1796.78	23850.44	2064.42	1207.46	32.03	1375.08	8.77	59.96
4540	C2-W-GS-2	79.41	0.26		1039.55	1560.35	18452.05	1620.25	930.86	26.08	864.78	6.81	45.90
4541	C2-W-GS-3	78.65	0.32		1113.03	1774.56	16214.44	1820.46	985.58	33.96	905.75	9.42	49.33
4542	C2-W-CP-1	35.97	1.08		4169.80	14508.48	51508.37	7666.61	3450.07	134.79	3409.73	29.60	172.44
4543	C2-W-CP-2	37.39	1.06		4306.88	14999.28	50503.06	7313.38	3113.55	146.00	3517.38	31.87	172.99
4544	C2-W-CP-3	39.63	1.06		4209.62	14572.19	50520.31	7216.67	3289.58	139.09	3104.85	28.14	163.42
4545	C2-W-EP-1	63.11	0.66		2121.66	9604.82	26057.16	4717.01	3272.32	68.40	1054.37	19.11	94.63
4546	C2-W-EP-2	44.17	0.92		3313.34	12107.80	43378.84	7092.84	4738.61	102.00	1725.62	27.62	150.12
4547	C2-W-EP-3	48.37	1.23		3578.93	8872.47	33531.08	6007.05	3655.35	106.72	1282.47	30.00	132.27
4548	C2-S-CP-1	12.95	1.44		5092.27	16808.85	98249.53	12391.20	5107.94	151.55	6415.39	37.08	342.71
4549	C2-S-CP-2	12.92	1.41		5038.57	16231.22	102434.61	13307.88	5004.61	148.82	5891.97	36.17	332.83
4550	C2-S-CP-3	11.93	1.43		4980.09	16776.42	105130.45	13179.83	4413.83	142.84	6093.23	36.34	356.40
4551	C2-S-MS-1	81.21	0.30		442.32	818.31	5401.46	923.54	693.74	23.88	515.61	4.64	28.32
4552	C2-S-MS-2	81.01	0.31		548.38	934.35	5453.21	1028.19	764.54	28.36	464.23	4.69	27.39
4553	C2-S-MS-3	79.50	0.34		574.22	880.30	5299.62	983.42	710.76	37.33	520.10	5.02	26.23
4554	C2-S-EP-1	57.41	0.98		2984.70	11517.15	27788.17	6451.94	4121.42	111.12	1188.68	18.75	123.13
4555	C2-S-EP-2	55.92	1.04		3114.55	12254.55	30632.41	9701.17	4109.83	115.31	1249.17	19.64	132.72
4556	C2-S-EP-3	59.68	0.96		2863.63	11192.82	25218.23	6028.86	3961.98	106.49	1085.45	17.50	118.63
64996	C2-S-FD-1	42.36		1.72	2070.47	8231.15	7647.25	2435.34	2822.11	70.55	26.12	8.98	64.85
64997	C2-S-FD-2	40.62		1.68	2212.38	8274.06	7601.28	2561.77	2856.15	72.30	22.17	9.44	68.25
64998	C2-S-FD-3	42.47		1.77	2325.36	8736.13	9137.62	2786.42	3112.31	79.78	13.32	9.53	65.12

64999	C2-W-TMR-1	46.78		1.69	2397.46	11065.52	8848.68	2851.42	3581.64	62.80	25.09	16.44	58.19
65000	C2-W-TMR-2	48.61		1.58	2496.69	10817.17	7167.33	2685.99	36860.76	55.00	31.03	17.70	56.08
65001	C2-W-TMR-3	46.33		1.61	2281.20	10147.21	7144.47	2612.15	3457.80	59.26	44.70	15.93	61.41

SAMPLES OF DAIRY C3 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4431	C3-W-PL-1		0.033		16.85	440.10	104.30	75.00	224.20	0.61	2.87	0.21	0.74
4432	C3-W-PL-2		0.045		43.94	612.00	202.70	114.90	264.10	2.05	3.34	0.83	1.44
4433	C3-W-PL-3		0.046		52.10	582.00	236.10	121.50	269.90	2.18	3.46	0.79	1.60
4434	C3-W-ML-1		0.013		20.46	698.00	209.30	103.30	269.00	0.97	3.57	0.43	1.02
4435	C3-W-ML-2		0.011		14.96	629.00	131.60	92.60	246.90	0.64	3.05	0.33	0.76
4436	C3-W-ML-3		0.015		32.12	715.00	286.90	122.20	263.00	0.75	3.08	0.29	1.21
4437	C3-S-LN1-1		0.06		206.20	682.00	524.00	218.90	280.20	4.31	3.31	0.81	4.09
4438	C3-S-LN1-2		0.06		221.00	696.00	323.80	220.40	291.10	4.63	3.95	1.35	4.13
4439	C3-S-LN1-3		0.07		242.60	1104.00	1273.00	312.70	325.10	8.42	9.07	1.58	11.08
4440	C3-S-LN2-1		0.08		251.70	1072.00	1484.00	312.00	279.40	10.06	8.76	3.19	12.37
4441	C3-S-LN2-2		0.07		207.10	1093.00	1267.00	283.10	323.50	8.16	7.32	2.45	9.17
4442	C3-S-LN2-3		0.05		50.40	780.00	258.40	159.80	415.30	3.59	3.01	7.56	1.36
4557	C3-W-SS-1		0.33		531.05	911.35	3935.55	822.92	893.37	31.55	265.28	4.89	27.59
4558	C3-W-SS-2		0.31		430.36	835.26	3307.15	682.19	780.95	30.40	434.21	4.52	26.10
4559	C3-W-SS-3		0.31		429.78	748.98	3189.57	642.50	764.68	30.79	269.94	5.31	24.89
4560	C3-W-OL-1		0.85		2153.77	8906.30	10967.75	3271.53	2998.20	93.24	506.15	18.11	91.19
4561	C3-W-OL-2		0.75		1886.50	7696.01	11351.20	2919.92	2522.28	80.35	476.91	15.66	81.30
4562	C3-W-OL-3		0.68		1794.23	7271.57	10013.02	2743.80	2511.46	76.03	461.45	14.80	77.32
4563	C3-S-MS-1		1.36		474.77	641.13	3753.76	548.94	546.57	28.62	332.44	3.86	22.61
4564	C3-S-MS-2		0.22		328.32	560.21	3061.86	592.01	441.90	16.48	252.86	2.64	16.48
4565	C3-S-MS-3		0.26		551.01	812.17	4541.98	797.24	728.69	41.50	360.57	4.29	24.79
4566	C3-S-OL-1		1.37		5433.07	19877.38	33699.74	7969.57	6622.40	205.13	1765.44	30.77	210.37
4567	C3-S-OL-2		1.81		5167.45	18491.91	33931.16	7591.35	5806.02	194.66	1743.98	30.48	241.34
4568	C3-S-OL-3		1.76		5301.69	18866.97	36895.16	7824.92	6198.93	202.77	2020.57	30.78	220.83
4569	C3-S-PS-1		1.15		3089.49	10592.48	24439.28	4860.46	3316.40	114.64	1739.92	17.42	149.11
4570	C3-S-PS-2		1.61		4997.03	17598.75	33453.07	7271.25	5793.04	182.56	2433.96	27.11	207.65
4571	C3-S-PS-3		1.66		5341.70	18518.10	35347.31	7819.25	5870.75	196.04	2688.04	31.48	221.65
4572	C3-S-LS-1		0.70		1848.61	5794.85	16935.16	3166.66	2098.22	75.61	813.86	11.37	84.52
4573	C3-S-LS-2		0.66		1671.42	5568.38	17074.74	3029.71	1857.32	68.22	877.16	10.37	79.81
4574	C3-S-LS-3		0.68		1437.53	5735.63	23059.23	2734.02	2135.44	61.16	1597.96	9.43	85.57
4575	C3-W-LS-1		0.60		1739.59	6741.69	15248.04	2516.42	2294.68	70.25	832.04	13.21	78.82
4576	C3-W-LS-2		0.58		1651.48	6661.73	11624.68	2345.78	2426.07	66.52	534.27	12.48	71.52
4577	C3-W-LS-3		0.54		1563.59	6634.27	10571.63	2222.12	2264.53	61	603.65	11.36	68.03
65002	C3-S-FD-1	43.2		1.56	2014.02	7847.28	7478.05	2275.73	2442.99	63.21	24.25	10.12	54.79
65003	C3-S-FD-2	41.2		1.59	1943.14	8611.92	7485.35	2232.04	2445.16	62.74	22.53	8.05	54.59
65004	C3-S-FD-3	43.3		1.58	2175.92	8108.31	6717.33	2293.22	2360.16	64.63	16.39	7.93	54.62

65005	C3-W-FD-1	50.7		1.7	2054.24	8838.99	6650.80	2637.76	3710.43	70.88	25.67	10.7	70.12
65006	C3-W-FD-2	51.3		1.62	1910.95	8555.71	7004.86	2499.95	3624.85	70.05	30.80	11.05	67.35
65007	C3-W-FD-3	51.5		1.65	1932.73	8531.83	7660.26	2470.32	3602.11	72.35	33.40	11.27	67.89

SAMPLES OF DAIRY C4 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4578	C4-W-GS-1	74.27	0.632		1081	7015	8758	2682	5663	77	2897	19.3	98
4579	C4-W-GS-2	74.22	0.500		1197	7850	8855	2883	5487	87	2951	24.2	102
4580	C4-W-GS-3	67.74	0.725		980	6362	7493	2515	5314	68	2828	18.3	89
4581	C4-W-OL-1	39.11	0.669		5529	19024	36145	10958	8111	350	3524	67.7	274
4582	C4-W-OL-2	38.92	2.055		5678	20425	36516	11056	9254	307	3413	68.2	279
4583	C4-W-OL-3	31.21	2.111		5628	19818	37933	11147	8483	303	3602	65.1	272
4584	C4-S-GS-1	50.34	2.108		432	1855	2811	832	3338	30	2726	5.3	50
4585	C4-S-GS-2	45.89	0.268		380	1667	2466	726	2884	24	3094	5.4	55
4586	C4-S-GS-3	72.34	0.252		1001	4157	4874	1707	4139	54	4098	14.1	89
4587	C4-S-OL-1	41.15	0.594		5344	25068	32260	9838	10269	236	3588	56.2	230
4588	C4-S-OL-2	32.75	1.874		5567	25013	39892	10663	9935	244	3313	58.6	231
4589	C4-S-OL-3	35.44	1.993		5493	24950	34485	9957	10148	238	2821	57.4	227
4443	C4-W-LN1-1		8.424		34286	86877	46715	31537	35416	824	517	250	628
4444	C4-W-LN1-2		7.057		10755	104162	51296	24385	54039	340	384	933	257
4445	C4-W-LN1-3		7.377		14211	95403	63122	23241	48101	366	435	869	316
4446	C4-W-LN2-1		6.295		4894	119241	23503	22831	54055	286	408	141	187
4447	C4-W-LN2-2		5.440		4350	101052	21123	20981	47154	248	325	98	171
4448	C4-W-LN2-3		5.986		4436	115270	20729	22412	53268	252	414	115	165
4449	C4-W-LN3-1		7.167		5620	168017	25491	28996	79648	275	577	132	192
4450	C4-W-LN3-2		6.562		5895	145665	27383	26182	69061	282	456	138	196
4451	C4-W-LN3-3		7.026		6794	152418	30878	27717	73426	314	468	151	221
4452	C4-S-LN-1		4.022		19742	34968	32308	17992	12951	718	278	241	552
4453	C4-S-LN-2		5.309		25899	42510	40500	20423	15595	707	355	274	629
4454	C4-S-LN-3		4.389		21689	33583	42293	17334	12524	802	328	246	577
65008	C4-S-FD-1	50.70		3.27	3502	12471	12412	4316	6170	138	102	27	110
65009	C4-S-FD-2	50.75		3.08	3404	11834	11307	4104	5995	132	81	26	107
65010	C4-S-FD-3	51.00		2.96	3537	11549	10918	3917	6210	147	100	25	110
65011	C4-W-FD-1	48.37		2.63	3101	16092	12337	4272	7223	139	149	26	103
65012	C4-W-FD-2	48.37		2.66	3183	16856	12930	4694	7487	142	185	24	109
65013	C4-W-FD-3	47.76		2.71	3250	16096	11923	4704	6926	136	78	28	92

SAMPLES OF DAIRY C5 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4455	C5-W-LN-1		0.04		29.28	500.00	193.60	74.30	227.80	1.148	5.57	0.61	0.81
4456	C5-W-LN-2		0.04		49.52	560.00	311.80	94.00	244.80	1.388	3.98	0.57	1.22
4457	C5-W-LN-3		0.04		54.30	600.00	345.90	98.60	257.80	1.597	6.50	0.59	1.24
4458	C5-S-LN-1		0.23		869.00	926.00	2260.00	279.40	330.40	22.220	12.88	4.63	16.41
4459	C5-S-LN-2		0.20		701.00	1034.00	2389.00	275.90	355.60	20.920	10.76	4.60	14.88
4460	C5-S-LN-3		0.12		341.30	948.00	1452.00	210.70	379.80	10.100	7.79	2.34	7.23
4590	C5-W-OL-1	74.16	0.52		1867.89	7161.50	12410.16	1825.00	1325.28	35.864	915.21	6.83	52.79
4591	C5-W-OL-2	66.88	0.70		2341.83	9711.81	14255.03	2230.87	1885.06	43.591	1090.43	8.79	63.40
4592	C5-W-OL-3	73.23	0.56		1898.80	7892.65	11828.39	1859.98	1443.64	35.100	940.03	6.66	54.19
4593	C5-W-VS-1	85.60	0.30		839.11	2772.99	4172.09	994.95	1311.82	25.061	464.78	6.13	23.56
4594	C5-W-VS-2	85.78	0.29		854.89	2761.56	4215.33	1016.09	1312.05	25.729	323.25	5.90	21.82
4595	C5-W-VS-3	85.86	0.30		836.39	2833.33	4141.52	983.05	1405.91	26.008	415.51	6.20	22.57
4596	C5-W-EP-1	30.87	1.46		3947.41	7652.87	19518.61	4360.82	4125.08	112.062	2170.04	24.94	113.38
4597	C5-W-EP-2	48.77	1.01		3173.40	5895.43	15948.96	3237.95	3045.83	85.611	1595.92	18.67	88.58
4598	C5-W-EP-3	58.71	0.84		2555.96	4883.60	12488.72	2563.80	2651.74	68.698	1236.07	15.10	68.49
4599	C5-S-EP-1	70.17	0.61		2166.23	3989.16	11225.73	2193.37	1955.06	59.174	952.33	12.88	55.74
4600	C5-S-EP-2	77.81	0.51		1618.42	2782.04	7863.59	1645.26	1371.94	45.214	761.62	9.77	42.24
4601	C5-S-EP-3	71.18	0.66		2088.86	3621.58	10597.32	2106.15	1834.71	59.073	861.88	12.81	52.79
4602	C5-S-OL-1	67.05	0.77		2817.27	8583.95	14442.55	2367.17	1822.17	48.536	1011.91	8.82	61.85
4603	C5-S-OL-2	66.49	0.76		2826.06	8695.31	13917.52	2363.31	1721.64	48.587	928.17	8.49	60.72
4604	C5-S-OL-3	63.45	0.83		3051.98	9125.60	15668.11	2542.52	1809.77	52.042	1007.95	9.76	66.48
4605	C5-S-VS-1	80.29	0.45		1513.67	1554.47	6528.49	1284.85	877.65	41.527	651.78	7.77	28.70
4606	C5-S-VS-2	81.62	0.36		1432.34	1471.49	5989.24	1257.94	822.39	36.626	360.75	8.07	24.90
4607	C5-S-VS-3	82.63	0.37		1382.66	1324.81	5516.38	1203.92	774.53	34.705	398.64	7.54	23.50
65014	C5-S-FD-1	49.62		1.41	1929.47	7259.04	5736.23	1889.24	2563.93	62.902	29.52	14.61	43.55
65015	C5-S-FD-2	48.25		1.28	2192.91	5493.30	5494.30	1744.52	1906.16	48.492	13.94	9.12	34.43
65016	C5-S-FD-3	48.37		1.56	2715.60	6069.51	5490.48	2189.51	2418.60	47.313	11.57	9.38	37.82
65017	C5-W-FD-1	48.70		1.16	1841.34	5058.75	5082.23	1652.60	2291.11	46.714	10.04	9.84	34.65
65018	C5-W-FD-2	52.47		1.51	2239.65	6800.05	5372.90	1842.96	2477.77	55.681	16.31	12.36	42.92
65019	C5-W-FD-3	62.18		1.34	1671.02	6352.07	4892.37	1605.67	2409.93	53.236	36.87	12.06	38.69

SAMPLES OF DAIRY C6 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4461	C6-S-LN-1		16.84		25709.6	207285.5	115446.9	48332.0	125331.2	815.9	1670.7	2223.3	642.1
4462	C6-S-LN-2		17.16		24509.9	221556.9	102486.4	51269.4	135759.2	884.4	3322.0	2249.6	625.2
4463	C6-S-LN-3		18.15		30685.9	226865.6	130165.8	53660.9	134283.5	919.5	1749.4	2628.0	741.7
4464	C6-W-LN-1		1.90		1479.2	32717.4	7501.5	9218.7	20160.7	28.4	107.6	56.4	34.2
4465	C6-W-LN-2		1.82		2059.1	30240.3	9781.9	9383.7	18704.0	61.5	359.0	86.0	39.4
4466	C6-W-LN-3		3.50		3427.4	60552.8	17740.1	17870.2	37455.2	89.5	727.3	130.9	78.3
4608	C6-W-OL-1	39.31	2.14		4685.0	10881.0	39495.0	7450.0	5959.0	181.2	5649.0	40.9	235.1
4609	C6-W-OL-2	43.77	1.53		4811.0	11975.0	41950.0	7883.0	6096.0	190.5	5594.0	45.9	243.2
4610	C6-W-OL-3	52.24	1.65		5058.0	11850.0	39690.0	7839.0	6137.0	200.7	6335.0	46.0	248.6
4611	C6-S-OL-1	55.95	1.79		6313.0	20730.0	44914.0	10260.0	9303.0	275.3	3725.0	58.2	270.1
4612	C6-S-OL-2	54.55	2.34		6367.0	20818.0	45013.0	10228.0	9201.0	284.4	3826.0	56.5	264.5
4613	C6-S-OL-3	56.66	2.34		6353.0	20627.0	49352.0	10049.0	9541.0	251.4	3589.0	56.3	261.9
4614	C6-S-LS-1	82.34	2.35		5376.0	13188.0	47446.0	8626.0	7795.0	245.3	2306.0	275.8	231.4
4615	C6-S-LS-2	83.98	2.28		5461.0	12642.0	45985.0	8604.0	7904.0	251.5	1880.0	281.6	229.6
4616	C6-S-LS-3	84.10	2.35		5509.0	12941.0	45392.0	8931.0	7833.0	250.4	1819.0	272.9	230.4
65020	C6-S-FD-1	39.19		2.87	3444.0	11273.0	12953.0	5498.0	5382.0	122.2	65.7	14.0	109.9
65021	C6-S-FD-2	42.29		2.95	3925.0	11731.0	13106.0	5181.0	5878.0	123.0	39.6	14.8	102.2
65022	C6-S-FD-3	50.62		2.89	3874.0	11497.0	13372.0	4537.0	5614.0	123.8	40.0	13.6	106.7
65023	C6-W-FD-1	67.55		2.67	3078.0	10162.0	12348.0	4068.0	5293.0	106.5	166.0	31.0	106.0
65024	C6-W-FD-2	46.98		2.84	3231.0	11127.0	12672.0	4729.0	5410.0	117.3	125.0	15.5	114.7
65025	C6-W-FD-3	49.80		2.91	3199.0	11497.0	11082.0	4014.0	4762.0	106.2	73.5	15.8	103.8

SAMPLES OF DAIRY E1 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4617	E1-W-OL-1	47.024436	1.22		3417.98	4518.82	9310.99	3039.74	2693.28	91.70	2809.82	19.08	162.37
4618	E1-W-OL-2	47.59962	0.79		3644.45	4555.16	9401.68	3183.32	2392.60	102.70	3571.61	16.85	180.05
4619	E1-W-OL-3	39.952756	0.93		3384.26	4513.75	8926.02	3060.61	2662.49	93.97	3657.48	14.83	184.89
4695	E1-S-LN-1		0.187		1363	1362	1040	359	482	25	18	104.3	37
4696	E1-S-LN-2		0.200		1349	1450	1568	366	510	24	18	101.6	38
4697	E1-S-LN-3		0.213		1464	1477	1652	367	501	26	18	108.8	41
4698	E1-S-OL-1	4.8116493	1.25		5466.67	5988.30	13840.39	4205.42	3285.90	128.79	6123.47	27.23	221.50
4699	E1-S-OL-2	3.7947764	1.09		6103.26	5800.21	16291.39	4791.02	3485.52	140.94	6108.07	29.66	252.92
4700	E1-S-OL-3	3.7932584	1.15		6123.56	5706.02	15207.40	4702.59	3541.37	140.94	6064.87	30.47	242.34
65230	E1-S-FD-1	22.27		2.16	3007.09	12727.60	8533.08	3112.99	5631.10	53.41	25.63	11.15	61.20
65231	E1-S-FD-2	32.87		2.30	3305.03	12006.67	8875.41	3253.84	5458.63	63.30	23.00	12.25	70.15
65232	E1-S-FD-3	28.95		2.12	2902.76	11169.94	7971.07	2963.74	5018.85	59.15	25.88	11.14	64.37
65026	E1-W-FD-1	42.538524		1.84	3266.11	7200.50	5541.58	2372.01	3287.37	60.79	15.60	10.40	65.39
65027	E1-W-FD-2	41.606822		1.93	3415.42	7497.68	4526.06	2352.66	3288.12	59.79	15.09	11.58	66.86
65028	E1-W-FD-3	41.884608		1.92	3785.06	7449.23	4983.39	2513.49	3431.13	68.52	15.00	12.85	72.12

SAMPLES OF DAIRY E2 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4620	E2-W-OL-1	63.76	0.47		1821.55	1744.37	5117.87	2072.66	1249.75	63.41	1963.23	14.69	125.30
4621	E2-W-OL-2	65.54	0.51		1658.42	1667.38	4749.51	1828.67	1363.75	73.89	1959.98	13.62	118.73
4622	E2-W-OL-3	68.62	0.43		1804.64	1432.79	5021.67	2121.26	1102.36	61.79	1224.74	15.13	114.57
4701	E2-S-LN-1		0.02	0.00	93.60	1421.00	214.70	158.70	660.00	1.60	4.43	0.38	3.19
4702	E2-S-LN-2		0.01	0.00	96.90	1470.00	221.50	164.90	680.00	1.64	4.31	0.38	3.30
4703	E2-S-LN-3		0.02	0.00	133.40	1511.00	283.20	160.80	677.00	2.22	5.10	0.53	4.81
4704	E2-S-OL-1	10.84	1.48		2238.75	4282.25	8887.25	3006.40	2581.12	95.13	6654.74	20.08	308.22
4705	E2-S-OL-2	9.69	1.54		2807.69	4764.68	11023.07	3662.92	2770.67	111.17	7650.94	26.42	337.84
4706	E2-S-OL-3	10.13	1.68		2430.19	4686.02	9657.84	3333.42	2883.15	100.57	6539.22	24.42	275.73
65233	E2-S-FD-1	39.23		1.44	1480.98	7866.19	7661.61	1604.50	1612.87	20.66	230.32	5.84	54.94
65234	E2-S-FD-2	27.36		2.11	1688.58	8206.13	10908.15	1788.65	1496.64	22.18	821.51	6.23	76.92
65235	E2-S-FD-3	31.59		2.07	1593.79	8701.62	9647.73	1629.25	1746.35	25.58	374.03	5.99	69.65
65029	E2-W-FD-1	8.14		3.30	6600.29	9948.66	5401.49	3276.72	14520.64	58.61	16.09	7.87	24.04
65030	E2-W-FD-2	7.96		3.35	6461.90	9932.61	4675.47	3396.16	16436.85	56.79	19.24	6.77	34.14
65031	E2-W-FD-3	66.16		1.17	2398.12	3577.39	1632.36	1182.99	6500.34	20.61	7.03	2.46	8.77

SAMPLES OF DAIRY P1 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4467	P1-S-WW-1		0.04		53.60	654.00	235.50	116.50	201.80	2.26	10.21	0.38	1.67
4468	P1-S-WW-2		0.05		59.80	654.00	270.00	117.70	195.80	3.31	7.85	0.48	1.97
4469	P1-S-WW-3		0.05		63.70	684.00	292.50	121.80	200.30	3.04	5.62	0.51	2.06
4470	P1-S-LN-1		0.10		187.50	1052.00	869.00	226.10	368.00	222.80	8.86	1.35	7.72
4471	P1-S-LN-2		0.08		118.10	977.00	631.00	190.40	349.50	103.40	9.02	0.73	4.62
4472	P1-S-LN-3		0.12		201.80	1005.00	744.00	241.70	360.20	169.60	12.62	1.31	7.90
4473	P1-W-LN-1		0.05		29.13	567.00	197.30	100.30	244.40	75.10	8.67	1.18	1.30
4474	P1-W-LN-2		0.05		28.87	620.00	204.50	104.60	244.30	69.80	8.76	0.26	1.32
4475	P1-W-LN-3		0.05		30.60	544.00	206.20	101.50	256.60	70.70	6.55	0.44	1.36
4476	P1-S-FF-1		0.09		116.10	919.00	521.00	180.40	302.30	4.82	7.58	0.61	3.69
4477	P1-S-FF-2		0.09		128.70	1070.00	474.00	191.20	324.30	4.56	8.44	0.65	3.81
4478	P1-S-FF-3		0.08		124.10	1048.00	469.80	184.30	313.70	4.46	8.63	0.69	3.66
4623	P1-S-OL-1	9.12	1.53		5493.42	30447.82	29171.93	7313.66	5712.43	125.23	4889.10	28.64	241.73
4624	P1-S-OL-2	8.68	2.21		5547.78	29561.70	29839.31	7523.07	5491.16	124.01	4884.79	17.41	237.98
4625	P1-S-OL-3	8.95	2.17		5575.65	29148.34	31269.71	7566.82	6161.07	129.65	4911.01	20.69	246.92
4626	P1-S-CP-1	49.66	1.24		784.82	3184.59	13523.18	2002.58	2207.97	1256.52	5132.30	8.53	139.50
4627	P1-S-CP-2	44.49	0.36		763.29	3619.37	20290.10	2431.97	2064.48	955.91	6226.20	11.14	156.43
4628	P1-S-CP-3	50.41	0.26		780.98	2818.97	15050.86	1875.84	1849.06	1363.12	4562.41	8.19	123.07
4629	P1-W-EP-1	25.12	0.52		1838.29	7368.89	19482.90	3281.97	2961.48	144.59	4332.53	14.55	148.41
4630	P1-W-EP-2	33.06	0.45		1978.15	6814.06	18758.59	3182.44	2591.34	113.00	3970.35	16.74	148.55
4631	P1-W-EP-3	21.64	0.55		1947.18	7238.65	19711.56	3337.24	2746.42	115.81	4504.76	16.28	154.68
4632	P1-W-OP-1	26.69	0.47		3626.82	23475.00	20481.61	5623.15	5162.74	122.95	3312.31	19.22	175.15
4633	P1-W-OP-2	28.27	1.43		3570.78	22992.00	18641.51	5271.53	5130.93	150.92	2800.39	17.50	156.80
4634	P1-W-OP-3	26.94	1.47		3687.30	22359.03	18728.72	5334.05	4873.78	118.72	2559.26	18.75	155.25
4635	P1-W-CW-1	68.85	0.65		356.05	1496.47	5039.22	777.52	1087.78	518.66	1769.35	2.95	42.52
4636	P1-W-CW-2	63.43	0.23		408.46	1569.86	7375.36	992.82	1303.64	660.41	2379.83	3.49	55.07
4637	P1-W-CW-3	66.34	0.20		388.47	1595.30	5758.11	899.15	1208.18	637.92	1868.99	3.29	45.88
4638	P1-W-FS-1	78.31	0.14		709.77	1396.12	4048.70	1102.06	886.72	54.28	777.43	4.71	40.21
4639	P1-W-FS-2	77.22	0.33		695.72	1463.88	3906.42	1045.63	960.89	40.60	837.87	4.21	40.57
4640	P1-W-FS-3	78.58	0.29		697.28	1309.95	3926.42	1130.43	889.44	38.56	799.89	93.76	38.90
4641	P1-W-WW-1	77.10	0.34		362.95	1185.02	2686.06	533.09	875.20	558.05	889.86	3.59	26.40
4642	P1-W-WW-2	74.89	0.25		385.21	1159.39	2778.58	565.26	994.66	607.70	922.09	2.95	29.18
4643	P1-W-WW-3	72.47	0.26		406.60	1161.71	3025.41	599.30	973.97	659.04	1121.80	3.07	31.60
65032	P1-S-FD-1	29.82		2.01	2233.21	13105.79	8303.68	3137.08	4252.01	64.12	77.12	8.71	54.74
65033	P1-S-FD-2	35.96		2.16	2556.81	15004.50	7977.91	3008.05	4321.20	61.56	58.06	8.72	62.80
65034	P1-S-FD-3	36.73		2.09	2845.71	15764.11	10103.71	3307.61	4778.59	79.46	148.71	11.05	59.82
65035	P1-W-FD-1	30.45		1.73	2017.12	11130.84	9321.93	2472.34	4388.54	74.39	281.11	9.29	73.90

65036	P1-W-FD-2	32.13		1.70	2072.61	11350.36	10009.98	2377.71	4536.03	71.78	333.83	9.12	73.70
65037	P1-W-FD-3	31.74		1.79	2090.83	11084.09	9890.01	2509.67	4422.64	82.89	414.09	11.35	79.90

SAMPLES OF DAIRY P2 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4479	P2-S-WW-1		0.02		41.96	261.70	159.20	68.50	234.50	1.29	6.54	3.84	1.38
4480	P2-S-WW-2		0.02		42.29	217.70	136.20	65.00	139.10	1.00	6.39	2.81	1.10
4481	P2-S-WW-3		0.02		37.20	218.90	122.40	61.90	138.30	0.59	3.80	1.63	0.93
4482	P2-S-OF-1		0.03		20.84	262.70	84.90	49.65	150.50	0.55	1.88	0.24	0.64
4483	P2-S-OF-2		0.03		22.59	287.60	87.30	52.10	152.60	0.71	2.14	0.44	0.66
4484	P2-S-OF-3		0.03		28.35	316.00	100.20	57.80	156.10	0.86	5.24	0.33	0.74
4485	P2-S-LN-1		0.04		241.00	354.90	478.30	112.80	180.10	2.23	7.79	11.72	5.69
4486	P2-S-LN-2		0.14		1129.00	560.00	1073.00	225.30	175.90	9.91	11.10	52.50	28.43
4487	P2-S-LN-3		0.03		160.80	370.80	334.80	103.10	187.70	1.40	5.14	6.92	3.65
4488	P2-W-WW-1		0.19		510.00	1070.00	1313.00	264.80	286.20	25.26	31.14	111.70	25.42
4489	P2-W-WW-2		0.17		327.00	869.00	1074.00	192.50	254.60	16.86	19.97	100.10	15.82
4490	P2-W-WW-3		0.18		400.60	876.00	1482.00	211.50	254.80	18.78	18.28	116.00	17.58
4491	P2-W-OF-1		0.01		21.25	113.50	123.70	42.47	105.30	0.68	2.97	0.75	0.89
4492	P2-W-OF-2		0.01		20.23	115.60	138.70	42.09	112.40	0.61	2.55	0.60	0.88
4493	P2-W-OF-3		0.01		19.97	116.20	117.20	42.60	109.60	0.59	2.08	0.62	0.85
4494	P2-W-LN-1		0.02		49.61	432.70	180.60	84.90	237.30	0.48	3.53	2.81	1.09
4495	P2-W-LN-2		0.02		44.84	429.70	148.90	81.20	232.50	0.72	5.38	2.50	0.94
4496	P2-W-LN-3		0.02		47.10	434.10	156.20	83.30	244.00	0.56	4.98	2.70	1.05
4644	P2-S-CP-1	24.14	0.66		5176.90	15078.54	19939.85	5641.94	4004.05	181.69	6556.84	35.50	254.14
4645	P2-S-CP-2	22.31	2.01		4213.23	13878.11	19577.59	5192.15	3689.59	124.70	6780.95	31.59	241.70
4646	P2-S-CP-3	32.18	1.57		5234.10	15677.90	24589.04	5573.87	3785.54	136.38	5007.60	31.05	227.19
4647	P2-S-OL-1	17.32	2.62		4590.42	15515.80	18214.49	5365.13	6657.42	124.76	6638.41	200.67	220.84
4648	P2-S-OL-2	15.47	1.44		4126.60	13813.38	17227.42	5022.58	6208.50	122.31	7256.63	294.07	238.79
4649	P2-S-OL-3	16.90	1.26		4429.94	14401.67	16914.54	5271.72	6452.54	122.40	6580.51	236.33	202.51
4650	P2-W-OL-1	46.73	0.86		3144.05	15811.87	9569.05	3398.68	7394.54	117.46	1211.38	40.22	106.12
4651	P2-W-OL-2	52.70	0.98		2984.18	15673.92	8899.56	3202.71	7179.25	85.52	1130.01	33.68	98.43
4652	P2-W-OL-3	49.61	1.03		3452.30	15265.99	10052.02	3518.81	7374.74	93.27	1168.57	35.58	110.41
4653	P2-W-CP-1	25.19	1.61		5269.40	16239.10	19627.86	7385.69	5722.73	172.73	9074.84	58.72	308.80
4654	P2-W-CP-2	26.31	0.97		4872.14	15087.29	19230.67	6850.62	5576.59	156.95	8657.41	55.19	282.96
4655	P2-W-CP-3	26.94	0.93		4815.08	14537.30	18228.79	6718.91	5338.89	158.68	8155.91	61.66	277.10
65038	P2-S-FD-1	37.64		2.22	2165.03	13247.45	9504.77	3939.63	3549.20	32.45	204.71	5.63	30.95
65039	P2-S-FD-2	33.95		1.74	3108.60	8737.98	4514.21	2273.17	2838.94	43.85	171.56	7.39	43.98
65040	P2-S-FD-3	34.05		1.83	2923.98	7962.22	3691.62	2048.08	2117.98	30.12	42.50	5.61	28.69

SAMPLES OF DAIRY P3 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4497	P3-S-LN-1		0.23		967.00	1270.00	975.00	604.00	285.00	31.11	15.88	5.36	32.76
4498	P3-S-LN-2		0.24		1007.00	1288.00	1374.00	633.00	273.60	33.64	17.79	5.76	37.26
4499	P3-S-LN-3		0.16		627.00	793.00	993.00	385.20	182.10	19.94	13.73	3.52	21.65
4500	P3-S-WW-1		0.06		87.30	935.00	341.20	232.50	378.50	1.97	5.13	0.37	2.14
4501	P3-S-WW-2		0.07		109.10	876.00	503.00	227.90	354.70	3.52	5.51	0.59	3.17
4502	P3-S-WW-3		0.07		94.60	911.00	314.70	230.50	384.30	2.47	5.80	0.47	2.48
4503	P3-W-FF-1		0.08		93.10	971.00	422.70	225.40	395.90	3.01	8.04	0.66	2.97
4504	P3-W-FF-2		0.08		95.70	976.00	438.40	225.80	401.80	3.09	6.22	0.71	3.08
4505	P3-W-FF-3		0.08		89.10	995.00	394.30	227.50	408.20	2.67	7.15	0.56	2.75
4506	P3-W-WE-1		0.09		99.70	947.00	442.40	222.40	397.00	3.33	6.39	0.60	3.17
4507	P3-W-WE-2		0.09		100.30	927.00	400.70	224.10	391.10	3.27	8.57	0.60	3.17
4508	P3-W-WE-3		0.09		112.60	926.00	481.30	231.90	389.20	3.81	7.09	0.68	3.62
4509	P3-W-LN-1		0.13		269.20	926.00	873.00	292.00	318.20	11.24	8.34	1.76	10.93
4510	P3-W-LN-2		0.10		191.80	866.00	787.00	230.90	329.80	7.44	5.34	1.19	7.54
4511	P3-W-LN-3		0.13		284.00	999.00	1148.00	314.40	345.20	11.62	5.87	1.86	11.85
4512	P3-S-FS-1		0.07		108.30	912.00	394.70	260.10	397.80	3.45	8.40	0.59	3.49
4513	P3-S-FS-2		0.07		105.00	871.00	460.60	245.30	384.50	3.50	6.07	0.57	3.40
4514	P3-S-FS-3		0.06		101.70	866.00	506.00	245.50	365.90	3.16	5.66	0.59	3.56
4656	P3-S-OL-1	21.54	1.06		3710.37	19050.84	13425.26	4981.42	5070.08	112.59	4872.36	14.99	185.48
4657	P3-S-OL-2	23.62	1.34		3392.77	17833.03	12513.22	4640.80	4515.54	102.27	4713.36	13.95	174.14
4658	P3-S-OL-3	22.60	1.28		3601.63	18110.34	13016.35	4896.61	4830.04	108.52	4765.02	16.01	179.58
4659	P3-W-SS-1	26.44	1.27		3336.16	13043.75	17631.97	5600.48	5015.64	132.93	4498.48	17.46	176.63
4660	P3-W-SS-2	26.36	1.26		3295.34	13102.56	19333.88	5836.62	5222.47	135.72	4897.72	19.25	182.85
4661	P3-W-SS-3	27.66	1.22		3462.72	14072.95	18235.16	5829.55	5841.85	137.58	4421.17	19.54	183.95
4662	P3-W-OL-1	81.75	0.33		402.32	714.87	2131.48	434.43	588.06	27.70	581.86	3.16	20.44
4663	P3-W-OL-2	83.60	0.22		318.11	730.82	1800.08	388.29	542.75	23.84	499.13	2.77	17.89
4664	P3-W-OL-3	85.89	0.20		273.60	593.77	1647.67	319.74	449.42	21.18	403.56	2.44	15.10
65041	P3-S-FD-1	46.20		1.59	2115.93	9945.69	7852.46	2945.55	3720.58	58.48	62.91	9.63	48.97
65042	P3-S-FD-2	44.20		1.66	2502.65	9565.29	9036.23	3360.36	4264.84	71.62	66.71	12.82	61.57
65043	P3-S-FD-3	45.98		1.55	2270.40	9816.94	8216.93	3147.50	4410.90	62.41	97.88	12.37	54.84
65044	P3-W-FD-1	46.74		1.39	2103.05	9540.42	6657.39	2654.03	2661.91	62.14	152.48	8.68	54.68
65045	P3-W-FD-2	44.68		1.33	1811.72	7944.20	6189.46	2209.19	2399.28	52.45	90.47	9.46	52.31
65046	P3-W-FD-3	45.59		1.68	2427.44	8710.87	6432.67	2737.14	2790.44	57.14	31.45	8.25	53.84

SAMPLES OF DAIRY P4 ON AS RECEIVED BASIS													
LAB	**SAMPLE**	**Moisture**	**Total N**	**Nitrogen**	**P**	**K**	**Ca**	**Mg**	**Na**	**Zn**	**Fe**	**Cu**	**Mn**
#	ID	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4515	P4-S-LN-1		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
4516	P4-S-LN-2		0.05		157.90	1273.00	850.00	145.80	396.80	3.34	6.00	19.74	6.54
4517	P4-S-LN-3		0.05		143.90	1252.00	635.00	138.00	391.80	3.01	6.76	17.96	5.79
4518	P4-W-LN-1		0.03		111.10	909.00	452.30	113.40	346.50	1.05	4.94	5.59	3.00
4519	P4-W-LN-2		0.03		101.20	892.00	452.50	102.10	346.60	0.94	4.14	5.87	2.80
4520	P4-W-LN-3		0.04		179.20	943.00	708.00	162.50	332.80	1.87	6.49	10.00	5.15
4665	P4-S-GS-1	82.20	0.25		405.69	554.33	2637.26	439.69	660.07	23.66	588.51	218.07	20.69
4666	P4-S-GS-2	82.14	0.30		455.67	557.09	3075.40	460.49	652.79	28.71	479.77	193.02	23.68
4667	P4-S-GS-3	81.58	0.35		376.39	402.55	2593.10	386.15	555.28	23.71	580.52	213.90	20.97
4668	P4-S-OL-1	8.86	1.65		5231.36	15905.52	25506.98	7506.18	7668.41	158.03	2461.66	123.68	177.99
4669	P4-S-OL-2	7.55	2.50		5419.56	18789.11	27786.59	7937.97	8622.12	160.41	2591.44	96.98	176.77
4670	P4-S-OL-3	6.00	2.58		5399.42	18505.05	27739.72	7998.55	8352.94	154.16	2727.91	79.05	178.13
4671	P4-W-GS-1	95.31	0.13		211.39	484.91	875.38	189.30	235.02	5.85	75.68	0.09	6.14
4672	P4-W-GS-2	95.39	0.12		179.69	454.21	1004.99	183.79	224.75	4.80	192.50	0.09	7.30
4673	P4-W-GS-3	94.79	0.11		217.63	456.20	918.08	186.17	240.03	5.71	69.12	0.10	6.02
4674	P4-W-OL-1	31.64	1.62		3832.31	20273.10	17513.37	5099.04	3675.76	131.80	1861.47	113.41	143.22
4675	P4-W-OL-2	24.54	2.13		4163.69	18584.16	21753.33	5807.88	3769.05	150.38	1902.26	31.62	160.19
4676	P4-W-OL-3	29.09	1.98		3785.25	19801.28	18677.33	5213.40	3717.17	136.86	2023.10	24.07	152.53
65047	P4-S-FD-1	43.20		1.36	1876.69	9100.69	6938.30	2670.43	3824.95	55.73	62.01	10.59	51.45
65048	P4-S-FD-2	39.58		1.63	1827.81	9127.17	7535.25	2393.22	3454.10	65.08	114.39	9.56	54.05
65049	P4-S-FD-3	40.18		1.78	1888.03	9609.81	7386.22	2578.78	4088.19	57.05	76.61	10.33	51.22
65050	P4-W-FD-1	44.11		1.86	2710.76	17019.61	8544.92	2608.33	1881.80	35.96	779.21	8.74	57.51
65051	P4-W-FD-2	42.16		1.48	2405.48	14351.16	7497.22	2105.32	1852.37	33.28	514.98	7.16	49.86
65052	P4-W-FD-3	42.36		1.50	2735.85	15933.80	8058.89	2441.20	1878.56	39.26	668.63	12.43	55.06

PROXIMATE AND ULTIMATE ANALYSES:

SAMPLES OF DAIRY C1 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4413	C1-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4414	C1-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4415	C1-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4416	C1-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4417	C1-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4418	C1-W-LN-3	34.10	20.01	2.61	4.14	0.81	38.33	#N/A	89.15	#N/A
4521	C1-S-OL-1	33.04	22.62	2.15	3.71	0.43	38.06	55.90	88.50	130.00
4522	C1-S-OL-2	32.08	23.41	2.04	3.71	0.43	38.33	54.18	89.15	126.01
4523	C1-S-OL-3	31.82	23.26	2.08	3.62	0.44	38.77	50.87	90.16	118.31
4524	C1-S-CVS-1	11.08	3.10	0.62	1.41	0.15	83.64	#N/A	194.50	#N/A
4525	C1-S-CVS-2	8.88	5.80	0.69	1.11	0.15	83.37	#N/A	193.89	#N/A
4526	C1-S-CVS-3	9.08	6.18	0.56	1.11	0.15	82.93	23.70	192.85	55.11
4527	C1-S-VS-1	10.58	4.76	0.67	1.29	0.11	82.60	22.97	192.09	53.42
4528	C1-S-VS-2	10.09	5.17	0.70	1.28	0.11	82.66	34.92	192.22	81.21
4529	C1-S-VS-3	10.02	6.37	0.75	1.23	0.12	81.51	23.63	189.55	54.95
4530	C1-W-OL-1	29.94	23.75	1.46	3.28	0.33	41.24	51.83	95.91	120.54
4531	C1-W-OL-2	30.06	25.41	1.82	3.48	0.42	38.82	49.19	90.27	114.40
4532	C1-W-OL-3	21.66	12.87	1.19	2.47	0.26	61.54	41.31	143.11	96.07
4533	C1-W-FSV-1	21.29	6.81	0.98	2.62	0.22	68.07	27.44	158.31	63.80
4534	C1-W-FSV-2	20.44	1.18	0.84	2.51	0.19	74.84	37.14	174.05	86.36
4535	C1-W-FSV-3	19.29	5.40	0.93	2.39	0.22	71.77	32.07	166.90	74.57
64990	C1-S-FD-1	46.50	37.92	2.53	6.07	0.25	6.72	79.61	15.63	185.14
64991	C1-S-FD-2	46.36	38.14	2.48	5.91	0.25	6.85	79.96	15.94	185.96
64992	C1-S-FD-3	46.57	37.76	2.67	6.14	0.26	6.61	59.47	15.37	138.30
64993	C1-W-FD-1	46.63	37.25	2.72	5.87	0.29	7.25	80.45	16.85	187.10
64994	C1-W-FD-2	46.87	37.62	2.75	5.81	0.28	6.67	88.93	15.52	206.81
64995	C1-W-FD-3	46.63	37.45	2.66	6.01	0.29	6.96	78.44	16.18	182.42

SAMPLES OF DAIRY C2 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4419	C2-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	58.71	#N/A	136.52
4420	C2-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4421	C2-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4422	C2-S-FF-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	65.32	#N/A	151.91
4423	C2-S-FF-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	64.15	#N/A	149.19
4424	C2-S-FF-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	64.68	#N/A	150.41
4425	C2-S-LN-1	32.83	22.70	2.85	3.77	0.68	37.16	#N/A	86.42	#N/A
4426	C2-S-LN-2	32.94	23.65	2.92	3.90	0.70	35.89	#N/A	83.47	#N/A
4427	C2-S-LN-3	33.01	22.96	2.92	3.68	0.69	36.74	#N/A	85.45	#N/A
4428	C2-W-FS-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4429	C2-W-FS-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4430	C2-W-FS-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4536	C2-W-SS-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4537	C2-W-SS-2	47.02	37.98	1.65	5.29	0.33	7.73	77.63	17.97	180.54
4538	C2-W-SS-3	47.57	38.59	1.30	5.48	0.32	6.75	76.24	15.69	177.31
4539	C2-W-GS-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	37.48	#N/A	87.17
4540	C2-W-GS-2	33.10	25.71	1.39	3.58	0.74	35.48	58.73	82.51	136.58
4541	C2-W-GS-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51.75	#N/A	120.35
4542	C2-W-CP-1	26.12	19.81	1.80	2.75	0.62	48.90	47.24	113.72	109.85
4543	C2-W-CP-2	25.59	20.61	1.88	2.72	0.66	48.54	46.42	112.89	107.96
4544	C2-W-CP-3	25.65	19.71	1.86	2.75	0.70	49.32	45.64	114.70	106.13
4545	C2-W-EP-1	36.34	26.73	2.10	4.17	0.51	30.16	60.99	70.13	141.85
4546	C2-W-EP-2	30.26	25.31	1.73	3.41	0.45	38.82	51.97	90.28	120.86
4547	C2-W-EP-3	37.94	26.35	2.26	4.41	0.46	28.58	60.32	66.46	140.27
4548	C2-S-CP-1	16.44	16.75	1.45	1.59	0.42	63.35	39.62	147.32	92.13
4549	C2-S-CP-2	16.19	16.76	1.44	1.55	0.42	63.65	36.43	148.03	84.72
4550	C2-S-CP-3	16.58	16.88	1.48	1.55	0.43	63.09	41.61	146.71	96.76
4551	C2-S-MS-1	47.97	37.13	1.54	5.63	0.43	7.30	76.54	16.97	177.99
4552	C2-S-MS-2	48.17	37.61	1.49	5.78	0.37	6.57	75.91	15.27	176.54
4553	C2-S-MS-3	47.69	37.72	1.56	5.56	0.38	7.09	74.90	16.50	174.20
4554	C2-S-EP-1	34.73	27.61	2.42	3.82	0.68	30.74	58.99	71.49	137.19
4555	C2-S-EP-2	34.89	27.95	2.37	3.94	0.66	30.18	61.65	70.18	143.37
4556	C2-S-EP-3	35.94	27.54	2.50	4.07	0.66	29.28	58.25	68.10	135.45
64996	C2-S-FD-1	46.01	37.46	2.92	5.76	0.34	7.50	78.77	17.45	183.19
64997	C2-S-FD-2	46.53	37.80	2.65	5.82	0.32	6.88	79.33	16.00	184.48
64998	C2-S-FD-3	46.25	36.94	2.80	5.97	0.33	7.71	77.84	17.92	181.02
64999	C2-W-TMR-1	45.28	37.03	2.87	5.63	0.32	8.87	79.70	20.63	185.35
65000	C2-W-TMR-2	45.16	37.90	2.67	5.44	0.29	8.54	76.63	19.85	178.20
65001	C2-W-TMR-3	44.90	37.07	2.68	5.43	0.28	9.64	77.18	22.42	179.49

SAMPLES OF DAIRY C3 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4431	C3-W-PL-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4432	C3-W-PL-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4433	C3-W-PL-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4434	C3-W-ML-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4435	C3-W-ML-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4436	C3-W-ML-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4437	C3-S-LN1-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4438	C3-S-LN1-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4439	C3-S-LN1-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4440	C3-S-LN2-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4441	C3-S-LN2-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4442	C3-S-LN2-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4557	C3-W-SS-1	48.49	40.03	1.37	5.78	0.18	4.15	95.85	9.65	222.91
4558	C3-W-SS-2	48.38	40.37	1.29	5.71	0.19	4.06	95.94	9.45	223.11
4559	C3-W-SS-3	48.67	39.96	1.40	5.67	0.19	4.10	95.90	9.54	223.01
4560	C3-W-OL-1	41.20	32.05	2.73	4.94	0.47	18.62	81.38	43.31	189.25
4561	C3-W-OL-2	43.21	32.79	2.71	5.21	0.46	15.61	84.39	36.31	196.25
4562	C3-W-OL-3	43.74	31.74	2.93	5.22	0.46	15.91	84.09	37.00	195.56
4563	C3-S-MS-1	48.35	35.66	2.08	5.52	0.37	8.02	91.98	18.65	213.91
4564	C3-S-MS-2	48.02	35.43	1.88	5.53	0.35	8.79	91.21	20.45	212.11
4565	C3-S-MS-3	47.50	34.83	2.17	5.52	0.37	9.61	90.39	22.36	210.20
4566	C3-S-OL-1	37.73	28.54	2.91	4.42	0.58	25.82	74.18	60.06	172.50
4567	C3-S-OL-2	37.39	28.73	2.75	4.32	0.57	26.24	73.76	61.03	171.53
4568	C3-S-OL-3	36.77	28.48	2.77	4.23	0.55	27.19	72.81	63.24	169.32
4569	C3-S-PS-1	33.90	25.40	2.48	3.91	0.61	33.70	66.30	78.38	154.18
4570	C3-S-PS-2	34.55	26.01	2.60	3.97	0.58	32.28	67.72	75.07	157.48
4571	C3-S-PS-3	31.96	24.48	2.39	3.59	0.55	37.02	62.98	86.09	146.47
4572	C3-S-LS-1	38.79	27.98	2.54	4.46	0.46	25.77	74.23	59.94	172.62
4573	C3-S-LS-2	39.89	29.05	2.46	4.62	0.47	23.51	76.49	54.67	177.89
4574	C3-S-LS-3	39.69	29.43	2.56	4.58	0.48	23.27	76.73	54.11	178.45
4575	C3-W-LS-1	39.10	29.85	2.25	4.47	0.45	23.89	76.11	55.55	177.00
4576	C3-W-LS-2	39.67	29.62	2.37	4.71	0.45	23.19	76.81	53.93	178.63
4577	C3-W-LS-3	41.60	30.67	2.40	4.88	0.46	20.00	80.00	46.50	186.06
65002	C3-S-FD-1	46.42	38.34	2.66	5.57	0.27	6.74	93.26	15.68	216.88
65003	C3-S-FD-2	46.51	38.09	2.65	5.65	0.27	6.84	93.16	15.90	216.66
65004	C3-S-FD-3	46.43	37.98	2.73	5.69	0.28	6.89	93.11	16.03	216.53
65005	C3-W-FD-1	45.92	36.81	3.04	5.73	0.36	8.14	91.86	18.94	213.62
65006	C3-W-FD-2	46.03	37.84	2.76	5.65	0.35	7.37	92.63	17.13	215.43
65007	C3-W-FD-3	46.60	37.35	2.71	5.68	0.33	7.33	92.67	17.04	215.52

SAMPLES OF DAIRY C4 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4578	C4-W-GS-1	30.80	7.74	1.06	3.87	0.14	56.38	43.62	131.11	101.44
4579	C4-W-GS-2	19.46	12.35	0.74	2.46	0.14	64.85	35.15	150.81	81.75
4580	C4-W-GS-3	20.97	11.57	0.82	2.60	0.13	63.91	36.09	148.62	83.94
4581	C4-W-OL-1	36.14	25.50	2.39	4.51	0.47	30.99	69.01	72.06	160.49
4582	C4-W-OL-2	34.88	26.12	2.43	4.30	0.47	31.80	68.20	73.95	158.61
4583	C4-W-OL-3	35.19	25.70	2.39	4.43	0.47	31.82	68.18	73.99	158.57
4584	C4-S-GS-1	11.38	4.12	0.59	1.46	0.07	82.38	17.62	191.59	40.97
4585	C4-S-GS-2	15.87	3.68	0.72	1.94	0.07	77.72	22.28	180.73	51.82
4586	C4-S-GS-3	17.73	3.13	0.60	2.12	0.08	76.34	23.66	177.53	55.03
4587	C4-S-OL-1	35.34	24.04	2.59	4.19	0.53	33.31	66.69	77.46	155.09
4588	C4-S-OL-2	35.56	25.51	2.57	4.26	0.54	31.57	68.43	73.41	159.15
4589	C4-S-OL-3	34.18	23.61	2.41	4.06	0.53	35.20	64.80	81.87	150.69
4443	C4-W-LN1-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4444	C4-W-LN1-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4445	C4-W-LN1-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4446	C4-W-LN2-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4447	C4-W-LN2-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4448	C4-W-LN2-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4449	C4-W-LN3-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4450	C4-W-LN3-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4451	C4-W-LN3-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4452	C4-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4453	C4-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4454	C4-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
65008	C4-S-FD-1	44.76	36.54	2.99	5.55	0.31	9.84	90.16	22.88	209.68
65009	C4-S-FD-2	46.67	37.34	2.88	5.78	0.31	7.02	92.98	16.33	216.23
65010	C4-S-FD-3	46.66	37.10	2.98	5.78	0.31	7.17	92.83	16.67	215.88
65011	C4-W-FD-1	46.36	38.24	2.52	5.74	0.26	6.88	93.12	16.00	216.56
65012	C4-W-FD-2	46.20	37.50	2.75	5.92	0.34	7.29	92.71	16.95	215.61
65013	C4-W-FD-3	46.56	37.78		5.99	0.27	6.77	93.23	15.74	216.82

SAMPLES OF DAIRY C5 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4455	C5-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4456	C5-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4457	C5-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4458	C5-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	50.43	#N/A	117.29
4459	C5-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	52.80	#N/A	122.79
4460	C5-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	52.87	#N/A	122.96
4590	C5-W-OL-1	35.75	27.13	2.39	4.13	0.56	30.04	58.52	69.86	136.08
4591	C5-W-OL-2	35.60	26.61	2.22	4.09	0.58	30.90	59.81	71.85	139.10
4592	C5-W-OL-3	35.75	27.35	2.37	4.17	0.58	29.77	62.26	69.24	144.80
4593	C5-W-VS-1	41.77	29.65	2.57	4.97	0.48	20.56	63.74	47.81	148.23
4594	C5-W-VS-2	42.72	28.35	2.70	5.09	0.51	20.63	62.51	47.99	145.37
4595	C5-W-VS-3	40.88	28.63	2.88	5.06	0.50	22.05	#N/A	51.27	#N/A
4596	C5-W-EP-1	39.20	27.30	2.50	4.65	0.42	25.93	63.58	60.31	147.87
4597	C5-W-EP-2	40.98	28.13	2.54	4.86	0.38	23.10	61.87	53.72	143.88
4598	C5-W-EP-3	39.04	28.05	2.47	4.64	0.40	25.40	64.93	59.07	150.99
4599	C5-S-EP-1	36.63	21.12	2.65	4.21	0.48	34.92	55.24	81.20	128.48
4600	C5-S-EP-2	35.80	24.28	2.71	4.10	0.49	32.63	54.23	75.89	126.11
4601	C5-S-EP-3	33.47	26.58	2.49	3.76	0.48	33.21	55.01	77.24	127.92
4602	C5-S-OL-1	36.83	26.37	2.45	4.22	0.59	29.54	62.69	68.71	145.78
4603	C5-S-OL-2	36.75	27.65	2.36	4.23	0.57	28.44	62.03	66.13	144.25
4604	C5-S-OL-3	36.98	27.64	2.43	4.30	0.59	28.06	58.97	65.25	137.13
4605	C5-S-VS-1	40.77	28.23	2.40	4.81	0.35	23.44	64.05	54.50	148.96
4606	C5-S-VS-2	41.44	28.42	2.44	5.00	0.33	22.36	66.85	51.99	155.48
4607	C5-S-VS-3	41.79	28.16	2.49	5.33	0.33	21.90	65.13	50.93	151.47
65014	C5-S-FD-1	46.78	38.28	2.43	5.64	0.26	6.61	79.64	15.37	185.20
65015	C5-S-FD-2	46.35	37.99	2.56	5.58	0.28	7.24	79.22	16.84	184.23
65016	C5-S-FD-3	46.76	38.49	2.38	5.58	0.24	6.55	79.13	15.23	184.03
65017	C5-W-FD-1	46.88	39.12	2.25	5.61	0.23	5.90	79.33	13.73	184.48
65018	C5-W-FD-2	46.84	38.75	2.36	5.68	0.25	6.12	77.97	14.24	181.31
65019	C5-W-FD-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	77.92	#N/A	181.20

SAMPLES OF DAIRY C6 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4461	C6-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4462	C6-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4463	C6-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4464	C6-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	41.91	#N/A	97.46
4465	C6-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4466	C6-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4608	C6-W-OL-1	27.58	17.82	1.82	3.29	0.38	49.11	53.47	114.20	124.35
4609	C6-W-OL-2	28.76	18.25	2.03	3.49	0.38	47.09	#N/A	109.51	#N/A
4610	C6-W-OL-3	30.60	20.63	2.13	3.68	0.41	42.54	45.62	98.94	106.10
4611	C6-S-OL-1	36.45	25.23	2.66	4.24	0.63	30.78	40.35	71.59	93.84
4612	C6-S-OL-2	36.80	24.05	2.62	4.31	0.64	31.59	41.12	73.47	95.64
4613	C6-S-OL-3	36.36	24.97	2.65	4.19	0.65	31.18	42.34	72.52	98.46
4614	C6-S-LS-1	42.52	29.29	2.42	4.91	0.52	20.33	#N/A	47.28	#N/A
4615	C6-S-LS-2	41.55	30.16	2.42	4.74	0.50	20.63	31.83	47.97	74.01
4616	C6-S-LS-3	42.59	29.69	2.48	4.90	0.53	19.82	31.38	46.09	72.98
65020	C6-S-FD-1	46.50	37.98	2.60	5.48	0.32	7.12	21.63	16.57	50.30
65021	C6-S-FD-2	46.03	37.32	2.68	5.60	0.33	8.04	22.28	18.70	51.82
65022	C6-S-FD-3	46.28	37.66	2.81	5.59	0.35	7.32	20.53	17.03	47.75
65023	C6-W-FD-1	45.19	37.08	2.69	5.54	0.30	9.19	21.63	21.38	50.29
65024	C6-W-FD-2	45.96	37.33	2.82	5.80	0.31	7.78	21.79	18.09	50.67
65025	C6-W-FD-3	46.46	37.79	2.64	5.76	0.28	7.08	21.17	16.46	49.22

SAMPLES OF DAIRY E1 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4617	E1-W-OL-1	21.35	16.01	1.75	2.53	0.30	58.07	37.85	135.04	88.02
4618	E1-W-OL-2	19.37	14.15	1.63	2.32	0.25	62.28	38.77	144.84	90.17
4619	E1-W-OL-3	22.92	15.05	1.77	2.73	0.25	57.28	47.73	133.20	111.01
4695	E1-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4696	E1-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4697	E1-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4698	E1-S-OL-1	14.49	8.58	1.26	1.97	0.22	73.47	#N/A	170.86	#N/A
4699	E1-S-OL-2	13.24	10.04	1.21	1.76	0.22	73.52	#N/A	170.98	#N/A
4700	E1-S-OL-3	12.15	8.57	1.11	1.57	0.23	76.36	32.99	177.59	76.72
65230	E1-S-FD-1	45.97	38.77	2.86	5.41	0.30	6.69	#N/A	15.56	#N/A
65231	E1-S-FD-2	45.82	39.73	2.25	5.49	0.30	6.42	76.98	14.94	179.02
65232	E1-S-FD-3	46.10	38.46	3.07	5.60	0.32	6.44	78.09	14.98	181.61
65026	E1-W-FD-1	47.09	37.52	3.05	5.62	0.27	6.45	86.01	15.01	200.03
65027	E1-W-FD-2	47.18	37.57	3.04	5.63	0.29	6.30	79.73	14.66	185.42
65028	E1-W-FD-3	47.05	37.62	3.03	5.62	0.29	6.39	#N/A	14.86	#N/A

SAMPLES OF DAIRY E2 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4620	E2-W-OL-1	32.55	24.44	1.77	3.87	0.20	37.16	61.25	86.43	142.43
4621	E2-W-OL-2	32.63	22.80	1.78	3.97	0.21	38.62	50.84	89.81	118.24
4622	E2-W-OL-3	39.48	29.76	1.86	4.76	0.22	23.92	63.58	55.62	147.87
4701	E2-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	21.02	#N/A	48.87
4702	E2-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4703	E2-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	17.30	#N/A	40.23
4704	E2-S-OL-1	34.92	28.63	1.91	4.27	0.21	30.06	66.18	69.91	153.92
4705	E2-S-OL-2	33.73	26.60	2.09	4.04	0.21	33.34	64.77	77.54	150.62
4706	E2-S-OL-3	33.86	27.27	1.88	4.08	0.19	32.72	60.04	76.09	139.63
65233	E2-S-FD-1	43.62	38.65	2.27	5.38	0.18	9.90	71.19	23.01	165.56
65234	E2-S-FD-2	41.70	37.44	2.44	5.09	0.20	13.14	#N/A	30.55	#N/A
65235	E2-S-FD-3	43.63	39.77	2.47	5.32	0.18	8.64	73.73	20.09	171.47
65029	E2-W-FD-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
65030	E2-W-FD-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
65031	E2-W-FD-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

SAMPLES OF DAIRY P1 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4467	P1-S-WW-1	37.55	25.87	2.53	4.78	0.88	28.39	#N/A	66.03	#N/A
4468	P1-S-WW-2	38.69	26.40	2.45	4.83	0.81	26.82	#N/A	62.37	#N/A
4469	P1-S-WW-3	37.71	26.73	2.49	4.72	0.88	27.45	#N/A	63.85	#N/A
4470	P1-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4471	P1-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4472	P1-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4473	P1-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4474	P1-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4475	P1-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4476	P1-S-FF-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4477	P1-S-FF-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4478	P1-S-FF-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4623	P1-S-OL-1	31.14	25.38	2.40	3.67	0.65	36.76	50.00	85.50	116.29
4624	P1-S-OL-2	31.33	24.59	2.47	3.84	0.68	37.09	49.99	86.26	116.25
4625	P1-S-OL-3	30.68	23.52	2.49	3.80	0.65	38.87	52.71	90.39	122.59
4626	P1-S-CP-1	11.56	7.89	0.77	1.39	0.17	78.22	26.76	181.90	62.24
4627	P1-S-CP-2	8.83	9.01	0.49	1.04	0.13	80.50	#N/A	187.21	#N/A
4628	P1-S-CP-3	13.63	8.98	0.81	1.50	0.21	74.87	23.51	174.12	54.66
4629	P1-W-EP-1	14.36	9.39	0.77	1.83	0.24	73.42	#N/A	170.73	#N/A
4630	P1-W-EP-2	15.11	11.26	0.83	1.79	0.21	70.79	#N/A	164.64	#N/A
4631	P1-W-EP-3	20.16	10.63	1.12	2.47	0.25	65.37	#N/A	152.01	#N/A
4632	P1-W-OP-1	34.86	26.53	2.17	3.89	0.50	32.06	111.00	74.56	258.15
4633	P1-W-OP-2	35.32	27.01	2.26	4.00	0.53	30.88	60.03	71.80	139.60
4634	P1-W-OP-3	36.49	27.48	2.23	4.12	0.53	29.14	61.27	67.77	142.48
4635	P1-W-CW-1	20.31	11.64	0.95	2.42	0.17	64.49	30.99	149.98	72.07
4636	P1-W-CW-2	21.63	7.34	0.88	2.58	0.18	67.38	#N/A	156.70	#N/A
4637	P1-W-CW-3	17.43	12.20	0.66	2.08	0.17	67.44	40.95	156.85	95.23
4638	P1-W-FS-1	33.68	17.55	1.99	4.03	0.26	42.49	57.07	98.81	132.72
4639	P1-W-FS-2	32.18	16.01	1.82	4.00	0.24	45.75	55.94	106.39	130.09
4640	P1-W-FS-3	31.23	17.92	1.92	3.81	0.24	44.88	#N/A	104.38	#N/A
4641	P1-W-WW-1	33.19	22.68	1.28	3.95	0.27	38.64	56.20	89.85	130.69
4642	P1-W-WW-2	30.94	20.28	1.12	3.59	0.23	43.86	49.30	101.99	114.64
4643	P1-W-WW-3	37.36	29.30	1.43	4.33	0.24	27.34	#N/A	63.58	#N/A
65032	P1-S-FD-1	45.04	36.84	2.90	5.49	0.32	9.42	#N/A	21.90	#N/A
65033	P1-S-FD-2	45.66	38.08	2.84	5.81	0.31	7.30	76.42	16.98	177.72
65034	P1-S-FD-3	45.55	37.85	2.87	5.81	0.33	7.58	77.53	17.64	180.29
65035	P1-W-FD-1	43.85	35.46	2.44	5.11	0.28	12.86	#N/A	29.91	#N/A
65036	P1-W-FD-2	45.02	35.90	2.53	5.45	0.28	10.83	73.73	25.18	171.46
65037	P1-W-FD-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

SAMPLES OF DAIRY P2 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4479	P2-S-WW-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4480	P2-S-WW-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4481	P2-S-WW-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4482	P2-S-OF-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4483	P2-S-OF-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4484	P2-S-OF-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4485	P2-S-LN-1	27.82	20.83	2.51	3.36	0.87	44.61	35.56	103.74	82.69
4486	P2-S-LN-2	28.03	19.00	3.46	3.31	0.81	45.39	46.05	105.56	107.10
4487	P2-S-LN-3	29.51	22.63	2.21	3.68	0.75	41.21	29.41	95.84	68.40
4488	P2-W-WW-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4489	P2-W-WW-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	45.54	#N/A	105.90
4490	P2-W-WW-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4491	P2-W-OF-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4492	P2-W-OF-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4493	P2-W-OF-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4494	P2-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4495	P2-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4496	P2-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4644	P2-S-CP-1	22.10	14.87	2.82	2.43	0.38	57.39	40.62	133.47	94.46
4645	P2-S-CP-2	15.13	12.39	1.83	1.69	0.27	68.69	38.64	159.73	89.86
4646	P2-S-CP-3	21.44	15.39	2.60	2.41	0.37	57.80	27.95	134.41	65.01
4647	P2-S-OL-1	29.08	21.59	1.97	3.55	0.56	43.24	55.54	100.57	129.16
4648	P2-S-OL-2	27.06	20.70	1.85	3.35	0.56	46.48	43.01	108.10	100.02
4649	P2-S-OL-3	24.49	19.64	1.78	3.12	0.54	50.43	46.01	117.28	107.00
4650	P2-W-OL-1	38.88	27.70	2.43	4.54	0.73	25.72	60.75	59.82	141.29
4651	P2-W-OL-2	39.59	27.38	2.55	4.74	0.74	25.00	62.84	58.13	146.14
4652	P2-W-OL-3	38.34	27.14	2.41	4.49	0.75	26.87	61.73	62.49	143.56
4653	P2-W-CP-1	12.95	7.66	1.35	1.62	0.43	75.99	24.20	176.72	56.28
4654	P2-W-CP-2	12.71	8.03	1.41	1.50	0.44	75.91	22.69	176.53	52.78
4655	P2-W-CP-3	12.65	8.24	1.37	1.53	0.45	75.77	24.46	176.20	56.88
65038	P2-S-FD-1	21.50	16.94	1.31	2.84	0.16	57.25	55.49	133.14	129.04
65039	P2-S-FD-2	46.02	37.79	2.95	5.80	0.33	7.11	72.12	16.53	167.72
65040	P2-S-FD-3	46.92	37.78	2.70	5.65	0.37	6.59	80.36	15.33	186.88

SAMPLES OF DAIRY P3 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4497	P3-S-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	44.43	#N/A	103.32
4498	P3-S-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	45.70	#N/A	106.29
4499	P3-S-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	45.34	#N/A	105.43
4500	P3-S-WW-1	40.97	35.44	1.50	5.02	0.46	16.62	64.42	38.64	149.82
4501	P3-S-WW-2	40.13	32.56	1.78	4.84	0.47	20.22	#N/A	47.02	#N/A
4502	P3-S-WW-3	40.25	33.19	1.70	4.97	0.52	19.38	#N/A	45.07	#N/A
4503	P3-W-FF-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4504	P3-W-FF-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4505	P3-W-FF-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4506	P3-W-WE-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4507	P3-W-WE-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4508	P3-W-WE-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4509	P3-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4510	P3-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4511	P3-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	53.70	#N/A	124.89
4512	P3-S-FS-1	37.00	28.89	1.95	4.70	0.53	26.93	#N/A	62.63	#N/A
4513	P3-S-FS-2	37.09	29.76	2.09	4.55	0.56	25.95	#N/A	60.35	#N/A
4514	P3-S-FS-3	31.30	27.24	2.08	3.95	0.55	34.88	#N/A	81.11	#N/A
4656	P3-S-OL-1	25.41	18.59	1.84	3.17	0.55	50.44	48.92	117.31	113.76
4657	P3-S-OL-2	25.37	18.93	1.79	3.07	0.54	50.30	58.50	116.99	136.04
4658	P3-S-OL-3	24.17	18.63	1.75	2.88	0.53	52.04	43.95	121.02	102.21
4659	P3-W-SS-1	43.86	32.47	1.67	5.00	0.27	16.73	-72.99	38.91	-169.74
4660	P3-W-SS-2	45.23	32.33	1.58	5.24	0.25	15.37	70.82	35.75	164.70
4661	P3-W-SS-3	45.86	33.58	1.54	5.28	0.25	13.48	71.58	31.36	166.46
4662	P3-W-OL-1	28.18	21.20	2.03	3.30	0.44	44.85	48.78	104.31	113.44
4663	P3-W-OL-2	25.74	19.69	1.88	3.07	0.43	49.19	47.26	114.39	109.92
4664	P3-W-OL-3	28.64	21.44	2.11	3.31	0.46	44.04	56.22	102.43	130.74
65041	P3-S-FD-1	44.99	38.60	2.67	5.48	0.35	7.91	78.92	18.40	183.53
65042	P3-S-FD-2	45.03	38.84	2.71	5.52	0.35	7.54	78.69	17.55	183.00
65043	P3-S-FD-3	45.36	38.74	2.75	5.60	0.34	7.22	80.03	16.78	186.11
65044	P3-W-FD-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	77.19	#N/A	179.52
65045	P3-W-FD-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	77.31	#N/A	179.80
65046	P3-W-FD-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

SAMPLES OF DAIRY P4 ON AS RECEIVED BASIS										
LAB	**SAMPLE**	**C**	**O (diff)**	**N**	**H**	**S**	**Ash**	**VM**	**HHV**	**HHV DAF**
#	ID	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**w/w %**	**%**	**KJ/Kg**	**KJ/Kg**
4515	P4-S-LN-1	21.06	17.90	1.97	2.64	0.58	55.86	#N/A	129.91	#N/A
4516	P4-S-LN-2	20.91	18.31	1.93	2.57	0.56	55.71	#N/A	129.56	#N/A
4517	P4-S-LN-3	21.97	17.94	2.02	2.64	0.57	54.86	38.77	127.59	90.17
4518	P4-W-LN-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4519	P4-W-LN-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4520	P4-W-LN-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4665	P4-S-GS-1	42.82	31.22	2.24	5.09	0.32	18.30	73.90	42.56	171.87
4666	P4-S-GS-2	42.71	32.22	2.37	5.06	0.34	17.30	70.25	40.23	163.37
4667	P4-S-GS-3	43.29	33.18	2.26	5.07	0.30	15.89	73.03	36.95	169.84
4668	P4-S-OL-1	37.27	29.28	2.81	4.22	0.39	26.03	61.31	60.54	142.59
4669	P4-S-OL-2	36.58	29.85	2.89	4.36	0.42	25.90	63.28	60.24	147.17
4670	P4-S-OL-3	36.09	28.65	2.85	4.28	0.41	27.71	61.75	64.44	143.61
4671	P4-W-GS-1	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4672	P4-W-GS-2	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	73.44	#N/A	170.80
4673	P4-W-GS-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4674	P4-W-OL-1	35.64	23.17	2.96	4.33	0.66	33.24	61.64	77.30	143.35
4675	P4-W-OL-2	37.17	26.43	3.18	4.43	0.64	28.15	64.88	65.48	150.89
4676	P4-W-OL-3	35.44	23.36	2.91	4.24	0.64	33.42	60.91	77.72	141.65
65047	P4-S-FD-1	45.16	38.46	2.96	5.53	0.21	7.68	76.78	17.86	178.55
65048	P4-S-FD-2	44.23	38.95	2.68	5.37	0.21	8.56	77.87	19.90	181.09
65049	P4-S-FD-3	45.33	38.25	2.72	5.54	0.21	7.95	78.16	18.50	181.77
65050	P4-W-FD-1	43.67	37.25	1.85	5.24	0.28	11.71	71.25	27.24	165.70
65051	P4-W-FD-2	43.68	37.09	2.32	5.16	0.28	11.47	#N/A	26.67	#N/A
65052	P4-W-FD-3	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Renewable Energy and Environmental Sustainability Using Biomass from Animal Production Systems

Task-D: Biomass Handling Methods

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**
Task Period: : **06/01/2006-08/31/2009**

Dr. Sergio C. Capareda
Assistant Professor
Office: 303D Scoates
Phone: (979) 458-3028
E-mail: scapareda@tamu.edu

Dr. Saqib Mukhtar
Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: mukhtar@tamu.edu

Recipient organization
Texas Engineering Experiment Station, Texas A&M University System,
College Station, TX 77843

Date of Report: 08/31/2009

Task number: D – Biomass Handling Methods

Task D.2. Efficient Collection, Harvest and Transport

The goal of this task is the development of a system for the efficient collection, harvest and transport of animal manure from CAFO's. A proposed system for handling, collection and use of animal manure in CAFOs' has been made.

A design for on-site manure handling, pre-processing and storage system has been completed with accompanying spreadsheet software to estimate the size of thermal conversion facility. Table 1 shows some important results of the study for a dairy facility and Table 2 for a feedyard facility.

An on-site thermal conversion facility for a 2,000 head dairy was estimated to generate about 320 kW of output electrical power. The estimated cost of this facility is approximately $322,000. For a 40,000 head beef cattle facility, a 2MW thermal power plant could possibly be installed.

Management changes at these facilities include the following (see Figures 1 and 2):

a. Collection and drying of wet manure to a centrally located site
b. Establishment of storage facility for the dried manure, and
c. Location of thermal conversion facility that could be tied-up to the grid.

Table 1. Results of spreadsheet sofware analysis on the design of on-site manure conversion in a dairy facility.

Dairy: Input Data		Output Data	
Population	2,000 head	Gasifier Data	
Manure Moisture	87% (w.b.)	Electrical Efficiency	15%
Amount P removed	62 tonnes/yr	Throughput	0.8 MMBTU/hr/ft2
Amount K removed	82 tonnes/yr	Feedrate to Gasifier	683 kg/hr
Dried Manure	16,664 kg/day	Size of Power Plant	322 kW
Recoverable Manure	16,400 kg/day	Diameter of FBG	3 ft
Manure HV	11.3 MJ/kg	Estimated Cost	$321,736

Table 2. Results of spreadsheet sofware analysis on the design of on-site manure conversion in a feedyard facility.

Feedyard: Input Data		Output Data	
Population	40,000 head	Gasifier Data	
Manure Moisture	92% (w.b.)	Electrical Efficiency	15%
Amount P removed	365 tonnes/yr	Throughput	0.8 MMBTU/hr/ft2
Amount K removed	1,240 tonnes/yr	Feedrate to Gasifier	4,400 kg/hr
Dried Manure	38,544 tonnes/yr	Size of Power Plant	2 MW
Recoverable Manure	105,600 kg/day	Diameter of FBG	8 ft
Manure HV	11.24 MJ/kg	Estimated Cost	$2,060,670

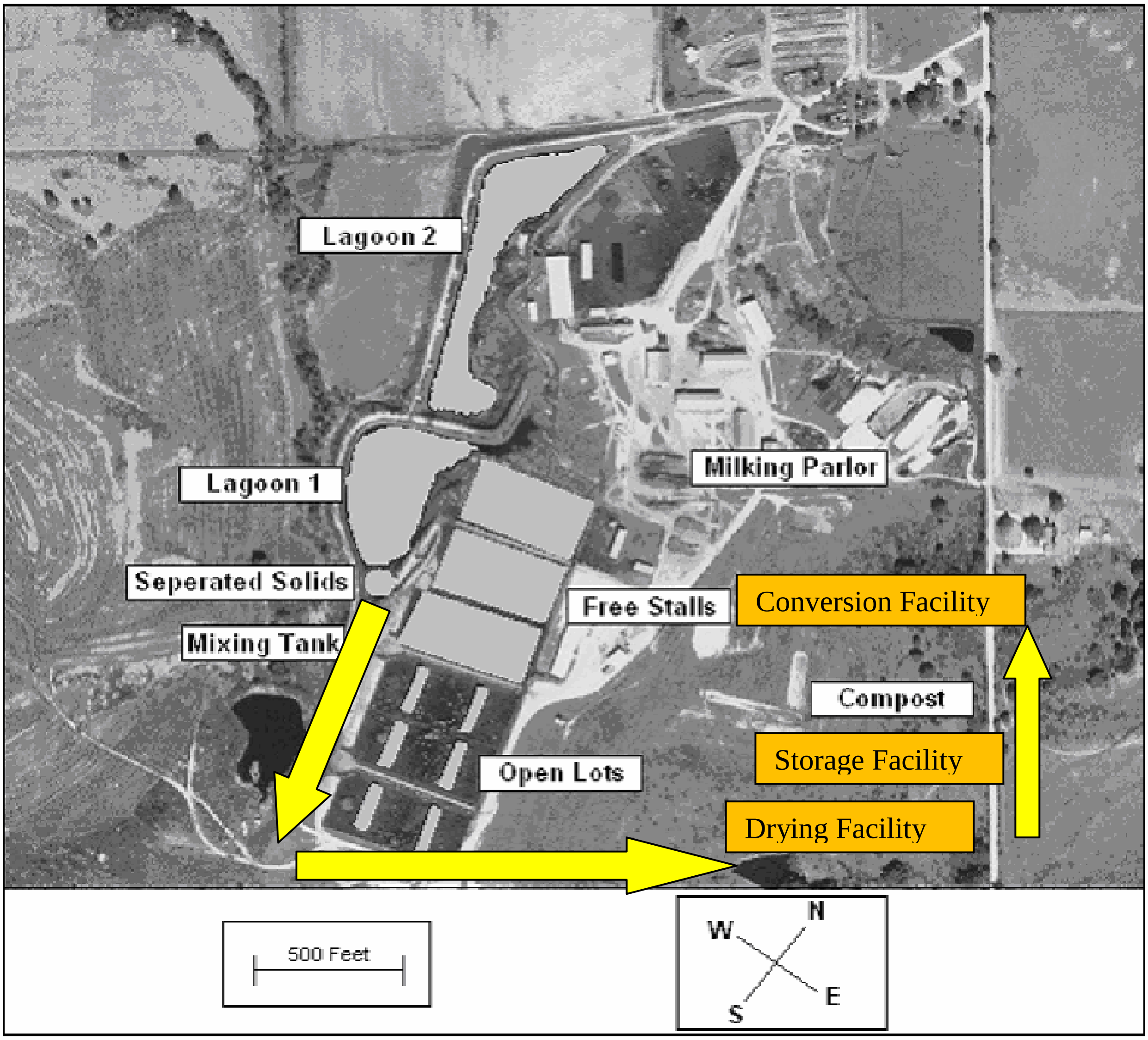


Figure 1. Typical lay-out in a dairy and the proposed on-site manure processing and conversion.

In a typical hybrid dairy facility (Figure 1), the bulk of manure could be gathered from the solids separator system. This will be transported into a drying facility. The drying facility could be of a mechanical dryer type or simple pavement dryer for lower cost. A covered manure storage facility may be required to prevent the absorption of moisture during rainy days.

The spreadsheet simulation software listed all associated sizes of drying, storage and thermal conversion facility including preliminary estimated cost.

In a beef cattle facility, the manure comes from routine scrapings in confined pens. The wet manure is normally scraped in mounds within each pen and left to dry for several days before being transported into the composting area. Likewise, a dryer or storage facility may be required in addition to the thermal conversion facility.

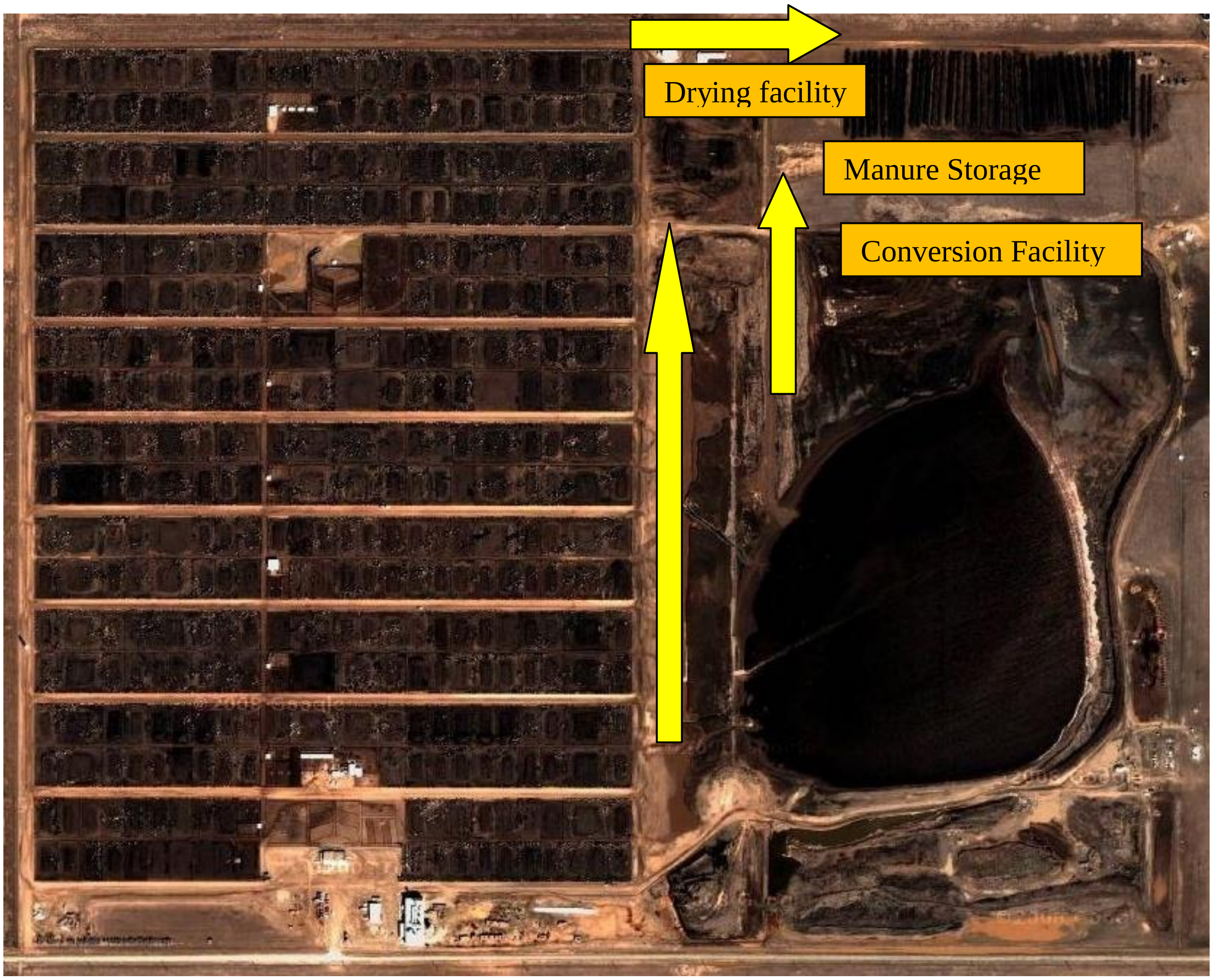


Figure 2. Typical feedyard lay-out and the proposed on-site manure processing and conversion.

Summary and Conclusions:

Observations noted from survey work are summarized below:

1. No single manure collection system is being followed by farm operators.
2. The most common manure disposal practice is by land applications.
3. Animal manure are normally scattered within the facility owned by the animal farm operator, most especially on their agricultural land.

The recommendations for efficient manure collection, handling and storage are as follows:

1. Animal manure should be consolidated in centrally located place,
2. Primary processing must be implemented as follows: drying, composting or aeration to reduce moisture content for safe storage.

The equipment required to implement proper handling and storage would include front end loaders, covered storage facilities with lined surfaces, drying or aeration facilities and manure quality measurement protocol (heating value, moisture and ash measurement facility.

Renewable Energy and Environmental Sustainability Using Biomass from Animal Production Systems

Task-E: Inventory, Characterization and Transport of Cattle Biomass

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**
Task Period: : **06/01/2006-08/31/2009**

Dr. Sergio C. Capareda
Assistant Professor
Office: 303D Scoates
Phone: (979) 458-3028
E-mail: scapareda@tamu.edu

Dr. Saqib Mukhtar
Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: mukhtar@tamu.edu

Recipient organization

Texas Engineering Experiment Station, Texas A&M University System,
College Station, TX 77843

Date of Report: 08/31/2009

Inventory, Characterization and Transport of Cattle Biomass

This task has been done in two parts. They are:

1. Transport Analysis of Dairy Biomass for Co-Firing in Coal-Fired Power Plants in Central Texas

2. Available Feedlot Biomass in the Texas Panhandle for Supplementing Coal Power Plants

In the first part i.e. Transport Analysis of Dairy Biomass for Co-Firing in Coal-Fired Power Plants in Central Texas, dairy manure samples were collected from twelve (12) dairies that serve as representative facilities in the state of Texas in terms of geography and management aspects. Ultimate, proximate, heating value, nutrient and trace metal analysis were made from all the samples taken.

The results of the analysis of the samples are combined with an analysis of the transport distance from the dairies in the Bosque watershed (Central Texas) using ArcGIS to the four closest coal-fired power plants in the state. The average distance to the various power plants is between 216km and 255km. Due to the required low ash content of power plant fuels only a small portion of the total dairy biomass currently generated is feasible for use in the coal fired power plants. Using the TMDL biomass removal targets as a metric for the quantity of biomass removal necessary, approximately 40% of the cattle in the watershed would need to be managed in a vacuumed freestall system with compost bedding. Exporting all the solids that are produced in this system would remove 470 tons of phosphorous from the watershed.

In the second part of the task i.e. Available Feedlot Biomass in the Texas Panhandle for Supplementing Coal Power Plants, estimates of available dairy and feedlot biomass in the Panhandle area were made as possible fuel for two power plants in the area, namely, Harrington and Tolk Coal Power Plants. The Network Analysis extension in ArcGIS 9.2 was used to perform the transport analysis of manure from permitted cattle feedlots to the coal power plants in the Texas Panhandle. Results showed that there is enough manure biomass to supply both the power plants with 10% of the fuel required to operate the plants. This requirement can be met by all feedlot within 50 miles off Tolk plant and within 100 miles of the Harrington power plant. This requirement will also be met if approximately 50% of the manure in each identified feedlot facility will be collected year round. The cost of delivering this manure was estimated to be around $46/ton for the Harrington plant and $40/ton for the Tolk plant using the economic model developed for this purpose. The detailed GIS transport analysis showed that on the average, the transport distance to the Harrington facility was 82 miles and 39 miles for the Tolk plant. The assumption was to use 50% of the daily manure production of 8.2 kg/day-HD for dairy facility and 2.6 kg/day-HD for cattle feedlot on dry basis.

Ideally, cattle biomass used for thermal conversion in coal power plants should have low moisture and low ash content prior to transport. The recommended criteria are as follows: (a) keep the moisture content to within 10% and (b) keep the ash content as low as possible by minimizing the gathering of soil during harvest. The average heating value of feedlot biomass used in this study was 8,500 Btu/lb on a dry ash free basis (DAF).

1. Characterization and Transport Analysis of Dairy Biomass for Co-Firing in Coal-Fired Power Plants in Central Texas

Introduction

The large number of concentrated dairy and beef cattle operations in the United States has necessitated the development of new, environmentally sound, methods of handling and disposing of the waste (biomass) generated by these facilities. The Bosque watershed in Central Texas implemented a total maximum daily load (TMDL) program after it was determined that runoff from the land application of dairy biomass (DB) produced excessive phosphorous (P) levels in the water system. The TMDL program set a goal of composting and removing 50% of the DB solids from the watershed. One possible use of the excess biomass is offsite thermo-chemical conversion of biomass for energy generation.

The manure characteristics of several representative animal facilities in Central Texas for possible input for co-firing in a coal power plant in Texas are evaluated. The specific objectives of this task are as follows:

a. To make an inventory of the available manure streams from the different sources within the dairy
b. To analyze the transport distances of the dairies to the nearby coal power plant in Texas and provide some cost estimates.

Methodology:

Transport analysis was conducted using ARCGIS version 9.2 (ESRI). Specific dairy locations were obtained for the North Bosque River Watershed. The coal-fired power plants were located using geocoded aerial imagery of the entire state. Dairy locations were verified using the same aerial imagery of the state.

Location of Dairies in Texas:

Figure 1 shows the location of majority of dairy facilities in Texas using the GIS study. In Central Texas, they are mostly concentrated in the Comanche and Erath counties and in Hopkins on the north east. In the Panhandle area, most dairies are located near Lamb County.

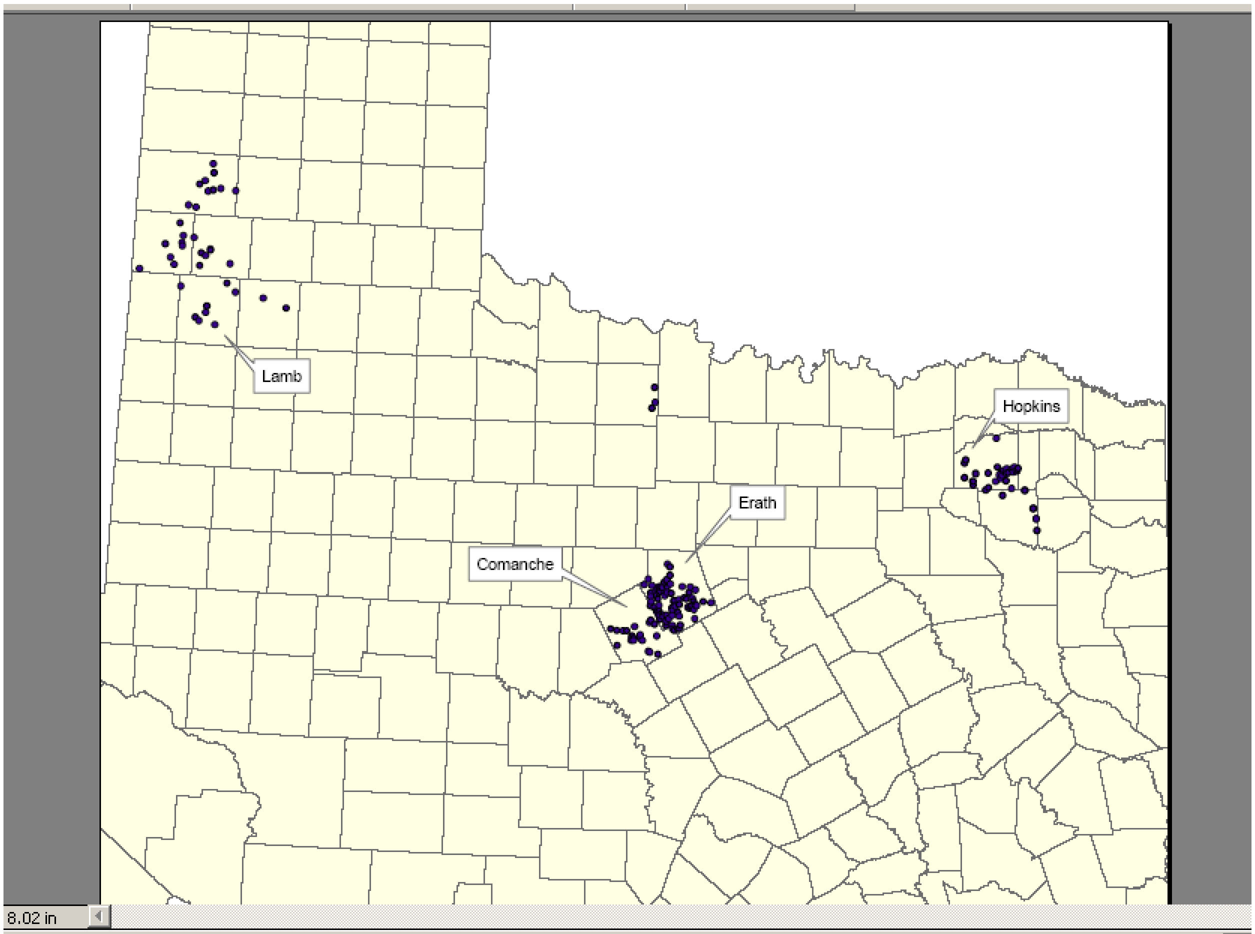


Figure 1. GIS map of dairy animal facilities in Texas.

The project has generated highly detailed maps of transport distances as shown in Figure2. The GIS work allows us to calculate transport distances using various criteria. This would include avoiding specific roads in individual cities. The route can also be based on load zoned areas. For example, Figure 3 shows the calculation of optimal route to four coal power plants in Central Texas. The average transport distances are shown in Table 1. The transport route varies between 150-200 miles.

Plant	Average Distance	Standard Deviation
TNP One	167	13
Reliant Limestone	180	13
Sandow	184	12
Big Brown	192	13

Table 1. Average transport distances from Central Texas dairies to the nearest coal power plants.

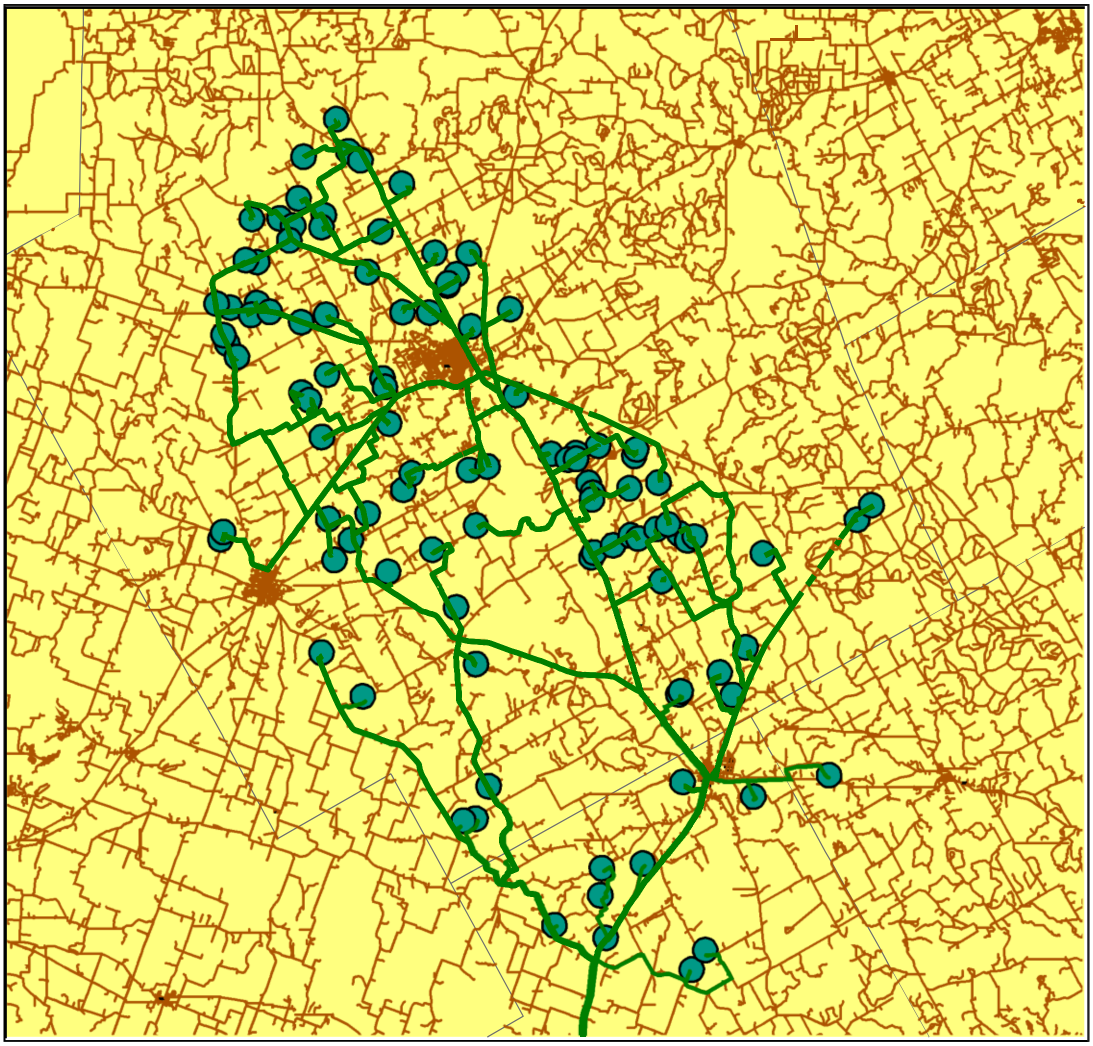


Figure 2. Transport map calculations for dairy facilities in the Central Texas area.

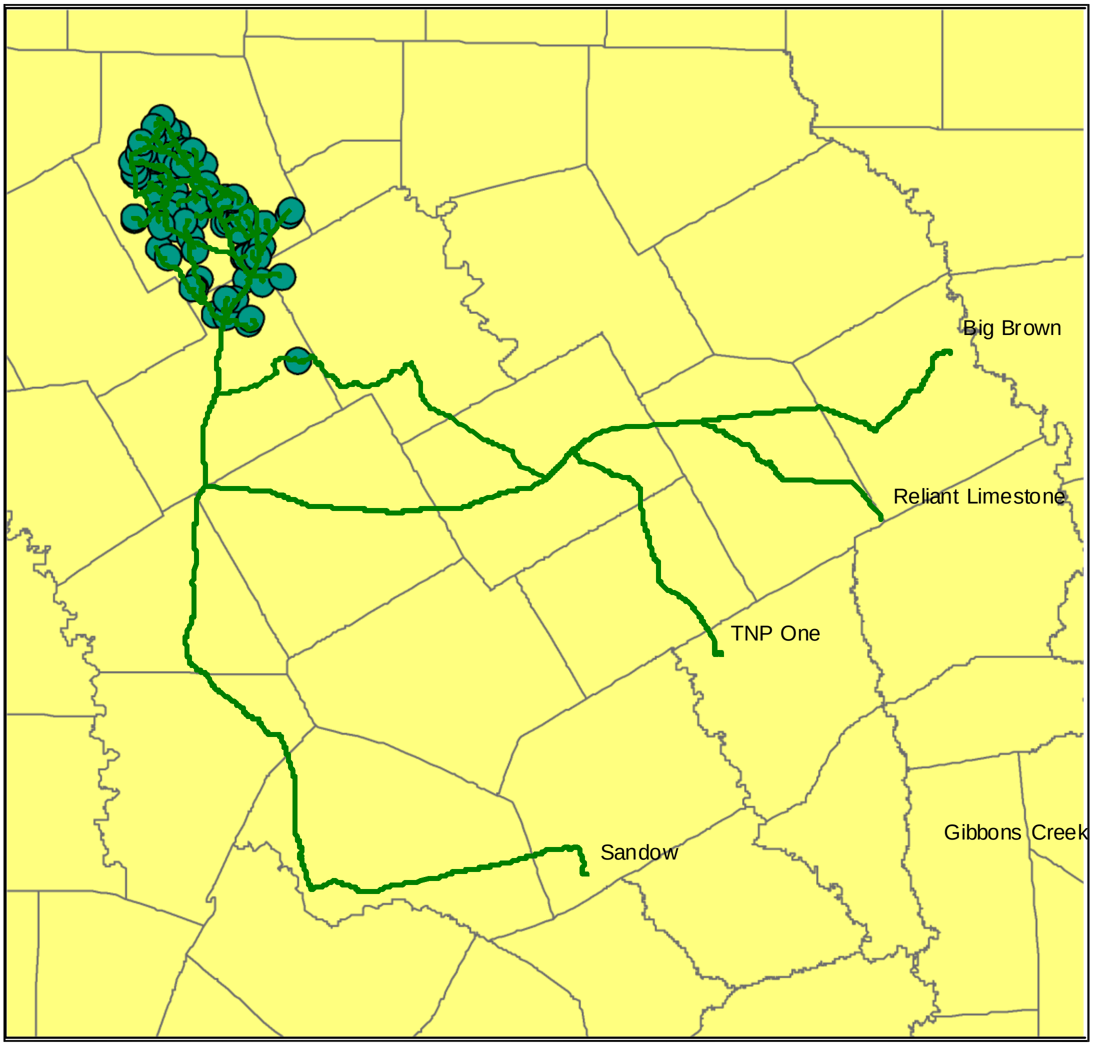


Figure 3. GIS map showing the shortest distance from the dairies in Central Texas to 4 coal power plants within the vicinity.

The roadmap database used to conduct the transportation analysis was obtained from ESRI as their Street Maps Pro data set version 7.0. This allowed for a complete set of roads for a reasonable transportation analysis. Routing was conducted with the idea that trucks would travel on the highways and major arteries in place of using the absolute shortest distance between the dairies and power plants. This prevents trucks from traversing downtown streets in towns where bypasses or multilane highways exist. One-way roads were restricted, forcing vehicles to travel on the correct side of divided highways. Making U-turns was only allowed at dead ends.

No single database contains the actual number of cattle in dairies in the Bosque watershed or their locations. Therefore, multiple datasets were used to acquire this information. The Texas Commission on Environmental Quality (TCEQ) has the beginnings of a GIS dataset populated but it is not a high priority at this time. Many of the TCEQ permits use physical descriptions of the permitted location in place of actual addresses. This information does not lend itself to GIS database inclusion. Therefore, a database developed specifically for the Bosque watershed was acquired from the Blacklands Research and Extension Center (BRC) that included all dairies identified through aerial photography in the watershed. These facilities were subsequently visited and their operational status was determined at that time, the last update of the database was October of 2003. This represents the most complete database of dairy locations but has no size information included.

The TCEQ database only contains permitted facility size and not actual facility size. In this region, this leads to a significant over estimation of the actual number of cattle in a region. The facility operators typically applied for the largest permit they expected to obtain, regardless of animal housing capacity. The result according to TMDL report by TCEQ is an overestimate of the cattle population of about 33%. Therefore, the permitted number of cattle in the watershed was reduced by 25% to determine the actual number of cattle in the watershed. The TCEQ dataset also does not include facilities with less than 200 cattle because these facilities do not need a permit. However, the BRC dataset contains the locations of the non-permitted dairies which were identified as locations that do not have a permitted facility within 1 km. There were a total of 27 of these facilities in the watershed according to this method which compares relatively well to the number listed by the TCEQ of 34. These facilities will be considered to have the maximum amount of cattle allowed, 199. Therefore, the total number of cattle in the watershed is 75% of the permitted head count of 62,541 plus the AFO cattle assumed to be 5,373 cattle totaling 52,279 cattle.

Results

The transport analysis combined several different databases of dairy locations to obtain a single comprehensive database. This database was used to analyze the transport distance to the four closest power plants in the state. The results are shown in table 6. Multiple variations of the databases were analyzed to determine the effect of having a less than complete database for dairy locations. Due to the relatively random nature of dairy locations across the Bosque watershed, there is no difference in the transport distance when a large number of the dairies are removed from the most complete database. This is due to the fact that all the databases used covered the same region and had some overlapping content. The result is that various subsets of the entire database were essentially missing a random subset of the total facilities. By having a large population of facilities to start with, using a randomly selected subset of the entire population for the transport analysis produces the same results as an analysis using the entire population.

Rank	Average Distance	Standard Deviation	Facility
1	216	14.8	TNP One
2	240	14.9	Limeston
3	249	18.0	Sandow
4	255	14.7	Big

Table 2. Average distance (km) to each power plant from all the dairies in the Bosque watershed.

The closest power plant in the region is TNP One at an average distance of 216 km from the dairies, while the farthest of the power plants is Big Brown at a distance of 255 km. Either of these distances is a significant barrier to using dairy biomass in coal- fired power plants. The cost of transporting raw dairy biomass at high moisture contents is excessive, even for short distances, when compared on an energy content basis. The result is that the cost of alternative emission control systems must be sufficiently high enough to allow the transport to be cost effective.

Figure 4 shows the results of the transport analysis graphically. The red circles indicate the location of all the dairies in the Bosque watershed. The Bosque watershed is the region delineated with the heavy red line extending Northwest of Waco. The transport routine starts each route from a given dairy to the power plant on the closest road to the dairy. As the distance traveled from the dairy increases, the transportation algorithm favors the higher capacity roadways. When this algorithm is applied to several dairy/power plant combinations, the result is a network of routes that start at many points using small rural roads and eventually gravitate to common transportation arteries across the region. The reason this is done is that the larger transportation arteries usually have shorter traveling times and route vehicles around the densely populated areas. A prime example of this is the use of the interstate bypass around towns. While it is typically a longer distance to travel than the business route, it can be traveled in a much shorter time, allowing for more efficient movement of vehicles.

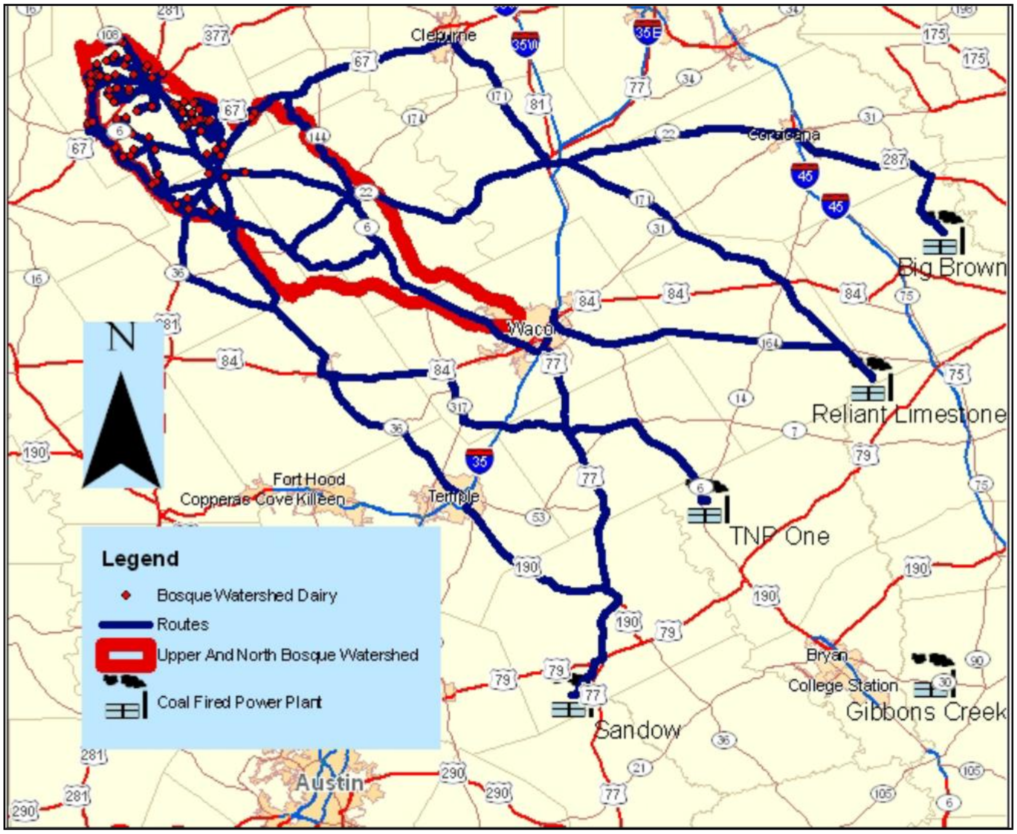


Figure 4. Transport analysis map for Bosque watershed dairies to the closest 4 power plants in the state.

Conclusions

Due to the nutrient loading in the Bosque watershed, there is a need to reduce the amount of dairy biomass that is applied to lands within the watershed. Coal is the most abundant fuel within the United States that can be used for power generation, but it is also considered as one of the dirtiest fuel due to the amount of various pollutants released during its combustion. By co-firing dairy biomass with coal it may be possible to remove a significant amount of nutrients in the biomass from the Bosque watershed that are currently causing environmental problems. Transporting the biomass more than 116 km on average presents a great challenge to using it in coal- fired power plants, but the transportation routines used in this analysis can be used for moving the biomass to any number of locations outside the watershed.

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2. Available Feedlot Biomass in the Texas Panhandle for Supplementing Coal Power Plants

Introduction

Texas, as the largest consumer of coal in the nation, uses more than 9 million tons of coal annually. The use of cattle feedlot manure as a reburn fuel has shown to reduce the Nox emissions by 80% while supplying 10-20 % of power by heat (Annamalai et al, 2003), thus providing a better reburn fuel than the traditionally used natural gas. In addition, large cattle feedlots often produce more manure than can feasibly be handled through land application; thus, adversely affecting the environment due to excess pollutants transported by runoff into waterbodies. The prospective benefits of using cattle biomass for co-firing or reburning in the combustion processes for coal has peaked the interest of power plant owners, cattle farmers, and researchers. Carlin et al. (2008) have worked on the economic feasibility of reburning with cattle manure biomass in existing coal-fired plants. The most cost prohibitive factor is the transport cost. Another concern is the sustainable supply of manure for coal power plants that operate continuously throughout the year. The panhandle region of Texas has a large concentration of both dairy and beef cattle feedlots and two coal power plants in close 94quivale to these feedlots. This area is ideal for implementing a manure-to-energy program. The available feedlot biomass in the Texas panhandle for transport to coal power plants for use as a fuel supplement is investigated. The specific objectives are as follows:

a. Determine the average transport distance between cattle feedlots in the Amarillo and Panhandle area to the Harrington and Tolk Coal Power Plants,
b. Estimate the amount of biomass available from feedlots given a certain travel distance of coverage,
c. Determine the amount of manure required to provide 10% energy supplement to the coal power plants, and
d. Provide manure quality criteria for supplying the power plants.

Feedlot Manure Management Systems in Texas

Methods of manure management in feedlots vary in each region in Texas. In the northeast, cattle are generally reared on pastures and the manure is not concentrated in one area so removal is not a major concern but collection is a problem. The feedlot facilities in the Panhandle, especially those that are confined employ simple manure management style. Manure are scraped on a routine basis and mounds are developed in each pen. Each pen would house approximately 200 cattle with a stocking density of around 150 heads per square foot (Baek, et al, 2006). The manure are collected using front end loader, dumped in a truck and transported to nearby compost area or to manure collection area within the vicinity of the feedlot facility. These facilities will be periodically scraped with a tractor and the manure piled in mounds in the pens.

Methodology

Transport Analysis

The Network Analyst extension in ArcGIS 9.2 was implemented to perform a transport analysis of manure from cattle feedlots to the coal power plants in the Texas panhandle. The Harrington power plant is near Amarillo and the Tolk power plant is northwest of Lubbock (Figure 5). The Closest Facility application was used to create routes from the feedlots (TCEQ permit locations) to the coal power plant facility locations (Figure 5). The feedlots were broken into two classifications – mature dairy cattle and finishing beef cattle. The travel routes were restricted by prohibiting U-turns, following direction rules (one-way), and following the shortest path with the maximum travel distance of 200 miles (which removed some of the feedlots from the analysis). Thus, routes were created from each feedlot to each coal power plant (Figure 5). The average travel distance from feedlot to either plant (Table 3) was calculated. Next, the closest power plant from the feedlot was determined and the average travel distance to the closest facility was determined (Table 4).

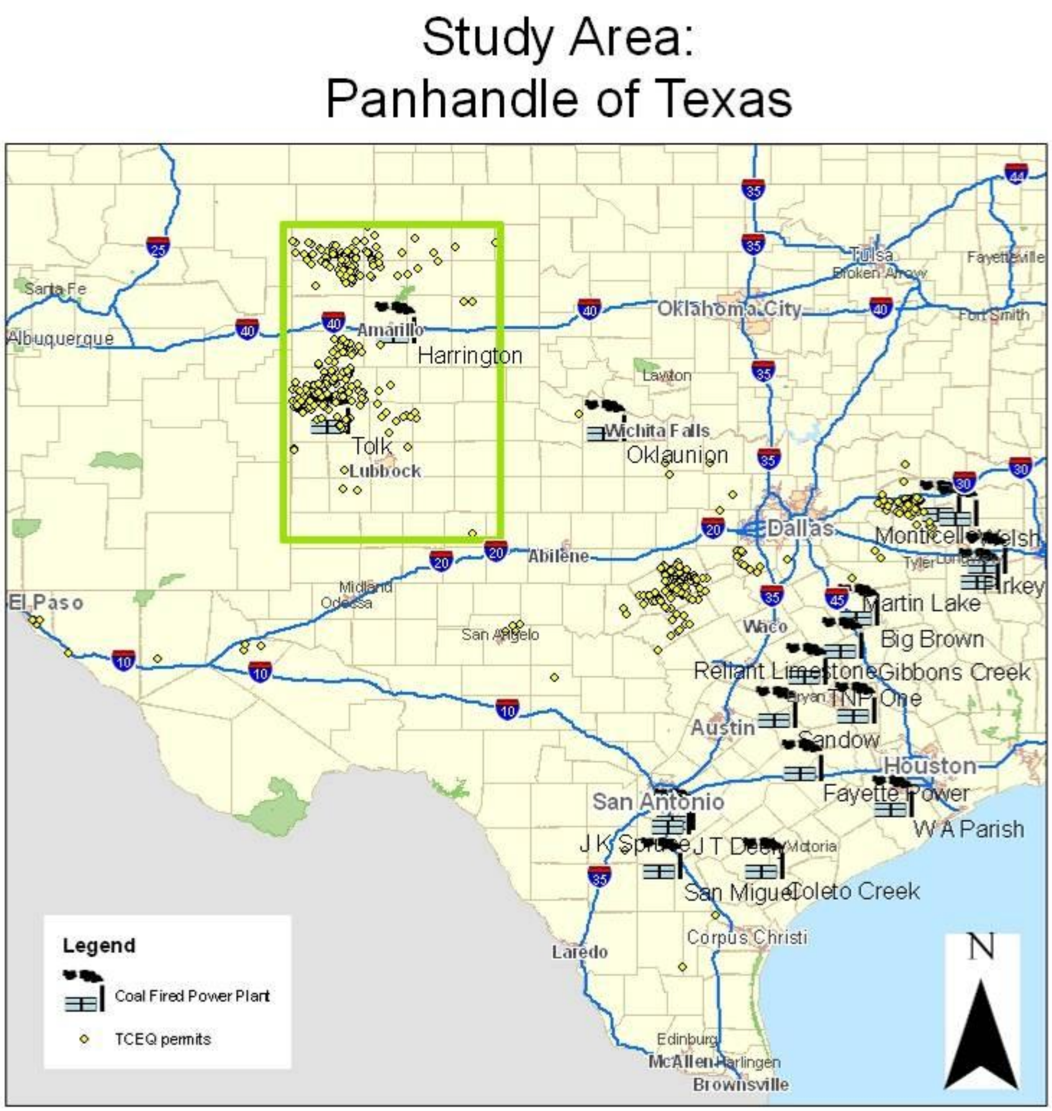

Figure 5. Location of Harrington and Tolk Coal Power Plants in the Panhandle of Texas with permitted dairy feedlots.

Dairy Cattle Feedlots

	Harrington		Tolk	
	km	**Miles**	**km**	**Miles**
Min	43.78	27.21	7.47	4.64
Max	286.56	178.10	451.12	280.38
Average	147.79	91.85	152.05	94.50
Std Dev	37.13	23.08	104.70	65.07

Beef Cattle Feedlots

	Harrington		Tolk	
	km	**Miles**	**km**	**Miles**
Min	7.15	4.44	12.06	7.49
Max	233.18	144.83	320.18	198.87
Average	133.58	82.97	139.38	86.57
Std Dev	43.66	27.12	93.44	58.04

Table 3. Average Travel Distance from Permitted Feedlots to Coal Power Plants in Panhandle

Dairy Cattle Feedlots

	Overall		Harrington		Tolk	
	km	**Miles**	**Km**	**Miles**	**Km**	**Miles**
Min	7.47	4.64	43.78	27.21	7.47	4.64
Max	213.65	132.78	213.65	132.78	157.79	98.07
Average	97.08	60.34	132.09	82.10	63.47	39.44
stdev	45.78	28.45	31.88	19.81	28.70	17.83

Beef Cattle Feedlots

	Overall		Harrington		Tolk	
	km	**Miles**	**Km**	**Miles**	**Km**	**Miles**
Min	7.15	4.44	7.15	4.44	12.06	7.49
Max	242.74	150.77	233.18	144.83	242.74	150.77
Average	102.51	63.67	122.55	76.12	74.86	46.50
stdev	51.26	31.84	48.16	29.91	41.97	26.07

Table 4. Average Travel Distance from Permitted Feedlots to Closest Coal Power Plants in Panhandle

Available Biomass

The amount of biomass available to the coal power plants within a given travel distance was determined by employing the Service Area application within the Network Analyst application. The service areas were broken into 25, 50, 100, and 150 mile travel distances from the coal power plants (Figure 7). Dairy feedlot biomass total solids production is estimated at 18 lb/day-animal (8.2 kg/day-animal) dry matter (Mukhtar, 2007) as excreted. Finishing beef cattle produce 5.1 lb/day-animal (2.3 kg/day-animal) dry matter total solids. The available biomass for collection is assumed to be 75% of the produced total solids on a dry basis. Thus, the available biomass for fuel thermo-chemical conversion was calculated by multiplying the permitted head count at each feedlot by 13.5 lb/day-animal (6.15 kg/dat-animal) for dairy cattle and 3.8 lb/day-animal (1.725 kg/day-animal) for beef cattle (Sweeten et al.). The total available biomass within the service areas was determined for each coal power plant individually (Table 5) assuming all the biomass within the region were to be transported to one power plant. Next the available biomass within the specified service area was determined assuming the manure from the feedlots would be transported to the closest of the two power plants (Table 6).

Dairy Cattle Feedlots

Harrington				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	0	0	0	0
50	8	70950	479	436
100	192	1539665	10393	9469
150	242	1825370	12321	11226

Tolk				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	39	240455	1623	1479
50	108	655230	4423	4030
100	150	996760	6728	6130
150	205	1535860	10367	9446

Beef Cattle Feedlots

Harrington				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	3	11600	22	20
50	14	361600	687	624
100	110	3446946	6549	5946
150	136	4066725	7727	7015

Tolk				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	11	208500	396	360
50	51	1579300	3001	2724
100	81	2540440	4827	4382
150	95	2906140	5522	5013

Table 5. Total Biomass Availability – Individual Coal Plant Analysis

Dairy Cattle Feedlots

Harrington				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	0	0	0	0
50	2	4350	29	27
100	103	883360	5963	5433
150	121	1040260	7022	6398

Tolk				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	26	154655	1044	951
50	96	575305	3883	3538
100	126	807110	5448	4964
150	126	807110	5448	4964

Beef Cattle Feedlots

Harrington				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	3	11600	22	20
50	12	288600	548	498
100	63	1847646	3511	3187
150	80	2261925	4298	3902

Tolk				
Service Area (Miles)	# Feedlots	Head Count	Biomass (tons/day)	Biomass (tons/day)
25	10	153500	292	265
50	37	1102800	2095	1902
100	56	1804800	3429	3113
150	57	1839800	3496	3174

Table 6. Total Biomass Availability – Assuming Transport to Closest Coal Plant

Available Energy Scenarios

The appropriate high heating value (HHV) of manure biomass is needed to calculate the amount of energy that can be obtained from cattle feedlots. Some have estimated the HHV on a dry-ash free basis (DAF) for beef cattle equal to 8,500 BTU/lb (Sweeten et al.). Goodrich et al. (2008) tested manure collected from 12 dairy feedlots in Texas to determine the HHV-DAF for various manure source streams (Table 7). The typical collection techniques include mechanical and gravitational separation from “flush systems”, scraped solids, and aged solids. The complete discussion on these collection techniques are outlined in a related publication (Goodrich, et al, 2008). The available energy from feedlot manure was calculated by multiplying the available biomass by the HHV-DAF. The available energy from beef cattle was determined using the baseline estimate of 8,500 BTU/lb. Various scenarios were setup (Table 8) for estimating the available energy from dairy cattle manure (Table 9).

Manure Source Stream	HHV-DAF (kJ/kg)			HHV-DAF (BTU/lb m)		
Mechanical Separation	16752.81	±	524.55	7203.71	±	225.56
Gravitational Separation	18216.69	±	3726.60	7833.18	±	1602.44
Scraped Solids	17630.98	±	1655.24	7581.32	±	711.75
Aged Solids	15622.49	±	5151.40	6717.67	±	2215.1
Average	17055.74			7333.97		

[1](Barry et al., 2008)
[2] Assume 1 kJ/kg = 0.430 BTU/lb m

Table 7. High Heating Values on Dry-Ash Free Basis (HHV-DAF) for Various Waste Streams

Scenario	Description	HHV-DAF (BTU/lb)	Collection Efficiency (%)
1	Manure Collected using Mechanical Separation	7203.71	25
2	Manure Collected using Gravitational Separation	7833.18	30
3	Manure Collected as Scraped Solids	7581.32	75
4	Aged Solids Manure	6717.67	75
5	Average of Collection Methods	7333.97	50

Table 8. High Heating Value on Dry Ash Free Basis for Various Manure Collection Scenarios from Dairy Feedlots

		Energy (T-BTU/year)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Harrington	Dairy	12.31	16.06	38.86	34.43	25.06
	Beef	26.67	26.67	26.67	26.67	26.67
	Total	38.98	42.73	65.53	61.10	51.73
Tolk	Dairy	9.55	12.46	30.15	26.72	19.44
	Beef	21.69	21.69	21.69	21.69	21.69
	Total	31.24	34.15	51.84	48.41	41.14

Table 9a. Available Energy from Manure within 150 miles of Coal Power Plant Facilities Assuming Various DB Collection Scenarios.

		Energy (T-BTU/year)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Harrington	Dairy	10.45	13.64	33.00	29.24	21.28
	Beef	21.78	21.78	21.78	21.78	21.78
	Total	32.23	35.42	54.78	51.02	43.06
Tolk	Dairy	9.55	12.46		26.72	19.44
	Beef	21.28	21.28	21.28	21.28	21.28
	Total	30.83	33.74	51.43	47.99	40.72

Table 9b. Available Energy from Manure within 100 miles of Coal Power Plant Facilities Assuming Various DB Collection Scenarios.

Energy Supplement to Coal Plants for Co-firing

The type and amount of coal consumed at each power plant was used to estimate the reduction of coal consumption that can be obtained by supplementing cattle biomass from feedlots. Both the Harrington and Tolk Coal Power Plants burn Wyoming sub-butiminous coal to generate electricity. According to the TAMU Coal and Biomass Energy Laboratory, Wyoming sub-butiminous coal has a high heating value of 11679.1

BTU/lb on a dry basis and 12,216.6 BTU/lb DAF. The operation capacity and feed rates at the coal power plants (Table 10) were used to determine the amount of energy that can be supplemented by cattle biomass. Harrington has three combustion units – one with 346 MW capacity and the other two have a capacity of 360 MW. The heat rate, defined as the amount of heat required to produce 1 kWh of electricity, is between 10,030 and 10,120 BTU/kWh. Tolk has only two combustion units with a capacity of 540 MW each. The facilities are assumed to operate 8,760 hrs per year at 80% capacity. The total heat requirement for the coal plant in BTUs/yr was calculated as the operating capacity multiplied by the heat rate and hours of operation and then added from all units (Table 11). The quantity of dry ash free fuel required was determined by dividing the heat requirement (BTU/yr) by the HHV-DAF.

	Unit	Capacity MW	Heat Rate (BTU/kWh)	Efficiency
Harrington	1	346	10121.7	33.7
	2	360	10259.9	33.3
	3	360	10030.0	34.0
Tolk	1	540	10045.2	34.0
	2	540	9900.8	34.5

Table 10. Operating Capacity and Heat Rate of Units within the Tolk and Harrington Coal Power Plants

		Total Input	Coal Input		Biomass Input		
	Unit	Energy (T-BTU/yr)	Energy (T-BTU/yr)	Quantity* (tons/yr)	Energy (T-BTU/yr)	Quantity** (tons/yr)	Quantity** (tons/day)
Harrington	1	24.54	22.09	904036	2.45	167322	416
	2	25.88	23.30	953459	2.59	176469	439
	3	25.30	22.77	932094	2.53	172515	429
	Total	75.73	68.16	2789589	7.57	516306	1283
Tolk	1	38.01	34.21	1400260	3.80	259165	644
	2	37.47	33.72	1380131	3.75	255439	635
	Total	75.48	67.93	2780391	7.55	514604	1279
* Assume 12,216.6 BTU/lb DAF							
** Assume 7,334.0 BTU/lb DAF							

Table 11. Energy Requirements for 90/10 Dairy Biomass Supplement to the Harrington and Tolk Power Plants

Results

Transport Analysis to Determine the Available Biomass

Dairy Cattle

A total of 247 dairy feedlots are within 200 miles of a coal power plant in the panhandle region (Figure 6a). The average travel distance to the Harrington plant is slightly shorter and has a smaller standard deviation than for the Tolk power plant. On average the closest coal power plant is approximately 60 miles away from the dairy feedlots (Table 4). The average distance from the closest dairy feedlots to Harrington is 82 miles away while the average distance from Tolk is 39 miles (Table 4).

The Tolk Coal Power Plant has more feedlots within a smaller travel distance but less total available dairy biomass within a 150 mile travel radius than the Harrington Coal Power plant (Tables 5 and 6). In other words, Tolk would be an ideal location for biomass supplement due to lower travel costs. However, the required biomass for fuel conversion needs to be estimated to determine if suffiecient supply would be available to the Tolk facility.

Beef Cattle

A total of 139 beef cattle feedlots are within 200 miles of a either coal power plant in the panhandle region (Figure 6b). The average travel distance from beef cattle feedlots to the Harrington plant is slightly shorter (4 miles) than that for the Tolk plant and has a smaller standard deviation. The beef cattle feedlots tend to be a little closer to the coal power plant facilities on average than the dairy feedlots. On average the closest coal power plant is approximately 64 miles away from the beef cattle feedlots (Table 4). The average distance from the closest feedlots to the Harrington plant is 76 miles away while the average distance from the Tolk plant is 47 miles (Table 4).

Again, the Tolk power plant has more feedlots within a smaller travel distance but less total available biomass within a 150 mile travel radius than the Harrington Coal Power Plant (Tables 5 and 6).

Available Energy to Supplement Coal Power Plants

The available energy for the coal power plants from manure ranges between 31 and 70 tera-BTUs/year (Table 9) depending on the manure management scenario (Table 8). For either coal power plant to operate at 90% coal / 10 % biomass requires approximately 7.6 tera-BTUs/year from CB (Table 11). This requirement can easily be met within a 150 mile or 100 mile radius of both of the coal power plants with any of the manure collection scenarios presented (Table 8). Further, the energy requirement can be reached with dairy manure alone. If only dairy manure is utilized for fuel conversion, both mechanically and gravitationally separated solids would not be recommended unless higher efficiency of solids removal is obtained. The Barry et al. report recommends vacuumed solids from compost bedding as the best biomass source stream. Unfortunately, few feedyards implement this type of collection system. The ideal manure for fuel conversion would be both low in moisture and ash contents prior to transport.

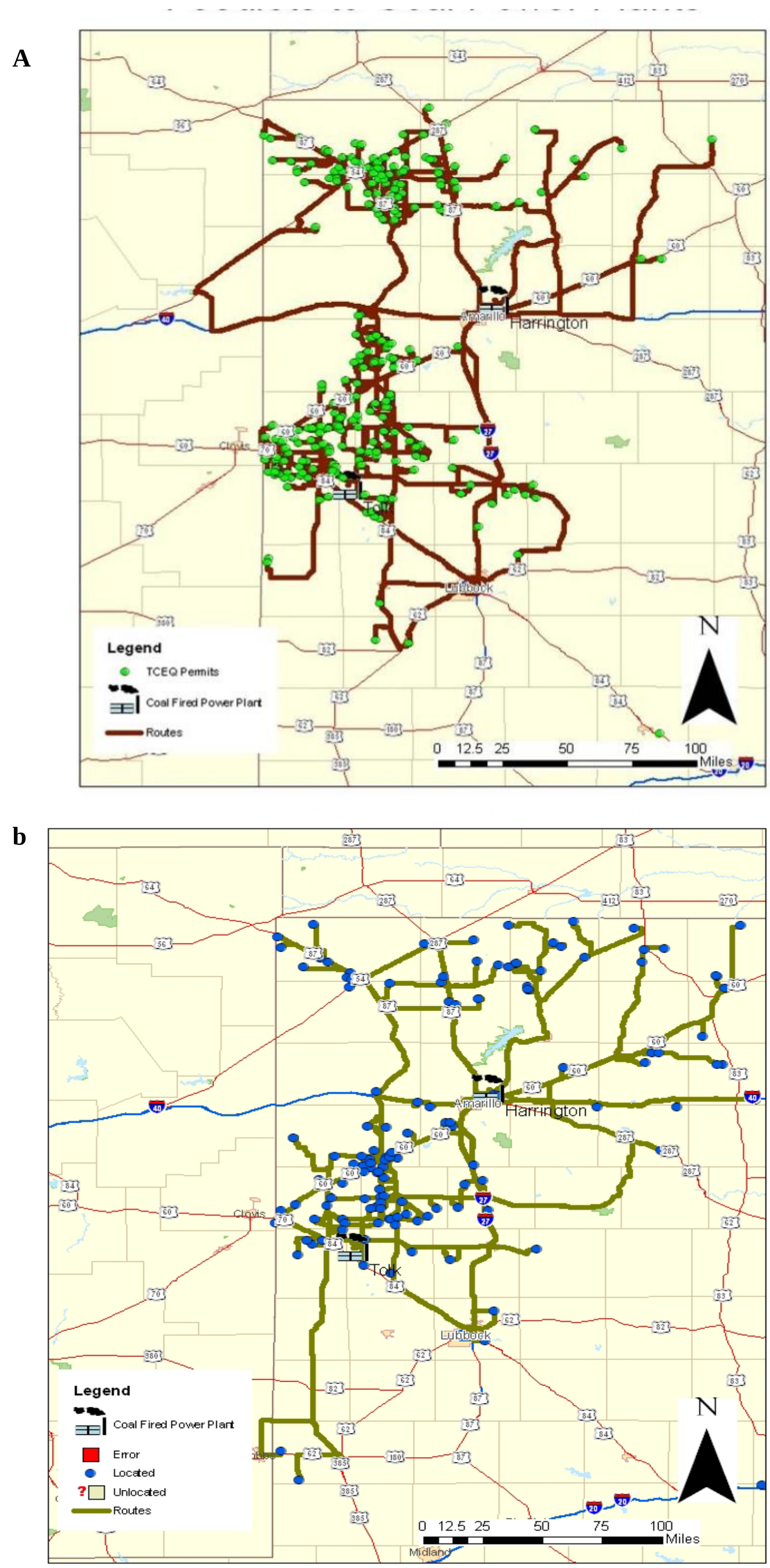

Figure 6. Travel Routes from Permitted Feedlots to Coal Power Plants in the Texas Panhandle: a) Dairy b) Cattle Feedlots.

Radial Distance from Coal Power Plants

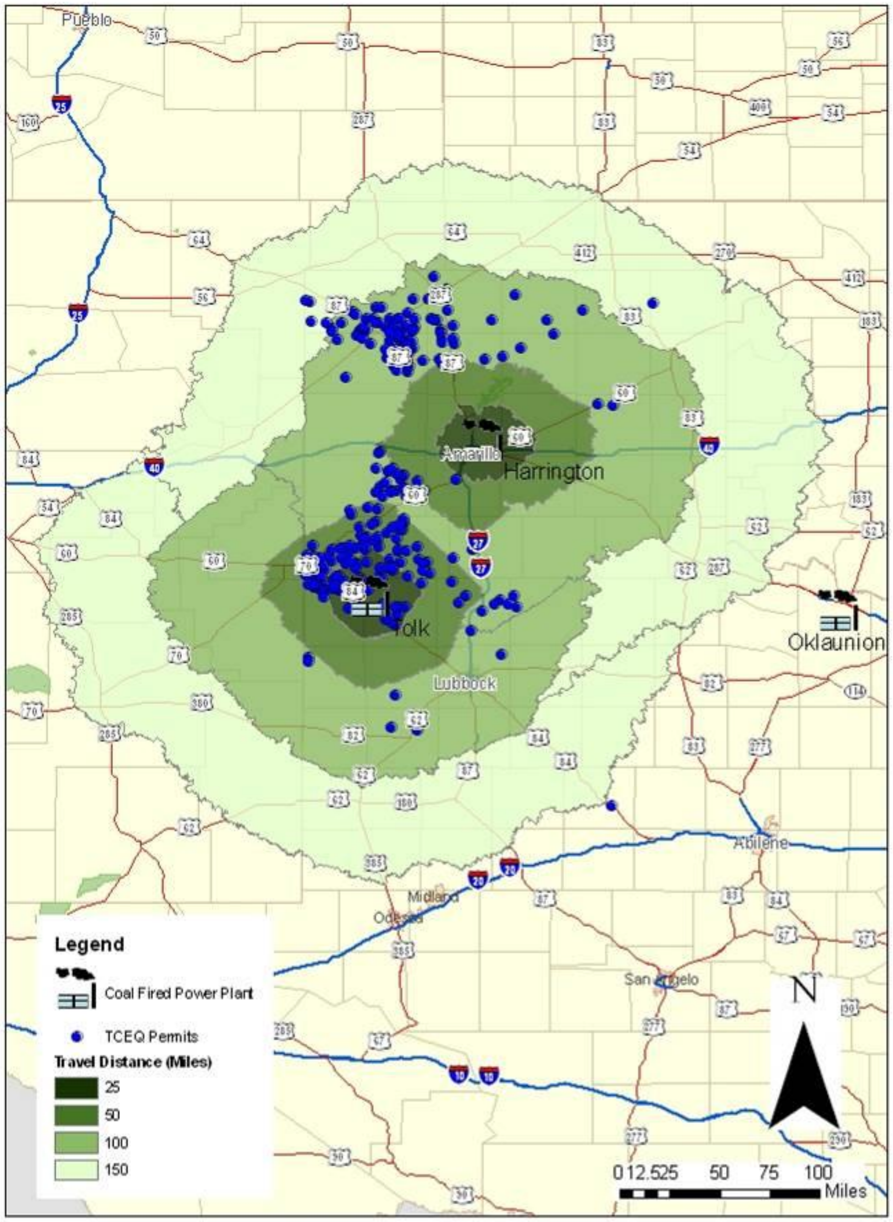

Figure 7. Service Areas based on Travel Distance from Coal Power Plants with Dairy Feedlot Permit Locations.

Conclusions

Availability

There is enough available manure biomass in the panhandle region to supply both the Harrington and Tolk Coal Power Plants with 10% of the fuel consumption. Further, within the required DB to supplement the coal power plants assuming the DB is transported to the closest plant can be met for the Tolk plant within 50 miles and within 100 miles of the Harrington power plant.

Delivery

Assuming manure is transported from feedlots within 100 miles to the closest power plant , to deliver sufficient manure for 10% fuel supplement to the Harrington power plant assuming 50% of the total dairy manure production (8.2 kg/day dry) with 15% ash content, approximately 42% of dairy feedlot manure would be needed. Within a 150 mile radius, 36% of dairy manure would be required to supply the Harrington plant. Applying the same assumptions for delivery to the Tolk plant requires 64% of dairy manure within 50 miles and 46% within 100 miles.

The cost of delivering this manure is estimated using the Carlin (209) economic model to be $45.66/ton for the Harrington plant assuming average transport distance of 82 miles and $41.30/ton for the Tolk plant assuming an average transport distance of 39 miles.

Quality

Ideally, cattle biomass to be utilized for fuel conversion should have low moisture and ash contents prior to transport. As moisture and ash is increased, the HHV is reduced and thus more biomass would need to be transported to the power plants and the expense of fuel conversion would also rise. Thus, it is important to define the criteria for delivered manure to CPPs in terms of ash content, HHV, MC. Example if the ash content is 10% and 1 ton is required to provide 8,500 btu/lb on DAF basis then the supplier would need to provide 1.1 tons of dry manure to meet the energy 108quivalency. Therefore, it is recommended that the feedlots perform proximate analysis to determine the ash and moisture contents of CB prior to transport. If the CB doesn't meet the recommended criterion, the farmer should consider modifying the solids collection practices if transporting excess manure to power plants is desired.

Recommendations:

- Investigate on-site manure conversion systems to reduce transport cost
- Develop centrally located conversion facilities (within counties) to take advantage of economies of scale
- Pursue co-firing or dedicated manure conversion projects with power plants that are very close to CAFO facilities (Panhandle Areas)

References

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TAMU, 2006. TAMU fuel data bank. Texas A&M University Coal and Biomass Energy Laboratory. Available at: http://www1.mengr.tamu.edu/REL/TAMU%20FDB.htm Accessed 11 June 2008.

Summary of Findings for Coal Usage and Manure Inventory

According to the Department of Energy's website (http://www.eia.doe.gov) there is approximately $9x10^6$ tons of coal used for electrical generation each year in the state of Texas. The "Manure to Energy Project" has a goal of examining the feasibility of replacing 10% of the coal used in the state with manure, a renewable fuel source, on an annual basis. Therefore, approximately 900,000 tons of manure is needed to achieve this goal.

According to the most recent numbers from the USDA department of agricultural statistics, there are currently 300,000 dairy cattle in the state of Texas. Using the ASABE standard for manure production (D384.2 March 2005) from dairy cows (20#/hd-day lactating and 11#/hd-day dry cows), there is approximately $1x10^6$ tons of total manure solids produced on an annual basis. This is enough manure if all manure production from dairies goes to power plants with minimal loss in the handling process. This is problematic due to the agronomic practice of using manure as a substitute for synthetic fertilizer products. Therefore other sources of manure must be considered such as beef feedlot manure.

Using the same statistics from the USDA there are approximately $3x10^6$ beef cattle on feed at any one time in the state of Texas. These cattle are kept in feedlots where corral scraping is a routing process that allows for the removal of vast quantities of manure. Once again using the ASABE standards for manure production from the beef feedlots (15#/hd-day), there is approximately $8.2x10^6$ tons of manure produced annually from beef feedlots. This represents a significant amount of manure above the amount needed for 10% co-firing in power plants.

Renewable Energy and Environmental Sustainability Using Biomass from Animal Production Systems

Task E.3.: Dairy and feed yard CAFO systems models

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**

Task Period: 06/Y06– 08/09

Dr. John Sweeten

Professor & Resident Director
Office: Amarillo
Phone: (806) 677-5600
E-mail: j-sweeten@tamu.edu

Dr. Saqib Mukhtar

Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: mukhtar@tamu.edu

Recipient organization

Texas Engineering Experiment Station, Texas A&M University System,

College Station, TX 77843

Date of Report: 08/31/2009

Task E.3. Dairy CAFO Systems Model Development

1. Introduction

Production and environmental quality models were develop for beef production and dairy operations. This newly developed model was based on an earlier manure management systems model developed by Dr. Sweeten (Sweeten and Schwart, 1999). The earlier model was modified to incorporate possible animal manure management processes. In addition, the model may also be used to describe life cycle analysis including material energy and mass balances.

2. Results of Model Development

The attached figures show the production and environmental quality models for beef production operations and dairy operations. The important components of the beef cattle the model is listed below:

a. Physical CAFO Beef facility (comprising receiving, processing, feeding shipping, marketing hospital area and value creation management);
b. Site features (such as climate, topography, geology, soil types, land area, land uses, water or presence of endangered species)
c. Feed mill facility
d. Wastewater treatment facility
e. Compost facility

The model can be expanded to cover other features of the animal operations as a result of activities within the components listed above as follows:

a. Inputs (feed types, supplements used, water usage, labor, pesticides, etc.)
b. Crop used as feed (grains, silage, hay, etc)
c. Utilization and application of manure (fertilizer, soil conditioner, etc)
d. Other uses of manure (fuel, bio-chemicals, horticultural, etc.)
e. Air and water quality (odor, dust, ammonia, pathogens, etc)
f. Soil quality (nutrient level, tilth, salinity, residue, erosion, etc.)
g. Product contamination and pests

Cross cutting issues for the operation of beef cattle yard are listed as follows:

1. Consumable product value,
2. Quality assurance,
3. Costs and benefits
4. Regulatory policies affecting the operations,
5. Property rights,

6. Productivity,
7. Animal health,
8. Profitability, Consumer perception, Public acceptance, consumer education and animal well being.

There were numerous other components of the model related to production information, environmental customers and feedback information. A similar model was established for open lot dairy operations.

3. Summary, Conclusions and Recommendations

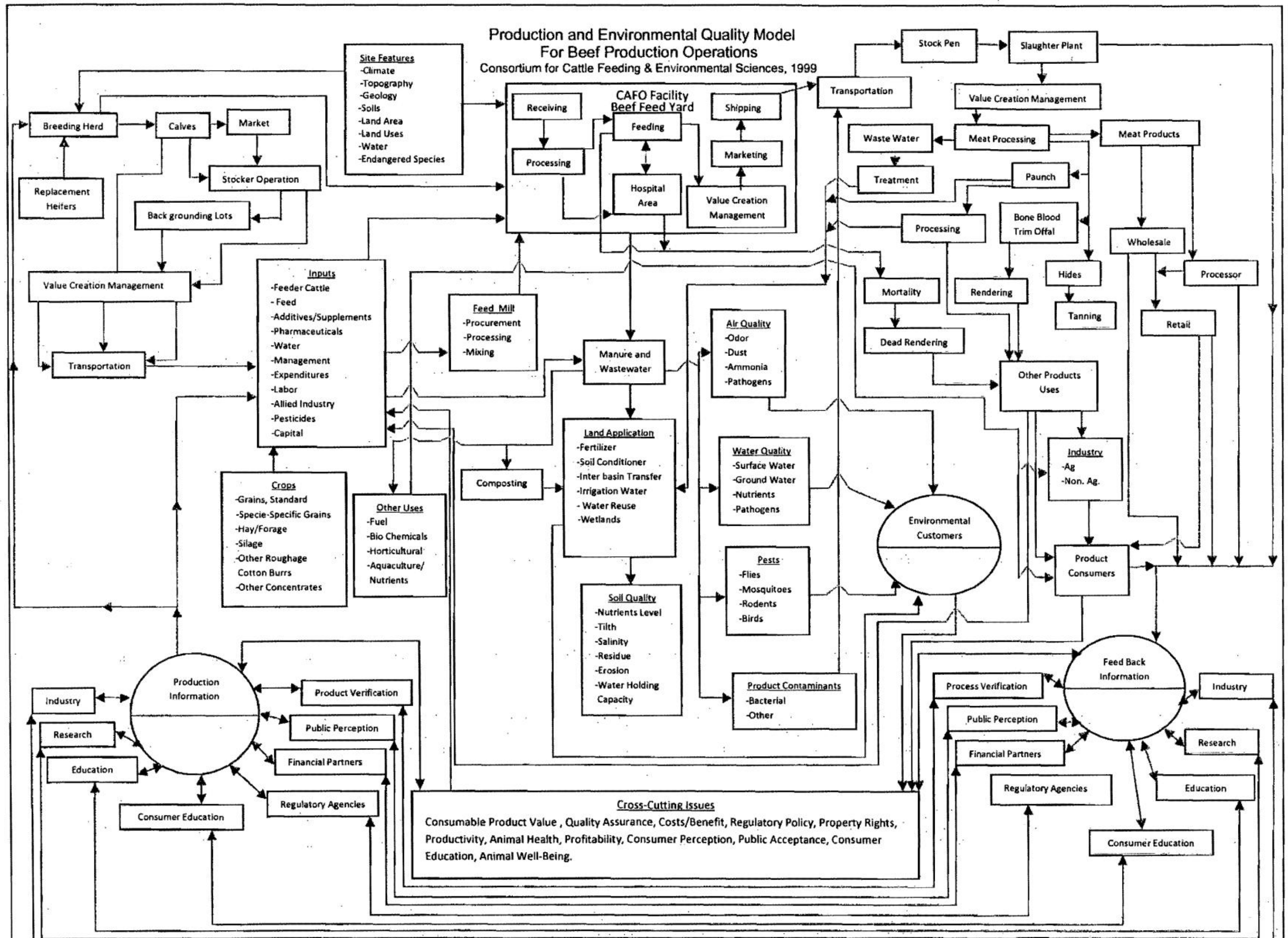
The conceptual, life cycle model developed for this task has numerous applications. One application would be concerning simulation modeling of manure production and conversion into energy or fuels. The concept of simulation modeling has been employed for many years in animal farm operations. The setting up of simulation models will become easier once the life-cycle production model has been established. Thus, one should be able to track the inflow and outflow of products (e.g. animal manure) generated from a given site and be able to determine the effect of manure conversion on the existing farm operations in place (water or air quality, additional revenue, etc).

Future work should be on the development of simulation models that would make use of animal manure as biomass resource for energy, power or fuel production purposes.

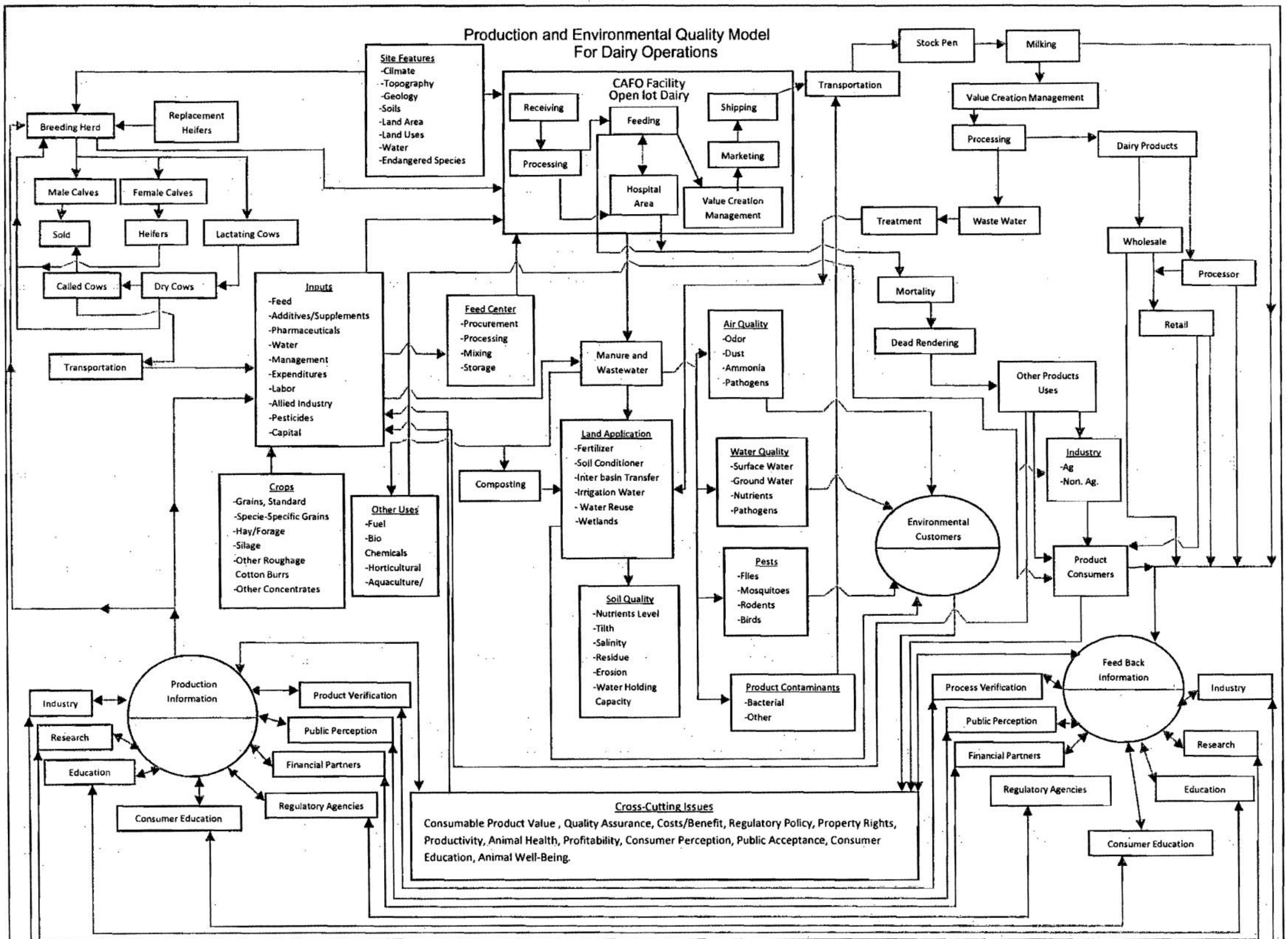
Submitted Extension Publications:

Mukhtar, S. and S. C. Capareda. 2006. Manure to Energy: Understanding Processes, Principles and Jargon. Texas Cooperative Extension Publication # E-428. November 2006. Texas A&M University System, College Station, TX.

Mukhtar, S. L. B. Goodrich, C. Engler and S. C. Capareda. 2008. Dairy Biomass as a Renewable Fuel Source. Texas Cooperative Extension Publication # L-5494. February 2008. Texas A&M University System, College Station, TX.



Conceptual, life-cycle model of the beef cattle feeding industry from conception to harvest and processing (Sweeten and Schwart, 1999



"Adapted from the Consortium for Cattle Feeding and Environmental Sciences 2001"

Renewable Energy and Environmental Sustainability Using Biomass from Animal Production Systems

Task F: Sensitivity Analysis of CAFO Energy Systems

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**
Task Period: : **06/01/2006-08/31/2009**

Dr. Sergio C. Capareda
Assistant Professor **Office:**303D
Scoates
Phone: (979) 458-3028
E-mail: scapareda@tamu.edu

Dr. Wyatte Harman
Agrcultural Economist
Office: Blackland Research and Extension Center, Temple
Phone: (254) 774-6000
E-mail: Harman@brc.tamus.edu

Recipient organization
Texas Engineering Experiment Station, Texas A&M University System, College Station, TX 77843

Date of Report: 08/31/2009

Task F. Sensitivity Analysis of CAFO Energy Systems

Task F.1. Feasibility Work

A simple feasibility analysis for CAFO energy systems was made. A draft of survey form was first developed (see attachment) to determine and estimate the transport costs for manure. This was followed by model development and analysis.

F.1.1. Introduction

Simple feasibility assessments were made for selected concentrated animal feeding operation (CAFO) facilities utilizing various biomass energy conversion systems. A total of four case studies were made on the use of dairy and cattle feedyard manure for energy conversion via anaerobic digestion and thermal gasification for heat and power production. In addition, three types of projects were outlines as follows: (1) on-site energy conversion, (2) centralized heat and power conversion systems and (3) co-firing in a coal power plants. The latter two types were shown to be costly due to high transport and investment cost and will not be discussed in detail.

F.1.2. Methodology

The general procedure for the feasibility study is provided below:

a. A typical dairy farm and a beef cattle feedyard was selected whose management practices represents the majority
b. On-site studies would not require GIS analysis and the centralized and co-firing projects take advantage of the results of GIS study for this project.
c. Transportation costs are assumed based on the survey conducted in the past
d. For the centrally located energy conversion facility, a proposed site was assumed which is equidistant from the facilities selected. For co-firing project, the results of previous GIS transport routes were used.
e. The magnitude of monthly and yearly biomass wastes produced was estimated and projected for annual distribution.
f. The size of the energy conversion facilities were estimated based on the resource availability considering a certain recovery factor (i.e. the practical amount of wastes that could be processed for conversion).
g. The fixed and variable costs for the operation of the conversion facilities were determined based on current available data for the feasibility studies.

F.1.3. Description of the Animal Facilities

The following section describes the proposed manure management and operation to generate revenue for manure conversion.

F.1.3.1. Dairy facilities

Dairy manure is characterized by having much higher moisture content and varying ash content depending upon the cultural practices implemented in a dairy farm. The most ideal source of fuel for conversion would be the separated solids derived from pen surfaces with compost bedding (as opposed to sand bedding with high ash content). The manure must be dried prior to thermal conversion or simply directed to a digester for anaerobic digestion processes. If the facility would adopt both the anaerobic digestion and thermal conversion processed one system could take advantage of the other to improve the system operation. We manure could be used directly in an anaerobic digester simply by adjusting the moisture required by the digester. The resulting sludge may be dried, and used in a thermal conversion facility for heat and power production. The spreadsheet model developed for this task showed that it is possible to satisfy the energy requirement of a dairy farm from the animal manure produced by the facility at any give population greater than 500 heads. Figure F1 shows an example of a thermal conversion system in a dairy facility.

F.1.3.2. Beef Cattle Feedyard
Beef cattle manure is characterized by having relatively low moisture but higher ash content depending upon the frequency of harvest cycle. Harvesting at frequent intervals would give rise to scraping of the soil layer resulting to high ash content. Thermal conversion system is the only recommended conversion facility to be installed in a cattle feedyard. The primary output would be heat and power generation. Likewise, the spreadsheet model developed for this task showed that it is possible to satisfy a large portion of the energy requirement of a feedyard if the population is greater than 1,00 heads.

F.1.4. Project Development
The feasibility study showed that it was possible to develop on-site conversion facility in animal farms instead of transporting the manure over longer distances. The scale of the facility was a factor and analysis showed that thermal conversion facility of at least 1MW is still feasible. The estimated Investment cost for this kind of facility ranged from $1M to $1.5M per MW of power output. The economic return is enhanced if the power plant could take advantage of generating more power at peak load conditions (summer months and during peak irrigation schedules). Currently, the spreadsheet model is being used for power production and generation in a cotton gin.

F.1.5. RETScreen Software and MS Excel Spreadsheet Software
The RETScreen Clean Energy Project Analysis Software (RetScreen) was initially used in this study. RetScreen is a decision support tool developed by the Natural Resource Department of Canada. It is used to evaluate the energy production and savings, costs, emission reduction, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software is free and comes with an engineering e-textbook. However, there would be numerous assumptions made if this software is used. Thus, the task relied on the development of software for feasibility analysis using them most common spreadsheet software (MS Excel). Input parameters include the following:

a. Population
b. Heating value
c. Moisture and ash content of manure
d. Recommended size of conversion facility
e. Fixed and variable costs

Output parameters include the following:

a. Internal rate of return (IRR)
b. Net present value

c. Benefit cost ratio
d. Power output
e. Sale of electricity and char among other minor outputs.

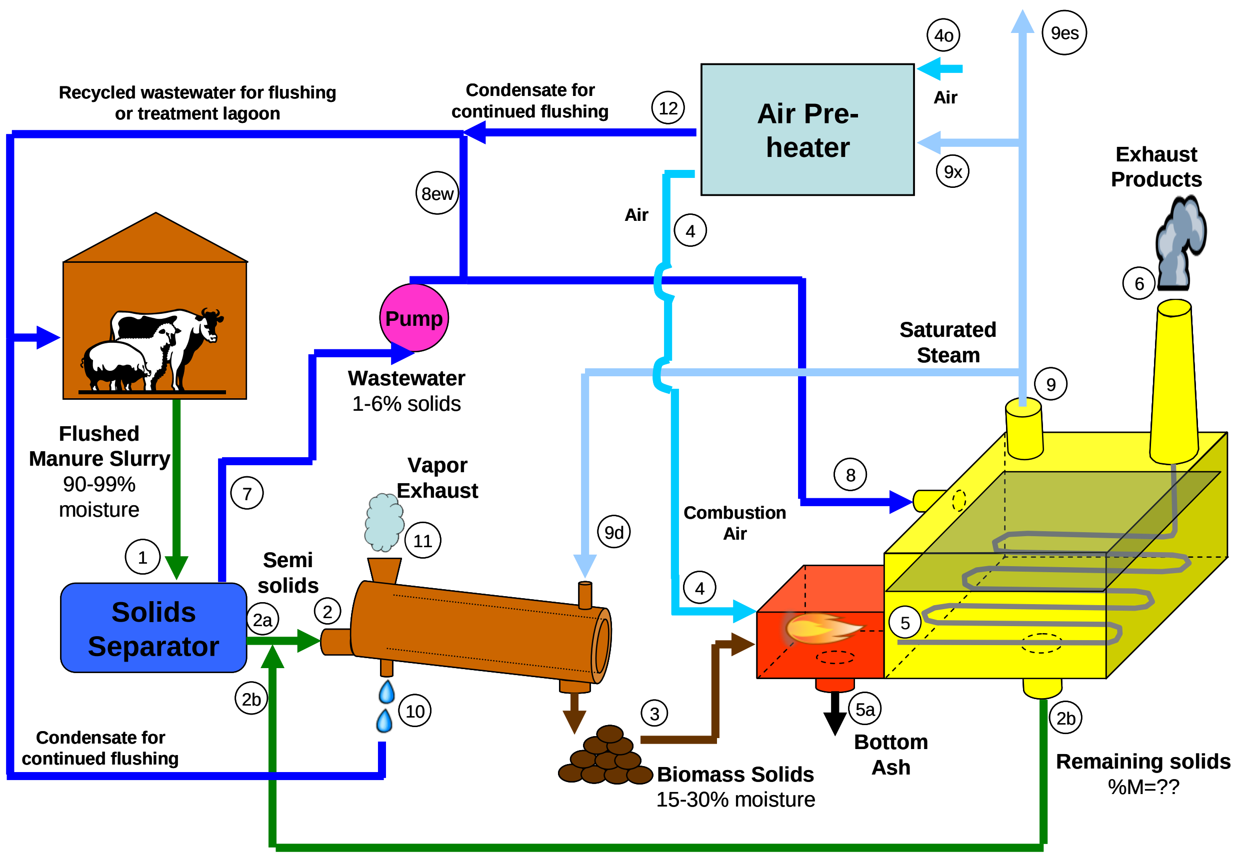


Figure F.1. Small Scale Manure Conversion System in a Dairy Facility. Adapted from: Carlin, N. T. 2009. Optimum Usage and Economic Feasibility of Animal Manure-Based Biomass in Combustion System. Ph.D. Dissertation, Texas A&M University, May 2009.

Task F.2. Developing Strategies for an Efficient Utilization of Manure

This task was developed to provide an outline of strategies for the efficient utilization of manure in CAFO's. The primary deliverable was the setting up of criteria for manure utilization for thermal conversion. The proposed strategies are summarized below:

a. Each animal facility (especially dairy facilities) must have an on-site drying and storage facility
b. Each farm must have an on-site conversion system to reduce the amount of animal wastes to be transported outside of the facility. If this Is not possible, a centrally locate conversion facility must be in place.
c. Manure quality criteria must be established with corresponding values or rates incentives for the production of high grade manure for conversion. The following criteria are being recommended for thermal facilities: low moisture of 10% (wet basis) and low ash content of about 15%.

Summary, Conclusion and Recommendations

The initial survey conducted to estimate the possible manure transport cost showed that manure transport cost ranged between $40-45/ton through a distance of less than 100 miles. This cost was used to provide input to generate feasibility results for numerous manure utilization schemes. The high transport cost affected the feasibility study for centrally located conversion system and the development of co-firing projects with coal power plants in Texas. The high capital cost of these facilities and the competing price of coal would make these utilization schemes impractical. The economic feasibility is very sensitive to the sale of by-products or carbon credits.

On site conversion facilities become attractive due to minimal transport cost of animal manure. A spreadsheet software was developed for this purpose. Results showed that it is feasible to install thermal conversion facilities for dairies with population greater than 500 heads and feedyard facilities with population greater than 1000. The most likely revenue would come from the sale of power to local utilities and the sale of char as soil amendment.

Attachment: Survey Questionnaire
Suggested Questions for Phone Interview of Truckers

Date________________ Time of interview____________________
Name____
Address____
Phone____

1. **Does your trucking company regularly contract hauling of animal manure?**
   YES__________(Skip to Question 3) NO___________

2. **Do you plan to begin trucking manure in the near future?**

   YES_________ NO___________ (Finish interview)
   (Interviewer instruction: If YES, questions should use the words in parentheses for determining "planned hauling rates", etc.)

3. **Knowing that this information will be kept confidential and will never be published in a form that will disclose your information, what is (will be) your basis for a hauling charge and the rate?**
   - **a. Rate per ton/mile __$_________________**
   - **b. Rate per truck load__$________________**
   - **c. Rate per mile__$______________________**
   - **d. Rate per ton___$______________________**
   - **e. Other rate (explain below in detail)_$____________________**

4. **Are there (Will there be) other charges in addition to the base hauling charge?**
   - **a. Loading charge__$_________________**
   - **b. Tipping fee__$____________________**
   - **c. Fuel surcharge__$___________________________,**
     i.e. if diesel prices increase over $X.XX/gal, an additional surcharge will be applied to the base rate.
   - **d. Distance surcharge__$______________________,**
     i.e. if the distance exceeds XX miles to the delivery point, an additional surcharge will be applied to the base rate.
   - **e. Overtime surcharge__$_____________________,**
     i.e. an additional surcharge for weekend hauling, holiday hauling, or night time hauling.
   - **f. Other extraordinary charges (Explain in detail)**
     $_________________________________

End

RENEWABLE ENERGY AND ENVIRONMENTAL SUSTAINABILITY USING BIOMASS FROM ANIMAL PRODUCTION SYSTEMS

Task I: Energy Analysis of Dairy Farms and Feed Yards

DOE Award No. DE-FG36-05GO85003

Project Period: **06/01/2006-08/31/2009**

Task Period: **06/01/2006 – 08/31/2009**

Dr. Cady Engler
Professor **Office:** 303I Scoates **Phone:** (979) 845-3685
E-mail: c-engler@tamu.edu

Dr. Saqib Mukhtar
Associate Professor & Extension Specialist
Office: 207A Scoates
Phone: (979) 458-1019
E-mail: mukhtar@tamu.edu

Dr. Sergio C. Capareda
Assistant Professor **Office:** 303D Scoates **Phone:** (979) 458-3028
E-mail: scapareda@tamu.edu

Recipient organization

Texas Engineering Experiment Station, Texas A&M University System,
College Station, TX 77843

Introduction

Increasing energy costs across the country have led to significant interest in the use of alternative sources of energy that may already be available at an animal feeding operation (AFO) such as manure or other biomass for power generation. There are three major forms of energy consumed on dairies in the southwestern United States: electricity, liquid fuels (diesel and gasoline), and gaseous fuels (propane and natural gas). The liquid fuels are typically used in vehicles for transportation and delivery of feed and equipment while the gaseous fuels are primarily used for heating water during winter months. The energy sources, each with different energy contents, are typically acquired from different suppliers creating a challenge for operators to accurately quantify the total amount of energy used at a facility.

Electricity is used primarily for milking operations, including cooling of milk. The primary use of gaseous fuels is for heating buildings and water, which would be a significantly larger requirement in colder climates.

The main objective of this task was to assess energy usage on dairies in the southwestern United States. For this work we quantified energy usage based on information available at the facility-wide level and then compared the energy usage between dairies with different management styles, relative ages, and locations.

Review of Dairy Management Systems in Texas and California

Dairy management systems in the Southwest are based on the type of housing used for the cattle. Two main types of housing are used, free-stalls and open lots. Free-stalls consist of open air barns with paved floors and individual stalls for the cattle which increase the comfort level for animals by providing full shade and a relatively dry bedding area. Fans and water dripping systems operated in free-stalls during warm months help cool cattle. Open lot facilities consist of earthen pens with a paved feed lane and small shade structures for the cattle but do not have any other cooling systems in the housing area. Most dairies consist of either a completely open lot facility or a combination of free-stalls and open-lots, known as a hybrid facility. Additionally, a small number of operations exist where dairy cows are housed on pastures.

The dairies studied in this task were located in three regions of Texas and in the San Joaquin Valley of California. Texas regions were Central, the Panhandle, and Northeast Texas. Table 1 shows the types and locations of the dairies surveyed in this study along with the types of energy used. The dairies in Central Texas consisted of one open lot and three hybrid dairies. Two dairies were selected for sampling in the Panhandle of Texas; one was an open lot dairy while the other was a hybrid system. The dairy surveyed in Northeast Texas was a small pasture dairy. Therefore, this dairy was expected to have significantly less energy usage than other types. The dairies in California were all located in the San Joaquin Valley (SJV). Dairies W1 through W5, located in the Modesto area, were owned and managed by a single company. The other two dairies in California were located in the Central SJV and were managed by a single company as well. All California dairies included in this study were hybrid facilities, which is the prevalent type of dairy operation in that region.

Table 1. Management system, size (number of dairy cattle), and types of energy used at the dairies surveyed.

	Dairy	Size	Management	Electricity	Liquid Fuels		Gaseous Fuels	
					Diesel	Gasoline	Propane	Natural Gas
Texas	C2	2200	Hybrid	9	9		9	
	C3	2100	Open Lot	9	9		9	
	C5	550	Hybrid	9	9		9	
	C7	990	Hybrid	9	9	9	9	
	P1	7000	Hybrid	9	9		9	
	P5	6000	Open Lot	9	9			9
	E1	180	Pasture	9	9			
California	D1	2400	Hybrid	9	9		9	
	D2	3500	Hybrid	9	9		9	
	W1	735	Hybrid	9	9	9	9	
	W2	1180	Hybrid	9	9	9	9	9
	W3	850	Hybrid	9	9	9	9	
	W4	1190	Hybrid	9	9	9	9	
	W5	1780	Hybrid	9	9	9	9	

Methods

Each dairy provided varying levels of information for the survey. For example, some dairies kept a detailed record of electricity usage on a monthly basis for every meter billed while others only had billing statements for a winter month and a summer month. Ultimately, utility companies were contacted to provide actual annual usage recorded by the various meters at a given dairy. The variation in available data was true for all three energy sources.

Electrical Usage

Total annual electrical energy consumption for each dairy was obtained from billing information provided by the dairy or from the utility company with the dairy's permission. Total electrical usage was subdivided according to use for milking, housing, waste management, feeding, and fresh water pumping. The most complete data for electrical energy usage was the availability of monthly bills for each meter installed at a dairy, with each meter dedicated to a specific process or operation. However, this detailed information was not available for all dairies surveyed, so alternative methods for estimating electrical energy usage from incomplete data were evaluated.

For Method 1, it was assumed that a bill for one of the winter months (December or January) represented usage for half the year and a bill for one of the summer months (June or July) represented usage for the other half of the year. The average of these two bills then represented the average monthly usage over the entire year and was used to calculate annual usage on a per-animal basis.

For Method 2, a portion of the year covering both summer and winter months was used to calculate an average monthly usage during that period. Total usage for the period was calculated by subtracting the starting meter reading for the period from the ending meter reading for the period. Total usage was divided by the number of months in the period to get an average monthly usage. This average was then used to calculate the annual usage on a per-animal basis.

For Method 3, the difference in starting meter readings for bills from the same month one year apart were used to estimate annual usage. One problem with both the second and third methods was estimating the number of times the meter reset to zero as it cycled past 100,000 kWh during the usage period.

USDA Farm Energy Calculator

The USDA has developed an energy estimator for animal housing to help operators estimate possible savings from changes in their operations (USDA, 2008). Inputs for the calculator include the region where the facility is located, the number of cattle, and milk production. Additionally, types of equipment used and operating parameters for the major consumers of electrical energy are specified by the user. The output includes estimates of the energy used for long-day lighting, air circulation, milk cooling, water heating, and milk harvest.

Results from the energy estimator provide an approximation of the energy used by some of the major systems on a dairy. However, direct comparison of the energy usage estimated by this calculator with results from the energy survey is difficult because the USDA energy estimator doesn’t take into account the use of electricity for pumping of fresh water and operations such as offices and break rooms that are present on most facilities.

Liquid Fuels

Liquid fuels were used to power all mobile equipment on the dairies as well as generators for backup power in emergency situations. The primary use of these fuels was to power the equipment used for feeding and for general use around the dairy facility. No liquid fuel use values could be assigned to individual operations because the fuel was bought and stored in bulk. One dairy operator in the San Joaquin Valley actually kept records as to how much fuel was consumed by individual vehicles, but the vehicles were used at all dairies operated by the management company making it difficult to determine liquid fuel used by an individual dairy. Typically, dairies use liquid fuel on an as needed basis without assigning it to specific uses (feeding, scraping etc.).

However, all dairies surveyed were able to separate fuel usage for farming from that used for dairy operations.

Gaseous Fuels

Gaseous fuels are typically used in only a few locations on dairies. The primary uses of gaseous fuels were for heating the water used for cleaning operations and heating buildings. Dairies thoroughly clean all milking equipment and keep a clean working area while milking, resulting in large amounts of energy used for water heating. The annual usage of these fuels was obtained from all facilities by compiling consecutive monthly bills for one year.

Results

Electrical Usage

Because the availability of data for electrical usage varied among the dairies, it was important to evaluate different methods developed to estimate annual usage. To determine the differences among the estimating methods, they were applied to data for dairies C2 and C3 for which complete records were obtained. These dairies were selected for analysis because they represented the two primary types of dairies in the Southwest, hybrid and open lot, and they were located in the same region of Central Texas. Results from applying these methods to estimate electrical consumption for various energy sinks at the dairies are shown in Table 2.

Table 2. Comparison of electrical energy usage on dairies C2 and C3 calculated using different estimation methods with actual usage (kWh/yr·a).

	Dairy C2				Dairy C3			
Method:	Actual	1	2	3	Actual	1	2	3
Milking	312	306	296	309	495	564	537	496
Housing	149	175	164	151	0	0	0	0
Waste Management	151	147	91	153	15	8	11	14
Feeding	13	8	8	11	5	5	5	5
Water	98	59	94	46	52	48	50	51
Total	723	695	652	670	566	625	602	566

The data in the “Actual” columns represent the electrical energy usage for an entire year as reported by the utility company for the period from March, 2006, through February, 2007. Method 1 assumed that the average monthly electrical usage was equal to the

average of a winter (December or January) bill and a summer (June or July) bill. This average was then used to calculate annual consumption per animal. For Method 2, a summer bill was selected to provide a starting meter reading and a winter bill for an ending reading. For example, the bill covering the usage period from June 28, 2006, to July 29, 2006, for diary C2 was selected to provide a starting meter reading and the bill covering usage from January 28, 2007, to February 28, 2007, provided an ending meter reading. The average monthly electrical usage for this period was then used to estimate annual usage. To apply Method 3, meter readings from bills one year apart, e.g., the starting meter reading for March, 2006, and ending meter reading for February,
2007. Annual usage was estimated by taking the difference between these readings. A drawback of both Methods 2 and 3 is that the number of times each meter resets to zero as it passes 100,000 kWh must be estimated to calculate usage during the period.

Texas Dairies

Ultimately, complete annual electrical usage data were obtained for all dairies except Texas dairies C5 and C7. Only data for one winter and one summer month were available for those dairies, so Method 2 was used to estimate annual usage. Table 3 shows the results of this analysis.

Table 3. Texas dairy electrical usage on an annual per animal basis (kWh/yr·a).

	Texas Dairies						
	C2	C3	C5	C7	P1	P5	E1
Milking	312	495	312	525	161	241	217
Housing	149	0	58	62	48	15	N/A
Waste Management	151	15	21	82	0	9	63
Feeding	13	5	N/A	13	6	2	N/A
Water	98	52	14	9	83	N/A	N/A
Total	723	566	406	692	299	268	280
Source[1]	A	A	2	2	A	A	A

“A” indicates actual data reported, and a number indicates which method was used to estimate values for that dairy.

Dairy C2 was a hybrid facility that used water to flush manure from the free-stall barns. This method consisted of pumping lagoon water into large storage tanks that subsequently released large volumes of water to remove the manure from the free- stalls. The water was then collected in a holding basin, pumped through a solids separation system, and drained back into the lagoon. The separated solids were stored for later composting. Additionally, this dairy had a rotary milking parlor built in 2003 that used a variable frequency drive vacuum pump that consumes less energy than the traditional constant speed pump. The feeding component of the electrical usage on this dairy was primarily attributed to a small feed grinding facility that was used occasionally.

Dairy C3 was an open lot dairy located in the same region and operated by the same owner as dairy C2. This facility had an older milking parlor that did not use a variable frequency drive pump or scroll compressors. Therefore, dairy C3 used approximately 59% more energy on a per animal basis for milking than dairy C2. However, being an open lot dairy, it used no electrical energy for housing. Additionally scraping manure from open lots with a tractor compared to flushing free-stalls in a hybrid dairy saved considerable amounts of electricity on an annual basis. Therefore, the total energy usage on a per animal basis at dairy C3 was less than that at a similar size free-stall dairy.

Dairy C5 used a vacuum system to collect manure from its free-stalls which was applied to fields in close proximity to the dairy. This dairy did not use a solids separation system for effluent flowing to the lagoon which resulted in lowered electrical usage. Additionally, the use of the vacuum system required significantly less pumping of water for flushing the free-stalls. Hence, the electrical usage of dairy C5 was lower than either dairy C2 or C3 on a per animal basis.

Dairy C7 was a unique dairy in this study because it contained an experimental covered lagoon biogas digester designed to use the methane produced to power an electrical generator. The resulting electrical energy was designated to aerate the effluent from the digester to accelerate solids settling leading to lower nutrient loading rates in the aerated effluent applied to the surrounding land. However, the digester operation was halted due to technical difficulties but the aeration system continued operation by using electricity supplied by the local utility company. This resulted in a 34% increase in the total electrical energy usage of dairy C7.

Dairies P1 (hybrid) and P5 (open lot) located in the Panhandle of Texas between Amarillo and Lubbock, had similar herd sizes and experienced similar climatic conditions. Both dairies used less electricity than the dairies located in Central Texas having similar management and housing systems.

Dairy P1 used significantly less electricity than all the comparable Central Texas facilities for several reasons. First, this dairy scraped manure lanes with tractors instead of flushing them with water or using a vacuum system. Additionally, a high capacity pre-cooler for milk that used well water to pre-cool the milk prior to its storage drastically reduced electrical usage for milking but increased electrical usage for pumping water compared to other hybrid dairies in Table 3.

The open lot dairy P5 used electrical energy primarily for milking. Security lights in open lots, feeding operations, and irrigation of wastewater to crop and hay fields required a very small amount of electrical energy usage as compared to milking.

Dairy E1 was a pasture dairy in Northeast Texas with approximately 180 cattle. The dairy only milked twice daily as compared to three times a day by hybrid or open lot dairies, decreasing its electricity usage. There were no housing structures for the cattle resulting in no electrical usage for housing. The waste management system consisted of pumping wash water from the milking parlor to a wastewater storage structure that was higher in elevation than the milking parlor. Hence, milking and waste management were the only electrical usage components for the dairy.

California Dairies

Table 4 shows the electricity usage for California dairies. The water and housing usage for all dairies was included in the milking center electrical usage as it was recorded on a common meter. Dairies labeled D1 and D2 were operated by the same owner with dairy D1 being the older of the two. Dairy D2 had newer pumps that were more appropriately sized for the milking parlor which accounts for the difference in electrical usage for milking. Dairy D2 pumped lagoon effluent a greater distance to flush free-stalls than dairy D1 and so consumed more electrical energy for waste management. The electrical usage for feeding was negligible on an annual per animal basis.

Dairies W1 through W5 were operated by one company with different site specific managers. All five dairies were located within a 5 mile radius in the Northern SJV. Like the other California dairies, these dairies recorded their water, housing and milking electrical usage on a common meter. Feeding operations were shared among them and are shown in Table 4 as the same average value for each dairy. The differences in electrical usage by dairies W1 through W5 were attributed to variable worker skills, pumping requirements and waste management systems among the dairies.

Table 4. California dairy electrical usage on an annual per animal basis (kWh/yr·a).

	California Dairies						
	D1	D2	W1	W2	W3	W4	W5
Milking Housing	383	314	686	492	413	576	550
Waste Management	28	65	102	207	245	255	262
Feeding	0	0	4	4	4	4	4
Water	-	-	-	-	-	-	-
Total	411	379	792	700	658	832	812
Source[1]	A	A	A	A	A	A	A

[1]Actual data were available for all dairies.

USDA Farm Energy Calculator

The USDA farm energy calculator was used to estimate electrical usage for a theoretical 1000 cow dairy in College Station, TX. Two cases were evaluated, a baseline scenario using the worst case assumptions and a peak efficiency scenario assuming the lowest energy usage. Equipment for the dairy included mercury vapor long-day lighting, fans that are not cleaned in both the free-stall and milking parlor, no pre-cooler or scroll compressor used for milk cooling, and constant speed drive for the vacuum pump. Daily milk production was assumed to be 29.5 kg/d·a (65 lb/d·a). Results for these two scenarios are presented in Table 5.

Table 5. Electrical usage at a dairy in Central Texas estimated using the USDA farm energy calculator for both the highest and lowest efficiency options.

	Energy Usage (kWh/yr·a)	
	Baseline	Peak Eff
Housing (lighting, air circulation)	291	116
Milking (milk cooling, milk harvest)	427	220
Total	718	336

In comparing these values to those obtained from the Central Texas dairies in the survey, the estimated usage for housing is somewhat higher but that for milking is comparable. This calculator does not estimate energy used for waste management and therefore, the total electrical usage cannot be directly compared.

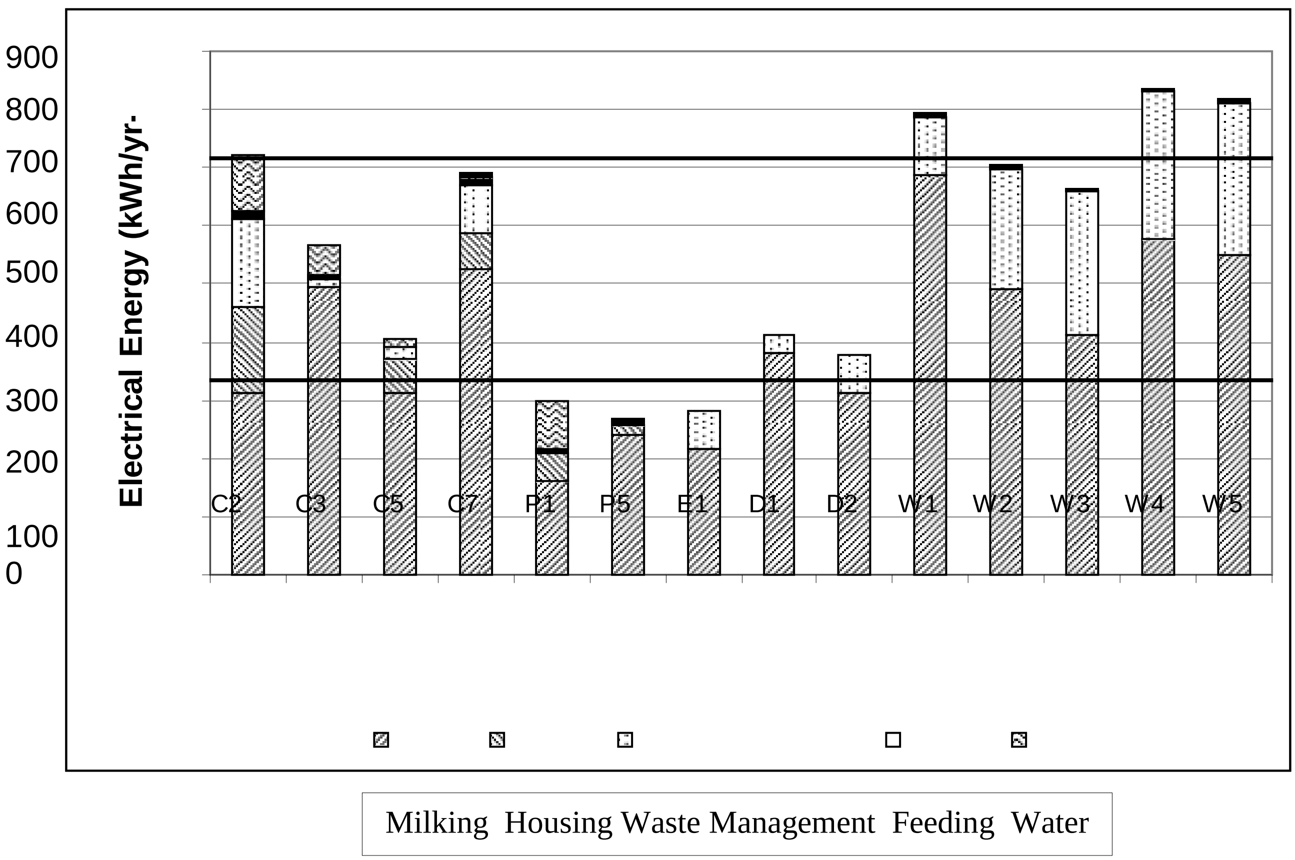


Figure 1 shows electrical consumption by process on each dairy included in the study. Values for total usage estimated using the USDA calculator are included as horizontal lines on the figure. The housing and milking usage total for all the dairies except the two Panhandle dairies, the Northeast Texas dairy and one California dairy are within the range estimated by the USDA calculator. The milking center was the highest energy user in all 14 dairies.

Liquid Fuels

Annual usage of liquid fuels on a kWh/yr·a basis for each dairy surveyed is shown in Table 7. The reason for higher fuel usage at diary C2 (hybrid with flush lanes) versus dairy C3 (open lot with scraped manure removal) was due to a large on-site composting operation at this dairy. Allocating fuel usage between dairy and composting operations was not possible. Dairy C7 had significantly lower fuel usage than others in the Central Texas region, but no specific reasons for this could be identified. Dairy P1 was a large operation that had numerous vehicles, some of which were assigned to several workers. This may have resulted in use of some fuel for non-dairy operations. Dairy E1, with cows on pasture, had the lowest fuel usage per animal due to the lack of activities that used such fuel. Dairies D1 and D2 were operated similarly by the same owner. The feed storage and mixing facility was adjacent to dairy D1 resulting in possible comingling of fuel usage between the dairies. Dairy D2 was further away resulting in the fuel used on this facility being strictly for the facility and nothing else. The five 'W' dairies were operated by a single company with a centralized fuel storage facility. Consequently, the fuel usage was tracked on a per vehicle basis and allocated to farming, calf raising, and dairy operations. Unfortunately, the fuel usage was not itemized on a per dairy basis. This resulted in dividing the total fuel usage reported equally among all five dairies (Table 7).

Table 6. Liquid fuel usage for all dairies (kWh/yr·a).

	Liquid Fuel		
Dairy	Diesel	Gasoline	Total
C2	800	0	800
C3	569	0	569
C5	776	0	776
C7	103	192	295
P1	619	0	619
P5	242	0	242
E1	122	61	183
D1	636	0	636
D2	394	0	394
W1	275[1]	78[1]	353
W2	275[1]	78[1]	353
W3	275[1]	78[1]	353
W4	275[1]	78[1]	353
W5	275[1]	78[1]	353
Average	454	110	487
Std Dev	260	71	222

[1]Liquid fuels were from a centralized storage facility and could not be allocated to each dairy separately so usage was divided evenly.

Gaseous Fuels

All dairies provided information on gaseous fuel purchases for one year for this survey except dairy E1 which did not report this type of fuel use. Operations that provided fuel usage as one sum across all processes and operations were treated as using the fuel equally for those processes and operations on a per animal basis. Table 6 shows the gaseous fuel use on a kWh/yr·a basis for all the dairies.

Overall, the energy expenditure for water heating was similar for all dairies on a per animal basis. The main variation in this value was for dairies P1 and P5, the newest dairies in the sample set equipped with heat exchangers that actually feed the heated water to the water tanks and not just to the watering troughs for the cattle. Dairy W4 had a higher energy usage because the propane storage was shared with a calf raising operation near the dairy. There was no information available to separate usage by the calf raising facility from that for the dairy, so the usage was divided evenly with 50% applied to the dairy. This resulted in significantly higher energy usage for this dairy.

Table 7. Gaseous fuel usage on all dairies (kWh/yr·a).

Dairy	Gaseous Fuel		Total
	Propane	Natural Gas	
C2	114	-	114
C3	134	-	134
C5	192	-	192
C7	168	-	168
P1	56	-	56
P5	-	41	41
E1	N/A[1]	N/A[1]	N/A[1]
D1	135	-	135
D2	131	-	131
W1	168	-	168
W2	53	71	124
W3	182	-	182
W4	306[2]	-	306[2]
W5	79	-	79
Average	143[3]	56	127[3]
Std Dev	69[3]	21	48[3]

[1]Dairy E1 did not report gaseous fuel use.
[2]Gaseous fuel use reported by dairy W4 included usage by a calf ranch that was combined with the dairy.
[3]Does not include dairies E1 and W4.

Total Energy Usage

Total energy usage subdivided according to energy source for each of the dairies involved in this survey is summarized in Table 8 and Figure 2. The maximum energy usage was 1637 kWh/yr·a on a free-stall dairy in Central Texas. This older dairy was undergoing expansion at the time of the survey which may have contributed to its higher energy usage. The lowest energy usage was 464 kWh/yr·a at the pasture dairy in Northeast Texas for which information on gaseous fuel usage was not provided. However, even if the higher end of gaseous fuel usage were added to the total for this dairy, it would still be one of the lowest energy users among those surveyed.

Making accurate comparisons of fuel use efficiencies across all dairies was difficult due to the broad range of management characteristics at dairy operations. Dairies C3 and P5 were both open lot facilities, but their total energy consumption varied by a factor of (1269 versus 551 kWh/yr·a). This difference was evident across all categories of energy usage and was most likely due to dairy P5 being a much newer facility.

Table 8. Total energy usage for all dairies (kWh/yr·a).

Dairy	Electricity	Liquid Fuels	Gaseous Fuels	Total
C2	723	800	114	1637
C3	566	569	134	1269
C5	406	776	192	1374
C7	692	295	168	1155
P1	299	619	56	974
P5	268	242	41	551
E1	280	183	N/A	464
D1	411	636	135	1182
D2	379	394	131	905
W1	792	353[1]	168	1314
W2	700	353[1]	124	1177
W3	658	353[1]	182	1193
W4	832	353[1]	306	1185
W5	812	353[1]	79	1244
Average	558	487	127[2]	1165[2]
Std Dev	210	222	48[2]	268[2]

[1]Liquid fuel usage was reported as an aggregate value for the five “W” dairies and so was simply divided evenly among them.
[2]Average and standard deviation values for gaseous fuel and total usage do not include E1 since no usage was reported for that dairy and W4 since the reported value included usage by a calf ranch.

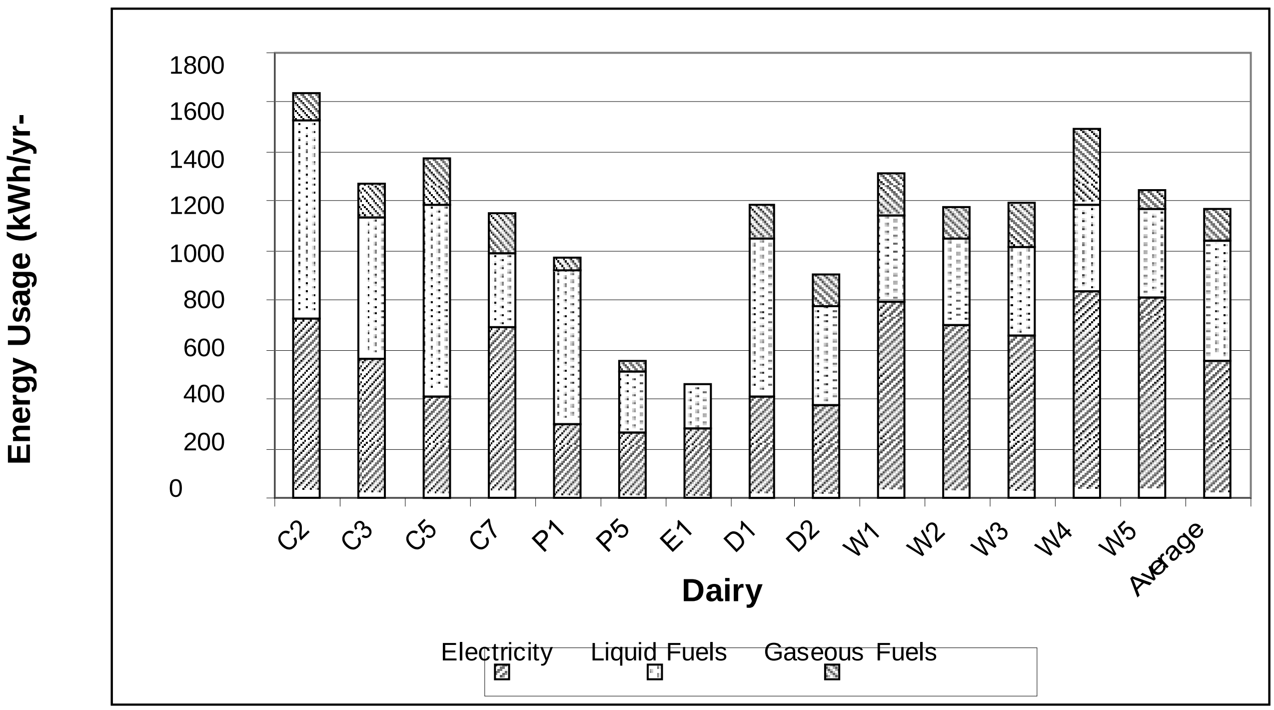


Figure 2. Total energy usage for each dairy in the study subdivided according to type of energy. The last column represents the average value for each type of energy across all dairies.

In general, newer dairies consumed less total energy per animal than comparable older dairies due to newer and more energy efficient equipment and facility design. Free-stall facilities typically used more energy than comparable open lot dairies because of the energy expended inside the free-stalls for flushing, cooling fans and lights.

Conclusion

Energy usage on 14 dairies surveyed in the southwestern United States was highly variable due to different housing systems, ages of facilities and energy efficiency of equipment used for milking, pumping wastewater and heating clean water. The greatest amount of energy used at all dairies was electrical, followed by liquid and gaseous fuels. Generally, newer dairies were more efficient in electrical energy use than their older counterparts, indicating that a significant amount of energy might be saved by upgrading facilities with new, more energy efficient equipment.

While this study looked broadly at dairy energy usage, more useful information can be gained by an intensive survey of energy usage for specific processes and operations at dairies. For example, installing energy consumption meters on specific motors in the milking parlors or specific fans in the housing structures would furnish process-specific information on energy use efficiency. The wide variation in energy usage on these dairies suggests that any dairy could benefit substantially from an energy audit of its facilities to identify potential areas for upgrading equipment or implementing energy conservation. An energy audit would be particularly important for facilities considering development of an onsite alternative energy system to match potential types of energy production to usage.

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Capareda, S. C., S. Mukhtar, C. Engler and L. B. Goodrich. 2010. Energy Usage Survey of Dairies in the Southwestern United States. Manuscript under review for publication in the Transactions of the ASABE, St. Joseph, MI (accepted)

Appendix E. Project Industry Advisory (PIAC) Committee (Task G)

Dr. John M. Sweeten, Texas AgriLife Research, Amarillo, TX
and
Dr. Kalyan Annamalai, Department of Mechanical Engineering & Texas Engineering Experiment Station, Texas A&M University, College Station, TX

E.1. Members of Project Industry Advisory Committee

E.2. PIAC Meeting Agendas
and Summary Feedback from PIAC Members

Appendix E.1: PROJECT INDUSTRY ADVISORY COMMITTEE
2006-2009

"Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities"

Mr. Ben Weinheimer, Vice President
Texas Cattle Feeders Association
5501 IH-40 West
Amarillo, TX 79106
Phone: 806-358-3681
Fax: 806-352-6026
Email: ben@tcfa.org

Mr. John Cowan, Executive Vice President
Texas Association of Dairymen
3500 William D. Tate Ave
Suite 100
Grapevine, TX 76051-8734
Phone: 817-410-4540
Fax: 817-410-4541
Email: jcowan@dfamilk.com

Mr. Paul Joiner, P.E.
The Panda Group (formerly)
4100 Spring Valley
Suite 1001
Dallas, TX 75244
Phone: 972-820-0278
Fax: 972-455-3880
Email: pjoiner@thepandagroup.com

Mr. Charles C. (Cliff) Clark, P.E.
TXU Power (currently Luminant Power)
500 N. Akron Street
Dallas, TX 75201
Phone: 214-875-8649
Fax: 214-875-8909
Email: cliff.clark@luminant.com

Mr. Ned Meister
Texas Farm Bureau
P.O. Box 2689
Waco, TX 76702-2689
Phone: 254-751-2457
Fax: 254-751-2671
Email: nmeister@tfb-waco.org

Dr. David P. Hutcheson
Animal-Agricultural Consulting, Inc.
P.O. Box 5037
Amarillo, TX 79159
Phone: 806-359-1091
Email: dhutch1941@sbcglobal.net

Mr. Olon Plunk
Vice President, Environmental Services
XCEL Energy
4653 Table Mountain Drive
Golden, CO 80403
Phone: 720-497-2015
Fax: 720-497-2087
Email: olon.plunk@xcelenergy.com

Appendix E.2. Initial Conference Call Summary

From: John Sweeten

To: Clark, Cliff; Cowan, John; Joiner, Paul; Meister, Ned; Weinheimer, Ben

Subject: Renewable Energy Biol"@.,ass Dairy & Beef--DOE grant

cc: Annamalai, Kalyan; Aut ermann, Brent; Capareda, Sergio C; Cawthon, Don; Craig, K ~ in; Engler, Cady; Gerik, Thomas J; Harman, Wyatte L; Hussey, Mark A; Lacewell, Ron D; Mukhtar, Saqib; Parker, David; Riskowski, Gary; Sweeten, John; Wall, Becky

MEMO TO: Cliff Clark, TXU, Dallas c1iff.clark@txu.com
John Cowan, Texas Assn. of Dairymen, Grapevine jcowan@dfamilk.com Ned Meister, TX Farm Bureau, Waco nmeister@txfb.org Paul Joiner, Panda Energy, Dallas pjoiner@pandaenergy.com Ben Weinheimer, TX Cattle Feeders Assn., Amarillo ben@tda.org

SUBJECT: Summary of Project Goals, Objectives & Tasks

1. WE really appreciated your participating in the conference call this afternoon (11/21/05) to introduce our project and some of the investigators (PI's) involved in this hopefully 3+ year study. I wanted to follow up on some things we touched on briefly.
2. The two agencies involved are: Texas Engineering Experiment Station (TEES), and Texas Agricultural Experiment Station (TAES), of the Texas A&M University System.
3. Faculty from the following research Units are receiving first-year funding and commissioned to perfor[l specific work plan elements: Department of Mechanical Engineering/TEES, College Station--Dr. Kalyan Annamalai; Biological and Agricultural Engineering Department/TAES, College Station--Drs. Saqib Mukhtar, Sergio Capareda, & Cady Engler; TAES-Amarillo--Drs. Brent Auvermann & John Sweeten; and, TAES-Temple--Dr. Wyatte Harman. Other cooperating faculty will include Dr. David Parker, WTAMU, Canyon, and Dr. Don Cawthon, TAES-Stephenville.
4. As of last month, the project is now officially funded by the USDOE/Golden (CO) Field Office. However, the starting date of record is June 1st, 2005--so we are already writing/submitting quarterly reports on the start up phase.
5. As promised, attached is the **4-page summary** of the full Work Plan (61-pages). This project summary lays out the Goals ($), Objectives and Tasks under each goal. Each task has one or more faculty assigned, along with a preliminary schedule. These will be furnished to you at our first meeting. '
6. Date and time for a meeting of the PI's and Project Industry Advisory Committee was tentatively agreed on as **January 27th (Friday) in Grapevine,** hosted by John Cowan. Address is: Texas Association of Dairymen, 3500 William Tate Ave., Suite 100, Grapevine TX 76051. Phone 817/410-4540~ As John said, it is only about 10-minutes northwest of DFW Airport (near the intersection of SH-114 & SH-12l, as I recall). Agenda will consist primarily of !pt's presentation of Work Plan elements (Goals/Objectives/Tasks) they are involved with, approaches, and early progress. We'll expect lively discussion by the Industry Advisory Committee that will help us shape/refine the project and guide the project toward positive outcomes.
7. We'll also set the next couple of meetings, presently envisioned for March in Stephenville (TAMU-AREC) and perhaps May in Dallas (TXU) perhaps. The DOE/Golden Field Office project officers (Kevin Craig & Becky Wall) may want to join us at one or more of these meetings.
8. We will make sure you receive the quarterly progress reports shortly after they are submitted to the DOE project officers.

Please let us know if you have any questions or comments at any time. I will have Coretta send you a list of e-mail addresses and other contact information, perhaps tomorrow. Thanks for your time this afternoon .... jms

Appendix E.2.

Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities

Texas Engineering Experiment Station & Texas Agricultural Experiment Station,
Texas A&M University System
Joint Meeting (1st) of Investigators & Industrial Advisory Committee (IAC)
Hosted by: Texas Association of Dairymen
3500 William Tate Avenue Grapevine, Texas 817/410-4540

January 27, 2006

Agenda

9:30 We1come & Introductions

Project overview

- Introduction of Team and-IAC (15 min.)
- Research funding agency: U.S. Department of Energy, Golden CO
  - (Grant no. DE-FG36-05G085003)
- Role of IAC in the Project
- Brief Update on Project (KA and JS) and Task List: PMP and AOP (15 min.)
- Review of Current Project Work Plan -objectives, tasks & participants (15 min.)
- Budgetary & reporting
- Upcoming TEES-TAMU Energy Conference, April, TEES

Project investigators' presentations

- Plans & approaches
- Progress to date
- Discussion

12:30 Lunch

Feedback from Industry Advisory Committee (1-2 page summary report by IAC)

Emphasis areas and Task list for pending Year 2 funding (use IAC feedback in defining 3 tasks)

Plans for next meeting(s) (15 min.)

3:30 Adjourn

Appendix E.2. Joint Meeting of Investigators & Industry Advisory Committee
January 27, 2009

A. Comments and suggestions provided by Project Industry Advisory Committee Members during or following Investigator Presentations:

Task 1.1.1. Fuel Characterization (Kalyan Annamalai)
Hutcheson: manure nitrogen N is in form of urea and anaerobic
Olon Plunk: more than 1-1.5% of Sodium (Na) causes slagging in coal-fired plants.

Task 1.1.9. (A.9) Ash Analysis
Paul Joiner: 75% of manure/25% cotton gin trash - 140 tons/hr, FB = 28 tons/hr ash.
- Plans and designs;
- Questions about what to do with ash; seeks ideas or guidance. Hoping to be able to pave the feedlot surfaces.

Dave Hutcheson: comments:
- Hard surfaced pens caused bacterial problems and foot problems.
- Industry has problems with hard-surfaced pen surfaces. May need to find other uses for manure ash.
- Calcium in ash comes from Ca that is fed beneficially.
- Finely ground Ca from sugar plant (CA S04 & CA CO_3).
- Paving feedpens may not pay out, considering animal performance.
- Also, feeding more sulfur in ration supplements.
- Key difference between dairy and beef feedlot manure is the dairies use sand for bedding, which is the gold standard for dairies. It is cheap, effective, comfortable, available, and less disease compared to cotton barns of other organic material.
- 90% of dairies in the High Plains use sand bedding.
- He is working on a process to take sand out; 90% effective.

John Cowan
Xenus Technology, Houston, TX has a gasification or combustion process. He has lined up two dairies for studies.

Ned Meister
- TCEQ rules faced by dairymen include phosphorous-limited (soil P) land application.
- Hoping to learn more about anaerobic digestion and energy production and balance.

Task A.2.2. Anaerobic Digestion of Mortality Biomass
Dave Hutcheson
- There is 25-30% fat in beef carcasses; consider that if considering use as biofuel.

Saqib Mukhtar
- Contaminated carcasses – digestion DHS suggested use anaerobic digestion to process.

Ned Meister

- Digester need to be practical – HRT – 15 days.

Ben Weinheimer

- Loading rate ~ 85 lbs/day; 12-13% solids.

Tasks C.1 and C.2.
Olon Plunk

- Bromine (Br) is a problem element in power plants; it is more reactive than Cl; is this present in manure or added to cattle rations?

B. Feedback from Industry Advisory Committee: Synopsis

- PIAC appreciated the opportunity to participate.
- Intense focus should be on-farm efforts.
- Develop technologies that are very scaleable.
- Feedyards – Keep dry fuel dry; no wet screening.
- Develop models for field-scale system (e.g. Panda Project and transportation models).
- Net energy for systems and economic feasibility are tied together
- Focus on recycling by products as to energy systems.
- Farm-scale use friendly - automated; simple; should receive focus.
- CAFO techniques – improve quality of raw material. What can be done with fuel to improve quality? (e.g. ash separation)

C. Individual PIAC Comments

John Cowan

- Historically – animal manure used as fertilizer.
- Today – a necessity to develop new uses of manure; manure could become valuable.
- Technology – has to be "doable"; affordable; simpler.
- He is excited to be a part of the project.

Ned Meister

- Renewable energy has been part of his job.
- High energy prices cause alternative energy to be reasonably high.
- Farm Bill is being revised; may reduce cop sub-tasks.
- Must pursue other venues of revenue streams regarding animal waste.
- He appreciates everyone's efforts.

Paul Joiner, Panda

- His project – ethanol, is stable business with known technology, but cattle manure conversion is "high risk".
- The more uncertainty they can remove through scientific knowledge will help them.
- Fresh manure is okay; any handling only reduces its face value.
- These studies need to have a broad applicability.
- Our studies are very specific; will have broader implications; and will be used in formal discussions.

- Uncertainty considerations by bankers can make or break financing.
- “Science needs to be translatable to pro-forma statements.”
- Economic studies needs to be “less time dependable” e.g. indexed to hours; cost of natural gas, etc.
- Economic efficacy vs. energy; net energy balances.
- Ethanol takes a lot of energy, but is a very attractive/useful fuel; portable.
- Manure is limited mainly to heat energy, so is a good chance if it can work technically.
- Energy costs – new platforms of 60^+/barrel of oil; 5 years from now it could be $100/barrel of oil; be prepared to give industry new ways to prepare fuels.

<u>Olon Plunk</u>
- Natural gas –rapidly escalating – still at an all time high.
- Coal cost relatively speaking last year was $6/MM BTU; this year was 20^+/MM BTU.
- New coal and natural gas contracts are very high.
- He appreciates our looking into manure as local biofuel, but challenges include for direct-fired plants; quality of feedlot manure-ash, waste, N, S; sulfur increases will be a major problem for power plants-costly to remove; Na-invasive fouling or slagging potential; P –invasive fouling or slagging potential; Cl-corrosive. These are less challenging for fluidized beds.
- Coal-fired plants have lower Hg, NOx limits than before.
- Investigating the idea to create higher value –manure over coal is value of Cl to remove Hg from exhaust streams.
- High Hg chlorine manure equals high Cl in powdered concentrated carbon.
- New driver is potential to remove Hg using FB.
- Reburn – been around for many years; glad to use manure if can reduce NOx emissions; looks encouraging; can it scale up?
- Hard to find commercial pilot plants to run replicated experiments.

<u>Mack Brown, Panda Energy</u>
- Natural gas is $8/MM BTU as of yesterday.
- “Ya’ll keep up the good work”.

<u>Cliff Clark, TXU Electric</u>
- Supply of biofuel may be limiting for power plants.
- TXU has huge boilers.
- Transporting coal vs. manure; relationship need to be better defined.
- Geography equals with manure as biofuel.
- Have to compete with coal as gold standard.
- Not every plant has NOx issues.
- TXU looks at it from standpoint of what it cost to a) remove a contaminant; and b) cost of alternative lower-contaminant supply of coal.
- Trading allowances for Hg, NOx etc.
- Calcium Bromide vs. Cl to capture Hg?

<u>Dave Hutcheson</u>
- Wants us to take a broad approach.
- Phosphorus is still in digested slurry from anaerobic digestion.

- All contaminants are in the feed fed to animals.
- Animals take out 90% of the carbon.
- The last 10% of carbon is excreted with the minerals fed.
- Can't recycle "dirty manure" for beneficial purposes.

John Cowan
- In relation to traditional vs. future production practices:
    - U.S. doesn't want to be dependent on foreign lands to produce food in the future
    - Farmers and ranchers realize they have to change, but must look at cost/benefit to them
    - It is hard to get focus farmers and ranchers to take risks out of their comfort zones

Cliff Clark
- Attitudes are also slow to change, but have to deal with:
    - Regulations – sue as implementation to change
    - Policies of alternative energy is underway already
    - Economics – reduce cost of production-price not regulated anymore; must compete with other utilities

Dave Hutcheson
Agricultural producers will change if they don't go broke first.

Saqib Mukhtar
Resistance to change is dissipating; more acceptance to change and new technologies
Advantages are being received as to alternative bioenergy.

Olon Plunk
- Message to graduate students – the work they are doing will absolutely be useful.
- XCEL Energy is a regulated utility.
- Efficiency and cost just as important.
- Probably will be CO2 regulations added to Hg regulations.

Dave Hutcheson
- Fiber separation; grinding cost increase with ash contents.

Olon Plunk
- Keep soil out of manure

Next meeting will be in Stephenville, TX, May 31st from 9:00 am -4:00 pm. It will include a tour of Broumly Dairy from 9-11 am.

Appendix E.2.: Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities

Texas Engineering Experiment Station & Texas Agricultural Experiment Station,
Texas A&M University System

Joint Meeting (2nd) of Investigators & Industrial Advisory Committee (IAC)
Hosted by:
Texas A&M Agricultural Research & Extension Center
1229 North U.S. Highway 281 , Stephenville Texas
254/968-4144

May 31, 2006

-- Agenda—

8:30 Arrive at TAMU Agricultural Research & Extension Center (AREC), Stephenville
Host: Dr. Don Cawthon, Resident Director

9:00 Depart from AREC parking lot for Broumley Dairy, Hico—vans, cars, etc,.
9:30 Arrive at Keith Broumley Dairy

- Tour anaerobic digester/biogas/methane recovery project
  - Tour guides: Saqib Mukhtar, Don Cawthon, Jay Bragg, Keith Broumley
  - Discussions

10:30 Depart for, Stephenville
11:00 Arrive at TAMU-AREC, Stephenville

11:10 Convene meeting; Recognition of Research Team and IAC members

- Status of research funding, U.S. Department of Energy, Golden CO
- Reporting or budgetary issues
- Begin investigator reports.

12:00 Lunch

1:00 Updates on project activities, plans & approaches, in relation to work plans, progress & accomplishments

- Investigator reports: KA, JS, SM, SC, VE, BA, WH, and graduate students.

Presentations (5 min each):
1. Brandon and Uday : Fuel Data Bank (Uday; Task A-1), Fuel Properties and fuel Pyrolysis (BM, Task A-2)
2. Lawrence: Cofiring TX lig and Wy Coal with FB/DB (Task A-3)
3. Paul : NOx (task A-4)
4. Brandon , Nathan and Paul: New Reactor construction, Feeder System (include Nathan's report); old reactor, Task (Task A-4)
5. Gerardo: Gasification (Task A-5)
6. Annamalai and Sweeten: Pilot Scale studies (Task A-6)
7. Giacomo: NOx and Hg modeling-Reburn (or Giacomo and Madhu can combine if time is limited) (Task A-7)
8. Carlin Nick: Exploratory Direct Energy Conversion Studies (Task A-7)
9, Carlin Nick NOx Economics (Task H-1)
10. Hyukjin Oh: Fouling (Task under TCEQ); did not attend since he was out of country

11. Hyukjin Oh and Uday: Hg instrument (Uday) and Hg Expts (Jin) (Task under TCEQ)
12. Madhu: Modeling Hg (Task under TCEQ)

- Budgetary & reporting
- Discussion

3:00 Feedback from Industry Advisory Committee

4:00 Determine emphasis areas for 2006

4:30 Plans for next meeting

5:00 Adjourn

Appendix E.2. Summary of PIAC Meeting
May 31, 2006 at Stephenville, TX
Brief Overview of Activities and Feed back from PIAC Members.

I. Site tour—Participants visited the Keith Broumley Dairy (Hico, TX) which featured a covered-lagoon/anaerobic digester and phosphorus-removal system (or removal in concentrated form as sludge). Tour participants who did not attend the subsequent meeting in Stephenville included: Joe Maley, TX Farm Bureau, Daniel Nichols of Congressman Chet Edwards office, and Keith Broumley.

II. Introductions—Returning to AREC-Stephenville, the meeting began at approximately 11:15 am; the agenda is attached (Appendix G-2). All PIAC members participated or were represented except for Cliff Clark, TXU-Dallas. George Caldwell substituted for Ned Meister, TFB. Several faculty/staff of Texas AgriLife Research and Extension/Tarleton, and visitors (Fred Moore & Van Kozak, USEPA-Region 6) also participated.

III. Project Status and Funding Update (Sweeten, Annamalai and Lacewell).

A. Sweeten: Distributed/overviewed project briefs FY07 Congressional initiative in the TAMUS request book; 2005 Federal initiative project accomplishment report; PIAC feedback (not prioritized) from the first meeting on Jan. 27 in Grapevine; and the 2-page summary project plan for Year 2.

B. Annamalai: Funding authorization for Year 2 is imminent (early June 2006)

IV. Project Investigator Progress Reports, Questions and Comments

A. Auvermann introduced Billy Chaffin, Gary Marek, Kevin Heflin and Brad Wilhite, Texas AgriLife Research and Extension –Amarillo/Bushland, involved in work plan elements on carcass process/utilization as feedstock.

B. Weinheimer asked about ash removal options at Bushland.

C. Sweeten provided update on manure preparation and characteristics (uncomposted vs. partial composting, drying, grinding etc.) for manure/feedlot biomass (FB) from traditional soil surfaced vs. paved feedlots, and use of FB/coal/gin trash blends for Panda Energy's test burns in Idaho.

D. Hutcheson urged us to feed cattle with high-sulfur by-products to reflect industry trends.

E. Plunk: Sulfur in low-sulfur manure products is already considerably higher than that of Powder River Basin coal; 4x S in manure from high-sulfur rations (e. g., wet distillers' grain) will exacerbate the problem.

F. Hutcheson: Higher mineral are fed in dairy rations than in beef rations.

V. Lunch—

a. Don Cawthon, Resident Director, welcomed the group to the at AREC-Stephenville;

b. Cawthon announced that $11,000,000 has been appropriated by the Texas Legislature in the recent Special Session to build a teaching, research and extension dairy under the auspices of Tarleton State University; expected capacity is 400 head; conceptual design to commence shortly.

VI. Project Investigator Progress Reports (continued)

A. Annamalai and graduate students:

1. *Brandon Martin & A. Udayasarathy*: Fuel Data Bank and Fuel Properties (Uday; Task A-1); fuel Pyrolysis (BM, Task A-2)

2. *Ben Lawrence*: Cofiring TX lignite and Wyoming Coal with FB/DB (Task A-3)

3. *Paul Goughnour*: NOx (task A-4)

4. *Brandon Martin, Nathan Coon & Paul Goughnour*: New Reactor construction, Feeder System (Include Nathan's report); old reactor, Task (Task A-4)

5. *Gerardo Gordillo*: Gasification (Task A-5) with potential application to FutureGen

6. *Annamalai & Sweeten*: Pilot Scale studies (Task A-6), being planned with GE-Systems, Santa Ana CA. Fall 2006

7. *Giacomo Colmegna & Madhu B. Pachakyslu*: NOx and Hg modeling-Reburn (Task A-7)

8. *Nick Carlin*: Exploratory Direct Energy Conversion Studies (Task A-7).

9. *Nick Carlin:* NOx Economics (Task H-1)--Tasks as Cost Sharing

10. Hyukjn Oh: Fouling (Task under TCEQ): Jin was out of Country and did not attend

11. *Udayasarathy, A:* Hg instrument and Hg Experiments; task under parallel TCEQ grant; paved feedlot biomass may have more Hg in fuel

12. Madhu, P: Modeling Hg; task under parallel TCEQ grant

B. <u>Goodrich</u> (for Engler, Mukhtar and Capareda)—Work by BAEN Department in College Station.

C. <u>Harman</u> --biomass reburn economics; Nick Carlin made a presentation on NOx reduction economics using Dairy and Feedlot biomass Fuels.

D. <u>Sweeten</u> (on behalf of DeOtte & Parker at WTAMU)--ash disposal alternatives for construction or fertilization.

VII. <u>Work Plan Renewal Discussion</u> (Annamalai; Harman)

VIII. <u>Industry Advisory Committee Feedback, Questions, and other Comments:</u>

A. <u>Hutcheson:</u> Document ration composition at each cooperating AFO including research facilities.

B. <u>Lacewell/Cowan</u>: Do not lose sight of the “FutureGen” opportunity in Central Texas; incorporate such a project, if it comes to pass, into the overall scheme of the DOE project, or at least capture data analogous to that of the Broumley Dairy digester study

C. <u>Annamalai:</u> In the renewal proposal, we added a task to study steam gasification in order to produce more H2 for potential application to FutureGen (Task A-5); a faculty from Univ of MI Ann Arbor will join Mech. Engg. He specializes in IC engines and may be interested in research on use of digester gas for IC engines similar to that of Broumley Dairy.

D. <u>Caldwell</u>—As per TFB, any suggested changes, modifications, or optimization strategies for Broumley Dairy digester/P-recovery system are expressly solicited from the project team

E. <u>Plunk:</u> Why is the electrical generation so variable at the Broumley Dairy? Mukhtar: Biogas composition varies; Annamalai: for example the % CH4 and CO2 (task A-1: Uday Fuel data bank may have some data based on mass/atom balance).

F. <u>Plunk:</u> Why not harvest more electricity for on-farm use? Capareda: Contract with utility will not accommodate that.

G. <u>Hutcheson:</u> What is the fresh water use of the Broumley Dairy?

H. <u>Weinheimer</u>: Is there a way to pre-separate the ash from the manure to increase net fuel value?

I. <u>Sweeten:</u> What would be the incentives/payback associated with paving feedyards that produce manure for combustion processes? Harman: How much government subsidy would be required to do it? Plunk: Can we project the net financial impact of paving based on projected changes in manure quality/fuel value? Hutcheson: Concrete pens caused great production problems in the 1960-70s; fly ash may be better than concrete but not properly evaluated.

J. <u>Hutcheson</u>: Explore alternatives for P removal from watershed.

K. <u>Sweeten and Plunk</u>: How would $100/bbl crude oil (and/or other fuel benchmarks: $/ton coal, $/mcf natural gas) change the technology options? What about other policy options (e. g., CO_2 taxes, GHG credits)?

L. <u>Plunk</u>: We don't know much about the scrubber on the Broumley Dairy; can we analyze gas stream and water discharge for sulfur compounds and learn what is going on there?

M. <u>Weinheimer</u>: Suggest this project provide a technical advisory team for Broumley Dairy to forestall mothballing the digester system; need Engler to add certain types of monitoring to the system to help evaluate the *full* net benefit/cost of the system; need to make sure we understand *why* the Broumley project succeeds or fails, not just *whether* it succeeds or fails

N. <u>Weinheimer</u>: Pull out TCFA "feedlot energy management guidelines" notebook (Sweeten et al., 1985) and update it with current data and process knowledge; can this be done in a year?

O. <u>Joiner:</u> Gas turbine vs. making pipeline-quality gas; fuel to liquid for storage; other alternatives to increase storage capacity and transportability, fuel quality, fuel value etc.; all environmental costs (GHG, landfill costs etc.) must be kept fully in view, as well as the scale dependence of all options and fuel and product streams; some of the combustion and gasification experiments use infeasible options (e. g. 50/50 manure/coal blends) that should be screened through pragmatic considerations

P. <u>Mukhtar</u>: What about the on-farm usage of biomass energy? Are there other technologies that can be scaled down?

IX. Next Meeting: Tentatively decided on September 28, TAMU AREC-Amarillo.

X. Adjourn

Appendix E.2.: Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities

Research Participants: Texas Engineering Experiment Station (TEES), Texas AgriLife Research and Extension, & West Texas A&M University, of the Texas A&M University System.

Sponsoring Agency: U. S. Department of Energy, Golden Field Office, Golden CO

Joint Meeting (3rd) of Investigators & Industry Advisory Committee (IAC)
Texas A&M Agricultural Research & Extension Center
6500 Amarillo Blvd.-West, Amarillo, Texas (806/677-5600)
September 28, 2006

-- Preliminary Agenda—

8:30 Arrive at TAMU Agricultural Research & Extension Center (AREC), Amarillo
Host: Dr. John M. Sweeten, Resident Director

8:40 Tour departs from AREC parking lot (vans, cars, etc.)
9:00 Arrive at Texas AgriLife Research/USDA-ARS Conservation & Production Laboratory, Bushland TX; security sign-in & badges. Tour includes:

- Pilot-scale anaerobic digester/biogas recovery for cattle carcasses (in construction);
- Cattle manure preparation/processing (beef & dairy) for thermochemical conversion research;
- Manure/carcass composting
    - Tour guides: Brent Auvermann, Gary Marek, Kevin Heflin, John Sweeten.

10:20 Depart for Amarillo
10:40 Arrival at TAMU-AREC, Amarillo; Reception/refreshments in foyer

11:00 Welcome & introduction of Project Industry Advisory Committee & Researchers

- Comments from project officers, U.S. Department of Energy, Golden CO--Kevin Craig & Rachel Trautner
- Discussion of any budgetary or reporting issues—Kalyan Annamalai (PI)
- Comments from Administrative Advisors—Bill McCutchen & Ron Lacewell

11:30 Begin investigator/research reports, progress & accomplishments
12:00 Lunch, catered in-house

12:30 Continue Investigator research reports, to include project activities, approaches, progress & accomplishments to date.

2:00 Feedback from Industry Advisory Committee & identify emphasis needs.

3:00 Plans for next meeting & Adjourn.

Appendix E.2.: Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities

Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities
Meeting of Investigators & Industry Advisory Committee, Amarillo, TX
Sept. 28, 2006

INDUSTRY ADVISORY COMMITTEE DISCUSSION, FEEDBACK, QUESTIONS and COMMENTS:

Cliff Clark, TXU Power

- Beginning to see some exciting results from some of the work, especially in the reburn area. Need to double check the work, but I'm seeing some rather exciting opportunities.

Paul Joiner, Panda

- Differentiate categories of manure, high ash vs. low ash.
- Needs to be greater work on targeting the fuel to the utilization priorities. Give some thought to what is low ash to high ash. Designer biomass fuel. Setting up a classing or grading system. We're going to have so much manure coming from this area, we need to know what fits what market.
- Need a way to get a field classification, determining the content of the manure in the lot. Look at moisture and ash content, a quick and dirty density test.
- Different characters of fuel – energy density is important here. Want properties with higher BTU. My biggest cost is transportation of that fuel. Some of what is taken to market, may have to look at further processing to tailor it to a market to sell.
- Essential to understand the mechanisms of how manure is used to control NOx. Separate on its inert properties.
- Ash – there are going to be a lot of opportunities for ash here – it's coming out of our ears. If we can research getting the phosphorous out or other chemical extraction to increase its value.

Ben Weinheimer, TCFA

- This project has to be careful thinking there's going to be changes in the infrastructure in the industry. We need to know what the industry is thinking. If we're not going to be able to haul manure on rail in the next 20 years, let's move on.
- Let's make sure we keep it to a scaleable model. Think regionally, rather than continually up.
- And also, can't lose site of net energy. It takes energy to grind manure to the microns we need. It will play into these technologies. What is the energy footprint.
- Be a multi-discipline as we need to be related to animal health, environmental, energy and other technologies, look at the whole system.

Tom McDonald – Five Rivers Cattle Company

- We heard awhile ago that only the low ash manure has value as a reburn fuel. 99 percent of the manure is not low ash. Are you going to convince all the feedyards to surface their feedyards or are we going to make low ash manure out of high ash manure.
- Also appears that transportation cost is a significant factor in the equation.
- As you weigh all of these things, what benefit is the feedyard getting from this. Maybe we're reducing a cost to the feedyard. There may be a tipping cost there. Is there a way the manure could be used at the feedyard level, reduces transportation costs. Onsite gasification plant.
- Renewable energy is something we should be focusing on. I'm glad to hear that a part of this whole project is looking at policy issues. I believe there has to be some obstacles removed from producing renewable energy.

Olon Plunk, Xcel

- Numbers out of reburn are pretty unbelievable, need to be sure of them.
- Also, chloride issues involved with the reburn.
- Grinding is a value addition that could be looked at. Expense has to be borne one way or another.
- The quality of manure. Dirt in the manure from a combustion standpoint is always going to be a problem. Something has to be done to make it viable.
- Market being developed for activated charcoal. If you can determine it is a viable product that can be produced, there's still some value.

Dave Hutcheson, consultant Animal Nutritionist

- Encourage that we look what we're working with. We're working with a waste product and we produce a waste product. You are extracting carbons on your way down. It's tough to get a whole lot of energy out of it toward the end.
- Use of it is still an issue – the ash put back onto the soil – need to look at the raw material we have in it. Zinc may be the most important part of it. We need to start looking at the minutia and details – phosphorous and zinc. Ash is the biggest issue and who ever uses it last has to get rid of it. That's the area some focus has to be put on.

<u>Forward Planning and Adjournment:</u>

Next meeting is planned for Dec. 12, prior to the Air Quality Initiative meetings, at the TXU "Big Brown" power plant near Fairfield, TX, off of IH-45, halfway between Dallas & Houston. Cliff Clark confirmed scheduled meeting and reserved conference room.

Appendix E.2.: "Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities"

Research Participants: *Texas Engineering Experiment Station (TEES), Texas Agricultural Experiment Station (TAES), & West Texas A&M University, of The Texas A&M University System.*

Sponsoring Agency: *U. S. Department of Energy, Golden Field Office, Golden CO*

Joint Meeting (4th) of the Industry Advisory Committee (IAC) & Investigators

Host: Mr. Cliff Clark, TXU, Dallas (214/812-8451)
Location: Texas Electric Utilities, Big Brown Power Plant
Fairfield, Texas

December 12, 2006

-- Agenda—

9:00 Arrive at **TXU Big Brown Plant**, 850 FM 2570, Fairfield TX

9:05 **Tour Big Brown Power Plant**

- Welcome & introductions—Cliff Clark, TXU
- TXU safety equipment & tour instructions
- Tour, by groups
- Return safety equipment, Q & A, & break

11:00 Begin **Project Industry Advisory Committee & Researchers**

- 11:00 Presentation: Sponsored Graduate Research, Dr. Paul Zweiacker, Director of Power Environmental Services, TXU
- 11:30 DOE Project Budget & reporting issues—Kalyan Annamalai (PI)
- 11:45 Update on the TAMUS BioEnergy Alliance—Theresa Maldonado, TEES, College Station
- 11:55 Update on Panda Hereford Ethanol project—Paul Joiner

12:00 Lunch, catered in-house

12:30 **Investigator research reports**, to include project activities, approaches, progress & accomplishments to date.

2:15 Discussion & Feedback from Industry Advisory Committee

2:45 Identify emphasis needs.

3:15 Plans for next meeting

3:30 Adjourn

Vers. #2, Dec.6 jms

Appendix E.2. Feedback from Industry Advisory Committee

December 12, 2008

Location: Texas Electric Utilities, Big Brown Power Plant
Fairfield, Texas

<u>Ben Weinheimer:</u>

- Good progress being shown.
- Lots more going on than anticipated.
- Still seems to be project elements that do not match up with real-world (e.g. Low-ash manure- not much of it).
- Needs to address: High-ash manure. What are the options?

<u>Dave Hutcheson:</u>

- Great progress.
- Nick Carlin's model is a good model
    - The best he has seen
    - Add a water treatment/reuse mode
- Digester on-farm—good information
- Chemical analysis of ash is good; is there a better way to analyze?

- HHV – production rates of ash and fuel value

    <u>Phosphorus -</u> Look at/focus on water soluble P; that is the problem; not total P.

    <u>Ash -</u> Zn= Think outside the box (e.g. Zn sulfate; price has tripled as mineral feed ingredient);
    Se= Selenium is a high-valued mineral in animal feed.

    <u>Ethanol -</u> Wet distillers grain is high P; Manure is concentrated P, which also has good fertilizer value.

<u>Jon Johnson, TFB:</u>

- Uses of ash in manure
    - Jon agrees with re-utilization of ash minerals
    - What happens to the P? Soluble or not soluble?

<u>Cliff Clark, TXU:</u>

It is beginning to get better (the understanding of the material side)

<u>Ben Weinheimer:</u>

Future meetings should spend less time on logistical progress reports, and more time on presentations.
Scales of technology-think on feedlot/on-site rather than supply focus on power plant scale.
Suggests planning a Science Review Panel for evaluation and Mid-Course corrections.

Jon Johnson asked about anaerobic digester residue. Saqib Mukhtar said that digestate from anaerobic digester can be burned or boiler fuel, ala Nick Carlin's model. Brent Auvermann said that net energy considerations need to be addressed.

Next Meeting will be in College Station to see laboratories, in March/April, 2007.

Appendix E.2.: Agenda of Investigator Meeting in College Station, TX

April 13, 2007

"Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities"

Sponsoring Agency: *U. S. Department of Energy, Golden Field Office, Golden CO*
Research Participants: *Texas Engineering Experiment Station (TEES), Texas AgriLife Research, & West Texas A&M University, of the Texas A&M University System.*

Joint Meeting (5th) of the Investigators With Industry Advisory Committee (IAC)

Hosts: Kalyan Annamalai (MENG/TEES), Saqib Mukhtar & Sergio Capareda (BAEN/Texas AgriLife Research)
Contacts: kannamalai@meng.tamu.edu, 979/845-2562; mukhtar@tamu.edu, 979/458-1019

Meeting Location: D. R. Cain/Engineering Physics Bldg., Mech Eng. Room 301)
Texas A&M University Campus
College Station, Texas
April 13, 2007
--Agenda—

Investigator (PI) Meeting:

8:00 AM Coffees Provided
8:10 DOE Project update, contract & reporting issues—Kalyan Annamalai

IAC Meeting with Investigators and Graduate Students:

8:45 Arrival of IAC Panel and Graduate students; Continental Breakfast Provided
9:05 Introductions
9:15 Welcome by Dr. Theresa Maldonado, Assoc. Vice Chancellor for Engineering
9:20 Update & discussion, the TAMUS Agricultural & Engineering BioEnergy Alliance—Theresa Maldonado, TEES, and Bill McCutcheon or Mark Hussey (Texas AgriLife Research).
9:45 Tour BioFuels labs, Mechanical Engineering Dept., Kalyan Annamalai
10:45 Transportation (provided) to Dept. of Bio & Ag Engineering BioEnergy Labs.
11:00 Tour of BAEN Dept. BioEnergy Labs—Sergio Capareda & Saqib Mukhtar.
12:00 Transport to Meng. Dept., Cain/EPB Bldg.
12:15 Lunch provided, catered in-house

* Invited Speaker(s): Updates on Federal and State Initiatives and Recent Rule Changes--Ron Lacewell, Texas AgriLife Research Federal Relations, and/or Cathy Reiley, TEES-Federal Relations. KA and JMS will report on recent meeting with DOE-Golden.

12:45 **Investigator research reports (task wise)**: Proposed tasks; progress, accomplishments, findings, remaining work—
Brent Auvermann, Saqib Mukhtar, Sergio Capareda, Cady Engler, Wyatte Harman, Robert DeOtte, Kalyan Annamalai, John Sweeten
Grad Students: Ben Lawrence, Hyukjin, Gerardo, Nicholas, Uday, Chris, Nathan
2:15 **Industry Advisory Committee** Discussion & Feedback from -Identify major accomplishments, industry needs, areas of greater emphasis needed.
3:15 Plans for next meeting & Adjourn (Optional Tour of George Bush 41st Library)

Appendix E.2.: Summary of Investigator Meeting in College Station, TX

April 13, 2007

The detailed meeting summary of this meeting is not available.

The following are some key points from feedback received:

Key points of feedback from the PIAC included the following:

1. The proposed tasks use several different paths to achieve energy conversion until "one " catches fire; it is for the industry to adopt the technology suitable to their need and suitability of their feedstock; for e.g. high ash FB suitable for gasification while low ash FB suitable for cofiring or reburn.
2. Dairy biomass is more fibrous and hence more difficult to grind.
3. Utilities: Transport FB with less ash and less water.
4. Feedlot operators: LAFB does not exist; should develop technologies for high ash FB; need scalable technologies. Needs small scale on site energy conversion systems.
5. DB Consulting Company feedback: Much more progress is made since last meeting. Nick's model (Task A.8) is great. Dry manure, take water to scrubber, clean it up; use dirty water in condenser.
6. Feedlots pay money to feed minerals. Can the minerals in ash be used as animal feed supplement?

Appendix E.2.: Industry input into energy-systems model development .

"Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities"

Research Participants: *Texas Engineering Experiment Station (TEES), Texas Agricultural Experiment Station (TAES), & West Texas A&M University, of the Texas A&M University System.*

Sponsoring Agency: *U.S. Department of Energy, Golden Field Office, Golden, CO.*

Investigators Joint Meeting (6th) with Industry Advisory Committee (IAC)

Location: Texas Farm Bureau
7420 Fish Pond Road
Waco, TX 76710
254-751-2457

December 10, 2007

AGENDA

Project Industry Advisory Committee & Investigators

10:00	Arrive at Texas Farm Bureau
10:05	Welcome and Introductions – Ned Meister
10:15	Update & Discussion, TAMUS BioEnergy Alliance –Bob Avant (TAES) and Theresa Maldonado, TEES
10:40 – 11:00	Update on Federal DOE Initiative –Ron Lacewell, TAMUS-Ag Federal Relations
11:00	DOE Project Budget & Reporting Issues –Kalyan Annamalai
11:15	Start Investigator Research Reports: Project Approaches, Progress Results & Accomplishments- Saqib Mukhtar, Sergio Capareda, Cady Engler, Brent Auvermann
12:00	Lunch, catered In-House
1:00	Complete Investigator Research Reports: John Sweeten Robert DeOtte, Kalyan Annamalai/Graduate Students, & Wyatte Harman
2:15	Feedback from Industry Advisory Committee and Discussion
3:15	Plans for Next Meeting and Adjourn

Vers. # 2, November 19, 2007

Appendix E.2.: Investigators Meeting Summary-December 10, 2007-Waco, TX

INDUSTRY ADVISORYCOMMITTEE

FEEDBACK SESSION

USDOE Project, "Renewable Energy from Cattle Biomass"
December 10, 2007
Waco Texas

Industry Advisory Committee Members:

Attending:	Not Attending:
• Ben Weinheimer, TCFA	Olon Plunk, XCEL
• Paul Joiner, Panda Energy	John Cowan, TX Assn. of Dairymen
• Cliff Clark, TXU/Luminant	David Hutcheson, Animal Ag Cons.
• Ned Meister, TFB	

Guest: David Pinkerd, Nouveu, Dallas

Industry Responses to Morning's Presentations and Previous Discussions:

Ben:

- Project has come a long way.
- Now, stop and interpret what we have learned.
- Package it better; how does sit relate to the feedyard industry.

Paul:

- Technology transfer; how do we interpret adntransferitt9ofeedlot operators?
  e.g. do/should feedlot operators go out and pave their pens? No, not without economic return
- But with the data showing the HHV benefits and a ready customer needing biofuel for a project, then it is possible, i.e. higher BTU biofuel = smaller, lower cost boiler).
- Can see the data showing alignment of how to produce better manure.

FB will be a limited resource, "opportunity fuel"; need business plans showing how to do it. Can be very beneficial resource if done properly.

- Panda represents a large scale use of manure; but still a lot of manure is left over. Encourage others to do the same; anyway they can help others succeed, then they succeed together. Make sure there is large scale success; every one benefits.
- Carbon credits will be a large benefit if it can be documented. Look at benefits of both NOx and carbon benefits of FB/DB. Carbon footprints: existing/proposed energy plans are not very effective nationally. *Industry, policy-makers and politicians need our best scientific data and advice to make rational policy*.

Ned.

- Very happy to be part of this group. Understands the quality of reseachers involved and trusts our results.

- His crystal ball shows continued ratcheting down of emissions and discharges. We are addressing both pollution control and renewable energy production; both beneficial routes endeavors.

- At some point, industry including TFB needs to kick in and help us go to the policy sector and get funding.

CLIFF:

- We're looking at costs that are estimates and not very well refined. Within 30-40% variability is essentially a "break-even" scenario.

- Volume of cattle needed to support a plant, their minimum is 600 Megawatt. Not enough volume to interest DOE. Thus co-firing is better alternative. What is minimum amount of manure that can make an impact on coal? 5% manure replacement of coal?

- Portfolio standards; power industry will be required to have more and more renewable in portfolio., crops, animal wastes, others will be considered; the industry will be committed to some, cost included.

Kalyan: any suggestions for pilot scale tests going forward?

David Pinkerd:
Portfolio standards; working with universities, Oklahoma State University.

JMS:

- Need to package together technologies:
  - Carbon vs. higher heating value (HHV)
  - Steps needed to preserve C will enhance HHV, and vice versa;
  - Density—conceptually should be able to use particle density for sizing and density separation. e.g. 100 lbs/cu.ft soil vs. 62.4 lbs/.cu.ft. water vs. 20 lbs /cu.ft. volatile solids Low ash manure ~ 30 lbs/cu ft vs. high ash manure ~ 50 lbs/cu ft bulk density.
- Reducing Carbon loss will solve 2 or three other environmental issues.
- EFT proposal possibilities: need industry to take leading role.

Saqib: pathogens losses are also a concern; need strategies and possible alternative fuel route is pathway.

Paul: with a fixed carbon sink, greater energy use efficiency is a key strategy to reduce or stabilize fossil fuel utilization. While most new projects are dominated by economies of scale, projects that utilize greater energy efficiency wil have a net gain due to credits from using fewer fossil resources, and also be considered as possible economic options.

Compiled: JMS 12/10/07; revised Jan 22, 2008.

Appendix E.2.: "Renewable Energy & Environmental Sustainability Using Biomass from Dairy & Beef Animal Production Facilities"

Research Participants: *Texas Engineering Experiment Station (TEES), Texas AgriLife Research-Amarillo and College Station, & West Texas A&M University, of The Texas A&M University System.*

Sponsoring Agency: *U. S. Department of Energy, Golden Field Office, Golden CO*

Joint Meeting (7th) of the Project Industry Advisory Committee (PIAC) Meeting
Host: Mr. John Cowan, Texas Association of Dairymen, Dallas, TX (817-410-4540)
Location: Texas Association of Dairymen/Dairy Farmers of America Office
3500 William Tate Ave, Suite 100
Grapevine, Texas 76051

May 22, 2009

-- Agenda—

8:30-9:00 **Arrive at Texas Association of Dairymen/Dairy Farmers of America Office**

9:05 **Meeting Begins**
- Welcome—John Cowan, Texas Association of Dairymen (TAD)

9:10 **Introductions** – John Sweeten

9:15-10:30 **Investigator Research Reports** (to include project activities, approaches, progress and accomplishments to date.
- PI's of DOE Project: Task A (Total:75 min)

10:30 – 11:45 **PI's of DOE Project: Tasks B to H** (Total: 75 min)

11:45-12:00 **Presentation on Design/operation of manure-powered Panda Hereford Ethanol –** Mike Murphy, Energy Products of Idaho

12:00-12:30 **Discussion**

12:30 **Lunch, catered in-house, courtesy of TAD**

1:30 **Discussion & Feedback from Industry Advisory Committee**

2:45 **Identify Emphasis, Priority, final report, and future plans**

3:30 **Adjourn**

Appendix E.2. Summary of May 22, 2009 Meeting

"Renewable Energy & Environmental Sustainability using Cattle Biomass" USDOE-Funded Research Project Industry Advisory Committee (PIAC) & Investigators Meeting Grapevine TX May 22, 2009

The meeting was hosted in Grapevine, TX by Texas Association of Dairymen Dairy Farmers of America. John Cowan opened the meeting with welcome and introduction of Darren Turley in his office. He also explained how the Texas Association of Dairyman operates. Everyone introduced themselves and their affiliation with the project.

Attendees were: John Cowan, Cliff Clark, Gerry Greathouse, Shay Simpson, Kalyan Annamalai, Kevin Heflin, Gary Marek, Dr. Jim Clark, Cady Engler, Sergio Capareda, Kay Ledbetter, Darren Turley, Ned Meister, Olon Plunk, Paul Joiner and Ben Weinheimer (by phone).

Presentations were given by Kalyan Annamalai (on behalf of himself and his graduate students), John Sweeten, Gary Marek and Kevin Heflin (on behalf ofBrent Auvermann and themselves), Cady Engler and Sergio Capareda. These talks directly summarized progress since the last meeting (December, 2007) regarding the different tasks they worked on and significant findings. The Power Point presentations are available

As the project is winding down. Dr. Kalyan Annamalai, Project Director (TEES, MENG, TAMU, College Station), advised that the DOE project officially ends June 30, 2009, and Final Report components are due from the Investigators by end of June '09, with the Final Report due July 31, 2009. However, Dr. Annamalai has requested a no-cost extension through March 31, 2010; this is not yet granted, but likely will be. This will extend the writing deadlines accordingly.

Discussion & Feedback from Industry Advisory Committee

Gerry Greathouse, Pecos Valley Biomass Initiative, d.ba. Pecos Valley Dairy Co-Op, Roswell, N.M. His dairy co-operative has been tasked to stop all sources of pollution (groundwater contamination concerns, primarily) if we are going to stay in the dairy business. What kind of system can we come up with that will get us out of this problem? We are in negotiations with a private company to furnish technology -TetraTech, Inc. As dairymen, we'll sign agreements to supply this company with our manure to specifications through anaerobic digestion. As discussed in today's presentations, we're going to map our pens and know where to harvest and when. We're going to be harvesting at 70-75 percent moisture manure. We have to get manure from 50,000-60,000 cows collected every week and the manure delivered to the central digester. Then we have to add air quality concerns on top ofthis. If we don't do it, we won't be here in 10 years. I would hope we could work with you on all the things we haven't done. Identify what we have and how it will work in the system. We've been on this for four years and we are ready to start moving. Dr. Sweeten suggested maybe some of the project investigator team, which is affiliated with the Southern Great Plains Dairy Consortium, could be invited to talk to some of the PVDC board.

Dr. Jim Clark asked about the status of the federal money for the Southern Great Plains Dairy Consortium, and if it had rolled down to the state level? Dr. Sweeten said New Mexico State University was in charge of developing and submitting the work plan to USDA-CSREES, due by May 25; it has four objectives, and the writing teams are off and running. The Project Director will be Dr. Robert Hagevoort, NMSU-Clovis.

Greathouse said it is time for them to start implementing some of these manure harvesting techniques and then put a value on their manure, incentivize it (plus and mjnus) to find people who will do it right. John Cowan said the missing component has been transferring value -you don't rebuild dairy facilities, you need to learn to collect that product as produced, and identify the value of it: fertilizer grade or energy grade.

Greathouse said there will be the liquid stream and fibrous stream that will come out of their anaerobic digester. They are trying to get a pipeline system designed to bring in. 1.5 million gallons of water per day. The fiber will be pelleted with nutrients added back for fertilizer. We basically just want to break even by delivering the manure to the facility and cleaning up the environment, and still be able to continue to produce as dairymen.

To summarize, the Pecos Valley Biomass Initiative Project will involve:

- Anaerobic digestion-producing pipeline quality gas production.
- Dairies with 50,000-60,000 head to supply manure
- $2.3 million earmark from DOE
- Aggressively going to proceed with this project; wants to work with all of us to gather ideas and inputs.
- Dairies will "have to do things the right way" to bring in manure of high quality.
- Collection methodology-will use boxscrapers made from split rubber tires.
- Fresh manure, high moisture manure; not worried about moisture content, because it will become slurry anyway for anaerobic digestion.
- Standard operating protocols-must be developed and adhered to.
- Has to meet the specs to produce the high quality manure.
- Manure collection must work in the dairy production system; will have to be well coordinated.
- He has learned from us today that they have to change practices to produce the high quality manure. Will have to incentivize collection process to produce high quality manure/feedstock.
- Already hauling to fields as high and low moisture manure, so transportation should not be more difficult than it already is.
- Digested fiber will be harvested from slurry and pelleted; to use as fertilizer.
- Water pipeline being designed--1.5 millio~ gal/day fresh water coming in to produce and transport the slurry.
- Appreciates what we are doing and wants to work with us through the Southern Great Plains Dairy Consortium.

<u>John Cowan, TAD</u>

The guys on the ground can make it work, when given the technol~gy. Survival is main mode/goal of most of them. Pecos Valley group is good case in point of dairymen needing help.

<u>Cliff Clark, Luminant (formerly TXU)</u>. Clark said his paradigm is large power plants, designed for fossil fuels, e.g. lignite or coal with higher energy density than manure. However, since he has been working with this group for several years now, he has come to the conclusion that distributed conservation use as opposed to centralized processing of biomass materials may be the way to go. He is thinking more now in terms of a unit-by-unit basis, per dairy. Perhaps individual CAFOs would have a digester or gasifier, i.e. decentralized. Kind of surprised that PVDC is looking at centralized conversion, except for the high concentration of dairies there. Luminant is looking at various sorts of biomass applications, and logistics is always an issue. If you could get it put into a more transportable form, i.e. synthetic methane or a

liquid oil, where you are transporting a much more dense energy material, then I think we can make it work. I think we are looking at it the wrong way; we need to tum around and look at it on a different level. With gasification, you are not bound to producing electricity. Whether you have small digesters or whether you consider a digester as a gas well and they are gathered into a central system. Methane is an easily sold commodity. There are several options as well, depending on the concentration of the sources. We might look for other technologies, e.g. energy-dense oils via pyrolysis, gasification, digestion, etc. Establish basic building blocks for specific applications--distributed generators, gathering lines like a small gas field to transport biogas to a central location for conversion/processing to pipeline quality. The higher the concentration of sources the better, e.g. Pecos Valley Dairy Co-Op; Hereford feedlots & dairies; etc. Maybe we need to look at something that is more regional and produce a commodity.

Olon Plunk, XCEL Energy. Most of what we as investigators have looked at is on target; taking a low-valued product and making a higher valued use for it. The co-firing is right on target. Examples have been in our efforts to reduce nitrogen emissions, and/or mercury emissions control. Reburn to achieve Hg (mercury) control when proven on a larger scale would further add value. It might be possible to convert some of this material into some kind of sorbent for mercury control and that could add value. Certainly what Cliff said about the transport distance is very valid. The logistics of the transportation study (Capareda et al.) for cattle biomass to the Tolk and Harrington Stations is great information; however, the results show the delivered biomass is still too costly at --$46/ton; coal is cheaper; this makes Cliff Clark's point about distributed energy generation, rather than hauling long distances to centralized facilities.

Olon believes that on the horizon is a cap-and-trade program. If dairy and beef waste can be used as offsets, they will be another revenue enhancer and probably there needs to be some economics done to define that contribution. The work you've done has been valuable. My question is how can the work you've done be taken another step forward toward commercialization? For example, for reburn, large volumes of pulverized material would be needed toward reburn. Somehow you have to also figure out how to keep it clean, or it won't have nearly as much value.

Ben Weinheimer, Texas Cattle Feeders Association (participated via conference phone call). Sorry not to be here today. Thanks to all the scientists and PIAC members for participating in this project. It has been valuable to the cattle feeding industry Project has produced on-the-ground results. It's been an important effort for the cattle feeding industry and one we want to see continued on a path toward technology transfer. It's not all about research, it's about how it will benefit the clientele the research works for. The other aspect of things we've learned: we need to focus on the product we have, and thec1eaner we can keep it, we know is good, but the economics of the industry haven't changed and these guys don't have a pot full of money for the purposes of improving feedlots. Reality is we'll largely be using high-ash manure. Profitability does not allow cattle feeders to improve facilities presently. We must follow our precepts to harvest best quality manure available. As the project proceeds through other grant funding, it will need to focus research and development energies and technologies on high-ash manure.
We need to package all that information so that feeders/managers can find, interpret, and use it. Since we have all this good information at lab and pilot scales now, the next thing would be to take this technology and make it into a simple operation with a single switch (on and off) so it would do what it needs to do at the feedlot. We have to have something where we can get some adoption, having a package or design for a feed yard management to implement into their portfolio of renewable energy. We also have the other aspect of a large footprint at feedlots, so we need to be looking at our wind energy and solar energy potential. Also, when we talk about cost, even in the past few months, the numbers have to make sense. Many companies approach the industry (TCF A, etc.) trying to sell technology, without knowledge or insight about the industry, e.g. proposing a $15 million renewable energy system for a feedyard that cost perhaps $ 3 -4 million, which is way

out of proportion. No way! Through R&D knowledge, we can help weed out those "opportunities" before they bother the industry.

Keep in mind also that the large footprints of feedyards could simultaneously lend themselves to developing solar and wind energy as well.

Ned Meister, Texas Farm Bureau. This project has been extremely valuable. It was a long study that has fruited well with knowledge. The issue of manure is one we've been dealing with for a long time. We knew the fertilizer value, but we have to do more than just dealing with the nutrient value. The studies you have done will lead to new uses of manure. While being focused so much on water quality and bioenergy issues generally, the ag industry in general has lost sight of air quality policy which now includes climate change and greenhouse emissions. The carbon credit concept is shedding a new light on the situation. I think there are some good opportunities into the economic aspect for carbon storage, but on the other hand, the input costs we'll experience due to cap-and-trade, we'd better well see SO lne compensation. As agriculture we need to get our feet under this carbon issue as quickly as we can or we'll be given something to deal with that we don't want to. House Agriculture committee is really starting to dig their heels in on the Waxman-Markey bill. We really have to be careful on what comes out of that legislation. But what are the right answers; I really don't think we know. One thing I also want to throw out is re-opening the federal Clean Water Act could be disastrous for many of us to deal with. They plan to remove the words "navigable water" from the legislation and then the feds will have authority over all water, even if it is in the bar ditch. Thanks for all the hard work put in this project. Putting out this information and technology you came up with as soon as possible is important.

John Cowan, Texas Association of Dairymen. He sees a lot of progress being made and "seconds" Ned's concerns about the water quality issues. Thanks to all involved. Regional issues are unique and require different solutions. A main asset of this project and our findings is showing how to increase value of manure. Anaerobic digestion has lots of inherent problems. Bottom line is we and the industry, are farther ahead today than when we began.

Translocations have/are occurring in the dairy industry; net loss of cattle numbers. We (academia) have to "keep the patient alive" (dairy) during these times, and work on how to complement their future, including injecting technologies that are affordable and add back to the knowledge and technology base.

We know there are not dollars to reconfigure how or where we farm, so the best method and measures won't work everywhere. Producers are concerned about surviving today; they can't look into the future. What we have to do is get into the hands of the producers this information and help them with the technology that best suits their area.

Paul Joiner, P.E., Panda Energy (formerly). Need to keep industry as research partners. The arena that should be looked at is environmental. He thinks we're at a turning point in society where resources are limited and government will be making choices for the people. They'll pick winners and losers based on the area/background they come from. You are having 1,500 people making decisions for 300 million people. Encourage you to be sensitive to the decisions your politicians are going to be making. Command and control, cap and trade, and carbon tax are the three major factors in play. It looks like there is a big push for the cap and trade method now. Effects of carbon trading will change the economics on the order of 20%. Public sentiment shifts quicker than companies can change their plans and investments; e.g. an ethanol plant was "right" choice 2-3 years ago, but appears to be wrong decision today. I think it is important to tell our legislators that the industry needs to look at systems, not technologies as a "box of band aids". Not everyone should follow down one path. Need boundaries that everyone can make a choice within. Information dissemination -he sees a lot of good technologies and a lot of information produced here. The research is done, but there has to be a connection to industry to build the equipment and the engineering systems that will be needed. Size issue-20% penalty on fossil fuels will increase costs; transportation is still biggest cost of coal, so that will go up.

How will economics play out at farm and feedlots level? Academia is focused on these narrow tasks and there needs to be work with industry to take it forward. What are the next practices for agriculture that I can make a buck on? When you look at some of these papers, they are designed to solve specific problems and how would I have access to look at these and see what will meet my business needs? Papers are designed for specific audience; how does one access the data bases?

Shay Simpson: Are there centralized data bases on cattle biomass as biofuel?

Kalyan Annamalai, Professor, Mechanical Engineering, TAMU. Kalyan said there is a Web site with all the field data, but there is one problem when something is submitted and put up on the Web site. The journals will not accept a paper if it has already been placed on a Web site. Within the department, we are evaluated on how many papers we publish. Can't figure out how to publish it free of cost and meet his requirements.

John M. Sweeten, Professor and Resident Director, Texas AgriLife Research-Amarillo. Dr. Sweeten said we almost have two conflicting views of the world: what industry wants is not necessarily What academia is good at. What academia needs to do is develop a system that works and be able to hand industry a package. The "rules of academia" are sometimes counter-productive to producing what industry says that they want and need.

Paul Joiner says you (academia) are incentivized to produce quantity of product (number of publications), but what about quality (usefulness)? The answer was that it is both quantity and quality, but not with the end-user in mind.

Ned Meister said Extension has always been our deliverer of research information. Gary Marek In looking at economic valuation of manure; he found that not much is being done or is usable.

Shay & Sergio Capareda: Need more people to translate technical material for users.
Cady Engler is trying to put more of their information into a form that can be accessible and useable.

Final Remarks &Wrap-up Session

Sweeten invited feedback from industry continually, i.e. continuing dialog. Letters of support from industry on proposals are valuable. The graduate students trained under this project potentially can help the industry for long time to come. Obviously, we need to be able to package things better as systems and not piece-meal.

Olon -had a clarifying point -he had mentioned potential benefits of cap and trade programs, but knows also there are potential costs.

Ned interpreting how agriculture can be a positive thing in the whole climate change debate is one area you scientists can play into and help us with.

Sergio said education will be a key factor in the climate change arena. Many people don't know about what is happening. You have to educate producers that they have to do something for it to be beneficial to them. Also, that they need magnitude or numbers. One person can't do it alone. Also, while we want to develop all of these technologies, there are steps that need to be done. Some technologies have to be converted to practical scale. The university is starting to do that, but everybody needs money to do that. Problem with anaerobic digestion is it leaves the same volume of material as digested slurry that you had to begin with.

Shay --said that a lot of corporations don't have the funds to put into renewable energy . . She said they are talking to some commercial entities; Corporate relations/federal relations group is looking at garnering more federal money with proposals for biomass conversion; e.g. demonstration scale systems and other funding opportunities.

Paul -industry has to look at the incremental costs vs. the incremental return. Have to be able to afford the savings. It may create a savings and reduction of something, but it has to be affordable.

Cliff -what our program has done is to provide a lot of basic tools that are needed; Luminant does not generate new technology rather applies it when practical. These tools provided to them are very vital and important as they consider potential for using the animal by-product as bioenergy feedstock. Now the job falls to make these findings into salable products.

Sweeten-On that note, he thanked the group for their participation and patience throughout the project and the meeting. The meeting was adjourned at 3: 15.