RENEWABLE ENERGY AND ENVIRONMENTAL SUSTAINABILITY USING BIOMASS FROM DAIRY AND BEEF ANIMAL PRODUCTION FACILITIES

Final Report
Volume II of Three Volumes
VOLUMEII: CATTLE BIOMASS FEEDSTOCKS: PROPERTIES, PREPARATION, LOGISTICS AND ECONOMICS

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Executive Summary for the Three Volume Final Report

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

Texas Engineering Experiment Station and
Texas AgriLife Research & West Texas A&M University
Texas A&M University, College Station, TX 77843-3123

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The Texas Panhandle is regarded as the "Cattle Feeding Capital of the World", producing 42% of the fed beef cattle in the United States within a 200-mile radius of Amarillo generating more than 5 million tons of feedlot manure /year. Apart from feedlots, the Bosque River Region in Erath County, just north of Waco, Texas with about 110,000 dairy cattle in over 250 dairies, produces 1.8 million tons of manure biomass (excreted plus bedding) per year.

While the feedlot manure has been used extensively for irrigated and dry land crop production, most dairies, as well as other concentrated animal feeding operations (CAFO's), the dairy farms utilize large lagoon areas to store wet animal biomass. Water runoff from these lagoons has been held responsible for the increased concentration of phosphorus and other contaminates in the Bosque River which drains into Lake Waco—the primary source of potable water for Waco's 108,500 people. The concentrated animal feeding operations may lead to land, water, and air pollution if waste handling systems and storage and treatment structures are not properly managed. Manure-based biomass (MBB) has the potential to be a source of green energy at large coal-fired power plants and on smaller-scale combustion systems at or near confined animal feeding operations. Although MBB particularly cattle biomass (CB) is a low quality fuel with an inferior heat value compared to coal and other fossil fuels, the concentration of it at large animal feeding operations can make it a viable source of fuel. The overall objective of this interdisciplinary proposal is to develop environmentally benign technologies to convert low-value inventories of dairy and beef cattle biomass into renewable energy. Current research expands the suite of technologies by which cattle biomass (CB: manure, and premature mortalities) could serve as a renewable alternative to fossil fuel. The work falls into two broad categories of research and development.

Category 1 – Renewable Energy Conversion. This category addressed mostly in volume I involves developing. Thermo-chemical conversion technologies including cofiring with coal, reburn to reduce nitrogen oxide (NO, N2O, NOx, etc.) and Hg emissions and gasification to produce low-BTU gas for on-site power production in order to extract energy from waste streams or renewable resources.

Category 2 – Biomass Resource Technology. This category, addressed mostly in Volume II, deals with the efficient and cost-effective use of CB as a renewable energy source (e.g. through and via aqueous-phase, anaerobic digestion or biological gasification).

The investigators formed an industrial advisory panel consisting fuel producers (feedlots and dairy farms) and fuel users (utilities), periodically met with them, and presented the research results; apart from serving as dissemination forum, the PIs used their critique to red-direct the research within the scope of the tasks.

The final report for the 5 to 7 year project performed by an interdisciplinary team of 9 professors is arranged in three volumes: Vol. I (edited by Kalyan Annamalai) addressing thermo-chemical conversion and direct combustion under Category 1 and Vol. II and Vol. III (edited by J M Sweeten) addressing biomass resource Technology under Category 2. Various tasks and sub-tasks addressed in Volume I were performed by the Department of Mechanical Engineering (a part of TEES; see Volume I), while other tasks and sub-tasks addressed in Volume II and IIII were conducted by Texas AgriLife Research at Amarillo; the TAMU Biological & Agricultural Engineering Department (BAEN) College Station; and West Texas A&M University (WTAMU) (Volumes II and III).

The three volume report covers the following results: fuel properties of low ash and high ash CB (particularly DB) and MB (mortality biomass and coals, non-intrusive visible infrared (NVIR) spectroscopy techniques for ash determination, dairy energy use surveys at 14 dairies in Texas and California, cofiring of low quality CB with high quality coal, emission results and ash fouling behavior, using CB as reburn fuel for NOx and Hg reduction, gasification of fuels to produce low quality gases, modeling of reburn, pilot scale test results, synthesis of engineering characterization, geographical mapping, a transportation cost study to determine potential handling and transportation systems for co-firing with coal at regional coal-fired power plants, software analyses for the design of off-site manure, pre-processing and storage systems for a typical dairy farm or beef cattle feedlot, recursive production functions/systems models for both cattle feedlots , systems modeling, stocks and flows of energy involved in the CAFO system, feedback from an Industry Advisory Committee (IAC) to the investigators on project direction and task emphasis and economics of using CB as cofiring and reburn fuel.

Volume II
Table of Contents

PAGE

LIST OF TABLES

TABLES

FIGURES **PAGE**

Volume III (separate document)

E.2. PIAC meeting agendas and summary

Executive Summary of Accomplishments: Volumes II and III

Experiments were conducted to characterize cattle feedlot biomass (FB) from open-lot feeding pens (un-paved/soil surfaced or paved/fly-ash surfaced) pursuant to Task A.1.1. for combustion/gasification related properties. Standard analyses performed in this project included proximate, ultimate, higher heating value, and elemental analysis of ash, as well as selected minerals (e.g. chlorine and mercury). A computerized Fuel Data Bank was established to archive the sample analysis data.

FB harvested from traditional un-paved soil-surfaced feedlot pens was contaminated with high ash content (50-60% d.b.) from underlying entrained soil; whereas FB from fly-ash paved pens had about one-third the ash content and twice the higher heating value (HHV) prior to composting as FB from soil-surfaced pens. Partial composting (e.g. 7-8 weeks) in windrows slightly increased ash content and HHV compared with un-composted FB. Long-term storage (e.g. 11 months) in either a windrow or a greenhouse continually reduced moisture to approximately 10-20% w.b., increased ash content, and contributed to ongoing reduction of volatile solids and HHV by up to 20%. Greenhouse bulk-stored partially-composed FB was superior in HHV to windrow-stored manure. The effect of seasonal rainfall on FB was substantial, as dry-year harvested FB (2006) had improved biofuel properties compared with wet-year harvested FB (2005), especially from traditional soil-surfaced feed pens.

The HHV for high-ash manure from soil-surfaced pens averaged ≈ 8,200 - 8,500 BTU/lb on a dry ash-free (DAF) basis, and averaged 8,931 – 9,500 BTU/lb DAF for the low-ash FB from paved feed pens. From data in this study, as-harvested HHV values for typical high-ash FB ranged from 2,710 or 3,521 BTU/lb w.b. (wet vs. dry year; un-composted); and as-harvested HHV was 6,168 or 5,685 BTU/lb w.b. (wet vs. dry year, un-composted) for low-ash FB. Partial composting for 51-55 days reduced as-received HHV by 2-20% to 5,704 BTU/lb (at 19.6% moisture) and 2,239 BTU/lb (at 17% moisture) for low-ash and high ash FB, respectively.

A bulk (19.5 ton) sample provided to two private companies for pilot plant combustion test burns in Idaho had a HHV of 2,710 BTU/lb as-received. This value was used as the design cut-point for a 100-ton/hr manure-fired bioenergy plant co-located with an ethanol plant in the Texas Panhandle to supply process steam.

From previous experiments (Sweeten et al. 2003), feedlot biomass samples pointed to a relatively narrow range of HHV values on a dry-ash free basis approaching ≈ 8,500 BTU/lb DAF for typical FB collected from an open-soil-surfaced cattle feedlot. A functional linear relationship was derived for use in conservatively estimating HHV as a function of moisture and ash for FB users.

From the data collected in these experiments (Task A.1.), a frequency distribution was developed for HHV-DAF based on FB samples analyzed in this project, which ranged from 7,696 -9,071 BTU/lb DAF with an average of 8,380 BTU/lb for all FB samples. Rather than a single-valued “constant” however, the high-ash FB was found to have a mode of 8,750 – 9,250 BTU/lb, while the low-ash FB had a mode of 9,250 -9,750 BTU/lb DAF basis. From 75-80% of FB samples had HHV of 9,000 BTU/lb DAF or greater for low-ash FB manure from fly-ash paved feed pens and 8,500 BTU/lb DAF or more for FB from traditional soil-surfaced pens. An Excel spreadsheet was developed to estimate the differential net economic value of FB feedstocks with high and low-ash contents and variable moisture.

Near visible infrared (NVIR) spectroscopy techniques were developed (Preece et al. 2009, and Sakirkin et al. 2010) to examine and reliably predict ash content of solid DB or FB mixed with varying soil content. A basic tool for rapid on-site testing of FB or DB quality as a biofuel can be developed as the NVIR research progresses.

Mortality biomass was studied as a biofuel also, featuring equine, beef or dairy carcasses and mixed with respective on-site manure sources in managed windrow composting. More than 100 bovine carcasses and 30 equine carcasses were composted with cattle or horse manure with or without other carbon or nutrient sources. These materials were evaluated for biofuel potential, and results shared with producers. Data showed the HHV peaked at 75-90 days composting time, at values of 8,750 - 9,200 BTU/lb DAF for equine morality compost. Thermodynamic scaling law functions were examined to describe the reaction kenitics.

Dairy biomass (DB) biofuel characteristics varied greatly with method of collection/harvesting, which produced materials ranging from solid, semi-solid, to liquid manure. Solid manure scraped from dairy corrals had comparable properties as FB from un-paved pens, with DB ash contents ranging up to 68%, while mechanically separated solids (high fiber) from liquid manure streams had only 3-20% ash content.

The ash and volatile solids (VS) contents were determined for fresh dairy biomass as a function of collection/harvesting processes. The samples included liquid manure from flushed alleys (before and after mechanical solids separation), mechanically-separated fibrous solids, or semi-solid manure vacuumed from concrete feed alleys. The ash content ranged from 12 -28% and volatile solids from 72% to 88% on a dry basis, or 1.5% -3.5% ash and 6 to 15.5% VS on a wet/as-harvested basis.

Low and high-ash dairy biomass was characterized for proximate, ultimate and ash analysis, and results added to the Fuel Data Bank. On a dry-ash free basis, DB showed 9,220 BTU/lb DAF versus HHV-DAF values of 12,236 and 12,721 BTU/lb for Texas lignite and Wyoming PRB coal, respectively.

Mercury and chorine contents of DB (separated solids vs. pen-scraped/partially-composted) were determined in relation to Texas lignite and Wyoming/PRB coal. Chloride (Cl) contents were an order of magnitude higher for both types of DB (1,427 – 2,691 ppm) than for lignite or coal samples (139 -309 ppm). However, mercury (Hg) concentrations from DB were about half (67-108 ppb) those for lignite or coal (258 -119 ppb).

The DB and FB bulk samples thusly characterized were used in on-campus experiments at Texas A&M University involving co-firing in 29 kW boiler-burner facilities at co-fire rates of 80:20, 90:10, or 100:0% coal: DB or FB (mass basis) or reburn fuels with particular focus on NOx emissions reductions with blend fuels vs. 100% coal. Results were reported in Volume I.

Bulk FB samples partially-composted and greenhouse-dried to <10% moisture content were processed by 2-stage particle size reduction to ≈ 50% passing a No. 200 mesh sieve (74 microns). This FB material was used by Annamalai et al. as reburn fuel in a 1 mW pilot test burn with Southern Research Institute (SRI), Birmingham, AL, a main purpose of which was to reduce NOx and Hg emissions. Results were reported in Volume I.

FB ash (≈6.7 tons w.b.) was obtained from fluidized bed combustion test burn of high-ash (≈58% ash d.b.) of FB from soil-surfaced pens at a 400-head research feedlot owned/operated by Texas AgriLife Research and USDA-ARS at Bushland. Ash fractions which included bottom ash, cyclone ash, and baghouse were subjected to appropriate tests (Task A.9.) to determine a) construction engineering properties, including chemical and physical analysis, and in admixtures with caliche, lime or gypsum and as soil stabilizers or highway abrasions; and b) plant fertility source, including soil/plant nutrients and greenhouse plant growth. Limited engineering uses were determined for the ash, which performed similar to class F-ash; these could include flowable fill, road base or abrasive road surface treatment for ice or snow conditions. The relatively inert chemical form of nutrients in the FB ash rendered it having low agronomic benefit as a fertility source, despite high phosphorous content (e.g. 3-13% d.b.). These tests were conducted by DeOtte et al. at West Texas A&M University.

A commercial scale covered-lagoon type mesophylic anaerobic digester at a 900-head dairy in Central Texas was instrumented. However, due to operations difficulties, outside the control of the investigators, the digester did not perform as expected, and operation was suspended before useable data could be collected for this project.

Dairy energy use surveys were conducted by the Biological and Agricultural Engineering Department (BAEN) at Texas A&M University at 14 dairies in Texas and California to determine energy use on an annual basis. Total energy use varied widely with type of dairy facility for electricity, natural gas, diesel, gasoline or propane. The daily on-farm energy requirement averaged 3.2 kWh/day/hd, compared with an estimated potential energy availability from manure of 25 kWh/day/hd, indicating good potential where >15% conversion efficiency could be obtained from DB to usable electricity.

A pilot-scale anaerobic digester of 155 cubic feet (cu. ft) capacity with a 21-day design HRT was constructed for a combination of feedlot mortality biomass and FB following partial composting. Operational startup is expected in 2011.

A dairy biomass characterization survey was conducted using 12 Texas dairies as DB sources, with 7 on-farm DB sources ranging from liquid flushed manure to semi-solids to solid/corral scraped. Analyses of DB were performed, showing 25-98% moisture content (median of ~ 30% w.b.); 8-82% ash d.b. (≈ 46% median value); and carbon from 10-42% d.b. (median of ≈ 25%). Highest quality DB was partially-composted mechanically separated fibrous solids, which unfortunately is a low-volume source at dairy farms. Where sand-bedding could be avoided, vacuum truck collected DB from free-stall barns was a good source of reasonable tonnage DB per farm. HHV values for corral-scraped solids averaged ≈ 2,600 BTU/lb as-received (7,500 BTU/lb DAF), to ≈ 1,000 BTU/lb as-received (or 8,600 BTU/lb DAF) for vacuum-truck collected semi-solid DB from free-stall barns. Gravity or mechanically-separated DB solids produced ≈ 900 – 2,100 BTU/lb as-received (6,500 – 9,000 BTU/lb DAF), the low wet basis values attributable to high moisture content.

Chemical analyses of DB ash was compared with cotton gin trash (CGT) combustion ash in terms of slagging and fouling potential and pellet strength at 550-900°C by BAEN/TAMU engineers. The melting point for DB ash was ≈ 600°C, compared with ≈ 800°C for CGT ash. Both slagging and fouling potential were likely for both these biomass ash materials during any thermal conversion process, especially for DB at elevated temperatures. Overall, coal indices were non-optimal indicators of slagging and fouling potential for DB and CGT.

A transportation cost study was conducted to determine potential handling and transportation systems for co-firing with coal at regional coal-fired power plants, a) in Central Texas and Northeast Texas using DB; and b) in West Texas using combination of DB and FB. Economic analyses were conducted using simulation models and sensitivity analysis. Transport routing of DB or FB to existing power plants was mapped according to CAFO locations and tonnages to provide for biofuel co-firing.

Software analyses study detailed the design of off-site manure, pre-processing and storage systems for a typical 2,000 head dairy farm or a 40,000 head beef cattle feedlot, both assuming a fluidized bed gasifier for on-site conversion, with output capacities of 322 or 2,000 kW, respectively. The estimated capital cost was approximately $1,000 per kW capacity connected to the electric grid.

Economic modeling was performed by Harman et al. at Texas AgriLife Research-Temple, Texas on combustion/reburn co-firing and/or gasification of FB and DB in coal-fired power plants (Task H). The analysis included quantifying investments and operating costs, together with benefit/cost, including all firing options. Analysis showed that for equal levels of NOx reduction, use of low-ash FB as reburn fuel was more cost effective than selective non-catalytic reduction (SNCR) or selected catalytic reduction (SCR), with specific NOx reduction costs of $7,150/ton, $10,614/ton, or $8,298/ton of NOx respectively. Carbon dioxide reductions using FB may provide added benefits.

Other economic studies included a) biomass drying systems for high moisture FB; and b) IMPLAN modeling of community economic impacts. The regional IMPLAN analysis revealed that co-firing at a DB inclusion rate of 5%, 10%, or 15% with coal or lignite could increase employment and economic activity by an estimated $27 million/year and 280 jobs; $29 million/year and 500 jobs; or $30 million/year with 720 jobs, respectively, assuming 150,000 dairy cattle as DB source in Central Texas and 135-mile one-way haul distance.

Resursive production functions/systems models were completed for both cattle feedyard and dairy CAFO operations. These systems showed inputs of feed, water and energy, and outputs of animal products, manure production, and utilization either as fertilizer or as biofuel. These systems were further modeled for manure quality consideration or consequences and marketing options, including fertilizer or biofuel feedstocks.

An Industry Advisory Committee (IAC) was organized and was engaged actively through 7 meetings with investigators. The IAC provided valuable guidance to faculty and graduate students through broad discourse and provided valuable recommendations as to project direction, task emphasis and further research questions, many of which were addressed in subsequent investigations.

For projects described in Volume II herein, co-funding was realized through faculty and scientific support staff salaries estimated total of $500,000 provided by Texas AgriLife Research, Texas AgriLife Extension Service, and West Texas A&M University. Additional co-funding included $200,000 in direct cash support provided in FY07-FY08 by Texas AgriLife Research, through a special lump-sum Hatch grant support from USDA-CSREES.

These research projects described in Volume II have resulted in 15 referred journal articles, 13 technical conference papers or posters, 2 graduate student theses, 5 disclosures of invention, 5 technical reports, 3 book chapters, and 7 Extension bulletins or fact sheets.

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

Volume II. Texas AgriLife Research & West Texas A&M University

Texas AgriLife Research, Texas A&M University, College Station, TX 77843-3577
USDOE Award No. DE-FE3605GO85003

Statement of Objectives

Introduction

The Texas Panhandle is regarded as the "Cattle Feeding Capital of the World", producing 42% of the fed beef cattle in the United States within a 200-mile radius of Amarillo. Manure produced from the 7.2 million head fed each year amounts to more than 5 million tons/year on an as-collected basis. Heretofore, it has been used extensively for irrigated and dry land crop production, and in some cases on CRP lands being converted to rangelands. Over half the grain fed in area feedlots is imported from out of state (e.g. Midwest). Declining water tables in the Ogallala Aquifer and increasing fuel costs have reduced irrigation water use per acre. As these trends continue, they will likely reduce demand for manure as fertilizer in a per-acre basis. Cattle feedlots will encounter longer hauling distances to achieve P- or N-based nutrient balances on irrigated crops or dry land situations. Apart from cattle feedlots, the number of dairy operations with more than 500 head of cows increased from 29% of all dairies in 1997 to 39% of all dairies in 2001. Furthermore, since milk cow inventory has increased in states like California, Idaho, and New Mexico, the amount of production and the number of operations has shifted from the southeast and Midwest to western states. Thus, although Texas lost 53,000 head between 1997 and 2001, it still had 325,000 dairy cows, many of which were milked and kept in larger dairy operations [NASS, 2002]. The changes in dairy operation size have increased concerns of water pollution because of the growing amount of manure biomass generated from these farms. This has been the case in the Bosque River Region in Erath County, just north of Waco, Texas. Presently, about 110,000 dairy cattle in over 250 dairies in Erath County produce 1.8 million tons of manure biomass (excreted plus bedding) per year. The dairy cows in this region make up about 25% of the total number of diary cows in Texas. The larger demand on each of the dairies as well as other animal farms has created a greater concentration of animals per farm. Currently most dairies, as well as other concentrated animal feeding operations (CAFO's), utilize large lagoon areas to store wet animal biomass. Water runoff from these lagoons has been held responsible for the increased concentration of phosphorus and other contaminates in the Bosque River which drains into Lake Waco—the primary source of potable water for Waco's 108,500 people. Thus the growth of cattle, dairy and swine industries will likely exacerbate nutrient balance situation. The goal of this research is to develop a system or process that disposes of manure in a way that minimizes the need for lagoons and land application and at the same time allow for energy conversion opportunities. The system should also be relatively simple and beneficial to the farmer.

Project Summary

The overall purpose of this interdisciplinary, system-oriented research proposal is to develop environmentally benign technologies to convert low-value inventories of dairy and beef cattle biomass into renewable energy. This research will help to mitigate the environmental stress posed by the geographical concentration of dairy and beef production (i.e. in concentrated animal feeding operations, or CAFOs) and will expand the suite of technologies by which cattle biomass (CB: manure, waste feed and premature mortalities) could serve as a renewable alternative to fossil fuel. The proposed work falls into two broad categories of research and development:

Category 1 – Renewable Energy Conversion. This category involves adapting, developing and refining technologies to extract energy from waste streams or renewable resources through (a) co-firing with coal, (b) combustions as a reburn fuel to reduce nitrogen oxide (NO, N_2O, NO_x, etc.) and Hg emissions from coal-fired power plants, (c) pilot-scale reburn tests, (d) thermochemical gasification to produce low-BTU gas for on-site power production and (e) extraction of energy from premature livestock mortalities via composting and thermochemical (non-biological) gasification *and* via aqueous-phase, anaerobic digestion (biological gasification).

Category 2 – Biomass Resource Technology. To use cattle biomass (CB) efficiently and cost-effectively as a renewable energy source – and in an environmentally benign way – its sources at the CAFO level must be (a) characterized with respect to its net thermal energy potential and (b) quantified both temporally and spatially. Further, for those CB sources that are not conducive to economical and environmentally benign extraction of energy, the CB production, collection, harvesting and processing systems must be examined and refined to make the CB suitable for energy production. This category is much broader than Category 1 and involves a synthesis of engineering characterization, geographical mapping, quality assessment, systems modeling, sensitivity and economic analysis of the sources, stocks and flows of energy involved in the CAFO system.

The long-term project deliverables are models of the energy systems involved in concentrated dairy and beef production in the south-central United States. These models will integrate engineering, economics; information technology and systems analysis to provide a rational basis for renewable-energy strategies for the industry that will mitigate water and air pollution, reduce dependence on foreign oil and increase options for disposal of premature mortalities.

All project work was conducted by agencies or departments within the Texas A&M University System (TAMUS), which is comprised of 10 Universities and seven state agencies. The recipient of the contract was the Texas Engineering Experiment Station (TEES), Texas A&M University System. Various tasks and sub-tasks under goals 1, 2, 3, and 4 were performed by the Department of Mechanical Engineering (a part of TEES; see Volume I), while other tasks and sub-tasks were conducted by Texas AgriLife Research at Amarillo; the TAMU Biological & Agricultural Engineering Department (BAEN) College Station; and West Texas A&M University (WTAMU).

Investigators

Prof. Kalyan Annamalai served as Program Manager and Principal Investigator (PI) for TEES in coordinating the tasks and timely delivery of progress reports. Dr. Annamalai was responsible for preparing Volume I, which is focused primarily on CB conversion experiments and results.

Dr. John M. Sweeten served as Principal Investigator (PI) for Texas AgriLife Research. Dr. Sweeten was responsible for preparing Volumes II and III of this report, which summarized the work of a team of biological and agricultural engineers, environmental engineers, and agricultural economists, which focused on cattle biomass as a viable feedstock. This team examined CB production, harvesting, analysis, characterization, transportation, logistics, and economic tradeoffs, in comparison with lignite or coal, for use in the conversion processes described by Dr. Annamalai et al. in Volume I.

The detailed list of co-principal investigators of various sub-tasks under goals 1, 2, 3 and 4 including the PI's or Co-PI's are listed alphabetically below:

Principal Investigators:

- Dr. Kalyan Annamalai (KA), Paul Pepper Professor of Mechanical Engineering, TEES, College Station, TX.
- Dr. John Sweeten, (JS), Resident Director and Professor of Biological and Agricultural Engineering, Texas AgriLife Research, Texas AgriLife Research & Extension Center, Amarillo & Vernon, TX.

Co-Principal Investigators:

- Dr. Brent Auvermann (BA), Professor of Biological and Agricultural Engineering, Texas AgriLife Research, Amarillo, TX
- Dr. Sergio C. Capareda, Assistant Professor of Biological and Agricultural Engineering, Texas AgriLife Research, College Station, TX
- Dr. Cady Engler (CE), Professor of Biological & Agricultural Engineering Department, Texas AgriLife Research, College Station, TX
- Dr. Wyatte Harman (WH), Professor of Agricultural Economics, Texas AgriLife Research, Temple, TX
- Dr. Saqib Mukhtar (SM), Associate Professor of Biological and Agricultural Engineering, Texas AgriLife Research, College Station, TX.
- Dr. Robert DeOtte (RD), Associate Professor of Environmental Science and Engineering, West Texas A&M University, Canyon, TX.

- Dr. David B. Parker, former Associate Professor, Agricultural Sciences and Engineering, West Texas A&M University, Canyon, TX.
- Dr. B.A. Stewart, Professor, Agricultural Sciences and Engineering, West Texas A&M University, Canyon, TX.

The responsibility of these faculty members for various tasks and subtasks is indicated within the text of this report.

The following are the abbreviations used to identify PI's and Co-PI's in the statement of tasks and subtasks in the immediately following sections:

Principal Investigators:
KA: Kalyan Annamalai, TEES; PI
JS: John Sweeten, Texas AgriLife Research; PI
Co-Principal Investigators:
BA: Brent Auvermann, Texas AgriLife Research
CE: Cady Engler, Texas AgriLife Research
DP: David Parker, West Texas A&M University(WTAMU)
JNR: J.N. Reddy, Texas Engineering Experiment Station (TEES)
RDO: Robert DeOtte, West Texas A&M University (WTAMU)
SM: Saqib Mukhtar, Texas AgriLife Research
SC: Sergio C. Capareda, Texas AgriLife Research
WH: Wyatte Harman, Texas AgriLife Research.
BAS: B.A. Stewart, West Texas A&M University (WTAMU)

Summary of Project Tasks and Assigned Investigators

Goal 1 – Renewable Energy Conversion
Task A: Thermochemical conversion and direct combustion methods

- Task A.1. (JS, BA, SM, SC, KA): Fuel resources and ash characterization for open-lot beef cattle feedlot and dairy manure biomass.
  - Task A.1.1. (JS, BA, SM, SC): Determine Fuel Characteristics of cattle biomass (CB), including feedlot manure biomass (FB), dairy biomass (DB) from free-stall barns and open lots, solids collected in a lagoon, vacuumed DB, settled solids in digesters and composted mixtures of CB and animal mortality carcasses.
  - Task A.1.2. (JNR): Improve quality of cattle biomass slurry (CBS) by reduction of water in CBS for application to direct firing.
  - Task A.1.3. (BA): Preparation and characterization of composted mixtures of CB and cattle carcasses for firing in gasifier and combustion unit.

- Task A.2. (KA): Fuel pyrolysis
  - Task A.2.1. TGA fundamental studies on the pyrolysis of DB and FB, and evolution of nitrogenous species (N in the form of NH_3 and HCN).
  - Task A.2.2. Relate ultimate and proximate analyses to volatile composition and evolution during controlled pyrolysis of DB.

- Task A.3. (KA): Co-firing
  - Task A.3.1. Co-firing with WYC and/or TXLC.
  - Task A.3.2. Co-fire the CB with low grade TXLC and chlorinated carbon.

- Task A.4. (KA): Reburn Process
  - Task A.4.1. Reburn experiments using FB and DB as reburn fuels, and measurements of fuel-N in the form of NH_3 and HCN.
  - Task A.4.2. Reburn experiments for reducing Hg emissions (Two different solid fuels).
- Task A.5. (KA): Gasification to produce low-BTU gas for on-site energy conversion
  - Task A.5.1. Modification of facility, air-steam gasification of CB, and measurements of HCN and NH_3.
  - Task A.5.2.a. Steam gasification of CB to produce chlorinated (in N_2) and activated carbon (in H_2O) for Hg emission reduction.
  - Task A.5.2.b. Pyrolysis with the gasifier using N_2/inerts and study of ash and gas quality.
  - Task A.5.3. Gasification of CB with the mixture of pure O_2 and $H_2O(g)$ (IGCC or FutureGen).
- Task A.6. (KA, JS): Pilot-scale studies
  - Task A.6.1. As a sub-contract to TEES, a pilot-scale facility will be used to generate the reburn data.
  - Task A.6.2. Pilot scale tests on Hg reduction using CB as "Hg-reburn" fuel and testing chlorinated activated carbon for Hg capture.
- Task A.7. (KA): Reburn modeling and exploratory studies
  - Task A.7.1. The modeling study includes zero dimensional reburn modeling with different CB streams as reburn fuels.
  - Task A.7.2. Reburn modeling for the new fuels and development of Fluent Code for reburn application.
- Task A.8. (KA): Exploratory Overall Energy Conversion studies
  - Task A.8.1. Exploratory global modeling studies; a) firing waste streams (DB + water) directly, b) replacing natural gas with DB as fuel in cement kilns around Waco and use the resulting ash on-site for various in-house purposes, and c) using DB as fuel in coal-fired power plants near Waco.
  - Task A.8.2. Direct firing of low quality CB slurry with regenerator.
- Task A.9. (JS, DP, RDO): Ash characterization for value-added uses
  - Task A.9.1. Characterize the ash from combustion and gasification experiments.
  - Task A.9.2. Engineering & fertility evaluation of fly ash utilization of combustion ash from fluidized beds.
  - Task A.9.3. Use of ash in flowable fill mixture
  - Task A.9.4. Use of fly ash as a soil amendment to reduce shrink-well capacity of soil
  - Task A.9.5. Technology Transfer. Dissemination and use of information
  - Task A.9.6. Use of bottom ash and cyclone ash as road surface application for winter weather.

Task B: Anaerobic Digestion Methods (CE, BA, SM)

- Task B.1. (CE, SM): Engineering analysis of a commercial digester
  - Task B.1.1. Engage in an intensive monitoring scheme to assess the net energy production of a new covered lagoon anaerobic digester and phosphorus reduction system.
  - Task B.1.2. Whole farm energy analysis when operating with the digester.
- Task B.2. (BA): Building research capacity for anaerobic digestion of mortality biomass
  - Task B.2.1. Build and test a research-scale, plug-flow, mesophilic, anaerobic digester.
  - Task B.2.2. Build a second research-scale anaerobic digester to provide parallel treatments (viz. treatment vs. control) in terms of substrate, operating variables and loading rates.

Goal 2 – Biomass Resource Technology

Task C: Biomass Characterization and Inventory (SM, SC)

- Task C.1. (SM, SC): Database development for CB as energy feedstock.
- Task C.2. (SM, SC, JS): Dairy biomass characterization survey.
- Task C.3. (SM, SC): Conduct robust analysis of the ash content in the DB and relate to slagging characteristics.

Task D: Biomass Handling Methods (BA)

- Task D.1. (BA): Stabilizing bovine carcasses for thermochemical gasification via carcass composting.
- Task D.2. (SC, SM): Efficient collection, harvest and transport.

Goal 3 – Energy System Modeling

Task E: Inventory, Characterization and Transport of Cattle Biomass (SC, SM)

- Task E.1. (SC, SM): GIS-based inventory and transport analysis.
- Task E.2. (SM, SC, JS, BA): Use of DB as a renewable energy source.
- Task E.3. (JS, BA, SM, SC): Quantitative Dairy and feedyard CAFO systems models.

Task F: Sensitivity Analysis of CAFO Energy Systems (BA)

- Task F.1. (SC, WH): Feasibility work.
- Task F.2. (BA, SM, SC): Developing strategies for an efficient utilization of manure.
- Task F.3. (BA, SM): Addressing engineering and other farm issues arising from manure-to-energy projects.

Task G: Industry Input into Energy-systems Model Development (JS)

- Task G.1 (JS, KA): Establishment of a project Industry Advisory Committee (IAC).
- Task G.2. (JS, KA): Use IAC feedback and output to guide research and technology transfer.

Task H: Economic Modeling of Cattle Biomass Energy Systems (WH)

- Task H.1. (WH, KA, JS): Economic Analyses of co-firing, reburning, and gasification of CB.
- Task H.1.1. Includes a benefit/cost analysis for using CB as fuel with or without coal.
- Task H.2. (WH): Estimate the opportunity cost (per unit of energy produced) of using non-renewable energy sources.
- Task H.3. Adapt and utilize the IMPLAN Economic Model (University of Minnesota).

Goal 4 – Process Sensitivity Analyses, Instrumentation and Information Technology

Task I: Energy Analysis of Dairy Farms and Feed Yards (SM, SC, BA)

- Task I.1. Utilize the 12 Dairies identified in biomass characterization study.

Task J: Process Sensitivity Analysis, Instrumentation and Information Technology (BA, SM)

- Task J.1. Effects of fuel preparation including drying at lower and higher temperatures.
- Task J.2. Net energy budgets for dairy and beef production systems in relation to CB and energy production potential.

Overview of Team Efforts per Project Goals, Tasks and Subtasks:

The purpose of Volume II is to summarize the research and technology dissemination of the team of biological, agricultural, and environmental engineers, together with an agricultural economist, in assessing cattle biomass (CB) as a bioenergy feedstock. This work has included both cattle feedlot manure/biomass (FB) and dairy manure/biomass (DB) in terms of production, analysis, characteristics, harvesting, transportation logistics and economics in relation to thermochemical or biological conversion processes presented in Volume I.

Goal 1 – Renewable energy: feedstocks and conversion processes. The approach that the project team followed in fulfilling Goal 1 of this multi-year research project was to assign specific tasks or subtasks to project team faculty members under the general coordination of the Project Co- PI's Dr. Kalyan Annamalai and Dr. John M. Sweeten. The assigned investigators were identified in the preceding section.

Task A.1. which focused on characterizing and supplying feedstocks of cattle manure/biomass (both dairy and feedlot) for later conversion experiments covered under other Tasks, was primarily executed by Drs. John Sweeten & Brent Auvermann and by graduate students or staff under Dr. Auvermann's direction at Texas AgriLife Research at Amarillo, TX. The Tasks A.2. through A.8. were primarily conversion-related experiments (presented in Volume I) performed by graduate students under Dr. Kalyan Annamalai's direction in Mechanical Engineering of TEES. Summaries of these major tasks as they relate to preparing and providing the feedlot, dairy, or mortality biomass feedstocks for the subsequent conversion experiments of Dr. Kalyan Annamalai, graduate students and collaborators in Mechanical Engineering Department and Texas Engineering Experiment Station are briefly covered under the appropriate Tasks A.2., A.3., A.4., A.5., A.6., A.7., and A.8. However, no attempt was made to duplicate Dr. Annamalai's reporting of the conversion processes and experimental data in Volume I. Task A.9. dealt with use of FB combustion ash and was subcontracted to Dr. Robert DeOtte at West Texas A&M University. Task B was led by Dr. Brent Auvermann using biofuel co-products supplied by the Texas AgriLife Research-Amarillo team.

Goal 2-Biomass Resource Technology. Major Task C, which focused on dairy biomass characterization and inventorying was led by Drs. Saqib Mukhtar, Sergio Capareda, and Cady Engler. Major Task D was led by Dr. Brent Auvermann, at Amarillo.

Goal 3-Energy Systems Modeling. The major Tasks E & F were led by Drs. Sergio Capareda, Saqib Mukhtar and Cady Engler, Biological & Agricultural Engineering Department, Texas A&M University. Tasks G and H involving the Project Industry Advisory Committee (PIAC) and Economics, respectively, were led by Co-PI's Drs. John Sweeten, Kalyan Annamalai and Wyatte Harman.

Goal 4-Process Sensitivity Analysis, Instrumentation and Information Technology. The two major tasks in Goal 4 were essentially added after initial meetings with the Project Industry Advisory Committee, and as such, were assigned low or no funding, since the anticipated third year grant was not forthcoming. Task I regarding dairy farm energy analysis was assigned to Drs. Mukhtar, Capareda and Auvermann, while Task J regarding sensitivity analysis, instrumentation, and information technology was assigned to Extension Agricultural Engineers Auvermann and Mukhtar.

Project Management:

In order to monitor the progress closely and assure timely accomplishments, aggregation and dissemination of results (e.g. through professional conference presentations, journal publications, etc.), the major tasks were further subdivided into subtasks or in some cases, sub-sub-tasks. Most of the tasks and subtasks were identified in the Year 1 Plan of Work. Additionally, several subtasks were added in Year 2 and during the course of this research project, sometimes at the suggestion of the PIAC. The previous section contains the initial and the added list of major tasks and subtasks.

Overview of Report Contents:

This Volume II report provides an account of the tasks and subtasks that were performed by Texas AgriLife Research faculty in Amarillo, College Station, or Temple, Texas, together with West Texas A&M University at Canyon, Texas. Again, these experiments and data analysis focused on the feedstocks involving FB and DB. Volume II cross-references the thermochemical conversion experiments described and summarized in Volume I, but without undue repetition.

Volume II of this final report was prepared by summarizing the accumulative progress for each task, subtask and/or sub-subtask, along with pertinent summaries derived from professional papers or abstracts prepared by the co-investigators as well.

Additional details were generally included in Volume III, comprised of Appendices C through E. These Appendixes relate back to the named sections of the Volume II report.

GOAL 1 – RENEWABLE ENERGY CONVERSION: FEEDSTOCKS AND CONVERSION PROCESSES

Task A. **Thermochemical conversion & direct combustion methods**

Research Team Involved:
Dr. John M. Sweeten, Dr. Brent W. Auvermann, Kevin Heflin, Dr. Kalyan Annamalai, Dr. J.N. Reddy, Dr. Saqib Mukhtar, Dr. Sergio Capareda, Dr. Cady Engler, Dr. Wyatte Harman, Dr. Robert DeOtte, Dr. David B. Parker, and Dr. B.A. Stewart.

Major Tasks Addressed: Research on the following tasks is summarized in the following sections of Volume II:

Task A.1. Fuel Resources & Ash Characterization for Open-Lot Beef Feedlot and Dairy Manure/Biomass (Sweeten, Auvermann, Heflin, Annamalai, Mukhtar, Capareda and Engler).

Task A.3. Co-Firing Coal and Dairy Biomass in a $29kW_t$ Furnace (Annamalai, Sweeten and Heflin)

Task A.6. Pilot Scale Studies (Annamalai and Sweeten)

Task A.9. Characterization of Beef Cattle Manure Combustion Ash for Value Added Uses (DeOtte, Parker, Stewart and Sweeten)

The following additional Tasks involved feedstock biomass that was characterized and supplied by the Task A.1. team to the on-campus conversion team, whose scientific exploits were adequately covered in Volume I by Dr. Kalyan Annamalai and his team of graduate students. Nevertheless, these tasks are referred to sequentially in the following sections to maintain the organization of this Volume II report:

Task A.2. Fuel Pyrolysis (KA)

Task A.4. Combustion as Reburn Fuel to Reduce NOx Emissions from Coal-Fired Power Plants (KA)

Task A.5. Gasification to produce low-BTU gas for on-site Energy Conversion (SC, SM, KA)

Task A.7. Reburn Modeling and Exploratory Studies (KA)

Task A.8. Exploratory Overall Energy Conversion Systems (KA)

The reader is referred to Volume I of this project final report for in-depth presentation and discussion of the Tasks A.2., A.4., A.5., A.7. and A.8. Experimental objectives, approaches, methods and results were not repeated in Volume II herein.

Task A – Thermochemical conversion and direct combustion methods (JS and KA):

Task A.1. (JS, BA, SM, SC, KA). Fuel resources and ash characterization for open-lot beef feedlot and dairy manure/biomass.

Subtask A.1.1. (JS, BA, SM & SC). Determine fuel characteristics of cattle biomass (CB), including feedlot manure biomass (FB); dairy biomass (DB) from freestall barns open-lots, and settled solids in lagoons or digesters; and composted mixtures of CB and animal mortality carcasses (MB).

Sub-Subtask A.1.1.1. Determine Fuel Characteristics of Typical Feedlot Manure (FB) & Dairy Manure (DB). *This task was completed as planned. Results are discussed in the following sections.*

Sub-Subtask A.1.1.2. Collection and Processing Fuels. *This task was accomplished in association with Sub-Subtask A.1.1.1. Results are discussed in the following sections.*

Sub-Subtask A.1.1.3. Fuel Resources and Ash Characterization, Including Mortality Biomass (MB). *This task was accomplished as planned. Results are discussed in the following sections.*

Sub-Subtask A.1.1.4. Chlorine and Mercury Content in Fuels. *This task was accomplished (see also Volume I). Some of the data are presented herein, while the majority of the work is described/reported in Volume I.*

Sub-Subtask A.1.1.5. Evaluating Combustion-related Derived Properties of Fuels. *This task was accomplished and results are reported herein (see also Volume I).*

Sub-Subtask A.1.1.6. Dissemination and Technology Transfer. *This task was accomplished. Numerous abstracts, papers, presentations and journal articles were produced as reported herein. See also Appendix B for a more comprehensive listing.*

Task A.1: Fuel resources

Introduction:

The Texas High Plains is at the center of the "cattle feeding capitol of the world", with 42% of the U. S. fed beef production within a 200 mile radius of Amarillo TX, including Texas and neighboring states of OK, NM, KS and CO. The region also supports a rapidly growing dairy production industry that has experienced a 10-fold expansion in the decade of 2000 – 2010. Environmental quality and natural resource challenges facing the livestock feeding industry in the Southern Great Plains include: declining groundwater supplies in the Ogallala Aquifer, air quality emissions, particulate matter, odor, ammonia, hydrogen sulfide, volatile organic compounds, water quality protection, nutrient/soil management, mortality disposal, and energy cost-efficiency. New manure management approaches are becoming necessary for a sustainable beef cattle feeding industry in this region. Innovative technology and multi-media environmental approaches to manure management that conjunctively address water and air quality, soil quality, energy usage, climate change, and biomass energy utilization are needed to meet future policies (Auvermann & Sweeten, 2005).

Energy use at cattle feeding operations is substantial (Sweeten, 1996), and costs continue to escalate. Potential exists for on-site production & utilization of renewable energy including biomass conversion (Annamalai et al. 2005 b). Renewable energy options involving animal wastes include: (a) methane capture from anaerobic waste storage/treatment units, and (b) thermochemical conversion using pyrolysis, combustion (including co-firing with coal or lignite) (Annamalai et al. 2003; Arumugam et al. 2005-b), gasification (Priyadarsan et al. 2004 & 2005), or reburn processes (Arumugam et al. 2005-a; Annamalai et al. 2005a).

Thermochemical conversion greatly reduces the volume of volatile materials, with residue (ash) material containing noncombustible minerals including N, K, P, and Cl which could be transported greater distances than bulk manure, if these materials can be utilized beneficially. Thermochemical conversion may provide a means of utilizing composted carcasses that could result from normal or even catastrophic mortalities on a local or regional scale (Auvermann & Sweeten 2005).

The main focus of the investigators was placed on maximizing higher heating value (HHV), minimizing ash content, and/or minimizing mineral contaminants (S, Cl, Na, K, P, etc) that can contribute to ash agglomeration or slagging in combustion units (Sweeten et al. 2003). The specific use of the data collected was to support research on (a) reburn technology to reduce nitrogen oxide (NOx) (Annamalai and Sweeten, 2005) and heavy metals (e.g. mercury, Hg) emissions); (b) utilization of ensuing combustion ash as potential construction or fertilization, and (c) preparing, characterizing, and supplying manure from the Texas AgriLife Research/USDA-ARS experimental feedlot at Bushland, or from commercial feedlots, to specification for use in combustion, gasification, and/or reburn experiments to be conducted in a 29.3 kW (100,000 BTU/hr) pilot facility in the TAMU Mechanical Engineering Department (MENG)/Renewable Energy Laboratory, Texas Engineering Experiment Station (TEES) (Annamalai et al. 2003).

The major thrust of this Task A.1 was to meet the need for primary data (as well as supplying the actual processed bulk feedstock) with which to evaluate the combustion properties and fouling potential of the cattle manure bio-fuels prior to combustion or gasification experiments. A standard methodology was needed for collecting and processing the dairy or cattle feedlot manure/biomass fuel. Thermochemical and physical properties were needed for both dairy biomass (DB) and feedlot biomass (FB) as a function of management factors at the farm or feedlot manager level, or at a biofuel manager level. Accordingly, protocols for collecting and analyzing FB and DB were developed in this project, and built on prior work by this research team. A database on FB fuel properties had already been initiated by investigators in previous research (Sweeten et al. 2003). An additional database on FB fuel properties was developed by the investigators in this project. Similar protocols were followed for DB and FB in field experiments and laboratory testing.

Partially composting livestock carcasses (MB) represents a simple and robust technique for stabilizing them with respect to the environmentally consequential biological or chemical properties before they are disposed or shipped. Although complete composting drives off much of the carcass' fuel value as CO_2, incomplete composting appears to incorporate relatively energy-rich materials (e. g., fats) into the compost matrix, temporarily increasing the recoverable energy in the carbonaceous amendments.
This compost could be highly variable due to the feedstock used.

Objectives:
The purpose of this research program was to evaluate feedlot biomass as a renewable energy resource for thermochemical processes. Specific objectives of Task A.1. were as follows:

1) Characterize harvested cattle feedlot manure from paved vs. un-paved feedpens as a biomass energy feedstock for combustion, gasification, reburn, or pyrolyis pilot plant test burns.
2) Determine difference in harvested feedlot manure biomass chemical control or heating value as a function of feedlot surfacing materials and partial composting.
3) Contrast cattle feedlot biomass (FB) with dairy manure/biomass (DB) from within the same region in order that strategic blends of these materials may become necessary to drive utilization.
4). Develop fuel resources and characterization for mortality biomass (MB).

The Texas A&M University System program focus was placed on open-lot manure characteristics for use in biomass energy conversion systems involving reburn or co-firing with coal or lignite as base fuel. The initial focus was on feedlot biomass (FB) as a feedstock, for which, ultimate, proximate and ash analyses were performed. Subsequently, dairy manure (dairy biomass, DB) was analyzed similarly using cost sharing within other grant (from the Texas Commission on Environmental Quality). The energy conversion potential via various pathways including pyrolysis, gasification, combustion, anaerobic digestion, etc. was estimated using ultimate and proximate analyses.

Materials and Methods:
The source of FB used in this intensive characterization project came from 18 feedpens of 8 head of beef cattle each in the 400-head Texas AgriLife Research/USDA-ARS research feedlot near Bushland, TX. The FB resulted from two successive 135-150 day beef cattle feeding trials which were concluded at the end of May, 2005 and May 2006. When the feeding trials were terminated, the FB was harvested using a skid-steer wheel loader from 12 feedpens that were paved in 1998 with 6-8 inches depth of hydrated, graded and compacted mixtures of crushed bottom ash and fly ash from the Harrington Station, a coal-fired power plant near Amarillo, TX. These paved pens provided a stable, hard pen surface. The 6 remaining 8-head pens were un-paved, traditional soil-surfaced pens, typical in the Southern Great Plains cattle feeding industry.

The 12 paved feed pens produced an average of 7,083 lbs FB/pen as collected. This material was termed low ash feedlot biomass (LA-FB). The 6 soil-surfaced (un-paved) feedpens yielded an average of 9.33 lbs FB/pen as collected, which was termed high ash feedlot biomass (HA-FB) in reference to its higher soil content. The as-collected LA-FB and HA-FB were placed into separate windrows for sampling prior to the start of composting.

Sampling Protocols: Manure and Compost:
To evaluate the combustion and fouling potential of the fuels, standard methodologies were developed in collecting and processing the fuel and thermo-physical and chemical properties for both dairy biomass (DB) and feedlot biomass (FB). Fuel properties reveal the combustion characteristics of a process, and the chemical content of ash shows the usability of the fuel in different thermochemical process applications. For example, low ash fuels could be used for firing in conventional fire tube boilers, while high ash fuels could be used in gasification processes.

Feedlot biomass (FB) samples collected from Texas AgriLife Research, Bushland, TX were processed in various stages to yield biomass fuels such as raw, partially composted or high ash/ low ash and their combinations. Samples prior to composting were termed as *Raw Manure (RM)*, and samples taken after 45+ days (range of 30-55 days) of composting involving successive wetting and turning cycles were termed *Partially Composted (PC)*. Samples taken after 120$\pm$ days of composting (involving continuing wetting and turning cycles) were termed *Finished Compost*

(FC). Initial samples used to obtain fuel characteristics were taken after FB harvesting and prior to composting. Three composite 2 kg samples (n=3) were extracted from 10 sub-samples randomly collected from each type of FB material: LAFB, HA-FB, LA-FB-PC, and HA-FB-PC. For analysis of metals and elemental analysis of ash, only one composite sample was analyzed for each type of manure due to expense.

In addition, prior to the start of composting, bulk samples of the freshly-harvested manure were extracted from each windrow using the skid-steer loader, with composite samples of 10 sub samples each totaling 2,100 or 700 lbs each of LA-FB or HA-FB, respectively. These bulk samples of FB were coarsely ground in a small hammer mill and placed in a greenhouse (June 2-10) to facilitate drying to less than 10% of moisture. Again, three 2 kg composite samples comprised of 10 sub-samples each, were extracted after grinding and prior to placement in the greenhouse, and these were submitted for analysis also.

Analyses:

Proximate, Ultimate and Ash Analysis on fuels were conducted, and results were used to plan and conduct gasification, combustion, pyrolysis or reburn experiments. The results could be useful as well for anaerobic digestion experiments. To determine physical and thermochemical properties, composite samples of all manure, compost, and coal and lignite materials were analyzed by Hazen Research Inc.(Golden, Colorado) for the following parameters:

- Proximate—Moisture, ash, volatile solids, fixed carbon (FC).
- Ultimate—Moisture, ash, carbon, hydrogen, nitrogen, sulfur, oxygen (by difference).
- Higher Heating Value (HHV)—As-received (wet) basis, dry basis, mineral-matter free (MMF) basis, and dry-ash free (DAF) basis.
- Selected Minerals—Chlorine, phosphorus, sulfur.
- Ash Elemental Analyses (oxide basis)—Silicon, aluminum, titanium, iron, calcium, magnesium, sodium, potassium, phosphorus, sulfur, chlorine and carbon dioxide.
- Metals in Ash (mg/kg)—Arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver.

A TAMU Fuel Data Bank (FDB) (Annamalai et al.) including salient data pertaining to thermochemical conversion (gasification, pyrolysis) continuous and emissions was updated regularly. The physical and chemical composition of the biomass and coal influence how effectively these potential fuels can be utilized. The biomass fuels collected and processed were analyzed to determine their composition and hence derive their combustion application in commercially certified labs. Proximate and ultimate analysis, together with selected constituent results were posted on the TAMU-FDB. Using the fuel analyses as input, the N, S and ash contents were presented on heat basis.

Partial Composting:

Composting in windrows for a limited time period was used as an available means of stabilization, moisture reduction, and homogenization of collected FB materials. When necessary to initiate composting, the moisture content of the windrow-stored FB was raised by adding water, using a tractor-towed tank wagon equipped with a sprayer. For instance, in June 2005, approximately 3,000 gallons of water was sprayed on the LA-FB windrow, and a week later following rainfall, only 900 gallons of water was needed on the HA-FB windrow to initiate composting.

The LA-FB and HA-FB windrows were partially composted (PC) for 55 and 51 days, respectively beginning June, 2005, being removed August 5, 2005. Composite 2 kg samples comprised of 10 sub-samples were extracted from both windrows on August 2, 2005 and were submitted for analyses as LA-FB-PC and HA-FB-PC materials, respectively.

Work continued in fall and winter of 2006/2007 in which partially composted low ash and high ash (FB) beef cattle manure was stored and dried in a greenhouse at the USDA-ARS-CPRL research facility at Bushland, TX. FB and DB stored at the Texas AgriLife Research-Amarillo/ARS Bushland research facility was processed to TEES (Dr. Annamalai's) specifications and then shipped to TEES/TAMU with excess being stored at Texas AgriLife Research-Amarillo/ARS Bushland.

Solid Biofuel Grinding and Pulverization:
Approximately 3,400-3,800 lbs of the LA-FB-PC and ~ 1,000 lbs of HA-FB-PC was pulled from the two windrows; ground in the hammer mill; and (if required by Annamalai et al. for reburn tasks), were further ground (pulverized) in the Vortec Impact Mill. The hammer mill was acquired from a nearby farm where it had been used for grinding grain.

The Vortec Impact Mill was purchased in June 2005 (with other cost sharing research funds), to process manure and coal for use in the combustion studies. The impact mill was used to provide a finely-ground finished product that was acceptable for reburn combustion testing by Dr. Annamalai. This Vortec Mill was capable of processing ~500 lbs of material/hour, when needed for subsequent reburn experiments by Annamalai et al. (see Volume I for discussion of the reburn and other thermochemical conversion tests).

Wyoming/PBR low sulfur coal was donated by XCEL Energy from the Harrington coal fired power plant in Amarillo, Texas. The coal was prepared for experiments being conducted at the Texas A&M University 100,000 BTU/hr small scale boiler burner, 100,000 BTU/hr Reburn (NOx and Hg reduction studies) and 30,000 BTU/hr gasification facilities. This coal was dried, pulverized with a hammer mill, and then processed with the Vortec Impact Mill to further reduce the particle size to Dr. Annamalai's specifications (>70% passing a 74 µm, No. 200 mesh sieve) for coal or lignite, or ~50% of FB or DB passing the No. 200 mesh sieve (74 µm). The processed FB, DB, lignite or coal was then shipped to College Station, or a contracted pilot test facility.

Results and Discussion
2005 Feedlot Biomass--Manure was removed, stockpiled, and began partially composted in late-May/early-June, 2005 following the winter/spring 2005 cattle feeding trials, which were conducted during a prolonged wet winter and spring. Because of the wet weather that prevailed, 15.1 inches of precipitation in the preceding nine months (September, 2004-May, 2005) there was maximum opportunity for entrainment of soil from hoof action on the feedlot surface. Runoff sediment basins and holding ponds may have been a factor also in loss of volatile solids. The fuel properties of raw (RM) or partially-composted (PC) cattle feedlot manure (FB) harvested in early June 2005 from the Texas AgriLife Research/USDA-ARS Research Feedlot, Bushland, Texas are presented in Tables A.1., A.2., A.3., A.4., and A.5.

The comparison of manure from the soil-surfaced (SS) pens yielding high-ash (HA) manure vs. the fly-ash paved (FA) pens yielding typically low-ash (LA) manure was readily evident regardless of composting (Sweeten et al. 2006a). Tables A.2., A.3. and A.4. summarize the analytical data from the windrowed manure harvested June 10, 2005 from the soil-surfaced (SS) pens and the crushed fly ash (FA)-surfaced pens following 51 and 55-day composting periods alongside the Texas AgriLife Research/USDA-ARS Research Feedlot at Bushland.

A 39,000 lbs truck-load sized bulk sample of 2005 HA-FB-RM manure from soil-surfaced pens (un-composted) was consigned to Panda Energy Group, Dallas, and was shipped in July, 2005 to Energy Products of Idaho (EPI) (Coeur d'Alene, ID). Our sample analysis data for this material is shown in Table A.1. This material was used for commercial pilot plant test burns in a fluidized bed combustion unit conducted in July 2005. At the test burn site, some of the HA-FB-RM was blended with cotton gin residue (CGR) from the Texas High Plains in weight ratios of 100:0%, 75:25%, or 50:50% in combustion tests. The data was used to help in design of a manure-fired ethanol production plant near Hereford, TX. The resulting 13,383 lbs of total fluidized bed combustion ash from these test burns was returned to Texas AgriLife Research-Amarillo as segregated, labeled and weighed fractions of fly ash, bottom ash, and bed ash. Subsequent engineering and agronomic tests were conducted by West Texas A&M University using the returned ash fractions from this test burn, as discussed below in Task A.9 and in Volume III, Appendix C.

This 2005 HA-FB-RM material had moisture content of 19.81% w.b.; ash of 58.73% d.b.; volatile solids of 33.77% d.b.; and HHV of only 2,710 Btu/lb w.b. and 3,380 Btu/lb d.b. (Table A.1., Figure A.1 and Figure A.2). However, the HHV on a dry ash free (DAF) basis was 8,200 Btu/lb. which clearly showed the effect of ash on reducing HHV as collected. The same material after 51 days of composting (Table A.2.) showed even higher values of ash, 64.88% d.b. and lower values of moisture 17.0% w.b.; volatiles (31.07% d.b.), fixed carbon (FC) of 4.05%, and HHV (2,239 Btu/lb w.b.; 2,697 Btu/lb d.b.; and 7,682 Btu/lb DAF).

By comparison, the low ash biomass from the paved feedlots (LA-FB-RM) though similar in moisture, had much lower ash content and higher volatile solids, fixed carbon, total carbon, and higher heating value than did the HA-FB-RM, as shown in Table A.1. and Figure A.2. The HHV of the LA-FB-RM was 5,764 and 7,229 Btu/lb for as-received (wet) and dry basis, respectively, and on a DAF basis, the HHV averaged 9,059 Btu/lb. These values would place it near, but still 20% below, the lower end of HHV values for Texas lignite samples examined in this project (Table A.6).

The LA-FB-RM material was sampled and analyzed again after 55 days of windrow composting, at which point it was considered partially composted (i.e. LA-FB-PC). As shown in Table A.3., characteristics showed essentially the same average moisture content (to 19.64±2.54% w.b.), ash content (to 20.53±0.52% d.b.), and volatile solids (to 65.11±0.59%). Fixed C and total C were lowered slightly to 14.36±0.28% and 42.05±0.14% d.b., respectively, and HHV was slightly less at 5,704±192, 7,097±17, and 8,931±38 Btu/lb on an as-received, dry, and DAF basis, respectively.

The processed 2005 LA-FB-PC material was subsequently used to evaluate various reburn fuel injector configurations with pulverized coal: FB fuel blends of 90:10; 50:50; or 100:0%, conducted by the Texas Engineering Experiment Station (TEES) Annamalai et al., 2006). Procedures and results of these tests were reported in Volume I.

Table A.4. shows direct contrasts between partially composted FB from soil surfaced pens (high ash FB) versus fly ash surfaced pens (low ash FB). Several large differences stand out in terms of HHV and content of volatile matter and certain minerals on both wet (as reduced) and dry basis. Most of the comparative differences are not surprising, given the continual loss of volatile matter that occurs during composting. Manure from the soil-surfaced pens harvested in early June 2005 after a wet winter and spring, had almost three times the ash content and less than half the as-received higher heating value (HHV) and volatile solids as manure similarly collected from the paved pens. Following 53 days of composting, the proximate and ultimate analyses were repeated with similar results, although the HHV was reduced by 10% due to loss of volatile matter during composting.

The above protocols and results were reported by Sweeten et al. (2006a) who authored a technical paper summarizing the 2005 feedlot manure/compost FB characterization results (essentially Tables A.1 through A.4., herein). The paper was prepared for the 2006 Annual Meeting of the American Society of Biological and Agricultural Engineers meeting in Portland Oregon (see complete list of project papers produced in Appendix B).

As a second phase of the Task A.1 research the work continued using bulk samples (2,100 – 3,400 lb) of FB from soil-surfaced and fly-ash-paved feedpens that were retained from the winter/spring 2005 feeding trial and summer, 2005 FB characterization study. This material was again sampled on June 7, 2006, and analyzed to determine effects of 10-12 months additional storage in a windrow greenhouse or a windrow on fuel quality parameters. The material was designated as “windrow” or “greenhouse stored”, depending on conditions of storage, i.e. outdoor or indoor.

The 2005*LA-FB-PC-windrow* (the same material as shown in Tables A.3. and A.4.) evidently continued to lose volatile solids and to concentrate ash and minerals during the subsequent 12-month continuous storage in the windrow, although no further moisture addition or turning occurred. When sampled June 7, 2006, final moisture content was 17.56 ± 3.78 % w.b., as shown in Table A.5., which was slightly lower (from 19.64± 2.54%) than a year earlier (Table A.3.). Ash increased further to 31.20 ± 1.37 % d.b. (from 20.53± 0.52%) and slight decreases appeared in volatile solids (56.02 ± 0.87), fixed C (12.78 ± 0.78 % d.b.), total C (39.13 ± 0.56%), hydrogen (4.49 ±0.15 % d.b.), and chlorine (0.84 ± 0.06%) compared with year-earlier levels. Slight concentration increases appeared in nitrogen (3.26± 0.11 % d.b.) and sulfur (0.73 ±0.02). Heating value averaged 5,075 ± 373 BTU/lb w.b. (11% lower than a year earlier), 6,150 ± 182 BTU/lb d.b., and 8,939 ± 87 BTU/lb DAF basis. Ash analysis showed elemental-oxide values as follows: silicon (27.90 ± 3.33% d.b.), alumina (4.47 ± 0.43 %d.b.), calcium (19.67 ± 1.58 % d.b.), and sodium (4.25 ± 0.43 % d.b.). Potassium and phosphorus oxide values in ash residue were both high at 12.53 ± 0.84% d.b. and 12.96 ± 0.83% d.b., respectively, and sulfur oxide was present at 3.89 ±0.15% d.b. Metals in ash were relatively low except possibly for chromium.

By comparison, the *2005 LA-FB-PC -greenhouse-stored* manure dried substantially (Table A.5.), but appears to have almost ceased to gain ash or lose volatile solids, fixed or total carbon, or heating value, compared with the same LA-FB-PC collected from the windrows on August, 2, 2005, almost 10-months earlier. Moisture, as of June 7, 2006 sample date was much lower at only 10.36 ± 1.14 % w.b., ash was 21.79 ± 1.27 % d.b., volatile solids was 64.40 ±1.21 % d.b., fixed C was 13.81 ±0.19, % d.b., total C was 44.21 ± 0.95 %d.b., hydrogen was 5.32 ± 0.15%d.b., and nitrogen was 3.08 ± 0.04 % d.b. Selected minerals showed dry-basis results of sulfur (0.65 ± 0.01% d.b) and chlorine (0.95 ± 0.05% d.b.). Heating value averaged 6,391 ± 158 BTU/lb w.b.; 7,129 ± 107 BTU/lb d.b.; and 9,116 ± 78 BTU/lb DAF basis. These values were 26%, 16%, and 2% higher, respectively, than the windrow-stored material, possibly reflecting the low moisture content maintained in storage. Ash analysis showed elemental-oxide values as follows, dry basis values: silicon (22.03 ± 0.90% d.b.), alumina (3.78 ± 0.22 % d.b.), calcium (21.20 ± 0.36 % d.b.), and sodium (4.72 ± 0.15 % d.b.). Potassium and phosphorus oxide values in ash residue were both high at 13.57 ± 0.29% d.b. and 13.90 ± 0.28% d.b., respectively, while sulfur oxide was present at 4.43 ± 0.35% d.b. and chlorine oxide at 5.06 ± 0.05% d.b. Metals in ash were relatively low except possibly for chromium.

Un-composted 2005 LA-FB-RW manure that had been placed in the greenhouse shortly after collection (*2005 LA-FB-Raw-greenhouse-stored)* had slightly better fuel properties than the *2005 LA-FB-PC-windrow*-stored manure of same origin. Selected results from the June 7, 2006 sampling (Table A.5.) including the following values: moisture (12.66 ± 1.24 % w.b.), ash (23.42 ± 1.07%d.b.), volatile solids (62.65 ± 1.09%d.b.), fixed C (13.93 ± 0.08%d.b.), total carbon (43.92 ± 0.83%d.b.), hydrogen (5.14 ± 0.10%d.b.), nitrogen (3.10 ± 0.05%d.b.), sulfur (0.72 ± 0.04%d.b.), and Cl (0.97 ± 0.01). Heating value averaged 6145 ± 163 BTU/lb w.b., 7035 ± 92 BTU/lb d.b., and 9186 ± 53 BTU/lb DAF basis. These HHV values were only 4%, 1%, and 0% lower, respectively, than the PC greenhouse-stored material, and were 22%, 14%, 3% higher than the windrow stored manure, which is an important finding. Ash analysis showed elemental-oxide values as follows, dry basis values: silicon (22.89 ± 0.68% d.b.), alumina (3.93 ± 0.05 % d.b.), calcium (21.03 ± 0.15 % d.b.), and sodium (4.23 ± 0.08 % d.b.); whereas potassium and phosphorus oxide values in ash residue were both high at 13.07 ± 0.32% d.b. and 13.56 ± 0.18% d.b., respectively, while sulfur oxide was present at 4.86 ± 0.28% d.b. and chlorine oxide at 4.82 ± 0.25% d.b. These ash-analysis values were almost identical to the 2005 LA-FB-PC greenhouse - stored material. Metals in ash were relatively low except possibly for chromium, which was higher at 193 ± 222 mg/kg. These data appeared to show that greenhouse-storage of raw manure is a good substitute for partial composting as a method of quickly stabilizing and preserving most biofuel related properties.

2006 Feedlot Biomass:

A third phase of the study involved harvesting and characterizing 2006 Feedlot Manure. In a similar fashion, Sweeten, Heflin et al. harvested, processed, sampled and characterized manure (FB) from a concluding cattle feeding trial at the Texas AgriLife Research/USDA-ARS research feedlot at Bushland for use as fuel source for a planned pilot plant reburn combustion study by Annamalai et al. in Fall 2006 (per Task A.6). These FB data represented a second (2006) replicate of the 2005 study and were designed to enhance data bases on HA-FB and LA-FB, both raw and partially composted. This 2006 manure was harvested/collected in late May 2006, following winter/spring 2006 cattle feeding trials. The 2006 manure was harvested and FB samples were collected, processed and analyzed using the same protocols as for the 2005 FB. The 2005/2006 feeding trials were conducted during one of the driest 9-month periods ever recorded (4.2 inches precipitation), based on official Amarillo weather records dating back the late 1880's. Hence, there was very limited opportunity for soil entrainment or runoff, except where water spillage might have occurred immediately around drinking water troughs. The major differences that were evident in the 2006 FB manure compared with the 2005 manure were attributed mainly to the higher precipitation in 2004/2005 vs. much less precipitation in the 2005/2006 cattle feeding period.

The *2006 HA-FB-Raw manure* was collected June 7, 2006, sampled, and immediately was placed in the greenhouse to dry to <10% w.b. for later processing as needed. 2006 HA-FB-Raw -greenhouse (*Samples 137-139),* were composite samples likewise taken from the feedlot biomass (FB) removed from the Texas AgriLife Research/ARS Research feedlot at Bushland Texas following cattle feeding trials that ended in May 2006. This manure was removed from soil surfaced feedpens and is considered to be high ash (HA) FB. Samples were taken of this un-composted (Raw) manure immediately after removal from feedpens and prior to composting. This data is summarized in Table A.5. and Figure A.3. Selected results sampling including the following values: moisture (27.31 ± 0.61 % w.b.), ash (45.23 ± 3.09% d.b.), volatile solids (44.71 ± 2.55% d.b.), fixed C (10.06 ± 0.59%d.b.), total carbon (32.34 ± 2.72% d.b.), hydrogen (3.85 ± 0.33% d.b.), nitrogen (2.31 ± 0.17%d.b.), sulfur (0.43 ± 0.02 % d.b.), and Cl (0.24 ± 0.18). Heating value averaged on a wet/as-received basis was 3,521 ± 210 BTU/lb w.b. (Figure A.4). Dry-basis HHV was 4,844 ± 295 BTU/lb d.b. and 8,842 ± 50 BTU/lb DAF basis. Ash elemental analysis showed oxide-basis values as follows: silicon was quite high (60.94 ± 1.62% d.b.), alumina (7.68 ± 0.39 % d.b.), calcium (9.91 ± 0.76 % d.b.), magnesium (2.91 ± 0.27) and sodium (1.78 ± 0.10 % d.b.). Potassium oxide value in ash residue was 5.94 ± 0.48% d.b. and phosphorus oxide was 4.39 ± 0.36% d.b., while sulfur oxide was present at 1.19 ± 0.12% d.b. and chlorine oxide at 1.12 ± 0.16% d.b. Metals in ash were relatively low except possibly for chromium, which was 100 ± 44 mg/kg.

2006 LA-FB-Raw -greenhouse-stored (*Samples 134-136),* were composite samples taken from the feedlot biomass (FB) removed from the fly ash surfaced feedpens at Texas AgriLife Research/ARS Research Feedlot at Bushland Texas. The 2006 *LA-FB-Raw-manure* was collected June 7, 2006 and immediately was placed in a greenhouse to dry to <10% w.b. for later processing as needed. Samples were taken of this raw manure immediately after removal from feedpens and prior to composting. This data is included in Table A.5. and Figure A.3. Selected results from the June 7, 2006 sampling included the following values: moisture (29.25 ± 1.12 % w.b.), ash (13.58 ± 0.85%d.b.), volatile solids (68.06 ± 0.67% d.b.), fixed C (18.36 ± 0.20% d.b.), total carbon (49.63 ± 0.41% d.b.), hydrogen (5.90 ± 0.08% d.b.), nitrogen (3.35 ± 0.07% d.b.), sulfur (0.54 ± 0.07% d.b.), and Cl (0.68 ± 0.04). Heating value on a wet/as-received basis averaged 5,685 ± 145 BTU/lb w.b., (Figure A.4) which despite low seasonal rainfall, was influenced by the higher moisture content on date of sampling compared to the 2005 FB materials. But the 2006 FB was very high in dry-basis HHV due to low ash content, having excellent heating value at 8,035 ± 89 BTU/lb d.b. and 9,298 ± 48 BTU/lb DAF basis. These values were very likely results of the very low rainfall, minimal decomposition on the feedlot surface prior to harvesting, and absence of ash entrainment or runoff. Ash elemental analysis showed oxide-basis values as follows: silicon which was unusually low (11.51 ± 2.33% d.b.), alumina also low (1.78 ± 0.30 % d.b.), calcium (20.90 ± 0.35 % d.b.), magnesium (7.97 ± 0.06) and sodium (5.57 ± 0.13 % d.b.). Potassium oxide value in ash residue was very high at 20.27 ± 0.57% d.b. and phosphorus oxide also high at 14.92 ± 0.51% d.b., while sulfur oxide was present at 5.53 ± 0.52% d.b. and chlorine oxide at 6.58 ± 0.32% d.b. Metals in ash were relatively low except possibly for chromium, which was higher than most prior samples at 167 ± 40 mg/kg.

Comparative Analyses of Lignite and Coal

Lignite and coal supplied by Texas Utilities (TXU) were ground in a hammer mill, and proximate and ultimate analysis were determined for three composite samples of each. These results are shown in Table A.6. The major differences between TXL and PRB coal related primarily to higher ash content of the TXL. These project data were used for direct comparisons of fuel values and chemical differences between TXL lignite and PRB Coal versus the feedlot manure (Tables A.1 through A.5. discussed previously).

Summary and Discussion of FB Results:

Research was conducted to determine the effects of feedlot surfacing materials (soil vs. coal-ash paved) and partial composting of feedlot biomass (FB) characteristics for use in thermochemical energy conversion involving reburn or co-firing with coal or lignite. In the first phase of the study, FB was harvested in early June, 2005 from 12 fly ash-paved pens and 6 soil-surfaced pens and was windrow-composed. Higher heating value (HHV) before composting was more than twice as high for manure from paved (LA-FB) vs. soil-surfaced (HA-FB) pens, and ash content dry matter basis was 66% lower for FB from paved (20.2%) vs. un-paved pens (58.7%). Partial composting (51-55 days) reduced HHV by 2-20% to 5,704 BTU/lb (at 19.6% moisture) and 2,239 BTU/lb (at 17.0% moisture) for the low-ash (LA-FB-PC)/paved pens and high-ash (HA-FB-PC)/un-paved pens, respectively.

The 2006 data in Table A.5. showed that greenhouse-storage for another year of the 2005 low-ash feedlot biomass (discussed earlier and depicted in Tables A.3. and A.4.), preserved fuel quality of raw manure and partially-composted manure to a greater extent than did continuous storage of the LA-PC-FB in a windrow with no further inputs of water or turning/aeration. This could mean that greenhouse storage is more effective than partial composting of FB fuel, without consideration of costs or logistics.

The 2006 FB, both LA and HA materials had lower ash contents than the counterpart 2005 manure (Sweeten et al., 2006a), probably because of the drier winter/spring climatological conditions that preceded the May/June manure harvest these two years (see Table A.5.) reduced hoof entrainment of soil below the manure pack.

The LA-FB-PC data was useful in representing perhaps the highest valued HHV from open beef cattle feedlot products practically attainable without further processing, such as an effective means of ash-separating post-harvesting. The authors do not mean to imply or suggest that feedlots must be paved to provide useful FB biofuel product for bioenergy conversion. In most cases that would be impractical from a cost standpoint. Moreover, similar results in preserving HHV might be obtained by excellent uniform manure harvesting in relatively dry seasons from conventional un-paved soil pens using precision equipment and trained operators coupled with storage. Ash separation techniques should be explored also for large-scale operations.

Dairy Biomass Characteristics for Reburn or Co-Firing Tests:
The Amarillo team (Sweeten, Heflin & Auvermann) and the BAEN research team (Mukhtar, Capareda & Engler) obtained fuel properties of DB fuels from selected Texas dairies. Basically, the same protocols were followed for sampling DB as were discussed previously for FB samples. The same analyses were obtained as for FB as previously discussed.

Methods and Materials Processing (Amarillo Team):
Three samples each of two dairy biomass (DB) materials, were extracted May 15, 2006, from the Mx 7 Dairy near Comanche County, Texas. Three composite samples were collected from low-ash (LA- DB) separated solids from a mechanical screening device used to remove coarse particles from the liquid stream from milking parlor and holding pen. These LA-DB-separated solids were then partially composted. Three composite samples were also taken of each of the following materials: high ash (HA) partially-composted (PC) mixture (HA-DB-PC) of corral-scraped solid manure; scraped semi-solid manure from the free-stall barns with concrete floors; and composted mixtures of DB and cattle mortalities.

DB-Sep solids-PC-2006 (*Samples 128-130)* large bulk composite samples were taken from dairy biomass (DB) separated solids (Sep solids) prior to partial composting. The separated solids were placed in a greenhouse to facilitate drying. Once the separated solids were dried to <10%, 1,000 lb w.b. bulk sample were processed with a hammer mill and/or the Vortec Impact Mill®. Materials from the hammer mill only grinding processes were required for TEES co-fire combustion research. Both the hammer mill and Vortec Impact Mill® were used for TEES reburn research.

DB-HA-PC-2006 (*Samples 131-133)* composite samples were taken from partially composted (PC) dairy biomass (DB). This PC DB (~1,000 lbs w.b.) was removed from a mixture of corral-scraped solid manure, scraped semi-solid manure from the free stall barns, combined with dead cattle carcasses as available, and then partially composted. This manure is considered to be high ash (HA) DB. The DB was placed in a greenhouse to facilitate drying. Once the DB was dried to < 10%, the bulk samples were processed with a hammer mill and/or the Vortec Impact Mill®. Material from both grinding processes was required for TAMU Combustion research. This biomass is termed as DB-HA-PC-2006.

Dairy Biomass (DB) Results:
Measured fuel properties of various types of DB are shown in Table A.7. (these results were also provided in Volume I, Table 1.3.6 and shown here for comparison). The very large effects of higher moisture in most of the DB samples were evident on carbon, volatile solids and HHV values. Flushed DB had more N compared to N contents of separated solids indicating that a part of dissolved N flows with separated water. Mineral content was included in the analysis. Table A.7 also shows comparison of DB samples with Texas lignite and PRB coal (likewise reported previously in Table A.6. as well as Table 1.3.8. of Volume I). The research on high water content/low solids DB, including attempts to fire the DB in flushed water or use the separated DB as reburn fuel (Task A.7) in order to determine the NOx capture, were described in Volume I, as a result of experiments or modeling by Carlin, Annamalai et al. The results will not be repeated herein.

The data in Table A.8 showed major differences in fuel quality between two types of dairy biomass samples: DB-separated solids vs. DB-corral-scraped solids, with the former having much higher heating value and much lower ash content. Table A.8 further illustrates the rather large differences that were found between these two types of DB and some of the FB samples discussed earlier.

As expected, the DB-Sep solids-PC-2006 , which represents only a small fraction of the total manure production from a dairy (e.g. 5%), had moderate moisture content (mean ± standard deviation) (25.26 ± 8.52% w.b.), low ash (19.97 ± 1.37% d.b.), high volatile solids (62.70 ± 1.14% d.b.), and average amount of fixed carbon (17.33 ± 0.87% d.b.). The as-received (wet basis) higher heating value (HHV) was very high for cattle biomass (CB)/manure at 5,522 ± 640 BTU/lb w.b., whereas the dry basis HHV values were 7,387 ± 98 BTU/lb and for DAF basis was 9,232 ± 116 BTU/lb. Total carbon averaged 47.09 ± 0.81% d.b., hydrogen 4.97 ± 0.08% db, nitrogen 2.58 ± 0.05% d.b., sulfur 0.57 ± 0.01% d.b., chlorine 0.18 ± 0% d.b. The elemental analysis of ash showed relatively low silicon 31.36 ± 0.65% d.b., low alumina 2.89 ± 0.14% d.b., and soluble salts including Na (2.26 ± 0.03% d.b.), potassium (6.90 ± 0.04% d.b.) and chlorine (0.92 ± 0.12% d.b.). Phosphorus was also low at 6.01 ± 0.03% d.b., while metals in ash were relatively low.

By contrast, the DB-HA-PC 2006 samples, which included entrained interfacial soil from open dairy corrals due to mixing by cattle hooves were much lower in moisture (12.21 ± 5.28% w.b.), while dry basis values of ash were very high at 68.24 ± 0 .74%. Low values of volatile solids 27.38 ± 1.39%, fixed carbon = 4.39 ± 1.75%; total carbon = 20.53 ± 0.52%; nitrogen = 1.31 ± 0.04%; and sulfur = 0.21 ± 0 .05% were most likely caused primarily by ash dilution from soil entrainment. The HHV averaged only 1,854 ± 133 BTU/lb w.b., 2,110 ± 46 BTU/lb d.b., and 6,645 ± 52 BTU/lb on a dry ash free (DAF) basis. These values are well below HHV values commonly found for beef cattle feedlot manure (FB) produced under similar conditions, and ~⅓ (one-third) below the design point (determined from FB studies in Table A.1 above) for the Panda Hereford Ethanol's FB manure-fired plant at Hereford, TX. The sulfur content of 0.21 ± 0.05 was half the concentration of the low ash DB-Sep Solids-PC manure, perhaps due to ash dilution effect. Elemental analysis of ash showed silicon, alumina and calcium were reasonably similar to the LA-DB-Sep Solids-PC material. Metals values were similar as well.

These DB data (in Tables A.7. and A.8.) and FB results (in Table A.4.. and others), were used for experimental designs and conversion experiments, including reburn or co-firing tests by the TEES Conversion Team in College Station (Annamalai et al. 2006).

Analyses of flushed, separated solids and separated liquid are illustrated in Figure A.5. The data appear to show that ash (minerals) preferentially flow with separated liquid possibly because ash particles are finer textured compared to fibrous DB particles or may be present in dissolved form. The biofuel quality of separated solid is enhanced compared with whole manure. Figure A.6 compares the as-received VS % for flushed, separated solid, separated liquid and vacuumed DB. It is apparent that VS % is higher for vacuumed solids compared to flushed solids but still less than that of mechanically separated solid.

TABLE A. 1 Fuel Properties of Feedlot Biomass (FB) from Texas AgriLife Research/USDA-ARS Research Feedlot, Bushland, TX. FB Materials Represent As-Collected/Mixed Raw Manure (RM)/Un-composted from Two Types of Feed Pen Surfaces:
A) Soil-Surfaced (SS) Feedpens (n-6); Designated as high-ash (HA-FB-RM)
B) Paved Pens, Crushed Bottom Ash/Fly Ash Surfaced (n=12); Designated as low-ash (LA-FB-RM)

Parameter	HA-FB-RM Average of #101-103* Collected 6/10/05 As-Rec'd% Basis		HA-FB-RM Average of #101-103* Dry, % Basis		LA-FB-RM Average of Samples #104-106 (6/1/05) As-Rec'd Basis		LA-FB-RM Average of Samples #104-106 (6/1/05) Dry, % Basis	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Proximate:								
Moisture (Dry Loss)	19.81	1.24	0	0	20.27	1.23	0	0
Ash	47.10	1.29	58.73	1.65	16.10	0.73	20.20	1.11
Volatile	27.08	1.25	33.77	1.26	51.47	1.34	64.56	0.94
Fixed C	6.02	0.36	7.50	0.45	12.16	0.40	15.24	0.27
Total	100.00		100.00		100.00		100.00	
HHV, BTU/lb	2,710	34	3,380	14	5,764	147	7,229	92
MAF/DAF, BTU/lb			8,200	327	-	-	9,059	13
Ultimate:								
Moisture	19.81	1.24	0	0	20.27	1.23	0	0
Carbon	17.39	0.90	21.69	1.14	34.35	0.77	43.09	0.49
Hydrogen	2.10	0.10	2.62	0.13	4.17	0.11	5.22	0.05
Nitrogen	1.56	0.04	1.94	0.07	2.48	0.04	3.11	0.03
Sulfur	0.34	0.02	0.42	0.02	0.53	0.02	0.67	0.01
Ash	47.10	1.29	58.73	1.65	16.10	0.73	20.20	1.11
Oxygen (diff.)	11.70	0.82	14.59	0.81	22.10	0.80	27.70	0.63
Total	100.00		99.99		100.00		99.99	
Chlorine (#101-103; 104-106 composite):								
Chlorine, Cl	0.301		0.375		0.302	-	0.377	-
Phosphorous, P_20_5%								
Ash Basis, %			2.74	0.08			12.87	0.85
Dry Basis, %			1.61	0.04			2.59	0.04
Contaminants, Energy basis:								
Ash, lbs/MM BTU			173.78	5.13	-	-	27.96	1.89
SO2, lbs/MM BTU			2.51	0.12	-	-	1.86	0.05
Ash Elemental Analysis (%), equal-weight-composite**:			%					

Parameter	HA-FB-RM Average of #101-103* Collected 6/10/05 As-Rec'd% Basis		HA-FB-RM Average of #101-103* Dry, % Basis		LA-FB-RM Average of Samples #104-106 (6/1/05) As-Rec'd Basis		LA-FB-RM Average of Samples #104-106 (6/1/05) Dry, % Basis	
Silicon, SiO2			64.68				25.55	
Aluminum, Al2O3			7.72				1.94	
Titanium, TiO2			0.44				-	
Iron, Fe2O3			2.90				1.37	
Calcium, CaO			7.09				20.20	
Magnesium, MgO			2.34				7.17	
Sodium, Na2O			1.38				4.94	
Potassium, K2O			4.50				12.70	
Phosphorus, P2O5			2.81				11.11	
Sulfur, SO3			1.06				4.46	
Chlorine, Cl			0.68				5.02	
Carbon dioxide, CO2			1.35				1.71	
Total ash analysis			96.95				96.44	
Metals in Ash, equal-weight-composite, mg/kg			mg/kg %				mg/kg %	
Arsenic			4.12				3.96	
Barium			669				2,620	
Cadmium			<1				2	
Chromium			<20				20	
Lead			20				20	
Mercury			<0.01				<0.01	
Selenium			<2				2	
Silver			<2				<2	
Total metals in ash			693.12				2,667.96	

*Refers to sample numbers of extracted samples composited from multiple (≈ 10) sub-samples.
**Ash was calcined @ 1100 deg. F (600 deg. C) prior to analysis.

Table A.2. BioFuel Characteristics: High Ash FB from Soil Surfaced Pens (n=6); Partially-Composted (PC) after 51 days composting from Texas AgriLife Research/USDA-ARS Research Feedlot, Bushland, TX. Composting Start* = 6/13/05; Ended 8/2/05. Sampled = 8/2/05.**

Parameter	**HA-FB-PC #107-109** As-Received Basis,%		**HA-FB-PC #107-109** Dry Basis, %	
	Mean	Std. Dev.	Mean	Std. Dev.
Proximate Analysis:				
Moisture	17.00	0.26	0	0
Ash	53.85	0.77	64.88	0.74
Volatile	25.79	1.04	31.07	1.31
Fixed C	3.36	0.78	4.05	0.95
Total	100.00		100.00	
HHV, BTU/lb	2,239	49	2,697	60
MAF/DAF, BTU/lb			7,682	169
Ultimate Analysis:				
Moisture	17.00	0.26	0	0
Carbon	14.92	0.16	17.97	0.25
Hydrogen	1.39	0.08	1.68	0.10
Nitrogen	1.13	0.02	1.36	0.03
Sulfur	0.31	0.02	0.38	0.02
Ash	53.85	0.77	64.88	0.74
Oxygen (diff.)	11.40	0.27	13.73	0.37
Total	100.00		100.00	
Chlorine (equal weight composite sampled):				
Chlorine, Cl	0.281		0.338	
Contaminants, Energy basis:				
Ash, lbs/MM BTU			240.66	7.13
SO2, lbs/MM BTU			2.79	0.13

Parameter	**HA-FB-PC #107-109** As-Received Basis,%		**HA-FB-PC #107-109** Dry Basis, %	
	Mean	Std. Dev.	Mean	Std. Dev.
Ash Elemental Analysis*** (% dry basis), equal-weight-composite sample:			% dry	
Silicon, SiO2			65.55	

Aluminum, Al_2O_3	11.20	
Titanium, TiO_2	0.52	
Iron, Fe_2O_3	2.99	
Calcium, CaO	7.47	
Magnesium, MgO	2.29	
Sodium, Na_2O	1.38	
Potassium, K_2O	4.66	
Phosphorus, P_2O_5	2.43	
Sulfur, SO_3	1.30	
Chlorine, Cl	0.41	
Carbon dioxide, CO_2	0.51	
Total ash analysis	100.71	
Metals in Ash, equal-weight-composite, mg/kg	Metals, mg/kg	
Arsenic	3.85	
Barium	800	
Cadmium	3.8	
Chromium	30	
Lead	27	
Mercury	0.03	
Selenium	<2	
Silver	<2	
Total metals in ash	864.68	
Phosphorus:	% dry basis	Std. Dev.
Phosphorus (Ash Basis), P_2O_5, %	2.43	0.05
Phosphorus (Dry Basis), P_2O_5, %	1.57	0.01

*Raw Manure (RM) was harvested from soil-surfaced (SS) pens & added to SS windrow ~ June 1-10, 2005. Composting start: windrow completed, water added & first turning (June 13, 2005).
**Composting ended Aug. 2, 2005: PC manure bulk-sampled from windrow, 1st grinding (hammermill), sampled and frozen. Samples shipped to Hazen Lab, Golden, CO, August 5, 2005.
***Ash was calcined @ 1100 deg. F (600 deg. C) prior to analysis.

Table A.3. Biofuel Characteristics: Low-Ash FB from Crushed Fly Ash-Surfaced (FA) feedpens (n=12), Low-Ash (LA) Feedlot Biomass (FB). Partially-Composted (PC) after 55 days Composting Texas AgriLife Research/USDA-ARS Research Feedlot.
(Composting start*=6/9/05; ended****** 8/2/05; Sampling Date = 8/2/05)

Parameter	**LA-FB-PC #110-112** As-Received Basis,%		**LA-FB-PC #110-112** Dry Basis, %	
	Mean	Std. Dev.	Mean	Std. Dev.
Proximate Analysis:				
Moisture	19.64	2.54	0	0
Ash	16.50	0.28	20.53	0.52
Volatile	52.33	2.12	65.11	0.59
Fixed C	11.54	0.32	14.36	0.28
Total	100.00		100.00	
HHV, BTU/lb	5,704	192	7,097	17
MAF/DAF, BTU/lb			8,931	38
Ultimate Analysis:				
Moisture	19.64	2.54	0	0
Carbon	33.79	1.10	42.05	0.14
Hydrogen	3.65	0.30	4.55	0.29
Nitrogen	1.97	0.07	2.45	0.02
Sulfur	0.51	0.02	0.64	0.04
Ash	16.50	0.28	20.53	0.52
Oxygen (diff.)	23.94	1.03	29.78	0.36
Total	100.00		100.00	
Chlorine (equal weight composite sample (1))				
Chlorine, Cl	0.727		0.905	
Contaminants, Energy basis:				
Ash, lbs/MM BTU			28.94	0.81
SO2, lbs/MM BTU			1.79	0.11
Ash Elemental Analysis ***(% dry basis), equal-weight-composite sampled:			% dry	
Silicon, SiO2			20.78	
Aluminum, Al2O3			4.94	
Titanium, TiO2			0.22	
Iron, Fe2O3			1.71	
Calcium, CaO			21.00	
Magnesium, MgO			7.54	

Sodium, Na2O			5.26	
Potassium, K2O			14.60	
Phosphorus, P2O5			13.77	
Sulfur, SO3			4.47	
Chlorine, Cl			5.07	
Carbon dioxide, CO2			0.59	
Total ash analysis			99.95	
Metals in Ash, equal-weight-composite, mg/kg			Metals, mg/kg dry	
Arsenic			2.81	
Barium			700	
Cadmium			8.2	
Chromium			40	
Lead			15	
Parameter	**LA-FB-PC #110-112** As-Received Basis,%		**LA-FB-PC #110-112** Dry Basis, %	
	Mean	Std. Dev.	Mean	Std. Dev.
Mercury			0.04	
Selenium			4	
Silver			<2	
Total metals in ash			770.05	
Phosphorus :			% dry basis	Std. Dev.
Phosphorus (Ash Basis), P2O5, %			13.30	0.69
Phosphorus (Dry Basis), P2O5, %			2.73	0.11

*Raw Manure (RM) harvested from crushed fly-ash pens & added to FA windrow ~ May 20-June 8, 2005. Composting start: windrow completed, water added & first turning (June 9, 2005).

**Composting ended Aug. 2, 2005: PC manure bulk-sampled from windrow, 1st grinding (hammermill), sampled and frozen. Samples shipped to Hazen Lab. August 5, 2005.

***Ash was calcined @ 1100 deg. F (600 deg. C) prior to analysis.

<u>Table A.4:</u> Contrasts between Biofuel Characteristics of Partially-Composted (PC) Manure (8/2/05) from Texas AgriLife Research/USDA-ARS Research Feedlot, Bushland, TX Used for Combustion & Reburn Experiments: HA-FB (from Soil Surfaced pens) and LA-FB (from Fly ash Surfaced pens); as-collected/as-received basis vs. dry basis.

COMPARISON: Soil-Surfaced (SS) feedpens (n=6) HA-FB vs. Crushed Fly Ash-Surfaced (FA) feedpens (n=12) LA-FB

Parameter	HA-FB-PC (51 day composting) #107-109 As-Rec'd,%		HA-FB-PC (51 day composting) #107-109 Dry, %		LA-FB-PC (55 days composting) #110-112 As-Rec'd,%		LA-FB-PC (55 days composting) #110-112 Dry, %		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	**Comments/comparison**
Proximate Analysis:									
Moisture	17.00	0.26	0	0	19.64	2.54	0	0	Similar in moisture content.
Ash	53.85	0.77	64.88	0.74	16.50	0.28	20.53	0.52	LA-FB had 1/3 ash as HA-FB.
Volatile Matter (VM)	25.79	1.04	31.07	1.31	52.33	2.12	65.11	0.59	LA-FB had twice the volatiles as HA-FB.
Fixed Carbon (FC)	3.36	0.78	4.05	0.95	11.54	0.32	14.36	0.28	LA-FB had 3.5 times the FC as HA-FB.
Total	100.00	0.00	100.00	0.00	100.01	0.00	100.00	0.00	
Sulfur (S)	0.31	0.02	0.38	0.02	0.51	0.02	0.64	0.04	LA-FB had 68% more S than HA-FB.
HHV, BTU/lb	2,239	49	2,697	60	5,704	192	7,097	17	LA-FB had much higher HHV as HA-FB (d.b.).
HHV, MAF/DAF, BTU/lb			7,682	169			8,931	38	LA-FB had 16% higher HHV/DAF heating value than HA-FB.
Ultimate Analysis:									
Moisture	17.00	0.26	0	0	19.64	2.54	0	0	Similar moisture, HA-FB vs. LA-FB
Carbon ©	14.92	0.16	17.97	0.25	33.79	1.10	42.05	0.14	LA-FB had over 2X the Carbon as HA-FB.
Hydrogen (H)	1.39	0.08	1.68	0.10	3.65	0.30	4.55	0.29	LA-FB had over 2X the Hydrogen as HA-FB.
Nitrogen (N)	1.13	0.02	1.36	0.03	1.97	0.07	2.45	0.02	LA-FB had 80% more N than HA-FB.
Sulfur (S)	0.31	0.02	0.38	0.02	0.51	0.02	0.64	0.04	LA-FB had 68% more S than HA-FB.
Ash	53.85	0.77	64.88	0.74	16.50	0.28	20.53	0.52	LA-FB had only ⅓ the ash as HA-FB.
Oxygen (diff.)	11.40	0.27	13.73	0.37	23.94	1.03	29.78	0.36	LA-FB had twice the Oxygen as HA-FB.
Total	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	
Chlorine (#107-112 composites)									
Chlorine, Cl	0.281		0.338		0.727		0.905		LA-FB had much higher Cl.

Contaminants, Energy basis:					
Ash, lbs/MM BTU	240.66	7.13	28.94	0.81	LA-FB had 1/8 the ash as HA-FB, heating-value basis.
SO2, lbs/MM BTU	2.79	0.13	1.79	0.11	LA-FB had 2/3 the S as HA-FB, heating value basis.
Ash Elemental Analysis* (% d.b.), equal-weight-composite:					
	%		%		
Silicon, SiO2	65.55		20.78		LA-FB had 2/3 less Si.
Aluminum, Al2O3	11.2		4.94		LA-FB had less than half the Al.
Titanium, TiO2	0.52		0.22		LA-FB had less than half the Ti.
Iron, Fe2O3	2.99		1.71		LA-FB had ~40% less Fe.
Calcium, CaO	7.47		21.00		LA-FB had nearly 3 times the Ca.
Magnesium, MgO	2.29		7.54		LA-FB had more than twice the Mg.
Sodium, Na2O	1.38		5.26		LA-FB had nearly 3 times more Na.
Potassium, K2O	4.66		14.60		LA-FB had twice more K.
Phosphorus, P2O5	2.43		13.77		LA-FB had nearly 5 times more P.
Sulfur, SO3	1.30		4.47		LA-FB had 240% higher S.
Chlorine, Cl	0.41		5.07		LA-FB had 11 times higher Cl.
Carbon dioxide, CO2	0.51		0.59		Similar.
Total ash analysis	100.71		99.5		
Metals in Ash, equal-weight-composite, mg/kg					
Arsenic	3.85		2.81		Similar.
Barium	800		700		Similar.
Cadmium	3.8		8.2		Similar.
Chromium	30		40		Similar.
Lead	27		15		Similar.
Mercury	0.03		0.04		Similar.
Selenium	<2		4		Similar.
Silver	<2		<2		Similar.
Total metals in ash	864.68		770.05		
Phosphorus :					
Phosphorus (Ash Basis), P2O5, %	2.43	0.05	13.3	0.69	LA-FB has much higher P.
Phosphorus (Dry Basis), P2O5, %	1.57	0.01	2.73	0.11	LA-FB has higher P.

***Ash was calcined @ 1100 deg. F (600 deg. C) prior to analysis).**

Table A.5. Fuel Properties* for low or high-ash FB samples from 2005 and 2006 late-spring manure harvest at Texas AgriLife Research/USDA-ARS Research feedlot, Bushland, TX. (Sweeten and Heflin, 2006b)**

Feedlot Biomass (FB) from Texas AgriLife Research/ARS Feedlot at Bushland, TX					
	LA-PC-FB-2005-Windrow #119-121	**LA-PC-FB-2005-Greenhouse #122-124**	**LA-Raw-FB-2005-Greenhouse #125-127**	**LA-Raw-FB-2006-Greenhouse #134-136**	**HA-Raw-FB-2006-Greenhouse #137-139**
Date of sampling:	**6/9/05**	**August-05**	**Aug. 05**	**6/7/06**	**6/7/06**
Date of analysis:	**July**	**July-05**	**2005**	**10/23/06**	**10/23/06**
Dry Loss (% Moisture w.b.)	17.56	10.36	12.66	29.25	27.31
Ash, % d.b.	31.20	21.79	23.42	13.58	45.23
FC, % d.b.	12.78	13.81	13.93	18.36	10.05
VM, % d.b.	56.02	64.40	62.65	68.06	44.71
Carbon C, % d.b.	39.13	44.21	43.92	49.63	32.34
Hydrogen, H, % d.b.	4.49	5.32	5.14	5.90	3.85
Nitrogen, N, % d.b.	3.26	3.08	3.10	3.35	2.31
Oxygen, O (diff) , % d.b.	21.18	24.95	23.70	27.00	15.84
Sulfur, S, % d.b.	0.73	0.65	0.72	0.54	0.43
Chlorine, Cl, % d.b.	0.84	0.95	0.97	0.68	0.24
HHV, BTU/lb w.b.	5,075	6,391	6,145	5,685	3,521
HHV, BTU/lb d.b.	6,150	7,129	7,035	8,035	4,844
HHV, DAF/lb	8,939	9,116	9,186	9,298	8,842

Table A.5. (continued) Ash Elemental Analyses Oxide Basis % d.b.

	LA-PC-FB-2005-Windrow #119-121	LA-PC-FB-2005-Greenhouse #122-124	LA-Raw-FB-2005-Greenhouse #125-127	LA-Raw-FB-2006-Greenhouse #134-136	HA-Raw-FB-2006-Greenhouse #137-139
Date of sampling:	**6/9/05**	**August-05**	**Aug. 05**	**6/7/06**	**6/7/06**
Date of analysis:	**July, 2005**	**July, 2005**	**2005**	**10/23/06**	**10/23/06**
Silicon, $Si0_2$	27.90	22.03	22.89	11.51	60.94
Alumina, Al_20_3	4.47	3.78	3.93	1.78	7.68
Calcium, Ca0	19.67	21.20	21.03	20.90	9.91
Magnesium, Mg0	6.86	7.28	7.23	7.97	2.91
Sodium, Na_20	4.25	4.72	4.23	5.57	1.78
Potassium, K_20	12.53	13.57	13.07	20.27	5.94
Phosphorus, P_20_5	12.96	13.90	13.56	14.92	4.39
Sulfur, $S0_3$	3.89	4.43	4.86	5.53	1.19
Chlorine, Cl	4.34	5.06	4.82	6.58	1.12

***** Analyses from Hazen Research Inc., Golden, CO**.** Data are mean values from 3 composites samples of multiple-subsamples each. All data are dry basis unless otherwise noted.

****** From: Sweeten, J.M. and K. Heflin. 2006. Preliminary Interpretation of Data from Proximate, Ultimate and Ash Analysis. Unpublished results of June 7, 2006 Samples Taken from Feedlot and Dairy Biomass BioFuel Feedstocks at Texas AgriLife Research/USDA-ARS, Bushland, TX.

Table A.6. **Texas Lignite (TXL and Wyoming Powder River Basin (PRB) Coal* (Sweeten et al. 2006a)**

Parameter	TXL #113-115 (n=3) As-Received %		TXL #113-115 (n=3) Dry, %		PRB #116-118 (n=3) As-Received %		PRB #116-118 (n=3) Dry %	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Proximate:								
Moisture	38.34	0.34	0.00	0.00	32.88	0.36	0.00	0.00
Ash	11.46	0.50	18.59	0.85	5.64	2.11	8.40	3.11
Volatile	24.79	0.26	40.20	0.53	28.49	0.62	42.45	1.02
Fixed C	25.41	0.63	41.21	0.80	32.99	1.31	49.15	2.15
Total	**100.00**		**100.00**		**100.00**		**100.00**	
Heating Value								
HHV, BTU/lb	6,143	127	9,962	170	7,823	282	11,657	455
MMF, BTU/lb	7,003	109	12,487	70	8,328	121	12,828	81
MAF/DAF, BTU/lb			12,236	84			12,724	97
Ultimate:								
Moisture	38.34	0.34	0.00	0.00	32.88	0.36	0.00	0.00
Carbon	37.18	0.66	60.30	0.92	46.52	1.74	69.32	2.82
Hydrogen	2.12	0.08	3.44	0.14	2.73	0.07	4.06	0.13
Nitrogen	0.68	0.01	1.11	0.02	0.66	0.03	0.98	0.04
Sulfur	0.61	0.09	0.98	0.15	0.27	0.02	0.41	0.03
Ash	11.46	0.50	18.59	0.85	5.65	2.11	8.40	3.11
Oxygen (diff.)	9.61	0.32	15.58	0.44	11.29	0.14	16.83	0.29
Total	**100.00**		**100.00**		**100.00**		**100.00**	
Chlorine One Composite of 3 samples								
Chlorine, Cl	0.01		0.016		0.009		0.013	
Phosphorus								
P-Ash Basis, $P_2$05, %			0.13	0.01			0.57	0.14
P-Dry Basis, $P_2$05, %			0.02	0.00			0.05	0.01
Contaminants, Energy Basis:								
Ash, lbs/MM BTU			18..67	1.17			7.28	3.02
S02, lbs/MM BTU			1.98	0.32			0.70	0.02

***Lignite and coal samples provided by TXU Energy, Dallas, TX; Sampling Date= 10/10/05. Data are means and standard deviations of 3 samples of each material.

Table A.7. High Moisture Dairy Biomass (DB) Analyses* supplied in 2006 by Texas AgriLife Research-Amarillo and BAEN-College Station Research Team to the TEES Co-Firing Combustion and Reburn Conversion Research Team compared with TXL (lignite) or PRB Coal.**

Fuel Constituents, % w.b.	Dairy Biomass, Separated Solid	Dairy Biomass, Partially Composted (3-4 weeks)	Dairy Biomass, Fully Composted (3-4 weeks)	DB Flushed	DB Lagoon Effluent	Texas Lignite	Wyoming Coal
Moisture Content	80.94	76.01	57.40	93.31	93.23	38.34	32.88
Ash	2.14	3.26	13.12	3.43	1.83	11.46	5.64
Fixed Carbon (FC)	3.64	4.83	7.04	0.45	-	25.41	32.99
Volatile Matter (VM)	13.28	15.90	22.44	2.81	-	24.79	28.49
Total Carbon, C	9.39	11.44	16.25	1.85	-	37.18	46.52
Hydrogen, H	0.98	1.09	1.46	0.17	-	2.12	2.73
Nitrogen, N	0.36	0.51	0.92	0.16	-	0.68	0.66
Oxygen, O	6.14	7.64	10.70	1.04	-	9.61	11.29
Sulfur, S	0.05	0.05	0.15	0.04	-	0.61	0.27
HHV (kJ/kg) w.b.	3,468	4,266	5,965	668	-	14,287	18,193
HHV Btu/lb w.b.	1,491	1,834	2,564	287	-	6,142	7,823

* These values are on a wet/as collected basis.

** These data were also shown in Volume I, Table 1.3.6. or in Volume I, Table 1.3.8..

Table A.8. Fuel Properties* for Dairy Biomass (DB) representing partially-composted (DB), separated solids verses high ash partially-composted pen-scraped DB manure (Sweeten and Heflin, 2006b)**

Dairy Biomass (DB from Dairy MX 7 in Comanche County Texas					
	DB-SEP solids-PC-2006 #128-130			DB-HA-PC, 2006 #131-133	
Date of Sampling:	5/15/2006			5/15/2006	
Date of Analysis:	10/23/2006			10/23/2006	
	Mean	Std. Dev.		Mean	Std. Dev.
Moisture % w.b.	25.26	8.52		12.21	5.28
Ash, % d.b.	19.97	1.37		68.24	0.74
FC, % d.b.	17.33	0.87		4.39	1.75
VM, % d.b	62.70	1.14		27.38	1.39
Carbon C, % d.b.	47.09	0.81		20.53	0.52
Hydrogen, H, % d.b.	4.97	0.08		1.65	0.10
Nitrogen, N, % d.b.	2.58	0.05		1.31	0.04
Oxygen, O, (diff), % d.b.	24.81	0.86		8.06	0.39
Sulfur, S, % d.b.	0.57	0.01		0.21	0.05
Chlorine, Cl, % d.b.	0.18	0.00		0.26	0.01
HHV, Btu/lb w.b.	5,522	640		1,854	133
HHV, Btu/lb d.b.	7,387	98		2,110	46
HHV, Btu/lb DAF	9,232	116		6,645	52

*Data are mean values from 3 composite samples of multiple sub-samples each. All data are dry-basis, unless otherwise noted. Analyses from Hazen Research Inc., Golden, CO

****From: Sweeten, J.M. and K. Heflin. 2006. Preliminary Interpretation of Data from Proximate, Ultimate and Ash Analysis. Unpublished results of June 7, 2006 Samples Taken from Feedlot and Dairy Biomass BioFuel Feedstocks at Texas AgriLife Research/USDA-ARS, Bushland, TX.

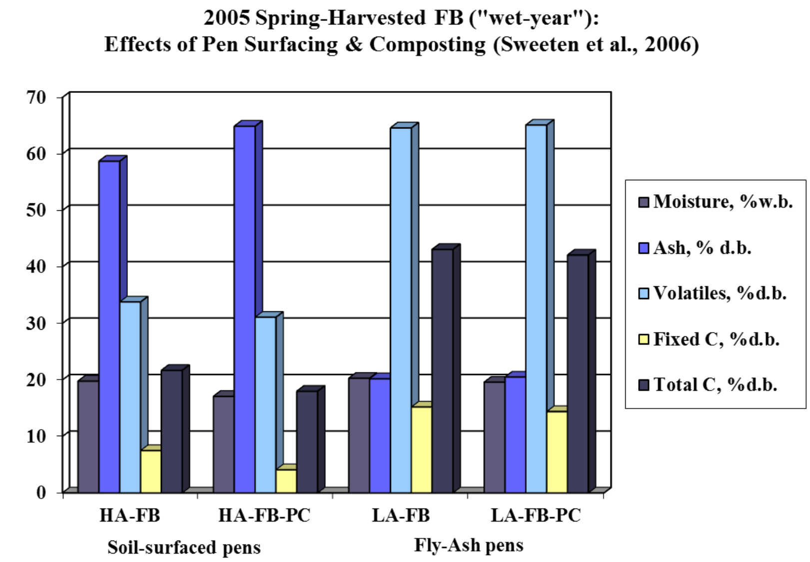


Figure A.1. 2005 Spring-Harvested FB ("wet-year"): Effects of Pen Surfacing & Composting (Sweeten et al., 2006)

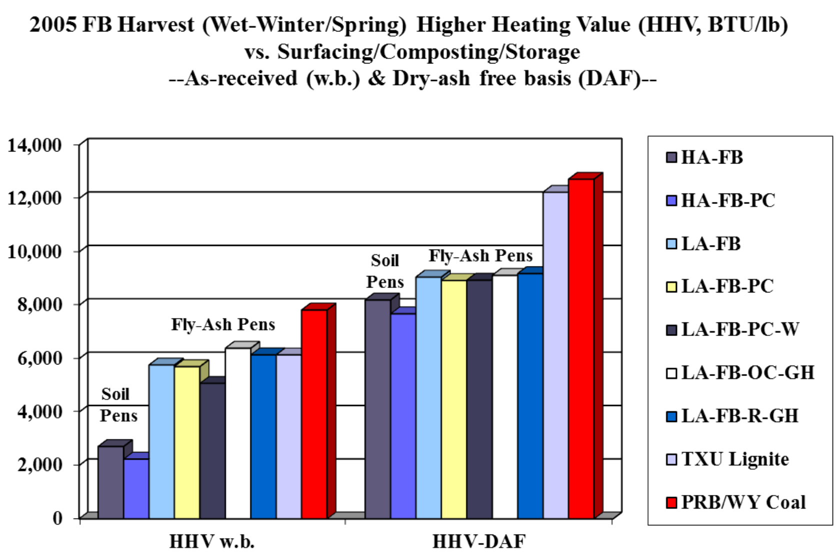


Figure A.2. 2005 FB Harvest (Wet-Winter/Spring) Higher Heating Value (HHV, BTU/lb) vs. Surfacing/Composting/Storage --As-received (w.b.) & Dry-ash free basis (DAF)

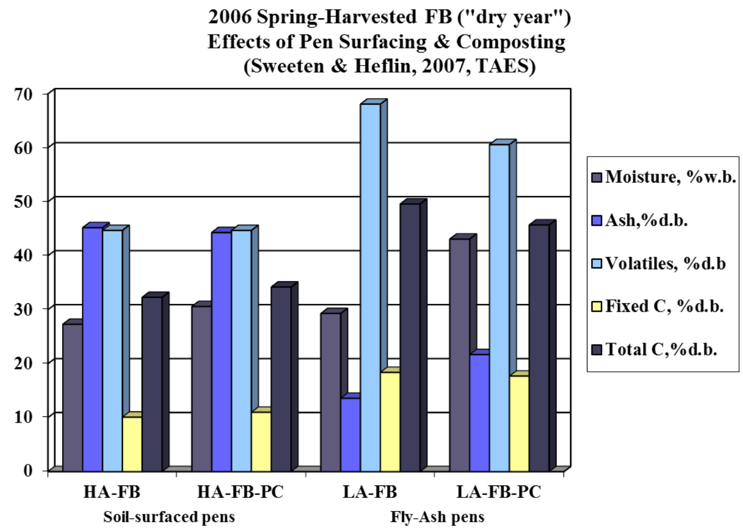
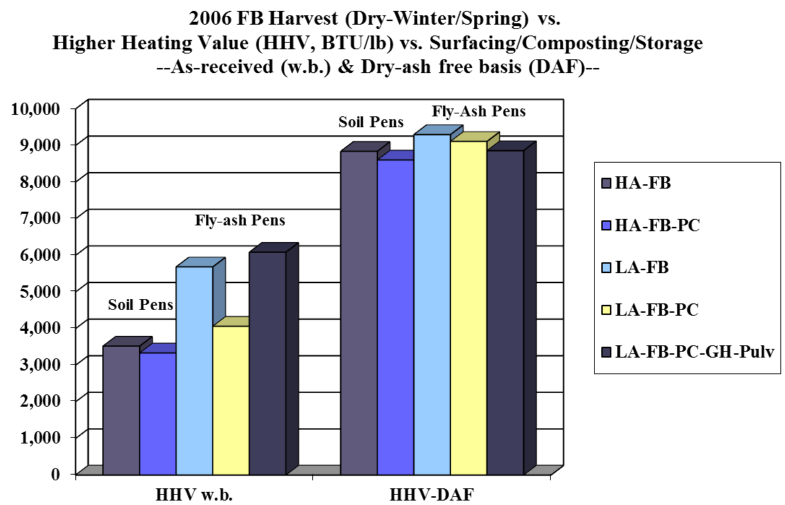


Figure A.3. 2006 Spring-Harvested FB ("dry year") Effects of Pen Surfacing & Composting



Figures A.4. 2006 FB Harvest (Dry-Winter/Spring) vs. Higher Heating Value (HHV, BTU/lb) vs. Surfacing/Composting/Storage --As-received (w.b.) & Dry-ash free basis (DAF)

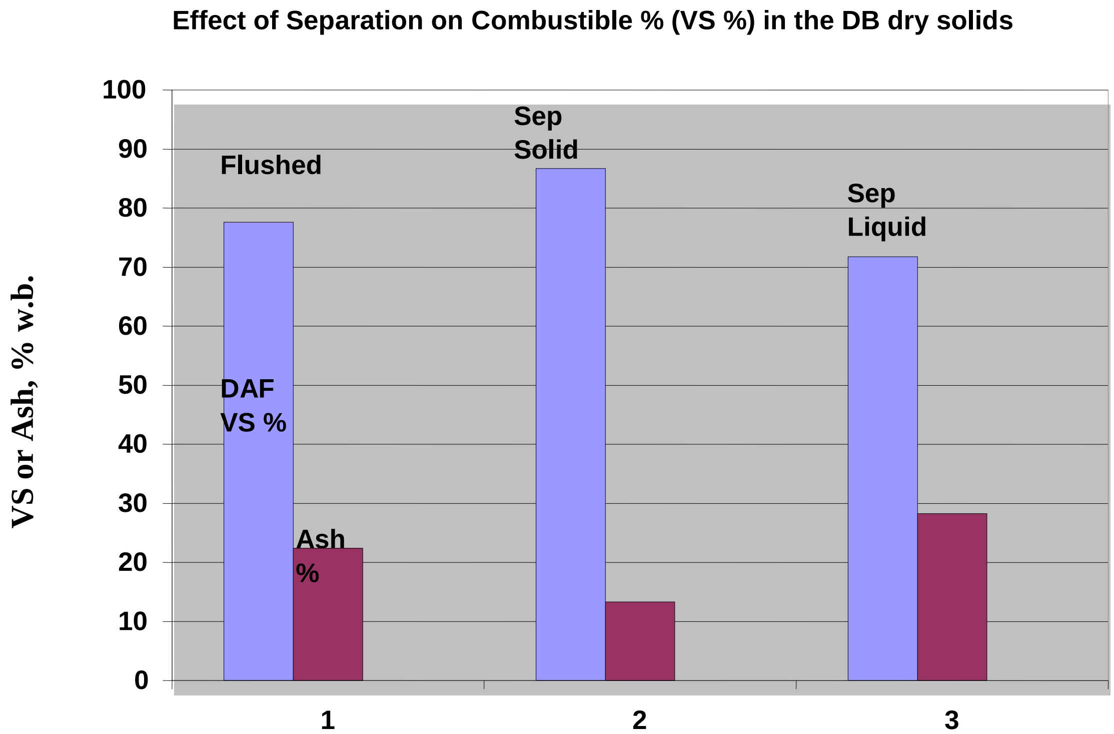


Figure A.5. Effect of Mechanical Separation on Volatile Solids (VS) and Ash % d.b. in Flushed DB.

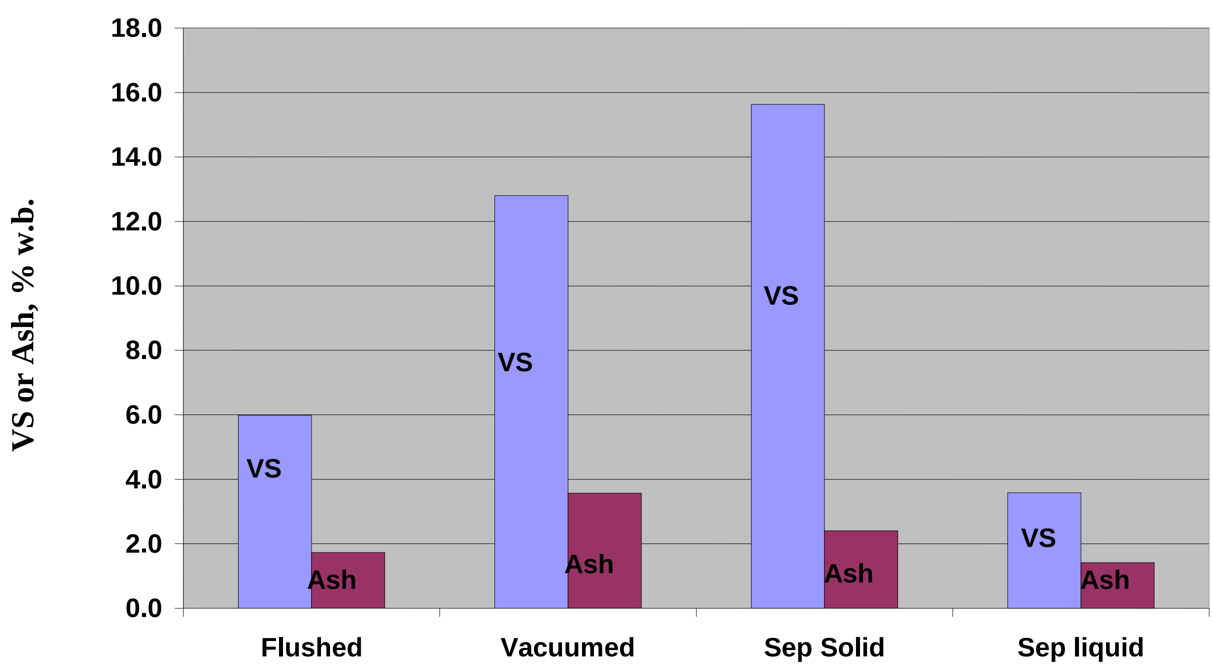


Figure: A.6. Effect of Vacuum Collection vs. Flushing on VS % in as-harvested (w.b.) dairy biomass from concrete surfaces.

Mortality Biomass (MB) for thermochemical conversion processing. (A.1.1.3.)

Because ash and moisture dilute the heating value, Dr. Auvermann developed an Excel spreadsheet tool that computes the expected differential net value of FB feedstocks on the basis of their respective moisture and ash contents, hauling distances, unit transportation costs ($/ton-mile), disposal costs or tipping fees ($/ton), and coal and/or natural-gas spot prices. This tool facilitates the economic evaluation of manure-processing techniques designed to remove water and/or ash. Auvermann's results (unpublished) showed that a 1,500 ton/day FB gasification or combustion plant would incur $1-2 million higher cost for high ash vs. low ash FB, based on properties shown in Table A.1. presented earlier. The same principles would apply for composted mixtures of FB and MB.

Theoretical Considerations for MB:

Consider the following scaling law [Advanced Thermodynamics engineering, K Annamalai, and I K Puri, CRC Press, 2001, Chapter 2]. The heat loss from an organism $\dot{Q}_L = \dot{Q}_L'' A = h_H A(T_b - T_\infty)$ where h_H, heat transfer coefficient (kW/m^2 C), A surface area (about 1.8 m^2 for 70 kg humans), T_b: Body temp (37 C for humans), T_∞, ambient temp. $\dot{Q}_L$ is equal to metabolic rate $\dot{Q}_G$. Assuming the heat transfer coefficient h_H to be constant (about 6 W/m^2 K) we note that $\dot{Q}_G = h_H A(T_b - T)$and specific metabolism rate $\dot{q}_G$ = $\{h_H A(T_b – T)/m_b\}$, $A \propto R^2 \propto m_b^{2/3}$ where R is characteristic size of the body; thus $\dot{Q}_G \propto m_b^{2/3}$ and $\dot{q}_G \propto m_b^{-1/3}$ (Euclidean geometrical scaling; metabolic rate per unit mass of body) . Experiments yield that $\dot{Q}_G$ (W) = $C_m m_b^{(1-n)}$ and $\dot{q}_G$ (W/kg) = 3.552 m_b^{-n} where C_m =3.552, n= 0.

Similarly the species transfer rate from composting biological species could be given as $h_m A(Y_{k,b} - Y_{k\infty})$ where h_m, mass transfer coefficient (kg/m^2 C) , A surface area, $Y_{k,b}$: mass fraction of of species k (species k mass in kg / kg mix in solid phase) near the body and $Y_{k\infty}$ species mass fraction far from the body; under steady state, this transfer rate is equal to decomposition rate. Assuming the mass transfer coefficient h_m to be constant we note that decomposition rate = $h_m A (Y_{k,b} - Y_{k\infty})$ and specific decomposition rate= $h_m A(Y_{k,b} - Y_{k\infty}) /m_b$, $A \propto R^2 \propto m_b^{2/3}$; thus decomposition rate $\propto m_b^{2/3}$ and specific decomposition rate $\propto m_b^{-1/3}$; i.e. smaller body mass will decompose much faster compared to larger body and hence decomposition time reduced. The experiments performed by Dr. Brent Auvermann confirmed the predictions qualitatively.

Objectives, MB Processing & Characterization:

The objective was to determine whether animal carcasses would be compatible with open-lot harvested cattle feedlot or dairy biomass in terms of biofuel properties. To verify this objective, it was necessary to prepare various compost mixtures with and without various types of carcasses, and under different conditions of composting. Some of these tests were strategically planned and others were opportunistic. Either bovine (beef or dairy cattle) or equine (horse) carcasses/mortalities were used in these studies. These were referred to as mortality biomass (MB).

MB materials and processing methods:

The Texas AgriLife Research–Amarillo team composted equine carcasses successfully with less than 1 cubic foot of feedstock per pound of carcass. Consider for a 1,000 lb equine; the benchmark would be 1,000 cubic feet of feedstock or approximately 7-8 cubic yards of co-composting material. A roughly conical or pyramid-shaped pile 5 feet high would have a base around 25 feet across. Our successful demonstrations at the Equine Center at West Texas A&M were considerably smaller than that.

Figure A.7. shows a picture of a managed carcass compost pile for cattle mortality of 700-900 lbs, conducted at Texas AgriLife Research, Bushland, Texas.

Figure A.7. Compost Pile for Cattle Mortality of 700-900 lbs

MB Fuel Properties Results:

Mortality biomass fuel properties were determined as a function of duration of composting. Figure A.8. shows HHV of the feedstock matrix surrounding composting of equine mortality biomass [Source: Brent Auvermann, Texas AgriLife Research]. Data from these experiments were included in publications and technology transfer opportunities. The MB data produced were included by Annamalai et al. in the continually updated biofuel data bank as further reference for estimating energy potential of MB biomass.

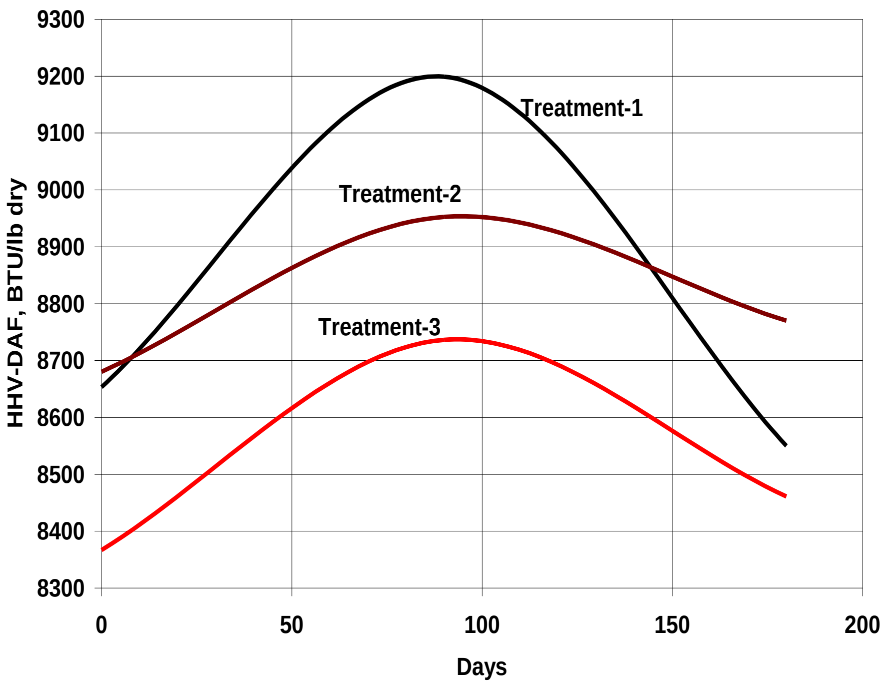


Figure A.8. High heating value of three MB composting treatments as a function of time.

Results of Rapid Assay of MB and FB Materials:

To improve on the ability to rapidly assess the biofuel properties, especially ash and HHV, which could be highly desirable in a MB mixture, a rapid-assy method would be highly desirable and important to the industry. In collaboration with Dr. Cristine Morgan (TAMU Department of Soil and Crop Sciences), Auvermann and his team evaluated near-visual infrared (NVIR) reflectance spectroscopy as a rapid, in-field technique to measure ash content of CB or MB. Auvermann et al. developed an experimental protocol to calibrate an existing NVIR instrument in Dr. Morgan's laboratory using partial least squares regression (PLSR). In Dr. Auvermann's laboratory, Ms. Sharon (Preece) Sakirkin produced custom-blend precision mixtures of feed yard manure and mineral soil, mixtures which spanned a range of 15 to 95% ash (dry basis).

The NVIR technique was used successfully to determine FB ash content as shown in Figure A.9 which illustrates the findings in terms of measured vs. predicted ash content. Results were presented in the following published article: Preece, S.L., C.L.S. Morgan, B.W. Auvermann, K. Wilke, K. Heflin. 2009. Determination of Ash Content in Solid Cattle Manure with Visible Near-Infrared Diffuse Reflectance Spectroscopy. Transactions of the ASABE. 52(2):609-614. The experiments and results are summarized in the following Abstract:

> *Visible and near-infrared (VisNIR, 350-2500 nm) diffuse reflectance spectroscopy (DRS)* is *increasingly being used to quantify constituents of organic matter both in the lab and in situ. However, it is unknown if DRS can be utilized as a tool for determining crude ash content of solid cattle manure. Ash content is a significant contributor to the suitability value of manure for use both as a biofuel and soil fertilizer, but conventional ash analysis is time-consuming and labor-intensive. In this study, we explored the feasibility of VisNIR-DRS for the rapid prediction of ash content in solid manure from beef feedyards in the southern High Plains. Proportionally mixed samples of soil and manure (n == 201) were evaluated for ash content by conventional analysis and then used to calibrate a statistical model for prediction of ash content by VisN1R-DRS based on multivariate partial-least squares regression and random test-set validation. Two thirds of the samples were randomly selected to build a calibration model, and the remaining third was used for validation. The coefficient of determination* (,-2), *root mean squared deviation (RMSD), and ratio of prediction to standard deviation (RPD) were calculated to assess the prediction model. The prediction model had an r2 of 0.94, an RMSD of* 5% *ash (d.b.), and an RPD of* 4. *The VisNIR-DRS model successfully predicted crude ash content with* ±5% *of the observed ash content (d.b.) as determined by dry oxidation using the accepted ASTM standard E1755-0*

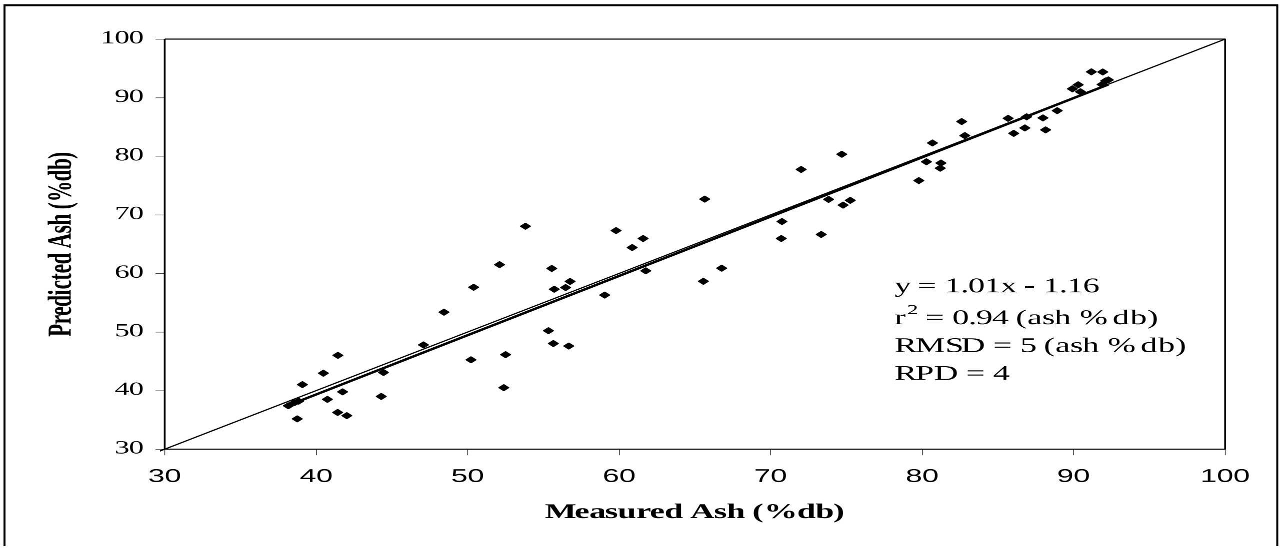


Figure A.9. Predicted versus measured ash content from the validation VisNIR-DRS model (n=66) for predicting crude ash % (db) in solid cattle manure. Comparison of the one-to-one line to the regression line indicates little bias in the mode (Preece et al., 2009).

In a subsequent experiment, the Auvermann team determined whether or not the composition of a beef animal's diet had any influence on the NVIR calibration parameters. Experiments were planned, conducted and evaluated. It was found that this technique can be adopted for several types of biomass fuels, including FB and DB. A second journal article was prepared. **Ref:** Sakirkin, S.L.P., C.L.S. Morgan, B.W. Auvermann. 2010. Effects of Sample Processing on Ash Content Determination in Solid Cattle Manure with Visible/Near-Infrared Spectroscopy. Transactions of the ASABE. 53(2):421-428. An Abstract of this study follows:

> *Visible and near-infrared (VisNIR, 350-2500 nm) diffuse reflectance spectroscopy (DRS) may be a useful tool for determining crude ash content of solid cattle manure (Preece et al., 2009). However, the effect of sample pre-processing protocols on the predictive ability of the VisNIR-DRS models is unknown. In this study we explored the effects of drying and milling on the prediction of crude ash in feedyard manure using VisNIR-DRS. Samples (n = 120) of beef manure from open lots were evaluated for ash content by dry oxidation and then subjected to four pre-processing treatment protocols: oven-dried and milled, air-dried and milled, oven-dried and not-milled, and air-dried and not-milled. Each treatment protocol was used to calibrate partial least squares regression models for prediction of ash content by VisNIR-DRS. Two thirds of the samples were randomly selected to build calibration models, and the remaining third was used for validation. The root mean squared deviation (RMSD) and the ratio of the standard deviation over the RMSD (RPD) for each treatment were assessed to determine the best pre-treatment protocol for ash determination of manure. The first derivative of the reflectance from air-dried, not-milled samples consistently generated the best predictive models with an RMSD of 5 crude ash % (d.b.), an RPD of 2, and a bias of 0 crude ash % (d.b.).*

Summary:

In summary, this subtask (A.1.1.3.) was accomplished and innovative technology with broad applicability was developed. Sharon L. P. Sakirkin completed her Master of Science thesis (Preece, 2008) and published two refereed journal articles on the use of visible, near-infrared diffuse reflectance spectroscopy (VNIR-DRS) for in-field determination of the ash and moisture content and HHV of feedyard manure. She and co-authors devised scanning and calibration methods and a fuel-specific data-analysis protocol that, taken together, is capable of estimating crude ash content to within +/- 5% of the value determined by ASTM-standard, gravimetric laboratory methods. She also showed that VNIR-DRS was a highly reliable method of making on-site "Pass/Fail" judgments about feedlot biomass relative to *a priori* fuel-quality thresholds that may be established by end users. Since the termination of this project, the DOE-funded work of Sakirkin et al. (2010) has spawned a range of additional experiments evaluating the reliability of the VNIR-DRS technique for feedlot biomass derived from cattle feeds with varying inclusion rates of distiller's by-products as a percentage of feed dry matter.

The impact of this research will be seen in years to come in terms of providing a reliable approach to rapid determination of FB ash content of harvested manure samples. Rapid, non-destructive, in-situ technology to measure and map the HHV of feedyard manure will facilitate the selective harvesting of high-quality manure for use as a biofuel feedstock. The technique developed is an important tool to support the capture of market value by cattle feeders who invest in the production, collection and proper storage of high-quality manure.

Chlorine and Mercury (Hg) Content in Fuels (KA)(Sub-Subtask A.1.1.4)
Mercury emissions from coal fired power plants are an issue nationally. There is strong emphasis nationally on developing a technology to reduce the mercury emissions in exhaust gas. In an attempt to quantify and reduce mercury emissions, the mercury content was analyzed on selected FB and DB samples, as well as coal and lignite to determine the effect of blending or reburn on Hg emissions. The data is useful for predicting emissions as well as heating properties or conversion protocols. These data will help determine the effect of blending fuels/biofuels on Hg emissions from power plants.

Our approach was to conduct combustion tests and we made an attempt to reduce the mercury emissions in exhaust gas. First we determined the actual mercury content in fuel/biofuels and realized the results of reduced emissions in the combustion testing experiments covered in Volume I. Texas Lignite Coal, Wyoming Sub-bituminous coal, Sep. Sol. PC-DB and HA PC-DB were analyzed for Mercury and chlorine content at Hazen Lab, Golden, CO. Table A.9 shows the summary of these properties. These data have been reported along with a few derived results in terms of chlorine, mercury and ash loading.

This Sub-Subtask A.1.1.4. was accomplished. Further results are covered in Volume 1.

Table A.9: Higher Heating Values, Chlorine and Mercury Properties of Texas Lignite & Wyoming Coal in Comparison to DB Samples

	TX Lignite	**WY Coal**	**DB-Sep. Solids-PC-2006**	**DB-HA-PC**
HHV (kJ/kg)	14,286	1,8193	1,2844	4,312
HHV, Boie Equation (kJ/kg)	14,582	18,347	14,799	7,336
HHV, DAF (kJ/kg)	28,459	29,593	21,473	15,467
Chlorine, Cl% (ppm)	**0.007 (70 ppm)**	**0.019 (190 ppm)**	**0.161 (1610 ppm)**	**0.398 (3980 ppm)**
Cl DAF % (ppm)	0.0139 (139 ppm)	0.0309 (309 ppm)	0.2691 (2691 ppm)	1.427 (1427 ppm)
Cl, g/GJ	4.90	10.44	125.35	922.91
Mercury, Hg g/kg (ppb)	**0.00013 (130 ppb)**	**0.00007 (70 ppb)**	**0.00004 (40 ppb)**	**0.00003 (30 ppb)**
Hg DAF g/kg (ppb)	0.000258 (258 ppb)	0.0001138 (118.8 ppb)	0.0000668 (66.8 ppb)	0.0001075 (107.5 ppb)
Hg, g/GJ	0.00910	0.00385	0.00311	0.0069
Ash Loading (kg/GJ)	8.02	3.10	11.62	138.92

Evaluate Combustion-Related Derived Properties of Fuels (JS, BA, and KA) (Sub-Subtask A.1.1.5.)

An analysis was conducted to determine the maximum allowable ash content in the biofuel so that the biofuel could be used for a desired application. A particular focus was placed on the higher heating value (HHV). Our findings (in Task A.1.1.1.) showed that HHV of dry ash free (DAF) FB ranged only from 17,900 to 21,100 kJ/kg (7,696 to 9,071 Btu/lb) with an average of 19,500 kJ/kg (8,380 BTU/lb). In essence, the heat value was reduced as ash and moisture were added through natural or extraneous circumstances. Further heat must be supplied to evaporate moisture. Then using thermo-chemistry one can estimate the minimum heat value as 6,280 kJ/kg (2,700 BTU/lb) so that the bed could be maintained between 1,340°-1,700° F (1,000°-1,200° K). Such minimum heat value can be obtained for various ash and moisture contents as shown in **Figure A.10.** This graph was based on the premise (assumption) that the DAF heat value of many animal waste based biomass fuels remains "constant" at about 20,000 kJ/kg (8,600 BTU/lb); also see Sweeten et al. (2003).

On further examination of the project data, the dry, ash-free HHV (HHV-DAF) of feedlot biomass (FB) was found to be not single-valued, as shown in the histograms below (**Figure A.11**). The mode of the high-ash FB was between 8,750 and 9,250 BTU/lb; the mode of the low-ash FB was between 9,250 and 9,750 BTU/lb. As expected, however, the HHV-DAF of low-ash FB fell into a much narrower and more predictable range than that of high-ash FB. Between 75 and 80% of the FB samples had values of 9,000 BTU/lb-DAF or more for low-ash FB, and 8,500 BTU/lb-DAF or more for high-ash FB, as shown in **Figure A.11**.

In summary, the goals and objectives of Sub-Subtask A.1.1.5. were completed.

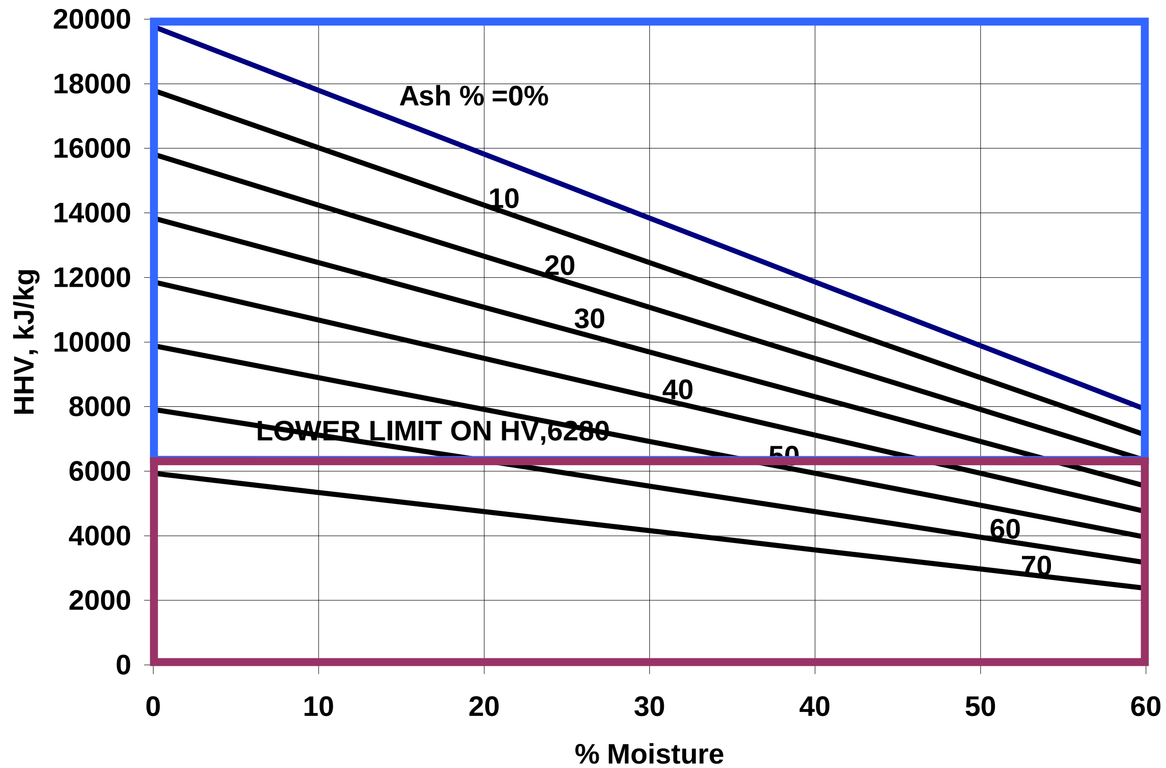


Figure A.10. Allowable moisture and ash contents to achieve a heat value of 6,280 kJ/kg (2,700 BTU/lb) for Feedlot Biomass Fuels (BWA & JS) assuming a median value (20,000 KJ/kg) 8,600 BTU/lb dry-ash free basis.

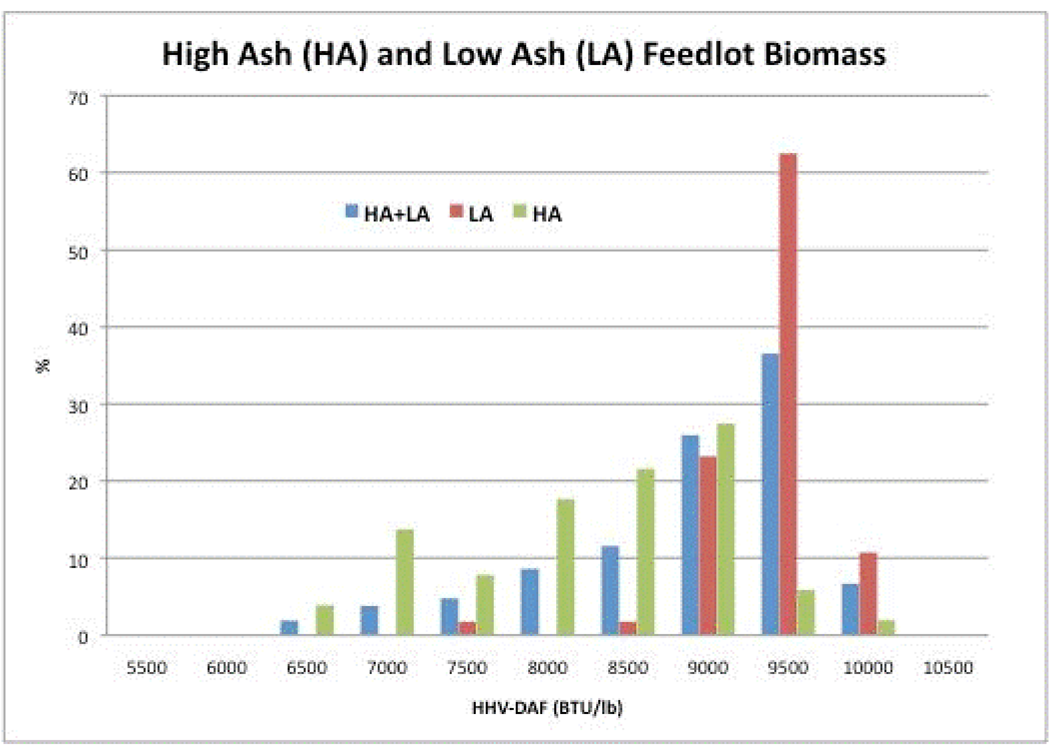


Figure A.11. Distribution of higher heating values (HHV, BTU/lb) on a dry-ash-free (DAF) basis for low-ash and high-ash cattle feedlot biomass.

Dissemination & Technology Transfer (Sub-Subtask A.1.1.6)
To have a wide range of choices of solid fuels, properties of various fuels were gathered from different sources and made available in the TAMU Fuel Data Bank (TAMU-FDB). The TAMU Fuel data bank (TAMU-FDB) maintains published data on fuel properties (coal, biomass, animal wastes etc.) at the web site: http://www1.mengr.tamu.edu/REL/index.html maintained by Dr. Annamalai et al. This is an ongoing process as the data are collected and available, including technical information produced by Sub-Subtasks A.1.1.1. through A.1.1.5. Papers and abstracts produced in this research effort are summarized below and in Appendix B.

A technical presentation by Sweeten, which included summaries of Tables A.1. through A.5. above, were presented at the 2007 ASABE Annual International Meeting in Minneapolis, Minnesota. Major thrusts of the presentations were contrasting FB properties a) from wet vs. dry year FB production cycles in an open-soil-surfaced feedlot or paved feedlot; and b) before and after 10-months storage in windrow or greenhouses;

An Alternative Energy Field Day at Bushland, TX (August 8, 2007), sponsored by Texas AgriLife Research, Texas AgriLife Extension Service, and USDA-ARS featured alternative energy tour and presentations, including the research work on FB processing as biofuel with subsequent results. Wind energy was also featured. The field day was attended by 150-200 participants.

The following publications (among others) were produced from data obtained in Sub-Subtasks 1.1.1. through A.1.1.6.:

- Annamalai, Kalyan, Nick Carlin, Hyukjin Oh, Gerardo Gordillo, Ben Lawrence, Udayasarathy Arcot V, J.M. Sweeten. 2008. Thermo-Chemical Energy Conversion Of Coal, Animal Waste Based Biomass, And Coal: Biomass Blends: An Overview. Paper No: Us-40, 19th National & 8th ISHMT-ASME Heat and Mass Transfer Conference, January 3 - 5, 2008, JNTU Hyderabad, India (also listed under Task A.3.).
- Annamalai, Kalyan, Nick Carlin, Hyukjin Oh, Gerardo Gordillo, Ben Lawrence, Udayasarathy Arcot V, J.M. Sweeten. 2008. Gasification of Coal and Animal Waste using an Air-Steam Mixture as Oxidizing Agent for 19th National & 8th ISHMT-ASME, Heat and Mass Transfer Conference to be held during January 3 - 5, 2008, JNTU Hyderabad, India.
- Annamalai, K., A. Udayasarathy and G. Gordillo. 2008. Energy conversion from Coal and Biomass: Direct Combustion and Gasification. Submitted for Plenary Lecture, Second International Conference For Resource Utilization And Intelligent Systems, Incruis–2008, Kongu Engineering College, Perundurai, India, January 3-5, 2008.
- Annamalai, K., J.M. Sweeten, S.Priyadarsan, and S. Arumugam . 2007. Principles of Energy Conversion For Coal, Animal Waste, and Biomass Fuels. Encyclopedia of Energy Engineering and Technology. Edited by Barney Capehart, Tyler and Francis, ISBN # 978-0-8493-3653-9; pp 476-497. Also listed under Task A.5.
- Auvermann, B.W. 2010. Estimating Manure Higher Heating Values as a Biofuel Feedstock. S-1032, USDA-CSREES/NIFA, National Facilitation Project, National Livestock & Poultry Environmental Learning Center, University of Nebraska, Lincoln, NE. May 2, 2010. 2 p. This received national distribution.
- Sakirkin, S. L. P., B. W. Auvermann, and C. L. S. Morgan. 2010. Effect of sample pre-processing and data post-processing methods on the determination of ash content in solid cattle manure with visible near-infrared diffuse reflectance spectroscopy. Transactions of the ASABE 53(2):421-428.
- Preece, S. L., C. L. S. Morgan, B. W. Auvermann, K. Wilke, and K. Heflin. 2009. Determination of ash content in solid cattle manure with visible near-infrared diffuse reflectance spectroscopy. Transactions of the ASABE 52(2): 609-614.

- Preece, S. L. 2008. Determination of ash content in solid cattle manure with visible near-infrared diffuse reflectance spectroscopy. Master of Science in Environmental Science, West Texas A&M University, Canyon, TX (conferred August 2008). Committee members: B. W. Auvermann (co-Chair), D. B. Parker (WTAMU; co-Chair), W. J. Rogers (WTAMU), and C. Morgan (TAMU-Soil & Crops Sciences).
- Sweeten, J.M., K. Heflin, K. Annamalai, F.T. McCollum, and D.B. Parker. 2006. Fuel Properties of Manure or Compost from Paved or Un-paved Cattle Feedlots. In: 2006 Beef Cattle Research in Texas.
- Sweeten, J.M., K. Heflin, B.W. Auvermann, and K. Annamalai. 2009. Combustion-Fuel Properties of Beef Feedlot Manure or Compost: Two-year Variations. Proceedings, Texas Animal Manure Management Conference, Austin, TX. September 29-30, 2009.

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Annamalai, K. and J.M. Sweeten. 2005. Reburn System with Feedlot Biomass. US Patent No. US 6,973,883 B 1. U.S. Patent & Trademark Office, Washington, DC, 20231. 12 p. Date of Issue: December 13, 2005.

Annamalai, K., J.M. Sweeten, S. Mukhtar, S. Arumugam, S. Priyadarsan. 2005a. A Novel Application of Feedlot Manure as Reburn Fuel for NOx Reduction in Existing Coal-Fired Plants. Final Report, Grant No. 93-36200-870-, National Center for Manure & Animal Waste Management, North Carolina State University, Raleigh, NC. January 31. 61p.

Annamalai, K., S. Priyadarsan, J.M. Sweeten, S. Arumugam. 2005b. Energy Conversion Principles. In: Barney Capehart (eds.) Encyclopedia of Energy Engineering and Technology. Marcel Dekker, New York, N.Y. 65 Pp. In Press.

Annamalai, K., P. Goughnour, J. Oh, and J.M. Sweeten. 2006. NOx Reduction with the use of Feedlot Biomass as Reburn Fuel. Proceedings Showcase-2006 Conference. May 30. 1 p.

Arumugam, S., K. Annamalai, S. Priyadarsan, B. Thien, J. M. Sweeten. 2005a. A novel Application of Feedlot Biomass (Cattle Manure) as Re-burning Fuel for NOx Reduction in Coal-Fired Plants. In: Proceedings of State of the Science: Animal Manure and Waste Management, Jan. 4-7, 2005, San Antonio. CDROM.

Arumugam, S., K. Annamalai, B. Thien, J. M. Sweeten. 2005b. Feedlot Biomass Co-Firing: A Renewable Energy Alternative for Coal-Fired Utilities. International Journal of Green Energy. 2 (4): 409-419.

Auvermann, B.W., J. M. Sweeten. 2005. Methodological Challenges to a Systems Approach to the Management of Animal Residuals. In: Proceedings of State of the Science: Animal Manure and Waste Management, Jan. 4-7, 2005, San Antonio. CDROM.

Preece, S.L., C.L.S. Morgan, B.W. Auvermann, K. Wilke, and K. Heflin. 2009. Determination of Ash Content in Solid Cattle Manure with Visible Near-infrared Diffuse Reflectance Spectroscopy. Transactions of the ASABE 52(2): 609-614.

Priyadarsan, S., K. Annamalai, J.M. Sweeten, S. Mukhtar, & M. T. Holtzapple. 2004. Fixed-Bed Gasification of Feedlot Manure and Poultry Litter Biomass. Transactions of the ASAE, 47(5): 1689-1696.

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Sweeten, J.M., K. Annamalai, B. Thien, and L.A. McDonald. 2003. Co-Firing of Coal and Cattle Feedlot Biomass (FB) Fuels. Part 1. Feedlot Biomass (Cattle Manure) Fuel Quality and Characteristics. Fuel, 82(2003): 1167-1182.

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Sweeten, J.M. and K. Heflin. 2006. Preliminary Interpretation of Data from Proximate, Ultimate, and Ash Analysis: Results of June 7, 2006 Samples from Feedlot & Dairy Biomass Biofuel Feedstocks at Texas AgriLife Research/USDA-ARS, Bushland, TX". TAES, October 23, 2006.

Subtask A.1.2. (JNR): Improve quality of dairy cattle biomass slurry (DBS) by reduction of water for application to direct firing.

Introduction:

Many dairies have used hydraulic flush systems for gravity removal of dairy manure (DB) from concrete floors in milking parlors, free stall barns, or feeding lanes. The practice of flushing systems has been commercially available for several decades. The relatively high volumes of wastewater with low solids content (typically <2% w.b.) have favored use of anaerobic lagoons for wastewater treatments. (Sweeten and Wolfe, 1991), followed by land application of effluent using irrigation systems, in accordance with state-or federally-approved nutrient management plans.

Typically, mechanical screen solid separators, settling basins and/or auger presses have been used to reduce the amount of solids entering the animal waste treatment lagoons. These types of separation methods have been described elsewhere (Mukhtar et al. 1999) An example of a solid-liquid separator for flushed dairy manure and wastewater lagoon water before it enters the lagoon system is shown in **Figure A.12**. The use and maintenance of anaerobic lagoons was discussed by Mukhtar (1999), while a discussion of sludge buildup and nutrient content in anaerobic lagoons effluent or sludge was provided by Mukhtar et al. (2004). Removal of suspended solids from the wastewater is one of the approaches for harvesting combustible solids, which also lowers the total and volatile solids load on the anaerobic lagoons. The types of solids separators can be either mechanical (static screen, vibrating screen, rotating drums, etc.) or gravity settling basins. Another conceptual approach might be to determine whether the whole flush manure could have value for thermochemical conversion, and that approach was explored by Carlin et al. 2007, in subsequent experiments, as described in Volume I.

Figure A.12. Separation of Solids from Flushed Dairy Manure (DB) Slurry

Objective and Purpose:

The ultimate goal of this Subtask A.1.2. was to study the separation of solids from DB slurry with lowest possible water content. The purpose of this task was to improve quality of dairy biomass slurry (DBS) for thermochemical conversion feedstock by reduction of water in DBS for application to direct firing by the TEES/Mechanical Engineering Team in College Station. The direct firing experiments themselves were carried out by Dr. J.N. Reddy and Nick Carlin. These experiments were developed and reported in Volume I and Carlin (2005).

Methods and Approach:

To pursue the modeling and analysis of solids separator approach as to use of DBS as biofuel, Reddy and Carlin developed a computational finite element modeling for the multi-phase flow problem. The governing equations for the fluid flow problem were defined. After a review of literature, the procedure to be used for the solution of equations was determined. This task involved multiphase flow simulation in two dimensions with the particulates in fluid being simulated with the appropriate kinematic equations and the fluid governed by the Navier-Stokes equations. The particulates in the fluid were composed of three different components: the DB combustibles, bedding sand or saw-dust, all of which were approximated individually as separate rigid bodies inside the fluid moving along with the fluid. The characteristic dimensions of each particle were determined and the shape of the particles were simulated as circular in two dimensions. The Navier-Stokes equations were used for modeling the multiphase fluid flow part of the problem. The equations were solved as a transient problem and as a coupled system.

Results:

Results were provided in Volume I of this final report (Annamalai and Sweeten 2010). The effects of moisture versus solids on combustion system and boiler efficiencies were evaluated to determine the amount of steam that can be generated for use as a thermal commodity for operations at or near the feeding system. The analysis preceded using a base-case of a 500 cow dairy with a manure flushing system in a free stall barn. Assumptions included 8 kg/day/hd of dry manure solids entrained in a 95% w.b. moisture slurry with a mechanical separator removing 40% of the entrained total solids having 80% w.b. moisture content vs. the 20% w.b. moisture content that is desired for combustion.

The combustion system performance varied greatly with moisture content of the flushed manure, and hence the ability of mechanical solids separator to remove solids is an important factor in efficiency. The disposal efficiency was reduced greatly as the moisture content of flushed manure increased from 94% to 99% w.b.(i.e. total solids were reduced from 6% to 1%). The solids remaining in the flushed manure separated liquid stream were detrimental to boiler efficiency when this water was converted into steam. Thus, having more solids left in the separated liquid steam following mechanical separation was detrimental to both boiler efficiency and disposal efficiency.

With increasing moisture content of the separated solids (from 60% to 85% w.b.), the rotary dryer must consume more steam and transfer more heat to the separated solids to dry them to 20% moisture needed for combustion system. Drying the separated manure solids before combustion added significantly to the small-scale thermochemical conversion system efficiency (Carlin, 2005).

Summary:

This task has been completed. Accomplishments have been reported in Volume I. In the interest of space, we will not repeat the analyses nor reporting results here.

Technology Transfer and Dissemination/Papers published:

1. Carlin, N.T., K. Annamalai, J.M. Sweeten, S. Mukhtar. 2007. Thermo-Chemical Conversion Analysis on Dairy Manure-Based Biomass through Direct Combustion. International Journal of Green Energy. Vol. 4:133-159.
2. Carlin, N.T. 2005. Thermo-chemical Conversion of Dairy Waste-based Biomass through Direct Firing. Master of Science Thesis. Department of Mechanical Engineering, Texas A&M University, College Station, Texas.
3. Lawrence, Ben, Kalyan Annamalai, John M. Sweeten and Kevin Heflin. 2006. Cofiring Coal and Dairy Biomass in a 29 kWt Furnace. Journal of Applied Energy 86(11) 2359-2372.
4. Oh, Hyukjin, Kalyan Annamalai1, John M. Sweeten, Christopher Rynio. 2009. Co-Combustion of Animal Wastes and Coals in a 30 kWt Boiler Burner Facility for Reductions of NOx and

Mercury Emissions. 11E4, US National Combustion Meeting, Ann Arbor, MI , May 17-20, 2009.

References Cited:

1. Annamalai, K., and J.M. Sweeten. 2010. Renewable Energy and Environmental Sustainability using Biomass from Dairy and Beef Production. Final Report-Volume I. Thermochemical Conversion and Direct Combustion Methods. (Draft). Project No. DE-FG36-05G085003, Submitted to U.S. Department of Energy-Golden Field Office, Golden, CO. October 31, 2010. 450 p. (In review).
2. Carlin, N.T. 2005. Thermo-chemical Conversion of Dairy Waste-based Biomass through Direct Firing. Master of Science Thesis. Department of Mechanical Engineering, Texas A&M University, College Station, Texas.
3. Mukhtar, S., J.M. Sweeten and B.W. Auvermann. 1999. Solid-Liquid Separation of Animal Manure and Wastewater. Texas AgriLife Extension Publication, E-13.
4. Mukhtar, S. 1999. Proper Lagoon Management to Reduce Odor and Excess Sludge Accumulation. Texas AgriLife Extension Publication, E-9.
5. Mukhtar, S, J.L. Ullman, B.W. Auvermann, S.E. Feagley and T.A. Carpenter. 2004. Impact of Anaerobic Lagoon Management on Sludge Accumulation and Nutrient Content for Dairies. Transactions of the ASAE 47(1): 250-257.
6. Sweeten, J.M. and M.L. Wolfe. 1991. Manure and Wastewater Management Systems for Open-lot Dairy Operations. Transactions of the ASABE. 37(4): 1145-1154.

Subtask A.1.3. (BA or KA): Preparation and characterization of composted mixtures of CB and cattle carcasses (MB) for firing in gasifier and combustion unit.

This subtask was completed. The Objectives, procedures and results of this Subtask (A.1.3.) are discussed in other sections. The co-composting and preparation of mortality biomass (MB) was presented earlier under Sub-subtask A.1.1.3. The economic aspects are further developed in a later section (Task H) of this report. To avoid repetition, these aspects will not be repeated here.

Task A.2. Fuel Pyrolysis (KA).

This task was completed by Dr. Annamalai et al. in the Department of Mechanical Engineering, TAMU/Texas Engineering Experiment Station (TEES).

Thermogravimetric analyses (TGA) were conducted in College Station using FB and DB samples supplied by Texas AgriLife Research-Amarillo. The TGA results were used to guide fundamental studies on DB and FB. All experimental protocols and results were described in Volume I and are not repeated here.

Task A.3. (KA, JS). Cofiring coal and dairy biomass in a 29 kW_t furnace.

Introduction:

Cofiring biomass with fossil fuels is emerging as a viable option for promoting the use of low quality renewable biomass fuels including energy crops. This research depended on dairy biomass feedstock that was harvested, samples were prepared and shipped by Mr. Kevin Heflin and others under the direction of Drs. Brent Auvermann and John Sweeten, Texas AgriLife Research-Amarillo, to the thermochemical conversion team (Annamalai et al.) in College Station, TX.

Objective:

The objective was to test burn selected bulk samples of DB characterized under Task A.1. in a 29 kW_t laboratory-scale pilot plant by co-firing DB with coal at different blend ratios to determine optimum blends, co-firing conditions, and effects on NOx and CO emissions..

Materials and Methods:

In Task A.3, dairy biomass (DB) which was prepared, characterized, processed and shipped by the feedstock team in Amarillo, was evaluated by the conversion team in College Station as a cofiring fuel with coal in a small scale 29 kW_t boiler burner facility, with an inside diameter of 15 cm using different blend ratios. Two types of coal (Texas lignite, TXL and Wyoming Powder River Basin coal, WYO) and two forms of partially composted DB fuels were investigated (low ash separated solids LA-PC-SepSol-DB and high ash soil surface HA-PC-SoilSurf-DB). Analytical data was reported under Task A.1 in Table A.8. Proximate and ultimate analyses performed on both coals and DBs revealed the following: higher heating value dry-ash-free-basis (HHV) of 28,460–29,590 kJ/kg (12,236-12,724 BTU/lb) for coal samples (Table A.6.) and 21,450 kJ/kg (9,232 BTU/lb) or 15,456 kJ/kg (6,645 BTU/lb) DAF basis for the two types of DB used in the study. Nitrogen loading was 0.36 and 0.48 kg/GJ for WYO and TXL, respectively, and was 1.50 and 2.67 kg/GJ for the LA-PC-SepSol-DB and the HA-PC-SoilSurf-DB respectively. Sulfur loading was 0.15 and 0.42 kg/GJ WYO and TXL, respectively, and was 0.33 and 0.43 kg/GJ for the LA-PC-SepSol-DB and the HA-PC-SoilSurf-DB respectively. Ash loading ranged from 3.10 to 8.02 kg/GJ for the coals and from 11.57 to 139 kg/GJ for the DB fuels.

The cofiring experiments were performed with 90:10 and 80:20 and 100:00 (mass %) coal:DB blend (96:4, 92:8, 100:00 % on heat basis). The co-firing experiments were completed by Dr. Kalyan Annamalai (TEES) using the biofuel harvested, prepared and shipped by Heflin et al. at Texas AgriLife Research-Amarillo.

Results:

Detailed results of the DB co-firing tests were presented in Volume I of this report, and are only summarized briefly here.

Results were obtained for burnt fraction, NO_x and CO emission. Pure TXL produced 1,505 ppm of CO at an equivalence ratio of 1.1. An 80:20 blend of TXL:LA-PC-SepSol-DB produced 4,084 ppm of CO at the same equivalence ratio. The NO_x emissions decreased with increasing equivalence ratio which was varied from 0.9 to 1.2. The NOx emissions ranged from 0.4 to 0.13 kg/GJ for pure TXL coal. The corresponding NO_x emissions were 0.8–0.10 kg/GJ for pure WYO coal. For 80:20 TXL:LA-SepS-DB blend they ranged from 0.375 to 0.05 kg/GJ.

In general, the coal:DB blends produced less NO_x than pure coal under rich conditions even though the DB contained more nitrogen. This result is probably due to the fuel bound nitrogen in dairy biomass which is mostly in the form of urea, which reduces NO_x to N_2.. in the course of combustion.

Summary:
This task was achieved, as the prepared and characterized samples of DB supplied by the feedstock team in Amarillo were successfully used by Dr. Annamalai and graduate students, which included Ben Lawrence in on-campus co-firing tests using DB, lignite or coal blends. This DB did have an impact on reducing NOx emissions under specified blends and test configurations.

Technology Transfer and Dissemination:
Results were reported in a referred journal article by B. Lawrence, K. Annamalai, J.M. Sweeten & K. Heflin. 2009. "Cofiring Coal and Dairy Biomass in a 29 kW Furnace". Journal of Applied Energy, 86(11):2359-2372.

Task A.4. (KA). Combustion as reburn fuel to reduce NOx emissions from coal-fired power plants.
Data from the above Task A.1 and subtasks thereof were reported to Kalyan Annamalai (KA) to plan and conduct his re-burn experiments using selected and prepared DB or FB bulk samples from the Amarillo-based feedstock team. Protocols and results of reburn tests were provided in Volume I. This task was achieved.

Task A.5. (SC, SM, KA): Gasification to produce low-BTU gas for on-site energy conversion.
An experimental program was planned by Annamalai et al. in which a laboratory-based pilot scale gasification unit was operated as pyrolyzer with N_2 injection. Planned studies included ash and gas quality. These experiments were completed using feedstock samples supplied by the Amarillo team and reported in Volume I.

Task A-6 (KA, JS): Pilot-scale studies:

Task A.6.1. (KA, JS): As a sub-contract to TEES, a pilot-scale facility will be used to generate the reburn data.

Task A.6.2. (KA, JS): Pilot scale tests on Hg reduction using CB as "Hg-reburn" fuel and testing chlorinated activated carbon for Hg capture.

Introduction:
The Texas Engineering Experiment Station (TEES), an agency of the Texas A&M University System (TAMUS) concurrently handled two contracts/grants involving: i) Feedlot Biomass: A Reburn Fuel For "Maximum NOx" Reduction In Coal-Fired Power Plants, a grant from Texas Commission on Environmental Quality (TCEQ); and ii) Renewable Energy and Environmental Sustainability Using Biomass from Dairy and Beef Animal Production Facilities, a grant from DOE-Golden, Colorado. Both

of these grants involved a common task involving external commercial pilot scale tests on using Texas lignite or Wyoming coal, animal waste-based biomass fuels (feedlot biomass, FB or dairy biomass, DB), or blends as reburn fuels for reduction of NOx and/or Hg in typical coal-fired combustion systems. Conceptually, the contracted studies might have included limited blends of Coal:FB and Coal:DB as reburn fuels.

We had proposed to conduct two pilot scale studies with these candidate biofuels using DOE-NETL-Pittsburgh pilot scale facility we had used earlier (Annamalai et al. 2003). However, DOE-Pittsburgh did not have funds to re-start and operate their facility. As such, the cost for pilot scale studies had increased greatly when we tried to look for private commercial facilities.

Objective:

The objective of this task was to validate the results of small-scale combustion tests that have shown significant reductions of NOx and moderate reduction of mercury emissions as a result of reburning /cofiring feedlot biomass (FB) and coal: FB blends. Successful tests could lead to commercial technology later in reducing emissions from fossil energy power generation systems. Commercial pilot plant vendors were contacted to determine capability and to schedule tests. This included estimating and developing the necessary FB fuel supply and logistics with ample lead time given to Texas AgriLife Research-Amarillo.

Materials and Methods:

Two vendors were contacted for pilot scale testing. Solicitations were prepared defining the tests and desired parametric studies, and addressed Texas A&M's ongoing research efforts to develop effective control strategies for NOx and Hg [http://www1.mengr.tamu.edu/REL/; US Patent # 6,973,883]. The total funds available for pilot scale tests constrained the number of experiments and the number of fuels to be tested. The objectives of the vendor solicitation were to competitively seek pilot scale based tests that provide data on NOx and Hg capture under conditions similar to coal fired boiler burners: Specific topics for tests were outlined with regard to NOx and Hg. The NOx could be simulated in primary combustion systems either using natural gas and ammonia mixture or using coal directly. The Hg (ppb) is produced by burning coal. The desired pilot scale system needed provisions for injecting reburn fuels and overfire air. The pollutant species to be measured by the vendors were NOx (NO2, NO), Hg, and SO2 in addition to CO, CO2, O2, N2 and soot. A requirement was that the ash must be collected and sent for analysis to make sure that fuel was burnt almost completely. Hg measurement methods and techniques were planned to detect 0-100 ppb of total mercury at a sampling rate, accuracy, and precision expected. Techniques capable of measuring the various forms of mercury (elemental, oxidized, particulate bound) were required.

The bids on pilot scale tests were organized so that funds for tests could be shared between funding from Texas Commission on Environmental Quality (TCEQ) as cost sharing towards DOE-Golden Project. A small scale commercial GE research facility located in Santa Ana, CA was available, but proprietary and intellectual property issues arose. Then we contacted Southern Research Institute (SRI), but their pilot scale facility was several times larger than the DOE-NETL-Pittsburgh 150 kWt pilot scale facility. When arrangements were worked out, TEES selected the pilot plant Vendor #2, Southern Research Institute, Birmingham, Alabama.

An out-sourced experimental program was planned, in which a sub-contract from TEES provided access to a commercial pilot scale facility that was used to generate reburn data using processed FB as reburn fuel. Texas AgriLife Research-Amarillo prepared sufficient amounts of fuel material to conduct the planned tests, namely PRB coal and Texas lignite coal as primary fuels (1,200 lbs each). The FB material chosen for this experiment was LA-FB-PC 2006-greenhouse dried, the analyses of which was reported in Table A.5. These materials were hammermilled and pulverized in the Vortec Impact Mill®, and were shipped to the contractor, Southern Research Institute (SRI), Birmingham, Alabama on May 4, 2007.

Pilot scale tests were performed over 2.5 days during May 24, 25 and 30, 2007 in the Combustion Research Facility (CRF) by Dr. Thomas Gale, at Southern Research Institute (SRI), Environment and Energy Department, Birmingham, AL. The purpose of the experiments was to confirm the small-scale experiments performed at Texas A&M University Mechanical Engineering (TAMU/MENG) Department laboratory-scale testing unit. The required reburn fuels were shipped in pallets (**Figure A.13.**).

The one mega watt (1 MW_{th}, thermal) pilot scale facility simulated the flue-gas path from the burner through the particulate collection devices, including a temperature-time profile that matches that of full-scale coal-fired power plants (**Figure A.14.**). The CRF had been designed to simulate the major boiler types in service today–specifically, wall-fired, tangentially-fired, tangentially-fired with overfire air, and low-NOx burner types. We had contracted with them to do the first pilot scale studies on Hg and NOx emissions using feedlot biomass as reburn fuel. Since they did not have reburn system, they had to modify the facility to install one.

<u>Results:</u>
Of the planned pilot-scale tests only one test was actually performed as planned. This pilot scale test had problems with location of reburn injection system from main burner and asymmetric injection. Since Alabama (Galatia) coal used in the main burner contained high Cl, the elemental Hg was almost negligible. Thus, the reduction in Hg could not be attributed to Cl in feedlot biomass. Further, SRI's reburn fuel injection was not symmetric since they radially fired fuel only on one side, while we wanted opposed radial injection. While we had NOx reduction almost 90% in our lab facilities, the reduction they achieved was considerably less. Combustion results showed a further NOx reduction of 75% which was achieved essentially due to staged combustion-like behavior of main burner (with less air) rather than due to reburn injection system.

Figure

Figure A.13. Fuel Pallets Prepared and shipped by Texas AgriLife Research-Amarillo/Bushland for TEES Pilot Scale reburn tests at SRI (Tests on May 24, 25, 30, 2007).

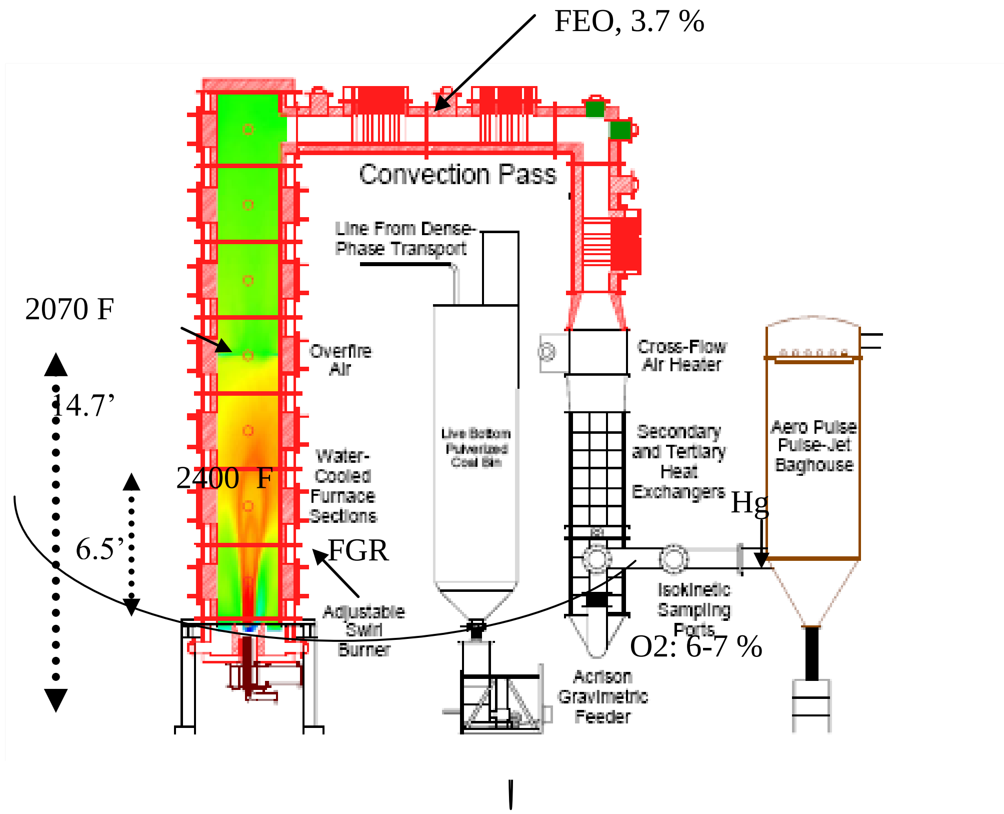


Figure A.14. Schematic of SRI (1 Megawatt) Pilot plant/Combustion Research Facility (CRF) used for reburn experiments using FB.

Due to problems and results of the first-planned reburn pilot plant tests at SRI, it was decided that the second test, which would require modification to the air flow and injection system might not be performed as planned. Thus, plans were made to seek permission from DOE to substitute the second pilot scale test with new tasks which would study the effects of asymmetric and symmetric injection on NOx reduction and effects of injection angles on NOx reduction or the effects of chlorinated char produced by gasification of DB on Hg reduction. It was not confirmed whether this substitution was allowed or was made. In either case, the amount of FB materials already prepared and shipped to SRI by the Amarillo-based feedstock team was sufficient for additional reburn tests.

<u>Summary:</u>
The subtask of preparing and supplying reburn fuel to PI Dr. Annamalai and to his vendor, SRI, on schedule was completed by Co-PI Sweeten and support staff, which included Mr. Kevin Heflin. The reburn pilot plant tests themselves were partially completed with results presented by Dr. Annamalai in Chapter 6 of Volume I. These detailed results will not be repeated herein.

Technology Transfer and Dissemination:
The following research report was prepared and submitted based on the first pilot-scale reburn test as SRI: Kalyan Annamalai, John M. Sweeten, Kevin Heflin and Thomas K. Gale, Pilot-Scale Testing of Coal and Biomass as Reburn Fuels, Task 3: Pilot Scale Tests. Report to Texas Commission on Environmental Quality (TCEQ), July 31, 2007.

References Cited:
Annamalai, K., J.M. Sweeten, M. Freeman, M. Mathur, W. O'Dowd, G. Walbert and S. Jones. 2003. Co-firing of Cal and Cattle Feedlot Biomass (FB) Fuels, Part II: Fouling Results from a 2,500 BTU/lb Pilot Plant Scale Boiler Burner. Fuel 82(2003): 1195-1200.

Task A.7. (KA). Reburn modeling and exploratory studies.
This task was completed entirely by Dr. Annamalai and his graduate students. The protocols and results of this task are provided in Volume I.

Task A.8. (KA). Exploratory overall energy conversion studies.
This task was completed entirely by Dr. Annamalai and his graduate students. The protocol and results are provided in Volume I.

Task A.9. (JS, DP, RDO). Characterization of beef cattle manure combustion ash for value-added uses.

Subtask A.9.1.: Characterize ash from combustion and gasification experiments.

Subtask A.9.2.: Engineering and fertility evaluation of fly ash utilization of combustion ash from fluidized beds, .

Subtask A.9.3: Use of ash in flowable fill mixture.

Subtask A.9.4: **Use of fly ash as a soil amendment to reduce shrink-well capacity of soil was investigated.**

Subtask A.9.5.: Technology Transfer, dissemination and use of information.

Subtask A.9.6: Use of bottom ash and cyclone ash as road surface application for winter weather.

Introduction:
Ethanol producers propose to use energy extracted from manure in 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.

The Task A.9. research was subcontracted by Texas AgriLife Research to Dr. Robert E. DeOtte, Associate Professor of Engineering and colleagues Dr. David B. Parker and Dr. B.A. Stewart at West Texas A&M University, Canyon, TX. To meet the goal of determining the construction properties of the combustion or gasification ash materials, large samples of combustion ash were obtained from a commercial fluidized-bed combustion pilot plant test, which used the un-composted (RM) feedlot biomass (FB) from soil surfaced/high ash (SS-HA) feed pens at Texas AgriLife Research-Amarillo/Bushland, as FB test fuel. (See Table A.1. for analysis of FB feedstocks that was used to generate the combustion ash used in Task A.9.).

The commercial test burn was conducted in July, 2005 by Energy Products of Idaho (EPI), Coeur d'Alene, Idaho, under a contract from Panda Energy Corporation, Dallas, Texas, to obtain design data for the Panda Hereford Ethanol Plant at Hereford, Texas.

Objective:

The fundamental goal of the research for Task A.9. was to identify and explore potential uses for ash produced by combustion of beef cattle manure. The objective of this task was to evaluate alternative value-added uses for ash produced by combustion of feedlot cattle manure as either a construction material or a fertilizer material.

Approach:

The approach used was to evaluate the ash factions from a commercial test burn of characterized FB from Task A.1. above (Table A.1.). The ash fractions were evaluated by physical and chemical tests to determine suitability for a) construction purposes, such as roads or potential reuse as dairy or feedlot paving material, or b) soil amendments, crop fertilizer. 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. The data could be used to identify environmentally acceptable disposal opportunities.

Details of the investigations of FB ash as either a construction material or as a soil/plant fertility source are presented in Appendix C, found in Volume III of this report. A summary is presented herein.

Materials and Methods:

Large combustion ash samples were obtained from a commercial fluidized-bed combustion pilot plant test, which used the un-composted (RM) feedlot biomass (FB) from soil surfaced/high ash (SS-HA) feed pens at Texas AgriLife Research-Amarillo/Bushland, as FB test fuel. The ash residue resulted from combustion or gasification of approximately 19 tons of HA-FB-Raw feedlot manure from a 400-head Texas AgriLife Research/USDA-ARS research feedlot at Bushland, TX from June 2005 pen harvest that was used in the EPI/Panda Energy test burn in EPI's fluidized bed combustion unit, Idaho in July-August, 2005. FB characterization data was presented in Table A.1. above. This test burn produced an array of ash fractions for testing. The FB manure combustion ash fractions included: bottom ash, fly ash, cyclone ash, and baghouse ash.

To meet the goal of determining the useful properties of the combustion or gasification ash materials, the approach by WTAMU (DeOtte et al.) was to evaluate this FB ash fractions to determine whether it is (a) cementitious and/or (b) rich in plant-essential nutrients, making it potentially suitable for recycling either as a paving material or as an inorganic fertilizer. WTAMU evaluated engineering properties relevant to ash use as a paving material and initiated small-scale greenhouse studies to evaluate the use of FB combustion or gasification residues as a fertilizer for field crops typical of the Panhandle and North Texas.

The ash residues were preliminarily tested for engineering properties and leachate chemical analysis by collaborators Dr. David Parker and Dr. Robert DeOtte, West Texas A&M University, for a commercial company interested in building one of more manure-fired plants in the Texas Panhandle. In preliminary work Dr. David Parker, West Texas A&M University, characterized the physical and chemical properties of the ash. The baghouse ash was finer textured than fly ash. The original hypothesis was that the ash would have properties similar to those from lignite and sub-bituminous coals allowing comparable applications.

Preliminary test results showed that the chemical composition makes the ash more similar to a Class F than a Class C ash and the potential applications were 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 was determined to be essentially inert and would be classified as a Nonhazardous Industrial Class 2 waste according to Texas state regulations.

These preliminary test results were used to guide subsequent literature reviews and experimental designs. A literature review was performed on use of ash for road treatments. Next steps included evaluating chemical and physical properties of the ashes for use in sequestering heavy metals and carbon dioxide.

A senior mechanical engineering student at West Texas A&M University was hired in 2006 to initiate the literature review on uses and properties of ashes with physical and chemical characteristics similar to manure ash. The student (Anthony Megel**)** completed the literature review which included: evaluated properties of a) road base material, and b) soil amendments. The literature review suggested several construction possibilities to be explored further, including:

1. Mixing with caliche subsoils to improve plasticity and suitability as a road base material;
2. Mix other amendments with the ash to include gypsum and quick lime, which are not as readily available as the local caliches;
3. Use of ash in flowable fill mixtures for construction. The literature review had demonstrated the similarity between manure ash and coal ashes which have proven suitable in this application;
4. Use of ash as a soil amendment to reduce shrink/swell capacity of soils.

In-depth soils engineering experiments were begun in 2007 at West Texas A&M University. Combustion ash was mixed with caliches, lime, and gypsum to improve plasticity index (P.I.) and suitability as road base material. Experiments included Atterberg limits tests (liquid limit, plastic limit, plasticity index), compressive strength, and cementaceous properties.

Fertilizer potential of cyclone and baghouse FB ash was determined by experiments at WTAMU designed to assess the impacts of FB ash application to soil characteristics and plant growth. This research was co-funded by a separate research grant to WTAMU, with Dr. B.A. Stewart as principal investigator on the grant. A major focal point was phosphorous, which was enriched in the FB ash, but its plant-availability was unknown.

The specific protocols used in the soils/construction engineering and the soil fertility tests are provided in Appendix C, Volume III of this report.

<u>Results:</u>
Engineering properties were identified. Selected results included:

a) Caliches did improve plastic properties of cyclone ash very slightly but not to a meaningful level (PI = 1), Caliches provide initial increase in cementing but could not withstand wetting cycles.

b) Lime did not increase plasticity but it did provide significant increase in compressive strength. Ten percent lime increased compressive strength by more than 50 percent compared with more than did 10 percent addition of Portland cement.

c) Gypsum did not increase plasticity and provided no increase in cementing of ash.

The manure combustion ash did 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 was 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. Results showed that Cyclone ash did not provide effective stabilization with regard to shrink-swell capacity of soil.

Results of physical testing showed that the ash was marginally suitable as a subgrade material for road construction. The ash was not self-cementing; however, because its composition was 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 showed that the ash would be classified as a Nonhazardous Industrial Class 2 waste according to Texas state regulations.

Bench scale studies were completed and demonstrated that with addition of lime, the manure ash was suitable as road base or as flowable fill. Manure ash alone showed promise for flowable fills, based on lab tests. Field tests are obviously required to conclusively determine suitability for these purposes.

Bench scale tests indicated that unprocessed manure bottom ash performed similarly to sand as a treatment for icy roads. Further comparisons with processed coal ash are warranted and samples of such ash were procured from Xcel Energy for comparison. Further tests were proposed in the project renewal proposal should funding become available. The manure ash should be modified to simulate the characteristics of coal ash used for treatment of icy roads.

Results from the soil incubation, sulfuric acid, and greenhouse studies used to evaluate fertility value indicated that a small fraction of the ash phosphorus (P) was plant-available. The agronomic studies indicated there was low or 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 was phosphorous but it was tightly bound and not easily released, even with reduction of pH. The P content of the ash was so low that extremely large amounts would have to be added to the soil to supply meaningful amounts of plant-available P (Darapuneni et al. 2009).

Summary and Discussion:

Chemical analysis showed the ash would be classified as a non-hazardous industrial Class 2 waste, according to Texas Commission on Environmental Quality regulations. Applications of a number of potential uses of manure ash were investigated resulting in a better technical understanding of the issues related to this product of combustion.

Ash produced by the combustion of beef cattle manure was found to have 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 at low rates so the total amount that can be applied was not determined. Care should be exercised in land applications of the ash as it provided no agronomic soil amendment capabilities and if applied too heavily could degrade agricultural properties of the soil.

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. It behaved 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. With proper amendment with lime or Portland cement, the ash can be used in road base and flowable fills. Perhaps the most promising application is a 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. Class C ash from the Powder River Basin has been used to capture and 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. Leachate studies of the ash to determine potential to sequester heavy metals were proposed in the renewal proposal which was not funded.

The physical-chemical characteristics of FB manure ash indicate that potential uses may not be as widespread as those for lignite and coal ash. Further study of the Class F ashes and similarity to manure ash is warranted. The relatively inert character of the manure ash may recommend use as a road surface treatment during ice and snow conditions. Possible co-combustion with other products might yield a chemical composition with better physical properties. Co-combustion with cotton gin trash (CGT) did not yield significantly different chemical composition compared with FB combustion

Further details of the investigations of FB ash as either a construction material or as a soil/plant fertility source are presented in Appendix C, Volume III of this report.

Technology Transfer and Dissemination:

Darapuneni, Murali, B.A. Stewart, C.A. Robinson, D.B. Parker, 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 Plant.* **Applied Engineering in Agriculture**, 25(6): 895-904.

Megel, A. J., D. B. Parker, R. Mitra, J. M. Sweeten. 2006. Assessment of Chemical and Physical Characteristics of Bottom, Cyclone and Baghouse Ashes from the Combustion of Manure. Paper No. 064043, Proceedings, 2006 ASABE (American Society of Agricultural & Biological Engineers), Annual International Meeting, Portland OR, July 9-12. 11 p.

Megel, A.J., R.E. DeOtte, Jr. C.A. Robinson. 2007. Investigation of Economically Viable Co-Products Developed from Ash from the Combustion of Manure. Poster presentation at West Texas A&M University student research competition, April. 1st place poster.

Megel, Anthony J., DeOtte, Robert E. Jr., Robinson, Clay A. 2007. Investigation of Economically Viable Coproducts Developed from Ash from the Combustion of Manure. Paper Number: 074066. 2007 ASABE Annual International Meeting, Minneapolis, MN, June 17-20, 2007.

Student Thesis:

Anthony J. Megel, 2007. Investigation of Economically Viable Co-Products Developed from Ash from the Combustion of Manure. B.S. Thesis, Mechanical Engineering, West Texas A&M University, May 2007.

Peer Reviewed Journal Article to be submitted:

Megel, A.J., R.E. DeOtte, Jr., D.B. Parker, C.A. Robinson, B.A. Stewart, M. Darapuneni. 2010. *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. (In preparation).

Industry Interaction:

Interaction was developed with Milestone Architectural Ornamentation, Inc., of Amarillo, which makes molded architectural products using sand and various chemical products using their patented process. Milestone had inquired of this research from us about the possible use of manure combustion ash in lightweight concrete architectural features. The WTAMU (DeOtte) and Texas AgriLife Research-Amarillo team (Sweeten) met with Milestone, Inc. This potential development was predicated on a future continuing supply of combustion ash, the source being the designed FB-fired Panda Ethanol Inc., which was predicted to be completed and come on-line in 2008 or 2009. This plant would produce approximately 20-30 tons of FB ash product per hour. The 2008 bankruptcy and eventual sale of Panda Ethanol which would have furnished the ash, postponed developments beyond the term of this USDOE grant. Reportedly, this plant was sold to Murphy Oil, Inc., but to our knowledge has not gone into production as of 2011.

Task B – Anaerobic digestion methods (CE, BA)

Task B.1. (CE, SM, BA). Engineering analysis of a commercial digester.

Subtask B.1.1.: Intensive monitoring scheme to assess the net energy production of a new covered lagoon anaerobic digester and phosphorus reduction system on a 900-cow, commercial dairy in Hamilton County, TX (in the Bosque River Watershed).

Introduction:

The purpose of this task was to assess the performance of a covered lagoon type of anaerobic digester (AD) 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 manure management demonstration project focusing on phosphorus reduction at the Broumley Dairy. The demonstration project involved several governmental agencies under the coordination of the Brazos River Authority. The phosphorus reduction system, including the covered lagoon anaerobic digester began operation in early 2006. 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 DB composition and flow rates on the inputs and outputs for the digester to determine its energy production efficiency under different operating conditions. One of the means of doing so would be to study volatile solids inflow, outflow, and reduction, and relate this to measurement biogas production. The system was equipped for the demonstration project with flow meters to measure inflow 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.

Objectives:

1. Monitor the composition and flow rate of the biogas stream and the lagoon influent/effluent to and from the digester.

2. Monitor power output biogas to determine energy conversion and system efficiency.

Approach, Methods and Materials:

The investigators, including Drs. Cady Engler and Saqib Mukhtar, met with the project coordinator from the Brazos River Authority (coordinating agency for the project), the system designer, and others involved with the project to discuss gas monitoring and energy analysis for the digester. This project used the Broumley Dairy which had a covered-lagoon type digester with a design capacity of 916,000 gallons (processing manure from 900 cows). Design parameters included hydraulic retention time of about 21 days with projected output of 10^9 cu ft/year of produced biogas having a heat value (HV) of 650 BTU/cu ft (or $650*10^9$ BTU total heating value produced). The digested manure solids were to be separated and used as compost.

Instrumentation specifications were developed for biogas analysis to be installed at the dairy to monitor production and composition of biogas from the covered lagoon AD. Once installed, monitoring of biogas production and usage were to begin. Also, the plan was to develop mass and energy balances to determine the efficiency of energy recovery from the digester.

A biogas analyzer and data acquisition system was installed at the Broumley Dairy to continuously monitor the methane content of the biogas stream. These were installed in June 2006 along with a data logger that was made available from another project to begin collecting data for this task. The produced biogas was to be scrubbed for H2S, then compressed and supplied to a distribution pipeline. At that time the AD 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.

Results:

The commercially-installed covered lagoon AD system did not operate properly due to various technical issues with design, maintenance and/or operation. Sporadic operation of anaerobic digester at the dairy operation did not allow collection of reliable data on biogas production. Throughout 2007, 2008, and 2009, the team continued waiting for digester operation so that the team could commence biogas monitoring immediately upon resumed steady-state operation. The team members developed alternative methods to obtain data that could include construction of a prototype digester system that would be under their control (see also Task B.2.).

Summary:

A robust biogas monitoring, analysis and data analysis plan was implemented at a 900 head dairy farm in Central Texas. It was not possible however, to gather any reported data on performance of the covered lagoon anaerobic digestion system. The operational difficulties described herein significantly delayed the research until this DOE project had ended, at which time, funds and manpower were no longer available. The planned Task B.1. could not be completed due to factors obviously outside the control of the research team. Nevertheless, the appropriate section of the Final Report was completed in 2009 (see Appendix D, Volume III) as summarized herein.

Subtask B.1.2.: Whole farm energy analysis when operating the digester.

Introduction:

The primary purpose of this sub-task was to conduct an analysis of all forms of energy usage throughout the Broumley Dairy in Hamilton County, Texas 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, 12-14 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 on-site energy conversion processes such as thermochemical conversion of DB for process heat; anaerobic digestion of manure to produce biogas; or to benefit various energy conservation practices with baseline data.

Objective:

1. Determine all energy inputs and outputs from 12-14 dairy facilities to include electrical usage, natural gas/propane usage, gasoline or diesel.

2. Provide baseline data on dairy energy use on dairy farms to help determine the feasibility of small scale onsite power generation.

Approach, Methods and Materials:

Interviews were conducted with the 12 Texas dairies that were used for dairy manure (DB) sample collection and characterization in previous work (Tasks A.1. and C.2.) plus the dairy that had the commercial anaerobic digestion system (Task B.1.1.). Energy use surveys were sent to these 13 dairies (see Appendix D, Volume III for the questionnaire). The on-farm energy supply sources included electricity, gasoline, diesel, propane and natural gas.

Upon follow-up, it was found that in the Central Texas region, one dairy had ceased operation since the last set of manure samples were collected and yet another facility did not keep records of energy use. The dairy with the anaerobic digester was keeping such records and hence was added to the survey effort.

In the Texas Panhandle, one of the open lot facilities had changed ownership subsequent to our last sampling and did not have the energy use records for this analysis; therefore a different open lot dairy facility was added as a replacement. Another cooperator for the DB sampling portion of the study was in the process of a major modification to the housing facilities and declined to cooperate in the survey. Energy use surveys were also conducted on two pasture dairies in Northeast Texas that were sampled in the DB manure quality survey.

To achieve the desired number of survey respondents, additional dairies were recruited. A total of 7 dairies were surveyed in California's San Joaquin Valley. This allowed for a broader comparison of dairy energy use across the Western United States, e.g. Texas vs. California dairies. One California operation consisted of 5 dairies all within five miles of each other. Each of these dairies housed 800-1,500 cattle. The other 2 California dairies were operated by a single company and were located across a public road from each other; these facilities housed 2,000 - 3,500 cattle.

An extensive literature review of combustion systems used to fire coal-water slurries, MSW, and tar sands was conducted along with design work on an on-site conversion system for DB, in order to develop a thermochemical conversion system that would be a suitable scale for on-site conversion and energy utilization.

Results:
Dairy energy usage numbers were compiled from survey data. Some of the data produced anomalous results. Further analysis showed that the method of acquiring electrical bills that were several months apart and using net meter readings produced inaccurate representations of the actual energy usage, due to meters that exceeded their maximum readings multiple times in a year and reset to zero. Additional information was required to obtain correct electrical usage data on all the dairies.

Total energy usage ranged from as low as 464 kWh per year per animal (kWh/yr/hd) for a pasture dairy in Northeast Texas, to as high as 1,637 kWh/yr/hd for a hybrid facility in Central Texas. Where possible, the electricity usage at the dairies was allocated to four main energy sinks: the milking parlor, the animal housing areas, feeding, and manure management. Generally, milking and housing components dominated the electricity usage for hybrid dairies, with the milking parlor being the primary consumer of energy for the open- lot facilities.

In addition, the estimated daily potential energy availability from manure (25 kWh/day/hd) was determined to be much greater than the average daily on-farm energy requirement (3.2 kWh/day/hd). This indicated the possibility of adopting on-site manure to energy conversion systems. Analysis showed that renewable energy conversion systems with more than 15% overall conversion efficiencies could be considered for on-farm energy production alternatives.

Summary:
A survey of 14 dairies in Texas and California was conducted to determine their total energy use on an annual basis. The goal of the survey was to evaluate the effect of production and management processes on energy consumption. 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. Milking centers and dairy cattle housing were found to be the major users of electricity for hybrid dairies, while the milking parlor was the chief electricity energy user at open lot dairies. Newer dairies were more efficient in electrical energy use than older facilities. A significant amount of energy could be saved by upgrading facilities with newer and more energy efficient equipment.

The total energy used on facilities varied widely with the type of operation, e.g., pasture, open-lot, or hybrid (a combination of open-lots and free-stall) systems, as well as with the relative age of the facility. The energy usage survey was conducted, and those results are described in this report under Task I, Volume III. Manure-to-energy projects could be feasible technically for on-site use if the overall efficiency for conversion and utilization were 15% or greater. Since the covered lagoon digester and electrical generator did not operate after the biogas monitoring system was installed, no data were collected to evaluate the potential contribution of biogas energy to the overall dairy operation.

Technology Transfer and Dissemination:
A technical paper was written for presentation to the American Society of Biological and Agricultural Engineering meeting held in Rhode Island from July 1-3, 2008. A manuscript was developed for Transactions of the ASABE. This paper reported on the whole-farm energy use surveys from the 14 respondent dairy farms.

Task B.2. (BA): Building research capacity for anaerobic digestion of mortality biomass.

Subtask B.2.1: Build and test a research-scale, plug-flow, mesophilic, anaerobic digester in the Texas Panhandle for use with both dairy and feedyard manure.

Subtask B.2.2.: A second research-scale anaerobic digester will be built alongside the original digester to provide parallel treatments (viz. Treatment vs. control) in terms of substrate, operating variables and loading rates.

Introduction:
The research team determined that it would be advantageous to design, construct and operate their own pilot-scale anaerobic digester (AD) system to develop data on biogas production from FB, DB, MB or other available feedstocks in Texas. The type of anaerobic digester selected was a plug flow unit to be operated at mesophilic conditions. The feedstocks to be tested would be selected for experimental purposes to include with dairy and/or feedyard manure, composted horse manure/wood shavings, waste feed, mortalities, or abbatoir waste (mainly viscera and un-harvested organ meats).

Objectives:
1. Design, fabricate, and operate a pilot-scale digester unit for on-site experiments and demonstration purposes.

2. Evaluate the digester performance using selected feedstocks at appropriate feed rates, flow rates, and feedstock compositions by monitoring gas yield, gas composition, and volatile-solids reduction.

Approach, Methods and Materials:
A trailer-mounted anaerobic digester system was designed as a pilot-scale mesophilic plug-flow anaerobic digester to be built and deployed at the USDA-ARS Conservation and Production Laboratory at Bushland, TX. This pilot digester was to be installed adjacent to the Texas AgriLife Research/USDA-ARS research feedlot (400/hd beef cattle capacity) to take advantage of feedlot biomass substrates close at hand, as well as dairy biomass from nearby dairies, horse manure from the TAMU Equine Center, or selected commercial meat processing waste products.

As required by USDA-ARS, the host agency for our digester, we submitted our AD system design and performance specifications for evaluation under NEPA. Upon ARS reviews, NEPA approval was granted in fall 2005. NEPA emissions targets were predicated on the successful integration of a high-performance gas flare into the biogas exhaust line.

The pilot-scale, trailer-mounted digester was designed for a slurry volume of 155 ft^3, a solids residence time of 21 days, an operating liquid depth of 30”, and an insulation value of R-38. To maintain mesophilic conditions, digester design temperature would be maintained between 99 and 101° F with three removable, copper-helix heat exchangers, with hot water supplied by an 80-gallon, 9kW electric water heater. Fabrication of the 316SS stainless steel digester began in October 2006, while fabrication and testing of copper-tubing heat exchangers was delayed until July 2007 (see Figures B.2. (a) and (b)).

Concrete pads were poured in 2006 to support the water-supply tank and the digester/trailer assembly (see Figure B.1). The surrounding project site was finished with crushed concrete.

The interior vessel with structural steel exoskeleton was completed in January 2008. Sensor and plumbing fittings, flanges, and access ports were fabricated spring-summer 2008. Temperature, oxidation-reduction potential (ORP), and pH sensors were purchased during fall 2008. Wireless (IEEE 802.11g) networking infrastructure linking the digester pad to the new Environmental Quality & Natural Research Program (EQNRP) headquarters laboratory was completed in spring 2009. Insulation, installation, and preliminary testing were expected in late fall/early winter 2010.

During the summer of 2008, bids were acquired for the purchase of a high-performance biogas flare meeting the specifications of our digester design and our NEPA emissions targets. The lowest bid obtained exceeded our available budget by $20,000, and because of significant price increases for metal components (SS sheeting, etc.) during 2008, we were not able to purchase a flare meeting our performance specifications.

The effluent side of the system would include incorporating digested sludge and supernatant discharge into active compost piles for final stabilization, drying and disposal via either land application or thermochemical gasification.

<u>Results:</u>
The rate of heat output by the coil heat exchangers was compared to the rate of temperature rise in the tank to compute the effective heat-transfer coefficient of the copper coil (Figure B.3). Exchanger calibration was in its initial stages as of January 2008.

For reasons related to lack of funding to purchase components meeting our performance specifications, coupled with delays in design/fabrication, the facility was completed, but feedstock loading did not occur until after the USDOE grant had expired. Because startup and stabilization of an AD system is a time-intensive process occurring over many months in order to gather the baseline gas production data from just one feedstock and loading rate, the planned operational and experimental phases did not occur as planned.

<u>Summary:</u>
This Sub-task (B.2.1.) was partially completed. The plug-flow mesophilic digester system was designed, fabricated and installed on-site. An experimental phase was not launched due to time and funding constrains. The system could be finished for NEPA purposes (i.e. adequate gas flare) and placed in operation based on funding from future grants of adequate scope and size.

Sub-Task B.2.2. was not attempted due to time constraints and lack of funding.

Technology Transfer and dissemination:
A quarterly meeting of the DOE project investigators and the Project Industry Advisory Committee was held in Amarillo at the Texas AgriLife Research and Extension Center on June 28, 2006. Along with that meeting, a tour of the AD system site and some of the fabricated components was provided.

Figure B.1. Finished concrete pads and water-supply tank for anaerobic digesters at the Bushland Texas AgriLife Research/ARS feedlot.

Figure B.2(a)

Figure B.2(b)

Figure B.2 a-b. Preliminary heat-exchanger tests, Bushland, TX.

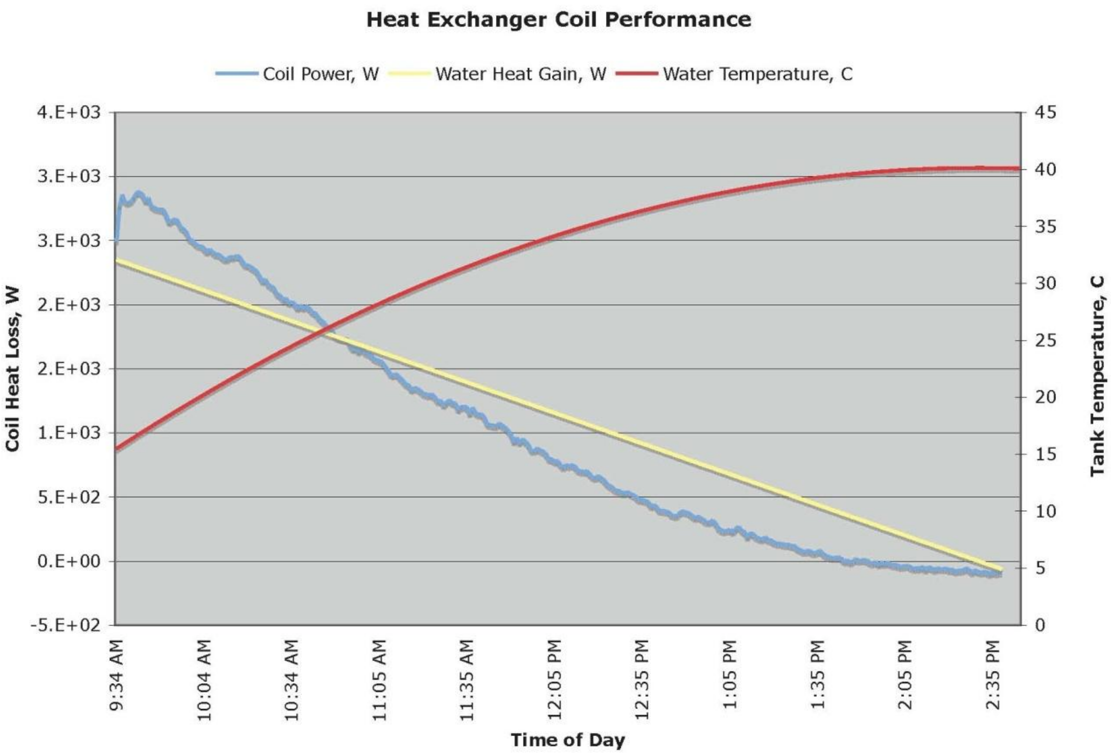


Figure B.3. Preliminary performance test of a single, helical, copper-tube heat exchanger.

GOAL 2 – BIOMASS ENGINEERING

Task C. Biomass Characterization and Inventory (SM)

Task D. Biomass Handling Methods (BA)

Goal 2 – Biomass Engineering

Task C – Biomass characterization and inventory (SM)

Task C.1. (SM, SC, JS): Dairy biomass (DB) characterization survey.

Task C.2. (SM, SC): Database development for DB as energy feedstock.

Task C.3. (SM, SC): Conduct a robust analysis of the ash content in the DB.

Task C.4. (SC, SM): Predicting fouling and slagging behavior of dairy biomass and cotton gin trash (CGT) during combustion.

Introduction:
The Bosque River watershed in Central Texas implemented a Total Maximum Daily Load (TMDL) program for P after it was determined by the Texas Commission on Environmental Quality (TCEQ) that runoff from land application of DB produced excessive P levels in the streams of the Bosque River watershed. The TMDL program set a goal of composting and removing 50% of the DB solids from the watershed for beneficial use outside the river basin. One possible use of the excess biomass was considered off-site thermochemical conversion of biomass for energy generation.

Based on prior work by the research team, reasonably good databases already existed regarding characteristics of beef feedlot manure and poultry litter for thermochemical conversion. However, similar data were scarce for dairy manure (DB), which typically is harvested in several forms (solid, semi-solid, liquid, slurry, etc.) from paved or un-paved corrals, free stall barns, feeding alleys, milking parlors, solids separators, or composting (with or without carcasses). Therefore, work included characterization of dairy biomass fuels for subsequent pilot-plant testing of appropriate conversion technologies such as identified in Task A (thermochemical conversion and direct combustion) and Task B (anaerobic digestion), as presented above.

Research under this Task was conducted under four major tasks focused on dairy cattle manure biomass (DB). These tasks were conducted concurrently using similar personnel, facilities and equipment. Details of methods and results are given in Appendix D, Volume III of this report. A summary of these tasks, background, objectives, approaches, and results follows.

Objectives
The goal of this study was to evaluate the manure characteristics of several representative confined dairy farms in Central Texas for possible input for co-firing in a coal power plant in Texas. The specific objectives were as follows:

a. To determine the ultimate, proximate, nutrient and trace metal properties of representative DB sources to assess potential value for co-firing in coal fired power plants.
b. To conduct an inventory of DB handling techniques that result in the most efficient harvesting of bioenergy feedstocks as well as manure nutrients from dairies.
c. To determine transport distances between dairies in the Bosque River watershed and regional coal-fired power plants using current dairy and power plant location databases.
d. Conduct a robust analysis of the ash content in the DB and relate the mineral ash content (Al203, CaO, Fe203, MgO, MnO, P205, K20, SiO2, Na2O, SO3, TiO2) to slagging characteristics for dairy biomass in comparison with cotton gin trash.
e. Predict fouling and slagging behavior of dairy manure (DB) and cotton gin trash (CGT) during combustion.

Materials and Methods:
Mr. Barry Goodrich, a Research Associate in the Department of Biological and Agricultural Engineering (BAEN), Texas A&M University, College Station, gathered information for DB sampling at dairies in the Bosque and Leon River watersheds of Central Texas, Northeast Texas and in the Texas Panhandle. Twelve (12) dairies were selected as being representative of the facilities in the respective regions, i.e. Central Texas (n=6), Texas Panhandle (n=4), and Northeast Texas (n=2). These 12 dairies represented two size categories defined as (up to 500 lactating cows) and: large (2,000 or more lactating cows). They also represented 3 types of dairies which were defined as: free-stall, open-lot, or hybrid systems. These 12 dairies were selected to collect representative samples of manure, process generated wastewater and feed stuffs for thermal and physicochemical process characterization and potential utilization.

The sampled dairies in the Central Texas region consisted of 4 hybrid dairies (having both open-lots and free stall barns) and 2 open lot dairies ranging in size from 1,500 to 2,500-head. The Panhandle region dairy selection consisted of 2 hybrid facilities and 2 freestall facilities, all with more than 3,000 head. The dairies in the Northeast region of the state were small pasture dairies with 300 head each. Table C.1. shows a summary of the 12 dairy facilities where DB was sampled.

Table C.1. Summary of dairy facilities sampled for DB analysis.

Region	Dairy	Head Count	Facility Type	Feedlane Manure Removal
Central Texas	C1	2500	Free Stall Vacuum	Vacuum
	C2	2200	Free Stall	Scrape
	C3	2100	Open Lot	Flush
	C4	1500	Hybrid	Flush
	C5	1500	Hybrid Vacuum	Vacuum
	C6	1500	Open Lot	Scrape
Northeast	E1	300	Pasture	N/A
	E2	300	Pasture	N/A
Panhandle	P1	4000	Hybrid	Scrape
	P2	3000	Open Lot Flush	Flush
	P3	3500	Hybrid	Flush
	P4	4000	Open Lot	Scrape

The DB streams that were sampled included open lot scrapings, free stall flush water, vacuumed manure, aged manure solids, lagoon sludge, and mechanically or gravitationally separated solids. Samples were collected in the winter and summer in order to quantify the variability of the biomass throughout the year. 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 was done for each of the triplicate samples. In all, more than 360 samples were collected over 2 seasons from 7 waste streams at 12 dairies having different sizes and manure management systems.

Sample Collection, Preparation & Analyses
Initial dairy manure/biomass sampling began in December, 2005, and sampling continued through February, 2006. Summer 2006 sampling was subsequently completed, followed by Winter 2006 -2007 sampling events.

Proximate, ultimate, and nutrient analyses of these DB samples were conducted to determine heating values, moisture, ash, volatile matter, and elemental composition. Standard ASTM analytical procedures were selected for manure-based biofuels conducive to standard procedures applicable to coal analysis. Other standard methods investigated for these materials included U.S. DOE Biomass Characterization Standards. A commercial lab was selected to receive samples for ultimate and nutrient analysis. Equipment was purchased to complete in-house portion of analysis, including a Bomb Calorimeter for testing high moisture biomass fuels.

Samples were prepared for analysis for in-house analysis or shipment to the selected commercial lab. Protocols were developed for in-house biomass analyses and for processing large number of manure samples over a wide range of moisture contents. The standard operating procedure for in-house HHV analysis of dairy manure was developed for commencement of analysis of all samples with the bomb calorimeter. Energy content measured as higher heating value (HHV) analysis was completed at BAEN/TAMU.

The ultimate analysis of the various streams of DB was conducted by Huffman Labs of Golden, CO. The ultimate analyses included dry matter, carbon, hydrogen, nitrogen, oxygen (by difference), sulfur, and ash content. Proximate analysis and higher heating value (HHV) analysis for these samples was done in-house at BAEN according to ASTM standards. Student workers were hired and trained on the operation of the analytical equipment, working on the volatile matter analysis of the DB. The BAEN laboratory conducted the higher heating value (HHV) analysis using ASTM E711-87.

DB samples from the 2005-2006 winter sampling campaign were sent for external analysis. The exception was the lagoon samples, which consisted of greater than 98% moisture, leaving very little material for commercial analysis after drying. Some highly diluted samples (e.g., lagoon effluent) from the same source had to be combined to provide enough solids for analysis.

Moisture content was determined for all samples by drying at 105° C to a constant weight according to ASTM E1756-01. A modification was made to the procedure that allowed for larger samples sizes. This was done to allow for further analysis to be completed on the dried sample after moisture determination. Due to the heterogeneous nature of DB, larger samples also allowed for more representative samples to be analyzed.

Of particular importance for effective thermal conversion of DB was the ash content and constituent analysis of the ash. The high ash content in biomass may create slagging and fouling problems upon heating and subsequent cooling on conveying surfaces depending on ash constituents. Ash contents less than 10% are normally acceptable. Those more than 20% may require increased maintenance of conveying equipment (Goodrich et al. 2007). The most promising waste streams for energy conversion were identified by their relatively low ash content (e.g. 40% d.b. or less), compared to other waste streams.

Ash content (% dry basis) was determined using ASTM E1755-01. The samples were once again dried to a constant weight in order to quantify the moisture absorbed by the sample during grinding. The adsorbed 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.

Nutrient analysis was performed by Texas AgriLife Extension Service's Soil, Water and Forage Testing Laboratory in College Station. A complete nutrient and trace metal analysis was conducted on all samples.

Ash analysis of animal manure (DB) was determined in relation to its slagging and fouling potential, and in comparison with slagging and fouling potential for cotton gin trash (CGT). Mechanical strength of the DB or CGT ash pellets (psi) versus exposure temperature was used as an indicator of slagging and fouling potential. The constituent analysis of ash was determined by Huffman Laboratories for dairy manure (DB) samples taken from various source streams that were described in Task C.1. Ash analysis included Al2O3, CaO, Fe2O3, MgO, MnO, P2O5, K2O, SiO2, Na2O, SO3, TiO2.

Numerous scanned electron microscope pictures of DB pelleted ash exposed under different thermal conversion temperatures were made. To perform Scanning Electron Microscope (SEM) analysis of dairy manure (DB) ash, ash samples of manure (DB) and cotton gin trash (CGT) were heated at temperatures of 550, 600, 700 and 800°C for four (4) hours. Additional ash samples of CGT were also heated at 900°C for the same length of time. Ten (10) g 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.

Results of DB Analyses:
Results of ultimate analysis for three types of DB are shown in Figure C.1. (scraped solids from open-lot dairy pens), Figure C.2. (vacuum-truck collected DB from paved alleys), and Figure C.3. (separated solids from mechanical screens or gravity settling basins). The following designations were used in Figures C.1 through Figure C.6.: Large = dairies with >2,000 cows; Small=dairies with <2,000 cows; Winter=Winter sampling; Summer=Summer sampling.

The ultimate analysis was used to determine the most promising waste streams for thermochemical conversion by analyzing the ash and moisture contents. The lowest ash content of all sources was the mechanically separated solids (<10% ash, dry basis). These solids were primarily composed of undigested fibrous materials from the manure. However this system still required a large anaerobic treatment lagoon for the liquid manure that passed through the separation system.

The most promising source of DB appeared to be through a vacuum truck collection system at facilities that use composted manure as their bedding source (rather than sand bedding). This significantly reduced the ash content while simultaneously removing as much as the phosphorous as possible. This system also reduced the size of the required anaerobic treatment lagoon(s) due to reduced volatile solids loading in wastewater influent.

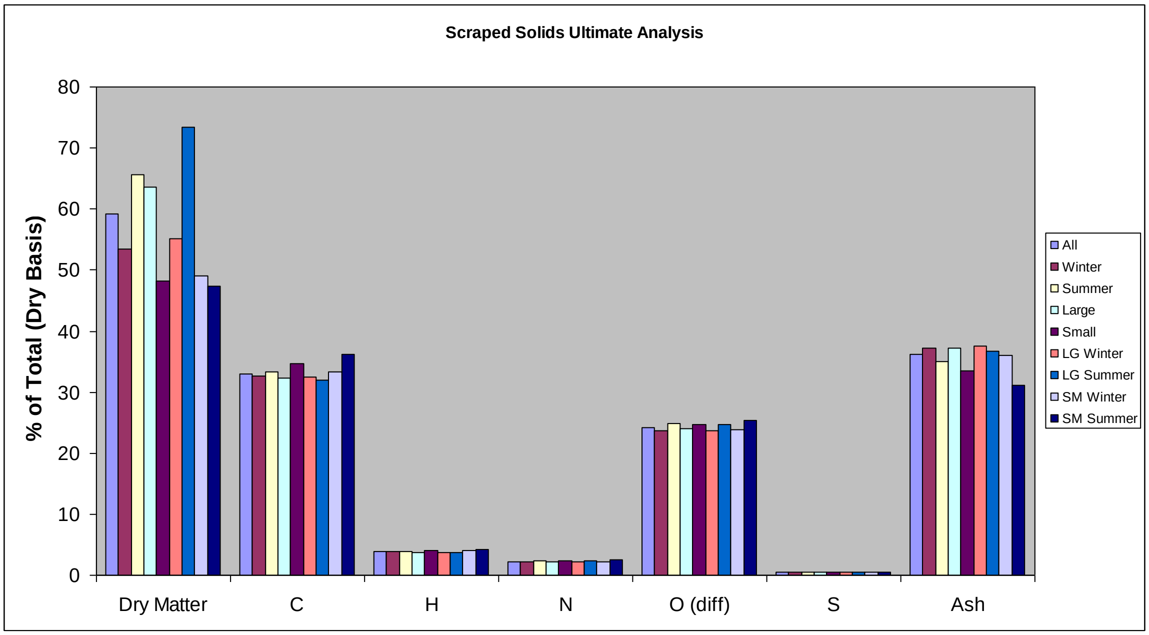


Figure C.1. Ultimate analysis of scraped solids from open-lot dairy pens.

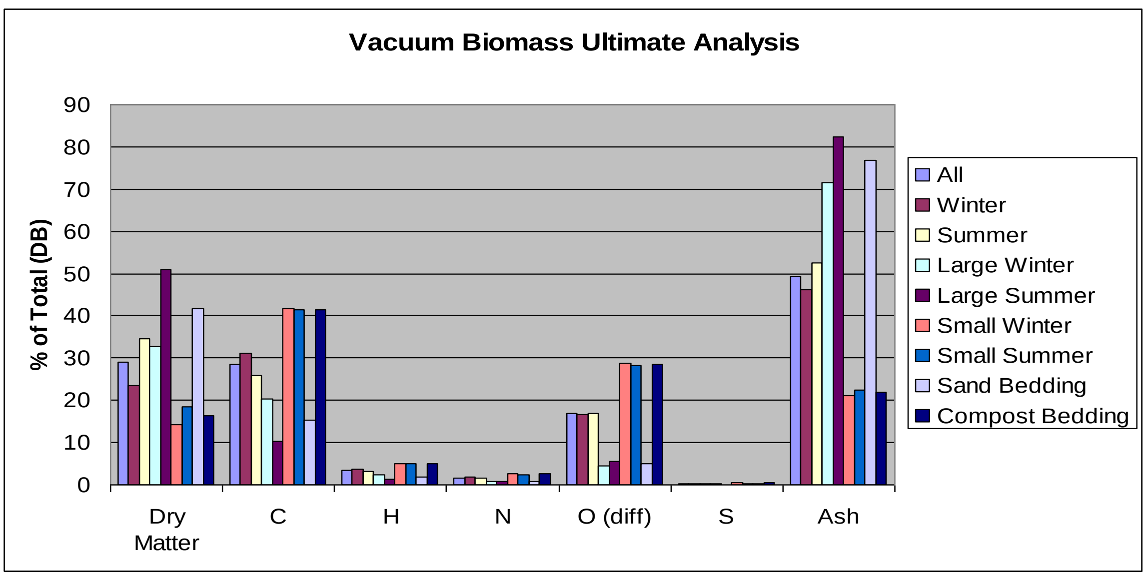


Figure C.2. Ultimate analysis of vacuum-truck collected dairy biomass from paved barns and alleys.

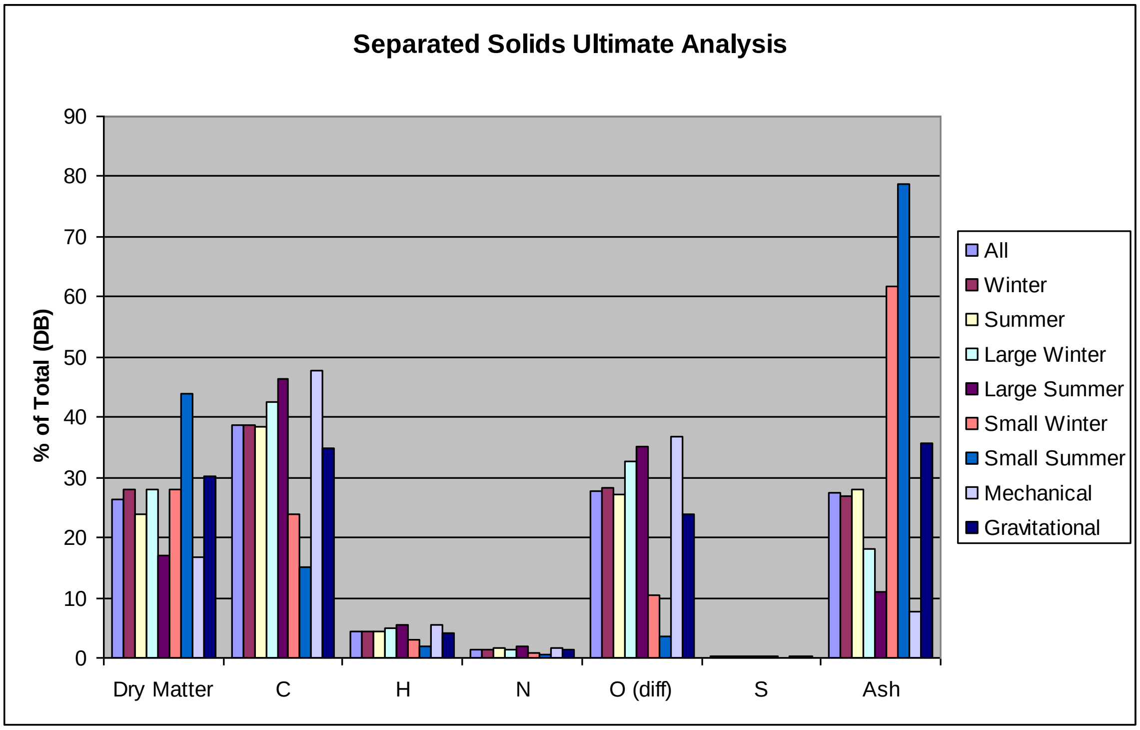


Figure C.3. Ultimate analysis of mechanically or gravity separated solids.

The HHV of the dairy biomass is shown in Figures C.4, C.5, and C.6 for the same waste streams as the ultimate analysis above. The three categories presented are HHV-dry basis, HHV-dry ash-free (DAF), and HHV as-received (AR).

Three dairy DB streams showed to be the most promising as a co-firing fuel for various reasons. The vacuumed solids from freestall dairies varied greatly in nature depending on the use of DB compost or sand bedding in the freestall areas. The ash content varied between 22% (compost bedding) to 79% (sand bedding). Separated solids also showed promise due to the consistency of the product produced from each operation as well as the relatively low ash content. Finally, scraped solids from open lot dairies and exercise pens at freestall dairies showed promise due to the much higher quantity available for conversion relative to other dairy manure sources, although these sources have much higher ash content which could lead to difficulties in certain thermochemical conversion process.

Vacuumed biomass was collected from Dairies C1 and C5 in Central Texas. Dairy C1 used sand bedding in their freestalls, while dairy C5 used composted manure. There was a clear difference in the quality of the manure collected at these locations as illustrated in Table C.2., which shows a summary of the results for all DB streams.

Figure C.7. shows a comparison of the aggregate HHV values for all the DB streams for all dairies sampled. The cattle feed was included in the analysis for baseline comparison. The HHV from the vacuumed DB/compost bedding was significantly higher than for vacuumed/sand bedding DB, both on an as received (AR) basis, and on a dry basis. However, on a dry-ash free (DAF) basis, the samples collected from the dairy with sand bedding had a higher HHV. This may have resulted from the lower HHV of compost contributing to the HHV of the compost bedding, whereas the HHV on a DAF basis only contained fresh manure at the sand bedding facility.

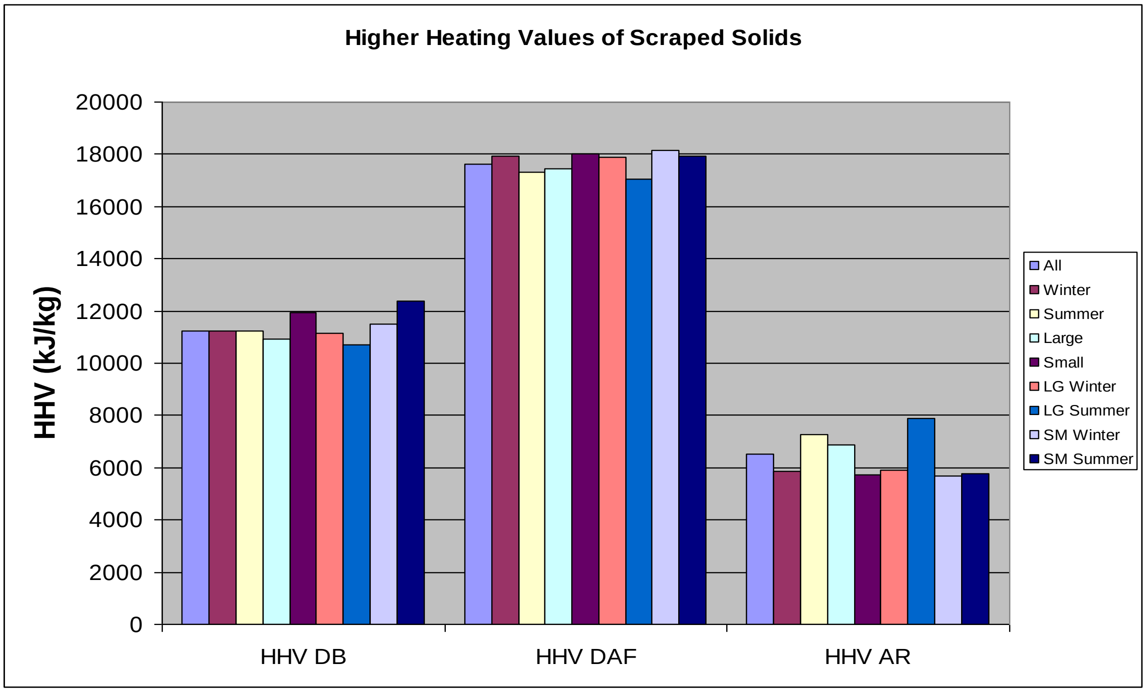


Figure C.4. Higher heating values (HHV) of scraped solids from open-lot dairy pens on dry, dry-ash-free or as-received basis. (Conversion factor: 1 BTU/lb = 2.326 kJ/kg).

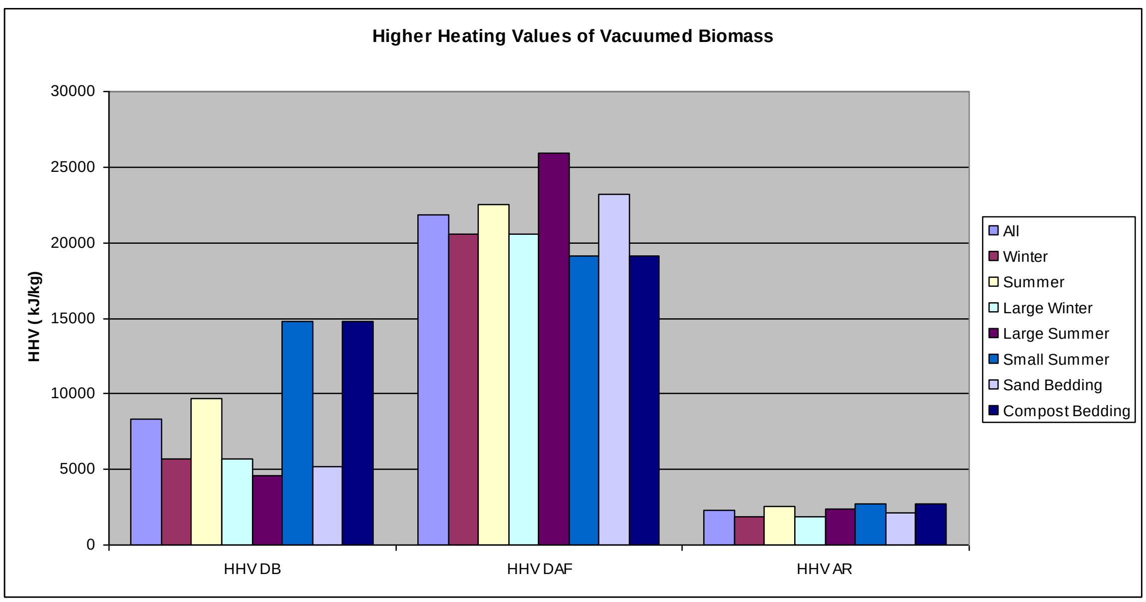


Figure C.5. Higher heating values (HHV) of vacuumed dairy biomass from free-stall barns and alleys on dry, dry-ash-free, or as-received basis.

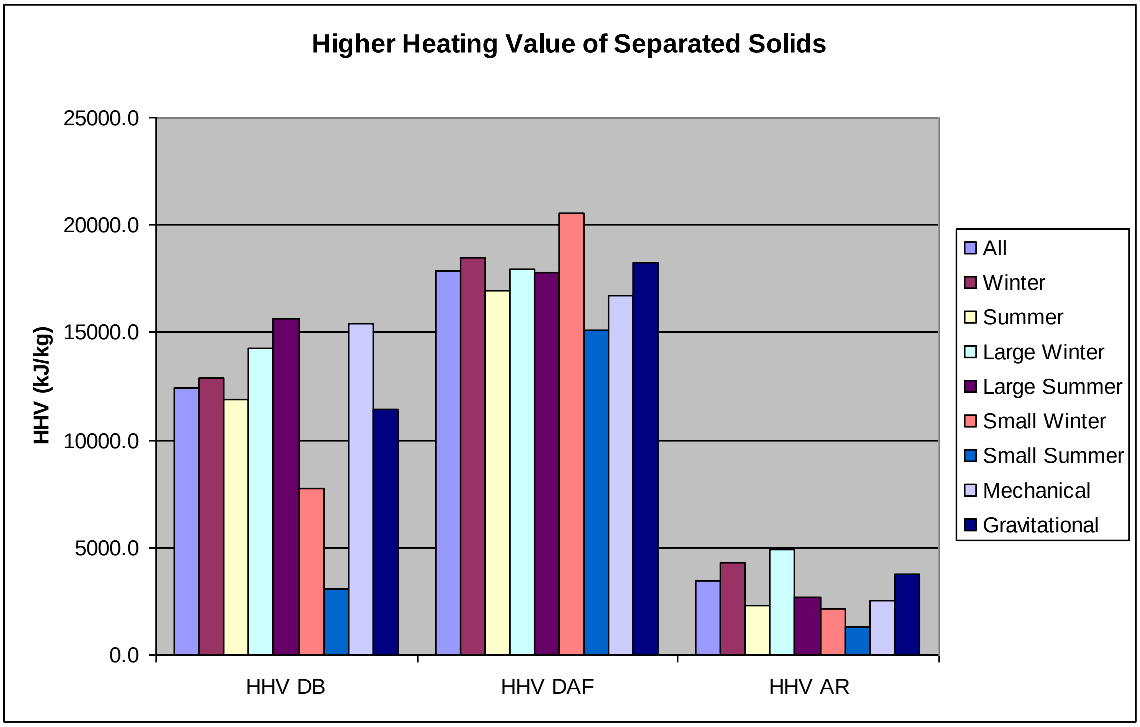


Figure C.6. Higher Heating Value (HHV) of Mechanically-or Gravity Separated Solids from dairy manure wastewater streams; HHV is expressed on dry, dry ash, free, or as-received basis.

Table C.2. Ultimate, high heating value and ash analysis of DB. (The elemental analysis is reported on a dry basis.)

Ultimate Analysis Parameters		Vacuumed w/ Sand Bedding n = 9 Mean ± SD	Vacuumed w/ Compost Bedding n = 6 Mean ± SD	Mechanically Separated Solids n = 9 Mean ± SD	Gravitationally Separated Soilds n = 24 Mean ± SD	Scraped Solids n = 81 Mean ± SD	Feed n = 69 Mean ± SD
Moisture	% w.b.	52 ± 10.0	84 ± 2.4	83 ± 2.9	70 ± 20.1	41 ± 22	41 ± 10.1
Carbon	% d.b.	13 ± 5.3	42 ± 0.7	48 ± 0.43	35 ± 12	33 ± 5.87	45 ± 3.32
Hydrogen	%	1.66 ± 0.6	5.04 ± 0.2	5.54 ± 0.14	4.10 ± 1.40	3.92 ± 0.68	5.58 ± 0.42
Nitrogen	%	0.75 ± 0.1	2.58 ± 0.2	1.71 ± 0.30	1.34 ± 0.54	2.29 ± 0.48	2.66 ± 0.29
Oxygen	%	4.97 ± 1.8	29 ± 0.6	37 ± 1.38	24 ± 13	24 ± 4.72	37 ± 2.81
Sulfur	%	0.16 ± 0.0	0.42 ± 0.1	0.36 ± 0.03	0.23 ± 0.15	0.51 ± 0.12	0.29 ± 0.05
Ash	%	79 ± 5.9	22 ± 1.1	8 ± 1.05	36 ± 27	36 ± 12	9 ± 6.58
HHV	kJ/kg	4845 ± 932	14782 ± 269	15448 ± 520	11430 ± 4873	11339 ± 2233	15759 ± 1380
HHV DAF	kJ/kg	23899 ± 4644	19091 ± 451	16753 ± 525	18217 ± 3727	17631 ± 1655	17304 ± 2409
HHV AR	kJ/kg	2254 ± 437	2733 ± 201	2548 ± 499	3768 ± 3329	6420 ± 2489	9141 ± 1214

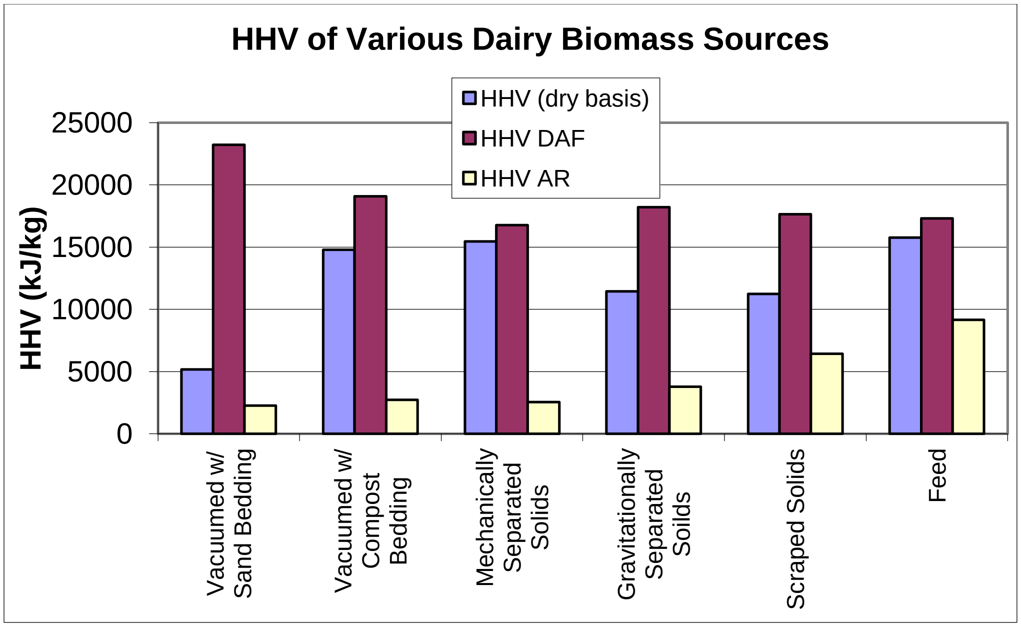


Figure C.7. HHV of various DB sources and feed.

Another method used to remove the manure from the feed lanes at a free stall dairy was to deploy large volumes of flush water multiple times daily to move the manure solids by gravity to the collection point. The flushed effluent was then processed through a solids separation system. The solids were separated from the water either mechanically or by gravitational settling. Mechanical separation involved pumping the flushed effluent across an inclined screen to separate out the larger particles, which fell off the front of the screen, while liquid drained through the screen into the lagoon. This process occurred on a relatively continuous basis due to the routine flushing of the freestalls.

Gravitational separators collected the effluent in large gently sloping shallow settling basins allowing it to slow down and the solids to settle out. In hydraulic theory, the carrying capacity of solids in water is an exponential function of the water velocity. While collecting samples of the solids at the bottom of these basins for analysis was difficult due to their size and configuration, the dairies had recently removed the solids and piled them for drying, allowing for representative samples to be collected from dewatering piles.

Finally, scraped solids from dairy corrals were identified as a promising source of DB due to their similarity to the scrapings collected from beef cattle feedlots. Sweeten et al. (2003) have provided data on the characteristics of feedlot biomass, as well as the data presented in Task A.1. above. Most dairies in the state of Texas have a small or large open lot area for a portion of their cattle. Many freestall facilities also have exercise pens next to the freestall allowing cattle to roam in a larger space. These open lot areas are routinely scraped producing large quantities of relatively dry DB. Table C.2. shows the moisture content of all the samples on an as-collected basis. It shows that the quality of the DB may be improved by simply drying it. Although this is an energy intensive process, it will provide savings for transportation costs.

Table C.3. shows the ultimate analysis parameters of each DB source along with coal expressed on an energy (kg/GJ) basis. This was done to allow for a direct comparison to the coal that the DB would be replacing in power plants. Any substitute for coal would be used on an energy equivalency basis to achieve the same generation capacity. The coal analyzed was Powder River Basin coal from Wyoming.

Table C.3. Ultimate analysis and ash on an energy basis for various DB sources and Powder River Basin coal. (Note: Values are expressed as an "Energy basis," kg/GJ)

Parameter Energy Basis(kg/GJ)	Vacuumed w/ Sand Bedding	Vacuumed w/ Compost Bedding	Mechanically Separated Solids	Gravitationally Separated Soilds	Scraped Solids	Powder River Basin Coal
C	29.6	28.1	30.9	30.4	29.4	25.43
H	3.6	9.8	3.6	3.6	3.5	1.53
N	1.6	5.0	1.1	1.2	2.0	0.40
O	9.6	55.3	23.9	21.0	21.6	6.12
S	0.3	0.8	0.2	0.2	0.5	0.10
Ash	148.9	42.3	5.0	31.1	32.2	2.25

The carbon content did not vary greatly across the fuels on an energy basis although coal is lower than all other sources. Hydrogen was also higher in all DB materials than coal. Nitrogen was significantly higher in the DB than in the coal due to the amount of nitrogen fed to the cattle that is passed through their system. The significant issue with using DB as a substitute for coal is the ash content of DB. The last line shows that the ash content on an energy basis (kg/GJ) with a high ash DB can be 66 times greater than for coal, especially vacuumed manure where sand bedding was used. However, when using mechanically-separated solids, DB will only produce roughly twice as much ash as coal.

The HHV of the solids shows that the heating value on an as-received basis for the vacuumed biomass was lower than the other types of DB due to the high moisture content, as well as high ash content in the case of sand bedding. The HHV of the mechanically separated solids and the compost bedding vacuumed solids was approximately equal on a dry basis. Therefore, these waste streams should receive focus of future work on developing DB as a viable biofuel feedstock.

Samples of as-excreted (fresh) manure were collected concurrently with the energy analysis. The as-excreted samples were collected for comparison purposes to published values (ASAE, 2005), as well as to allow for the establishment of a baseline for dairy biomass quality. The various uses of dairy biomass for energy conversion require the best quality of manure available (lowest ash and moisture content). The various management strategies for removal of dairy biomass all change the characteristics to some degree by adding soil content or moisture. By collecting samples of as-excreted manure, the best DB quality achievable can be determined.

Results of Ash Analyses:

As shown in Table C.4., these analyses indicated that DB manure ash is higher in oxides of silicon, calcium, magnesium, and phosphorous, but lower in potassium compared with cotton gin trash (CGT) ash. Ash content was related to slagging characteristics for DB use as fuel. Slagging potential was calculated by taking the ratio of the base and acid components and multiplying with sulfur content. Another way to evaluate slagging potential was to perform compressive strengths on different manure ash exposed to different temperatures. Initial results showed that the slagging potential for manure ash was at a temperature below 1200° F.

Table C.4. Ash analysis of dairy manure (DB) compared with a common crop residue biomass (cotton gin trash-CGT) in Texas.

Ash Component	CGT Ash	DB Manure Ash
% SiO2	21.70	32.46
% Al2O3	3.46	3.115
% CaO	23.295	27.41
% Fe2O3	1.11	1.845
% MgO	5.685	10.9
% MnO	0.06	0.14
% P2O5	2.245	4.98
% K2O	24.625	5.285
% Na2O	0.76	1.815
% SO3	7.395	6.12
% TiO2	0.245	0.22

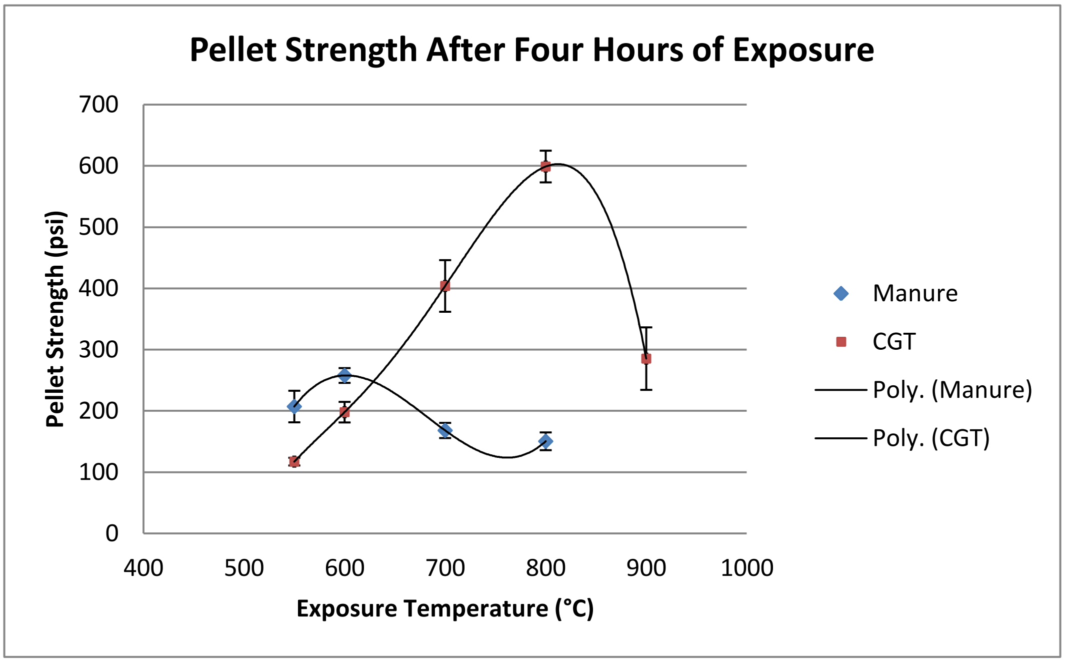


Figure C.8. Slagging and fouling potential of DB manure compared with cotton gin trash using mechanical strength of ash pellet as indicator.

Following are several observations or conclusions based on the DB ash analysis and evaluations using ash analysis in Table C.4 or pellet strength as a function of temperature in Figure C.8:

a. The melting point for DB manure ash was approximately 600 °C compared with CGT at 800° C using mechanical pellet strength as an indicator (Figure C.8). This appears to indicate that the ideal thermo-chemical process for DB is gasification rather than combustion due to its lower melting point compared with cotton gin trash.
b. The bed agglomeration index for DB was found to be 0.26 compared with 0.04 for cotton gin trash ash (GCT). Bed agglomeration occurs when this 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 (DB) was 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. Two other slagging and fouling indexes examined were the slagging potential (Rs) and the fouling potential (Rf) commonly used for coal. The results showed that DB has an Rs of 0.08 and an Rf of 0.02. The degree of slagging typically 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 result contradicts the bed agglomeration and alkali values, including the results of mechanical testing of DB pellets.
e. 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 the indexes used for biomass wastes on alkali index.
f. Thus, we do not recommend the use of the coal indexes for evaluating slagging and fouling potential for DB or CGT, primarily due to the higher ash contents of most biomass residues.

Figure C.9 illustrates the Scanning Electron Microscope (SEM) images of agglomerated cotton gin trash (CGT) samples as temperature was increased. At a lower temperature of 550° C, ash particles were spread out. As temperature was increased to 600° C, formation of small colonies of agglomerated slag was observed. A large agglomerated rock-like structure appeared at a temperature of 800° C, and a much bigger slag agglomerate appeared at 900° C.

Results for dairy manure (DB) samples are shown in the Figure C.10. At 550° C particles have started to fuse and formed bigger clumps as temperature increased. The images also indicated that even at lower temperatures, the ash contained in animal manure began to form slag which may lead to formation of even bigger agglomerates at higher temperatures. Thus, it may be difficult to convert DB 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 DB ash was observed), some slagging and fouling may be expected. Therefore, in using DB for thermal conversion work, there must be regular maintenance schedules to evaluate the formation of slag through hot conveying surfaces.

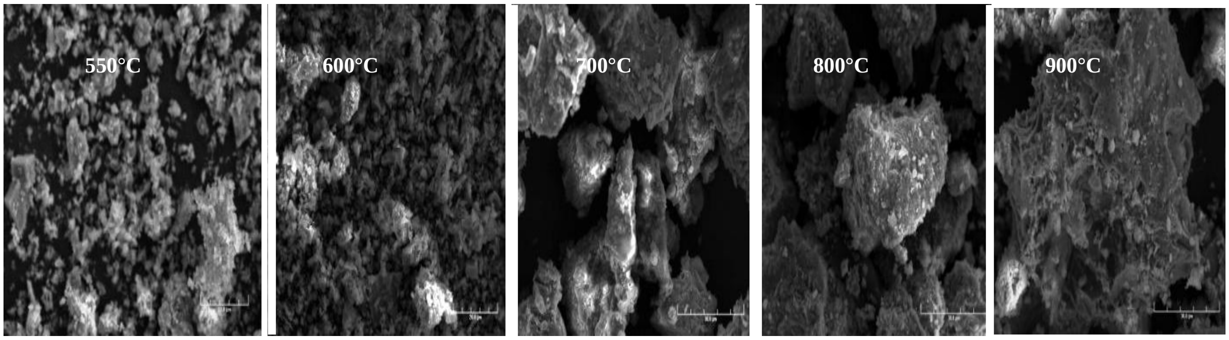


Figure C.9. Scanning Electron Microscope **(**SEM) pictures of CGT ash at 1200X magnification as a function of temperature, ranging from 550° C to 900° C.

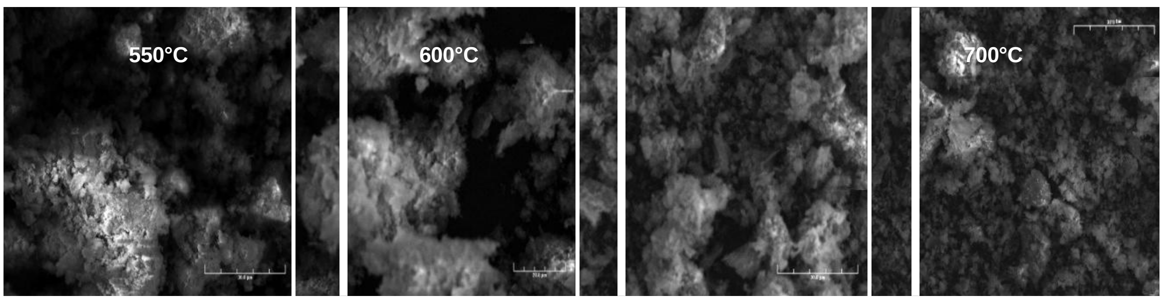


Figure C.10. Scanning Electron Microscope **(**SEM) pictures of dairy cattle manure (DB) ash at 1200X magnification as a function of temperature, ranging from 500° C to 700° C.

Summary:

A manuscript concerning DB manure ash slagging and fouling was prepared to be submitted for journal publication (Maglinao and Capareda, 2010). The Abstract of the paper follows:

> "The slagging and fouling behavior and tendencies of ashes from dairy manure (DB) and cotton gin trash (CGT) were evaluated and predicted using different indices and measurements. Based on the characteristics and composition of the biomass and ash samples, fouling was expected to surely occur. The calculated values of the alkali index, base-to-acid ratio and bed agglomeration index further support this inference. Measurement of the compressive strengths of the ash pellets and scanning electron microscopy (SEM) of the ash subjected to different temperatures contributed additional information to better describe the conditions for slagging. Slagging is expected to occur at a higher combustion temperature of 800°C for CGT compared with the 600°C temperature for DB manure. The results of the study clearly indicate that reliably predicting fouling and slagging tendencies of biomass ash cannot simply be based on a single index or measurement. An investigation of a combination or combinations of indices and measurements appears to be the logical approach.*"*

Task Co-PI's final report on Tasks C.1. and C.2. were completed and sent to the Co-PI's, Drs. Kalyan Annamalai and John Sweeten. These in-depth reports are included in Appendix D, Volume III of this report.

Technology Transfer and Dissemination:
A presentation delivering the preliminary summary of DB analytical results was provided at the Annual International Meeting of the American Society of Agricultural and Biological Engineers in July, 2007 in Minneapolis, MN. Authorship was Goodrich et al. (2007).

As-excreted DB sample analysis were completed and analytical results were included in an Extension publication concerning the properties of dairy manure in Texas, along with in-house proximate analysis of as-excreted manure. Additionally, an Extension publication on the properties of dairy biomass was published and is available as an Appendix to this report.

A manure characterization paper on the analysis of the nutrient content of the dairy biomass was presented at the ASABE meeting in June 2008, as follows:

Goodrich, B.L. S. Mukhtar and S.C. Capareda. 2008. Characterization and Transport Analysis of Dairy Biomass for Co-firing in Coal-Based Power Plants. Technical Paper #084068 presented at the 2008 ASABE Annual International Meeting, Providence, Rhode Island, June 29-July 3. Meeting sponsored by the American Society of Agricultural Engineers (ASABE, ST. Joseph, Michigan.

A manuscript was submitted for publication and is under review as follows:
Maglinao, A.L., Jr., and S.C. Capareda. 2010. Predicting Fouling and Slagging Behavior of Dairy Manure and Cotton Gin Trash (CGT) During Combustion. Transactions of the ASABE, ST. Joseph, MI. In review.

References Cited:
ASAE, 2005. Manure Production Characteristics, D384.2. In: ASAE Standards-2005 American Society of Agricultural & Biological Engineers, St. Joseph, MI.

Goodrich, B., S. Mukhtar, S. Capareda and W. Harman. 2007. Characterization and Transportation Analysis of Dairy Manure in Texas for Cofiring in Coal-Fired Power Plants. 2007 National Conference on Agriculture and the Environment, Agricultural Water Quality Alliance. Pacific Grove, CA. November 7-9, 2007.

Sweeten, J.M., K. Annamalai, B. Thien, and L.A. McDonald. 2003. Co-Firing of Coal and Cattle Feedlot Biomass (FB) Fuels. Part 1. Feedlot Biomass (Cattle Manure) Fuel Quality and Characteristics. Fuel, 82(2003): 1167-1182.

Task D – Biomass handling methods (BA & SM)

Task D.1. (BA): <u>Stabilizing bovine carcasses for thermochemical gasification via carcass composting.</u>

<u>Introduction:</u>
Ongoing demonstrations (not funded under this USDOE contract) of mortality biomass (MB)carcass composting techniques were conducted to produce an environmentally stabilized biomass suitable for TAMU thermochemical gasifier conversion.

<u>Objective:</u>
Demonstrate mortality composting for cattle and horse carcasses involving a range of regionally-available feedstocks (e.g. hay, wood shavings, manure, and cotton "gin trash"), and evaluate the physical and chemical properties of the composted mixtures for potential future use as a bioenergy feedstock.

<u>Approach:</u>
This task addressed the following elements:

- Composting of beef and equine carcasses at the Texas AgriLife Research-Amarillo James Bush Research Farm and the WTAMU Equine Center, respectively, including continuous monitoring of pile core temperatures using alternative types of composting media as carbon sources;
- Collecting well-mixed subsamples of compost ingredients and finished compost, and subjecting both the feedstocks and the composting end products to proximate, ultimate and nutrient analysis;
- Devising numerical schemes of ranking compost-process quality based on degree-day calculations (analogous to crop-growth models) using arbitrary reference temperatures of 100^0F and 131^0F;
- Publishing an Extension bulletin describing best management practices for on-farm composting of large livestock carcasses; and
- Providing educational presentations on proper composting techniques to livestock producers, renewable-energy specialists, veterinarians and livestock consultants in TX and NM.

<u>Results:</u>
Through not significantly funded, the results of this task included the several substantive outputs. Nearly 100 beef cattle carcasses were composted in static piles and windrows at the Texas AgriLife Research James A. Bush Research Farm near Bushland, TX (Figure D.1). Several different feedstocks were used as carbon sources, porous media and moisture absorbents. These included horse manure with wood shavings bedding; feedyard manure; feedyard manure mixed with ground hay; cotton gin trash; and waste sugar beets.

Nearly 30 equine carcasses were composted in windrows at the West Texas A&M University Equine Center in Canyon, TX (Figure D.2), using various mixtures of horse manure, wood shavings bedding, and waste hay. Continuous temperature monitors were installed in most of the windrows (Figure D.3).

Samples of MB compost from selected windrows and static piles were set aside for testing as a biofuel feedstock. The tests included proximate and ultimate analysis, and bomb calorimetry.

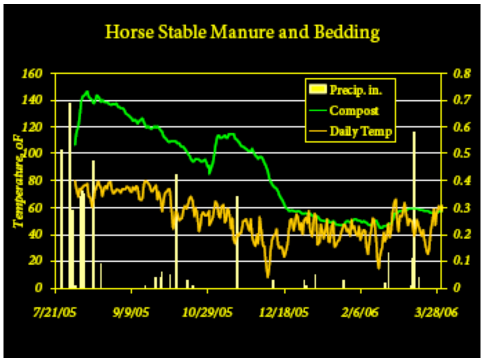
Composting "recipes" were evaluated on a semi-quantitative basis using narrative standards for assessing the degradation of identifiable carcass components (soft tissue, hide, small bone brittleness) after composting (Figure D.4). A simple spreadsheet tool was devised to evaluate process quality on the basis of integrated degree-day calculations with a variety of temperature reference thresholds.

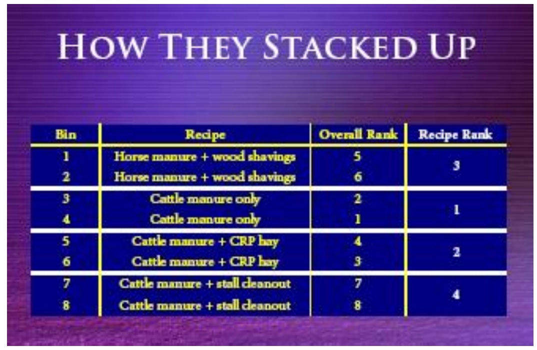
Use of composted, euthanized equines as a biofuel feedstock was identified as an important management option to ensure that environmentally persistent, biologically active barbiturates are destroyed instead of being introduced into soils, water, or air during land application.

During the course of this USDOE research project, the U.S. Congress passed a law in 2007 prohibiting the harvesting of live horses for use as human or animal consumption (e.g. dog or cat food). As a result, more than a dozen horse slaughter plants in the U.S. were closed. The natural deaths of horses obviously proceeded unabated. Consequently, the composting of equine (or cattle) mortality assumed a higher profile as a possible method of environmentally-acceptable processing and potential utilization of MB as biofuel feedstock.

Figure D.1. Stabilizing bovine carcasses mortalities for thermochemical gasification via carcass composting, using alternative materials as carbon source.

Figure D.2. Static pile composting equine carcasses with horse stable manure and bedding as biofuel feedstock.





HOW THEY STACKED UP

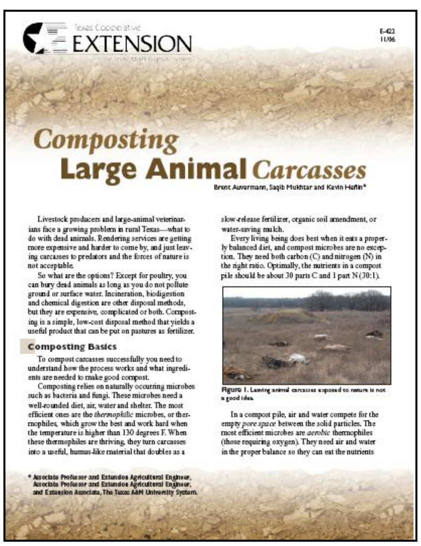
Bin	Recipe	Overall Rank	Recipe Rank
1	Horse manure + wood shavings	5	3
2	Horse manure + wood shavings	6	
3	Cattle manure only	2	1
4	Cattle manure only	1	
5	Cattle manure + CRP hay	4	2
6	Cattle manure + CRP hay	3	
7	Cattle manure + stall cleanout	7	4
8	Cattle manure + stall cleanout	8	

Figure D.3. Temperature results of horse carcass composting.

Figure D.4. Comparative ranking of carcass composting "recipes."

<u>Technology Transfer and dissemination:</u>

- Composting techniques were presented at a two-state dairy meeting in Clovis, NM, and at a county stocker-cattle meeting in Hereford, TX, where one of the attendees was a technical official from Panda Energy, Dallas, TX, who expressed keen interest in further information on the potential fuel value of composted carcasses.
- Extension Bulletin was produced: Auvermann, B. W., S. Mukhtar and K. Heflin. 2006. Composting large animal carcasses. College Station, TX: Texas Cooperative Extension. Bulletin E-422. 6 pp (Figure D.5).
- Brown, L. C. 2007. The effects of various co-composting materials on the decomposition of equine carcasses. Master of Science thesis (Environmental Science), West Texas A&M University, Canyon, TX. Committee members: L. A. Baker (WTAMU; co-Chair), B. W. Auvermann (co-Chair), J. Pipkin (WTAMU), and D. B. Parker (WTAMU).
- Cottle, L. M., L. A. Baker, J. L. Pipkin, D. B. Parker, R. E. DeOtte, Jr., and B. W. Auvermann. 2010. Sodium pentobarbital residues in compost piles containing carcasses of euthanized equines. Proceedings of the International Symposium on Air Quality and Manure Management for Agriculture, Dallas, TX, September 12-15.



Texas Cooperative EXTENSION

E-422
11/06

Composting Large Animal Carcasses

Brent Auvermann, Saqib Mukhtar and Kevin Heflin*

Livestock producers and large-animal veterinarians face a growing problem in rural Texas—what to do with dead animals. Rendering services are getting more expensive and harder to come by, and just leaving carcasses to predators and the forces of nature is not acceptable.

So what are the options? Except for poultry, you can bury dead animals as long as you do not pollute ground or surface water. Incineration, biodigestion and chemical digestion are other disposal methods, but they are expensive, complicated or both. Composting is a simple, low-cost disposal method that yields a useful product that can be put on pastures as fertilizer.

Composting Basics

To compost carcasses successfully you need to understand how the process works and what ingredients are needed to make good compost.

Composting relies on naturally occurring microbes such as bacteria and fungi. These microbes need a well-rounded diet, air, water and shelter. The most efficient ones are the *thermophilic* microbes, or thermophiles, which grow the best and work hard when the temperature is higher than 130 degrees F. When these thermophiles are thriving, they turn carcasses into a useful, humus-like material that doubles as a slow-release fertilizer, organic soil amendment, or water-saving mulch.

Every living being does best when it eats a properly balanced diet, and compost microbes are no exception. They need both carbon (C) and nitrogen (N) in the right ratio. Optimally, the nutrients in a compost pile should be about 30 parts C and 1 part N (30:1).

Figure 1. Leaving animal carcasses exposed to nature is not a good idea.

In a compost pile, air and water compete for the empty *pore space* between the solid particles. The most efficient microbes are *aerobic* thermophiles (those requiring oxygen). They need air and water in the proper balance so they can eat the nutrients

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Figure D.5. Extension Bulletin on composting large animal carcasses, (Auvermann et al. 2006).

Task D.2. (SC, SM): Efficient collection, harvest and transport.

Introduction:

Due to the lower energy-density of most of the available forms of DB or FB, relative to more abundant coal or lignite, the delivered cost of uniform and predictable supplies of these biomass feedstocks must be reasonable relative to the fossil fuels. Large-scale handling methods must be available and logistical resources in place to meet the competitive advantages of the fossil fuels the DB or FB would replace or supplement in conversion processes and bioenergy utilization systems.

Objectives:

- Evaluate the design of harvest and transport facilities for safe storage and transport of CB over longer distances.
- Propose design of efficient collection of manure from individual facilities.
- Evaluate drying, energy and storage requirements for pre-processing of CB before transport.
- Propose quality standards for CB collection, handling and transport. processes so that CB quality is maintained for energy extraction.

This task was closely related to Task E.1. regarding GIS-based CB inventory and transport analysis discussed later.

Approach:

Current handling, collection, harvest and transport system for dairy biomass at dairy CAFO facilities were evaluated. Of the numerous facilities surveyed and documented, it was observed that no single DB collection procedure was being followed within or among dairies. Dairy animal manure (DB) is being collected at several areas for transport as follows: (a) separating of solids from wastewater streams, and (b) composting facilities for separated solids or pen-harvested manure. The transport activities currently implemented generally involved land application to nearby company-owned agricultural areas.

We proposed the following options for the effective use of DB manure as a biofuel feedstock:

a. Reducing the mass of DB material prior to transport outside of dairy CAFO's through pretreatment and drying for large-scale centralized use of animal manure; and/or
b. Develop on-site conversion technologies such as biochemical conversion (anaerobic digestion to generate biogas/methane) and/or thermal conversion (gasification to generate heat and power).

A system for efficient handling, collection and storage of dairy biomass was developed with the goal of consolidating animal manure in a centrally-located place within the facility; implement simple pre-processing activities for solids or semi-solids (mainly drying or aeration); and provide covered storage stalls for processed manure. This proposed handling, collection, pre-treatment and storage concept would require minor investment. Some facilities may already have the needed resources to implement the above proposed system.

Figures D.6. through D.8 show typical handling and transport systems in use or considered by large dairy CAFO facilities for the efficient collection, handling and transport of animal manure. A front-end wheel loader with a open top truck to collect the air-dried stacked manure is shown in Figures D.6 and D.7. In some facilities, a conveying system similar to that shown in Figure D.8, may be needed to quickly convey all animal manure produced in one site within the CAFO facility for truck loading, or to a central conversion facility. Efforts were made to develop and propose a system for the efficient collection, harvest and transport of animal manure from dairy CAFOs. If the conversion process requires lower moisture content (e.g. 20% or less) and/or particle size reduction, a dryer or storage facility may be required in additon to the thermal conversion facility.

Typical “hybrid” dairy facilities (Figure D.9) were comprised of a free-stall barn, open lots and milking center. A large fraction of useable DB could be gathered from the solids separator system, whether mechanical or gravity, to 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 associated sizes of drying, storage and thermal conversion facility including preliminary estimated cost.

In a beef cattle feedlot facility (Figure D.10), the manure (FB) comes from routine scrapings of manure in confined pens. Typically, the collection occurs after every “turn” of cattle (i.e. feed pen becomes vacant), or approximately 120 - 180 days. The manure which has air-dried to approximately 15-45% moisture content (wet basis) in situ is normally scraped into mounds within each pen for several days before being loaded and transported either to land application or into a composting area for longer-term storage.

Figure D.6. Typical front-end loaded utilized by CAFO facility to collect and load animal manure (DB or FB) for transport to a biofuel conversion facility.

Figure D.7. An open-top truck with movable cover may be required for collection and transport of solid DB to large dairy facilities, or FB for cattle feedlots.

Figure D.8. A mechanical conveyor system can be used to collect animal manure (DB or FB), and transport to a centrally located collection and storage yard for subsequent conversion process (e.g. gasification).

<u>Results:</u>

A design for on-site manure handling, pre-processing and storage system was completed with a spreadsheet software to estimate the appropriate size of a thermal conversion facility, using a fluidized bed gasifier (FBG) as a conversion system model. A software analyses/study for a 2,000 head dairy facility was conducted (Table D.1.) The analysis assumed an initial as-excreted manure content moisture of 87% w.b. and a recoverable DB amount harvested of 16.4 metric tonnes per day, with a HHV of 11,300 kJ/kg (4,858 BTUl/b.). A similar analysis was conducted for a 40,000 head beef cattle feedyard facility. The analysis assumed an as-excreted manure moisture content of 92% w.b. with recoverable manure amount of 105.6 metric tonnes per day, having a HHV of 11,240 kJ/kg (4,832 BTU/lb) (Table D.2.).

A fluidized-bed gasifer (FBG) was assumed to be the basic conversion 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 was approximately $322,000. For a 40,000 head beef cattle facility, a 2 MW thermal power plant could possibly be installed at an estimated cost of $2.06 million. Note the conversion facility cost estimates are equivalent to approximately $1,000 per kW capacity.

Typical layouts for a 2,000 head dairy and a 40,000 head beef cattle feedlot are shown in Figures D.9 and D.10. Management changes at these facilities might include the following:

a. Collection and drying of wet or as-received manure to a centrally located site;
b. Establishment of storage facility for the dried /reduced-moisture manure;;
c. Location of thermal FBG conversion facility that could be connected to the grid.

Plans were made to conduct an energy balance to investigate the possibility of using on-site gasification of a portion of the DB to power the drying of the remainder of the DB. Gasification tests were conducted to determine the feasibility of an onsite fluidized bed gasifier to produce electricity and heat for the facility. A total of 3 gasification runs were planned on each of 7 treatments, resulting in a total of 21 gasification analysis runs, with at least one gasification run per week on dried animal manure in preparation for on-site energy conversion and analysis.

Quality standards for collection, handling and transport processes were determined so that CB quality could be maintained for energy extraction.

Summary and Conclusions:

The research team of Capareda, Mukhtar, and Harman determined three methods for decreasing transportation cost: a) reducing the mass of material prior to transport to conversion facilities through pretreatment and moisture reduction; b) develop on-site conversion technologies; and/or c) large-scale conversion systems to reduce the volume of DB needed to be transported out of an impaired watershed.

Recommendations for efficient manure harvesting, handling, and storage prior to conversion included: a) consolidating DB or FB in centrally-located sites, followed by primary processing, such as drying, composting or aeration to reduce moisture content prior to storage or transport; b) conventional manure handling equipment (e.g. wheel loaders); c) covered storage facilities with paved or lined surfaces to reduce soil entrainment or moisture exposure; d) drying or aeration system; e) manure quality management protocols; and f) monitoring the product DB or FB for heating value, moisture and ash.

Table D. 1. Results of spreadsheet software analysis on the design of on-site manure conversion fluidized-bed gasifer (FBG) in a 2,000 head 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/ft^2
Amount K removed	82 tonnes/yr	Feedrate to Gasifier	683 kg/hr
Dried Manure	16,664 kg/day	Size of Power Plant	322 kW_e
Recoverable Manure	16,400 kg/day	Diameter of FBG	3 ft
Manure HV	11.3 MJ/kg	Estimated Cost	$321,736

Table D.2. Results of spreadsheet software analysis on the design of on-site FB manure conversion in a 40,000 head cattle 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/ft^2
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_t
Recoverable Manure	105,600 kg/day	Diameter of FBG	8 ft
Manure HV	11.24 MJ/kg	Estimated Cost	$2,060,670

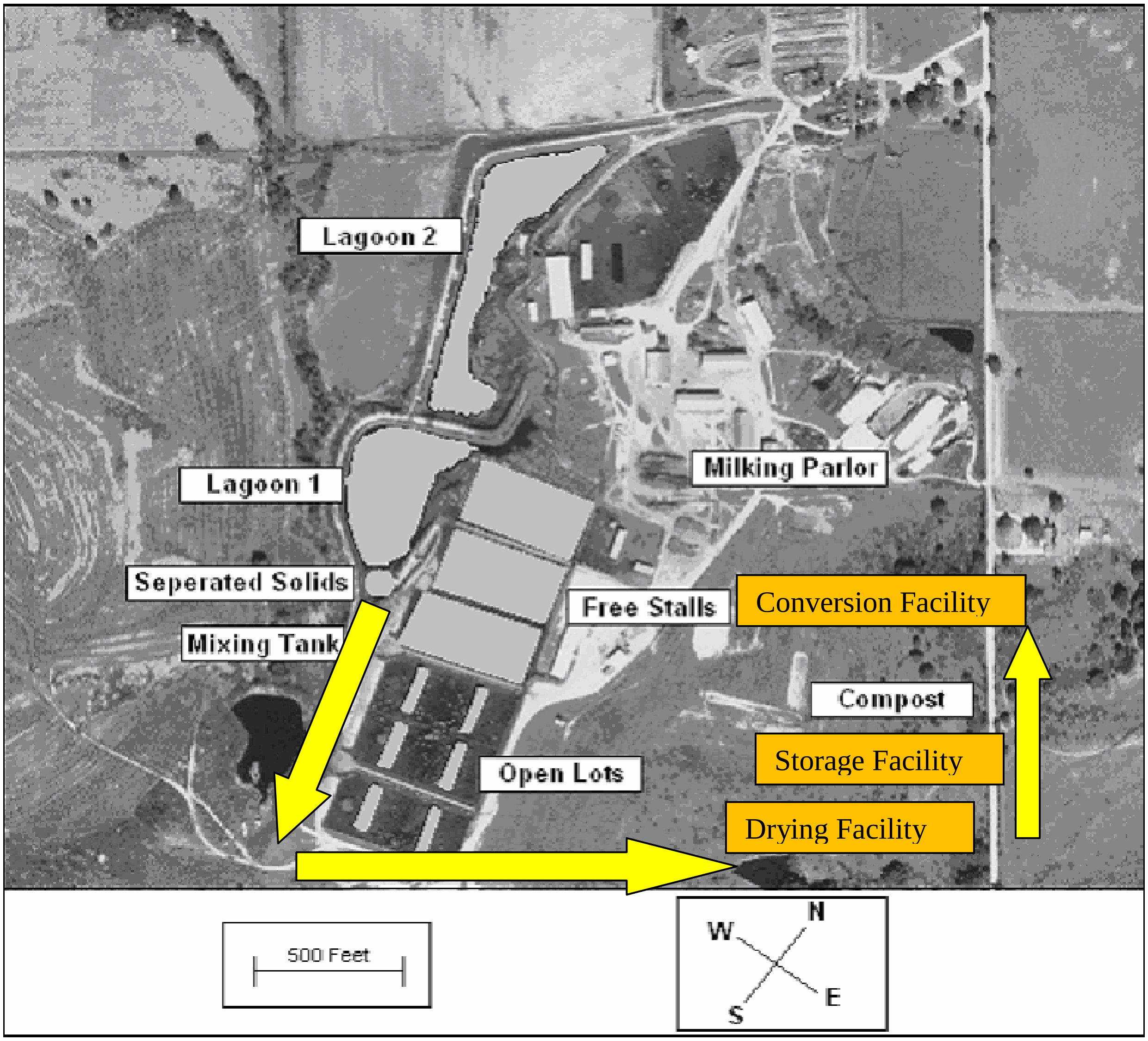


Figure D.9. Typical lay-out in a hybrid dairy (free-stall and open lots) and proposed on-site manure processing and fluidized bed gasifier (FBG) conversion facility using DB as biofuel source.

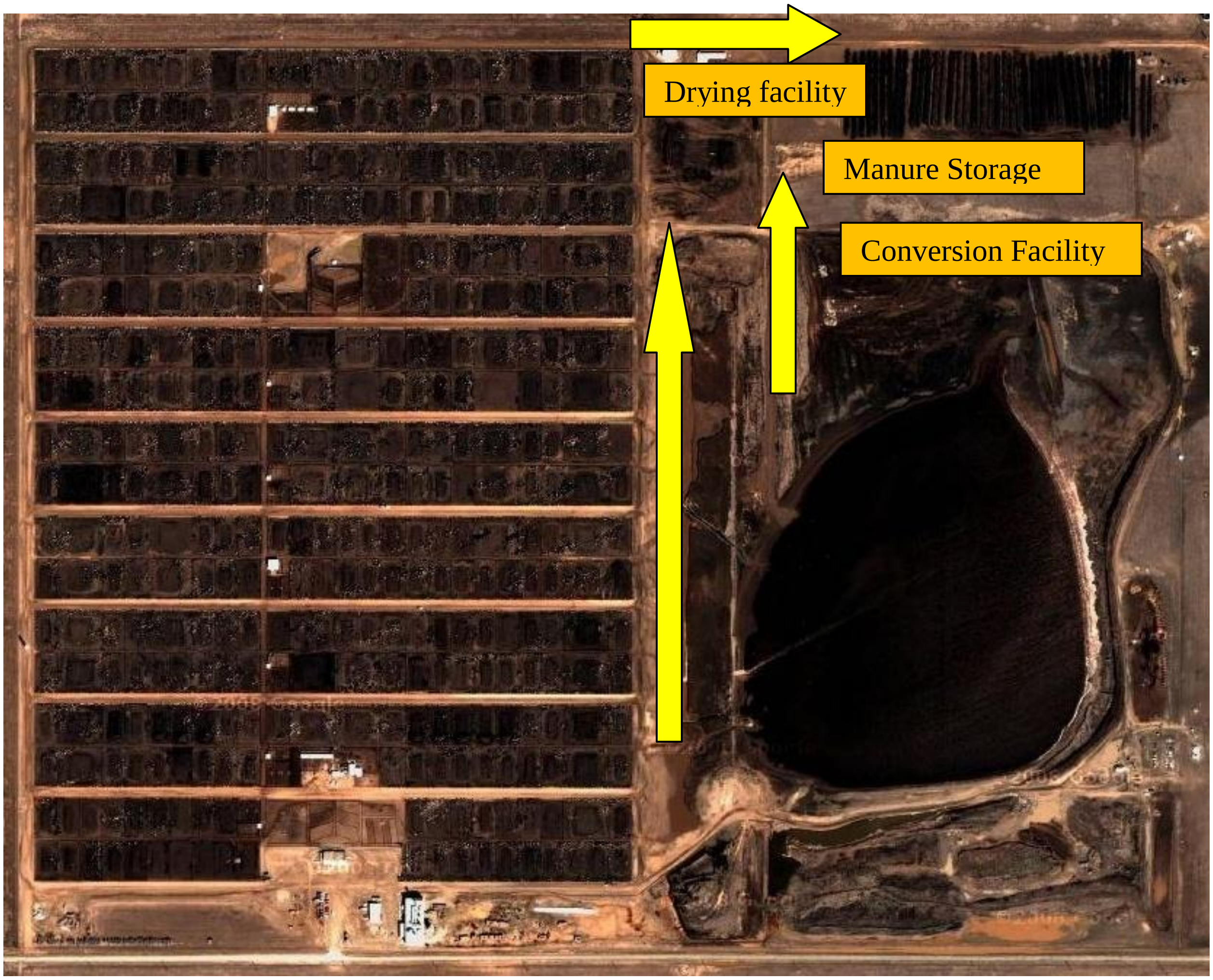


Figure D.10. Typical beef cattle feedyard lay-out and the proposed on-site feedlot manure (FB) processing and FBG conversion facility.

Goal 3 – Energy systems modeling

Task E. **Inventory, Characterization and Transport of Cattle Biomass (SC, SM)**

Task F. **Sensitivity Analyses of CAFO Energy Systems (BA, SC, SM, WH)**

Task G. **Industry Input into Energy-Systems Model Development (JS)**

Task H. **Economic Modeling of Cattle Biomass Energy Systems (WH)**

Task I. **Energy Analyses of Dairy Farms and Feedyards (SM, SC, BA)**

GOAL 3 – ENERGY SYSTEMS MODELING

Task E (SC, SM) – Inventory, characterization and transport of cattle biomass

Task E.1. (SC, SM, WH): GIS-based inventory and transport analysis.

Task E.2. (SM, SC, JS, BA): Use of DB as a renewable energy source.

Task E.3. (JS, BA, SM, SC): Quantitative dairy and feedyard CAFO systems models.

Introduction:

To determine and actually realize the potential energy value of feedlot and dairy biomass for energy conversion, it is necessary to evaluate routing and transportation methods that will deliver the manure to the point of use. An effective transport and logistics system must be in place for the system to be activated. This task involved a GIS-based evaluation of the feasibility of harvesting and transporting manure bio-fuel resources for alternative energy. This task evaluated the availability of animal manure in Texas for co-combustion or biochemical conversion processes.

An underlying purpose of developing CB as a biofuel is to facilitate the diversion of CB from traditional, widely used treatment lagoon/land –application systems to renewable energy conversion systems. Achieving this broader purpose will relieve stress on the environment in the form of phosphorus-based, non-point source water quality impairment in designated watersheds and streams, such as the Bosque River watershed in Central Texas.

Objectives:

1) Development of a GIS-based evaluation of the feasibility of using CB as a renewable energy resource (Task E.1.).
2) Determine whether there is enough CB in CAFO regions or the state for thermochemical and/or biochemical conversion processes (Task E.1).
3) Describe the transportation scenarios required to move the CB from its CAFO sources to the coal or lignite-fired power plants where it could be used. (Task E.1.).
4) Develop adequate quality specifications for DB to be used as biofuel for thermochemical or biochemical conversion (Task E.2.).
5) Develop production systems as an environmental materials flow models for dairies and feedyards (Task E.3.).

Approach and Methods:

The agronomic value of manure was determined through characterization of various DB waste streams in Task C above. The nutrient removal (P, N, K) potential can then be based on the type and amount of DB stream on a per ton, per head, or an annual basis if utilized for biofuel rather than strictly land application.

Research Associate Barry Goodrich at BAEN Department at TAMU in College Station, conducted the inventory and transport analysis using a new ARC-GIS software version. The first steps involved data base development. Specific dairy locations with facility size for GIS mapping and transport cost analysis were needed. Locations of CAFO facilities and associated permitted head counts were acquired from Texas Commission on Environmental Quality (TCEQ). These data were updated regularly by comparing data from NASS (National Agricultural Statistics Service), TCEQ, and other sources as appropriate.

A GIS base map was drawn showing locations of coal power plants in Texas from TCEQ and industry sources. Road maps compatible with ARC-GIS were acquired for transport simulation and analysis.

Database development for dairy and power plant locations included needed up-grades to computer and software for database development. Some difficulties were encountered in finding data with actual dairy herd size, so other sources of data were explored. Accuracy of statewide Texas Commission on Environmental Quality permitted dairy size was questionable and further refinement of the database was an ongoing concern. Discussions with various producer groups yielded sources for possible augmented data sets, but those were not as helpful as anticipated. Additionally, due to the size of the network and computing requirements, we found that the database must be divided into regions for timely computational analysis.

Routing/Transport Analyses:
Road maps of entire United States were acquired and personnel were trained on advanced features of the Network Analyst package in ARC-GIS. The national maps were available for use in subsequent analyses, should funding eventuate. Small scale transport analysis routines were developed for transport of available CB from Central Texas dairies. This was successful in determining the limits of the program for data sets of increasing size.

Dairies in the Bosque River watershed were allocated to the four closest coal-fired power plants in the state using ArcGIS. The average distance to the various power plants was between 216km (134 miles) and 255km (158 miles). The analytical results of the dairy biomass samples from 12 dairies (discussed under Task C) were included in the DB routing database. Due to the required low ash content of power plant fuels, only a small portion of the total DB currently generated is feasible for use in the coal-fired power plants.

The transport analysis needed to be conducted with the most accurate up-to-date data available. It was determined that the best method for determining the number, location and approximate size of facilities was to contact the Texas Commission on Environmental Quality (TCEQ) to obtain their permit records, including GIS coordinates. Accordingly, the latest GIS based water quality protection permits were obtained for all CAFO operations in the state of Texas. Due to variations in permitting requirements across the state, as a function of watershed and species of confined animals, the data was not as complete as we had hoped for. The minimum facility size that required a TCEQ permit varied greatly depending on the watershed, based on water quality status in watersheds where the facility was located. Many CAFO facilities did not currently have a permitted head count in the state records. Also, many facilities that were permitted for a maximum number of dairy animals and had not achieved that size at this time. Finally many property owners with or without dairy experience had obtained CAFO permits in order to attract dairymen (potential buyers) from other regions. Together these factors led to significant data gaps for determining an accurate dairy cattle inventory regionally and across the state. Hence, resolving multiple datasets was an ongoing issue concerning the GIS data. In place of a single statewide database, analysis continued on the Bosque River watershed dairies as an intensive pilot program where density of TCEQ permitted dairies was highest.

Engineers worked with Dr. Wyatte Harman, Professor of Agricultural Economics, concerning the transportation costs and various transportation alternatives for dairy biomass. A map of dairies and highway routes from the dairies to the four closest coal or lignite-fired power plants in Central Texas was developed. Transport routines were developed for all separate sources in order to determine multiple transport alternatives, with final transport analysis developed through collaboration of engineers and economists. An analysis of running transportation routines for various databases in the Bosque River Watershed showed that all the databases produce similar results. This allowed for an expanded analysis to a statewide data set.

The transport routine was designed to start each route from a given dairy to the power plant on the closest road to the dairy. As the distance traveled from the dairy increased, the transportation algorithm favored the higher capacity roadways. When this algorithm was applied to several dairy/power plant combinations, the result was a network of routes that started at many points using small rural roads and eventually gravitated to common transportation arteries across the region. The larger transportation arteries usually had shorter traveling times and routed vehicles around the densely populated areas, e.g. the use of the interstate bypassed around towns.

The foregoing analytical methods were expanded to include dairies and feedlot CAFO's in other regions of Texas. Transport analysis of dairy manure was performed in the Texas Panhandle area to determine the average transport distance from dairies to the two closest coal-fired power plants (450 megawatts each) (Tolk Station near Muleshoe, Texas and Harrington Power Plant near Amarillo, Texas). This study included the most current dairy cattle population inventory. The availability of beef cattle feedlot biomass (FB) in the Texas Panhandle Region for transport to coal power plants for use as a fuel supplement was examined also. The GIS beef cattle feedlot inventory and transport analysis portions were completed as well as the estimate of biomass available for fuel conversion.

The last portion of the analysis was on the humid northeast portion of Texas where most dairy facilities are dispersed, with a pasture component along with a milking center. Due to higher humidity and rainfall, open-lots are not a feasible option in this region of Texas. A transport and inventory analysis for dairy cattle biomass similar to the Panhandle study was conducted in the northeast region of Texas. A large concentration of poultry farms exists in that region as well. A simple spreadsheet software analysis was used instead of extensive GIS analysis to estimate necessary parameters.

Results:
The GIS based cattle inventory and transport analysis was completed as of April 30, 2009 for dairy manure (DB) for Central Texas, Texas Panhandle and Northeast Texas regions. The estimate of biomass available for fuel conversion, together with biomass characterization data from preceding tasks, were completed as well.

Transport analysis of dairy manure was performed in the Bosque River Watershed in the vicinity of Erath County Texas to determine the average transport distance from dairies to the four closest power plants, which were located to the east or southeast 4 to 5 counties away (Table E.1.). Figure E.1. shows a GIS transport routine for co-firing DB on the four existing coal power plants in Central Texas.

Table E.1. Average distance (km) to each power plant from all the dairies in the Bosque River watershed.

Rank	Average Distance	Standard Deviation	Power Plant
1	216	14.8	TNP One
2	240	14.9	Limestone
3	249	18.0	Sandow
4	255	14.7	Big Brown

The closest power plant to the Bosque River watershed region was TNP One at an average distance of 216 km (134 miles) from the dairies, while the farthest of the power plants was Big Brown at a distance of 255 km (158 miles). Either of these distances was a significant barrier to using DB in coal- fired power plants. The cost of transporting raw DB at high moisture contents and/or high ash was 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 high enough to allow the transported DB to be cost effective.

Figure E.2 shows results of a GIS routine to find a suitable location of a centrally located energy conversion facility within Erath County, Texas. The proposed site (red circle) was selected as a potential conversion facility site following the criteria of equidistant transport from all available facilities, constraints included being outside of the commercial and residential zoning area and with suitable land for manure handling, pre-processing (drying) and conversion.

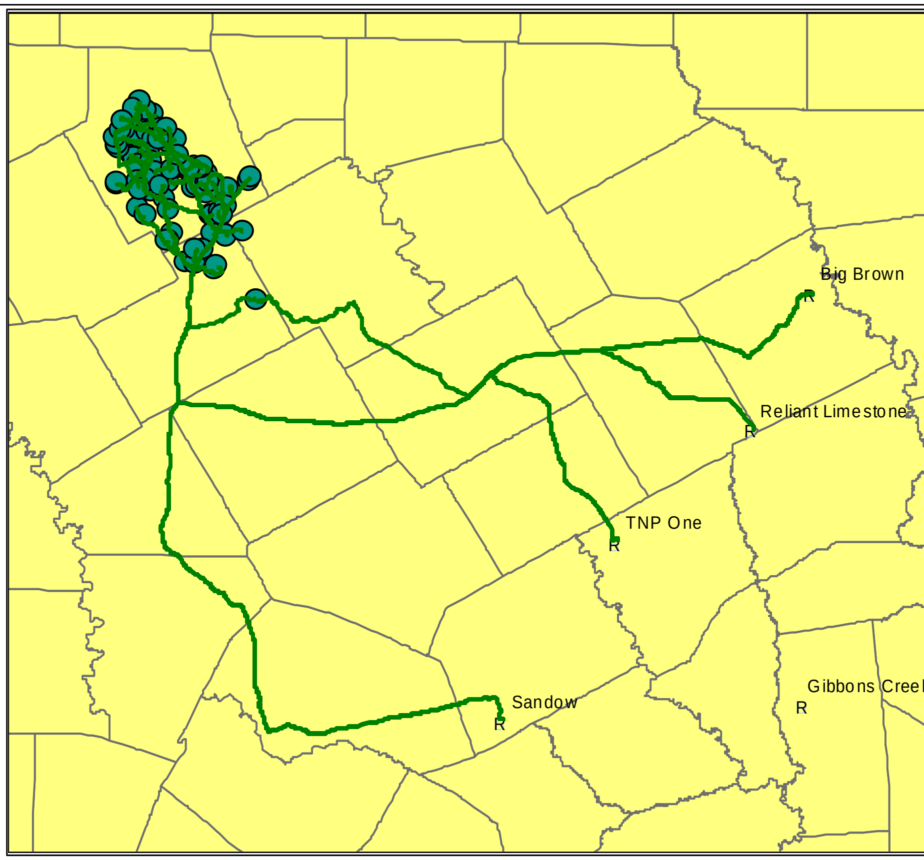


Figure E.1. Transport analysis for DB from Central Texas dairies in the vicinity of Erath County to four regional coal or lignite-fired plants, assuming co-firing option for conversion to energy.

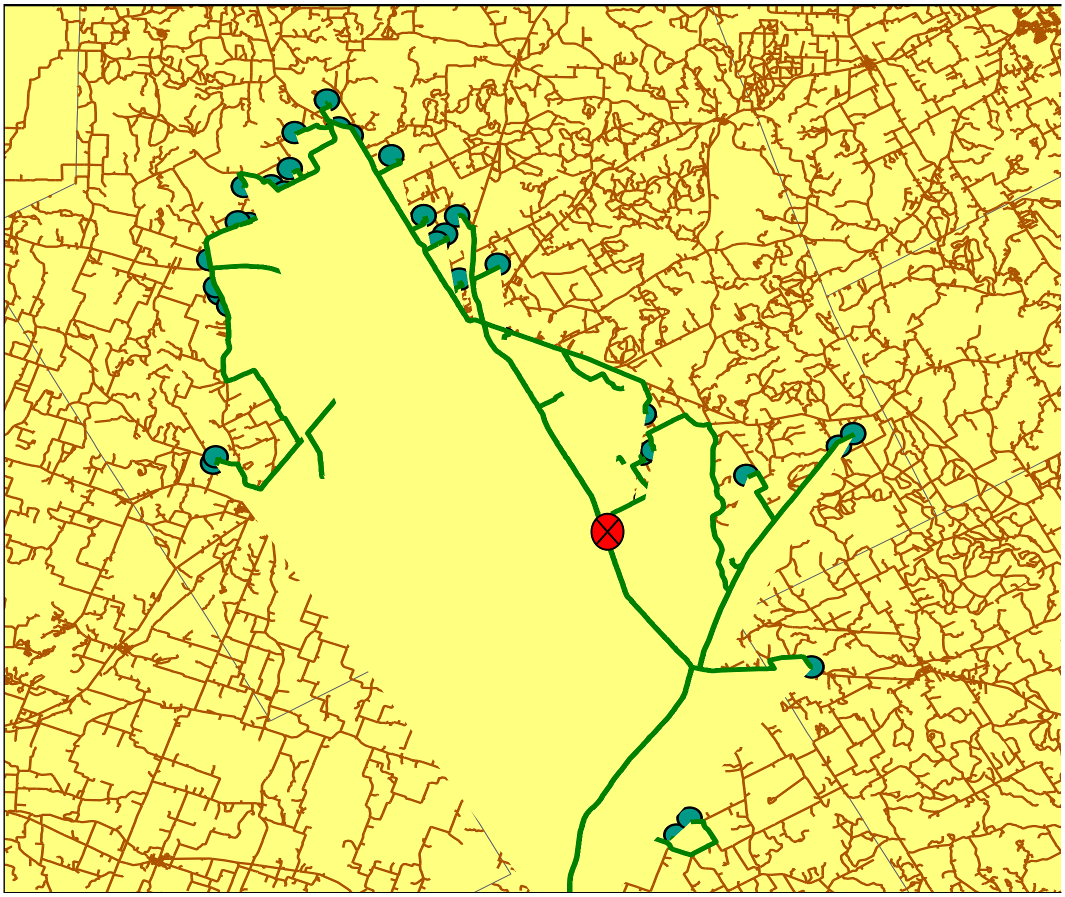


Figure E.2. Development of a potential centrally-located animal manure (DB) conversion facility using GIS mapping and routing of dairy CAO's in Erath and neighboring counties in Bosque River Watershed of Central Texas.

Figure E.3. Expanded transport analysis of DB from all permitted dairies to the closest coal or lignite-fired power plants statewide.

Figure E.3 shows the routes from each of the permitted Texas dairies statewide whether or not operated at permitted capacity, to the closest coal fired power plant. The TCEQ-permitted dairies located south/southeast of El Paso were shown in this analysis but are no longer operating due to animal health or economic issues, and were therefore not included in the transport distance analysis. The average distance to the closest power plant was 91 miles (146 km) excluding the El Paso dairies. This analysis did not evenly distribute the dairy manure to all the power plants.

From these GIS and transportation routing/analysis results, different energy conversion options were evaluated as follows: a) on-site conversion applications; b) centrally-located conversion facility; and c) biofuel for co-firing with coal or lignite in existing power plants.

<u>Summary of Tasks E.1 and E.2:</u>
The manure inventory in a major dairy (Bosque River) watershed for dairy biomass was completed and finalized. We concluded it may be possible to remove a significant amount of nutrients in the biomass from the Bosque River watershed that are currently causing environmental water quality problems. Transporting the biomass more than 134 miles (216 km) on average presents an economic challenge to using it in coal-fired power plants. However, the transportation routines used in this analysis can be used for moving the biomass to any number of locations or alternative uses outside the watershed.

The state-wide transport analysis was completed and finalized for major CB sources, focusing on dairy or feedlot biomass routed to power plants for co-firing or to centrally-located conversion facilities.

The analysis explored the feasibility of animal manure (DB) as fuel for the following alternative bioenergy applications: a) on-site conversion to energy; b) centrally-located conversion facility; and c) biofuel for co-firing with coal or lignite at existing power plants. Technologies such as fluidized bed gasification may be applicable to CB supplies.

The low-ash content of mechanically-separated solids in relation to the other DB streams showed that this material is the most promising DB form for transporting because it has the lowest ash content. However, the efficiency of mechanical separation systems does not yield enough DB to achieve the targeted removal mass from the watershed or a critical mass for central conversion facility. Therefore, the next most logical source of DB for removal is vacuumed solids with compost bedding (rather than sand-bedding). While the ash content of this DB is higher than ideal, it removes the greatest amount of DB compared to all the other handling systems. The high ash content in vacuumed solids where sand bedding was used as well as corral-scraped DB solids renders these a lower quality higher-ash biofuel that would limit transport distance for economical use.

<u>Quantitative dairy and feedyard CAFO systems models. (Task E.3.) (JS, BA, SM, SC):</u>
<u>Introduction:</u>
Prior to this USDOE research project, CO-PI's Sweeten and Auvermann, along with animal scientists had already completed a proposed systems model of the beef industry, including industry segments both upstream and downsteam of the CAFO proper. The main thrust chosen for this Task E.3. was to distill and further refined that beef cattle systems model and then modify it to describe the dairy CAFO system as well.

<u>Objective:</u>
The objective of Task E.3. was to develop quantitative production systems and environmental materials flow models for dairy and beef-cattle CAFOs. These models could provide a comprehensive framework for constructing energy flow and mass balances related to (a) total CB resources and (b) CB resources of sufficient quality for use as renewable energy feedstocks.

<u>Approach:</u>
Two graduate students, Gary Marek and Kevin Heflin, began their PhD studies at WTAMU, which included developing a conceptual basis for quantitative dairy and feedyard CAFO systems models in an "embedded energy" framework. Their major professor, Dr. Auvermann, facilitated this endeavor by assembling two 1-page summaries of "Facts and Figures" for typical Panhandle dairies and cattle feedyards, including capacity, production, sales, feed usage, water usage and economic throughput.

Heflin, Marek and Auvermann developed and presented preliminary ideas on the embedded energy signature of bovine CAFOs at the annual meeting of USDA-CSREES Multistate Committee S-1000 in Aguadilla, Puerto Rico, in May 2007. Their analysis included developing systems frameworks for mass and energy flows in dairy and beef CAFOs, respectively. A third PhD student (Sharon Sakirkin) began developed a system framework for mass and energy flows in ethanol plants whose boilers are fired by manure-derived biogas via thermochemical conversion.

Four PhD graduate students (Emalee Buttrey, Gary Marek, Kevin Heflin, and Sharon Sakirkin) at WTAMU presented a conceptual model of the water, nutrient, and energy flows and feedback controls that describe a system involving cattle feeding, manure-fueled ethanol production, and irrigated corn production. The students presented their model and its major components at the annual meeting of USDA-CSREES Multistate Committee S-1032 in Boulder, CO, in May 2008.

Mr. Gary Marek and Mr. Kevin Heflin continued their development of beef- and dairy-systems models in the Stella^{TM} programming environment (www.iseesystems.com) under the auspices of a PhD-level "Directed Studies" class (AGRI 8095) at West Texas A&M University (Dr. Brent Auvermann, Instructor). The students presented their Stella models to the WTAMU graduate faculty and students in March 2009.

Dr. Jeetendra Upadhyay, Post-Doc in environmental engineering, developed a conceptual model of the carbon cycle of open-lot livestock facilities and presented a poster on that model at the Boulder meeting as well. He found that a mass-conserving simulation model for solid feedlot manure can be used to create incentives by which cattle feedlot operators can capture marginal revenue from investment in more intensive manure-harvesting practices that produce higher-HHV manure. The market logic can be expanded to address participation in a carbon-dioxide equivalent market as well.

Results:
Dr. Auvermann and the above graduate students drafted a "Production and Environmental Quality Model for Dairy Operations". Their draft was derived in part from beef cattle systems model flow chart (Figure E.4) developed in 1999-2001 by a multi-university team of scientists affiliated with the Consortium for Cattle Feeding and Environmental Sciences, lead by Texas AgriLife Research-Amarillo, Texas AgriLife Extension Service, WTAMU, USDA-ARS-Bushland, and Texas Tech University.

With subsequent review, feedback and analysis by Mukhtar et al., the flow-chart model for dairy CAFO's was finalized: "Production and Environmental Quality Model for Dairy Operations," which is shown in Figure E.5.

Summary:
The flow charts in Figures E.4 and E.5 essentially completed the main objective of this task at this point. The feedyard and dairy models are conceptual and qualitative rather than quantitative at this point. However, components and pathways are subject to quantification on an individual CAFO, regional, or industry-wide basis as future scholars desire. This could include biofuel feedstocks consumed by or produced within the dairy or beef cattle CAFO's.

Technology Transfer and Dissemination:
A professional conference paper was prepared to summarize these studies and will be published in due course:

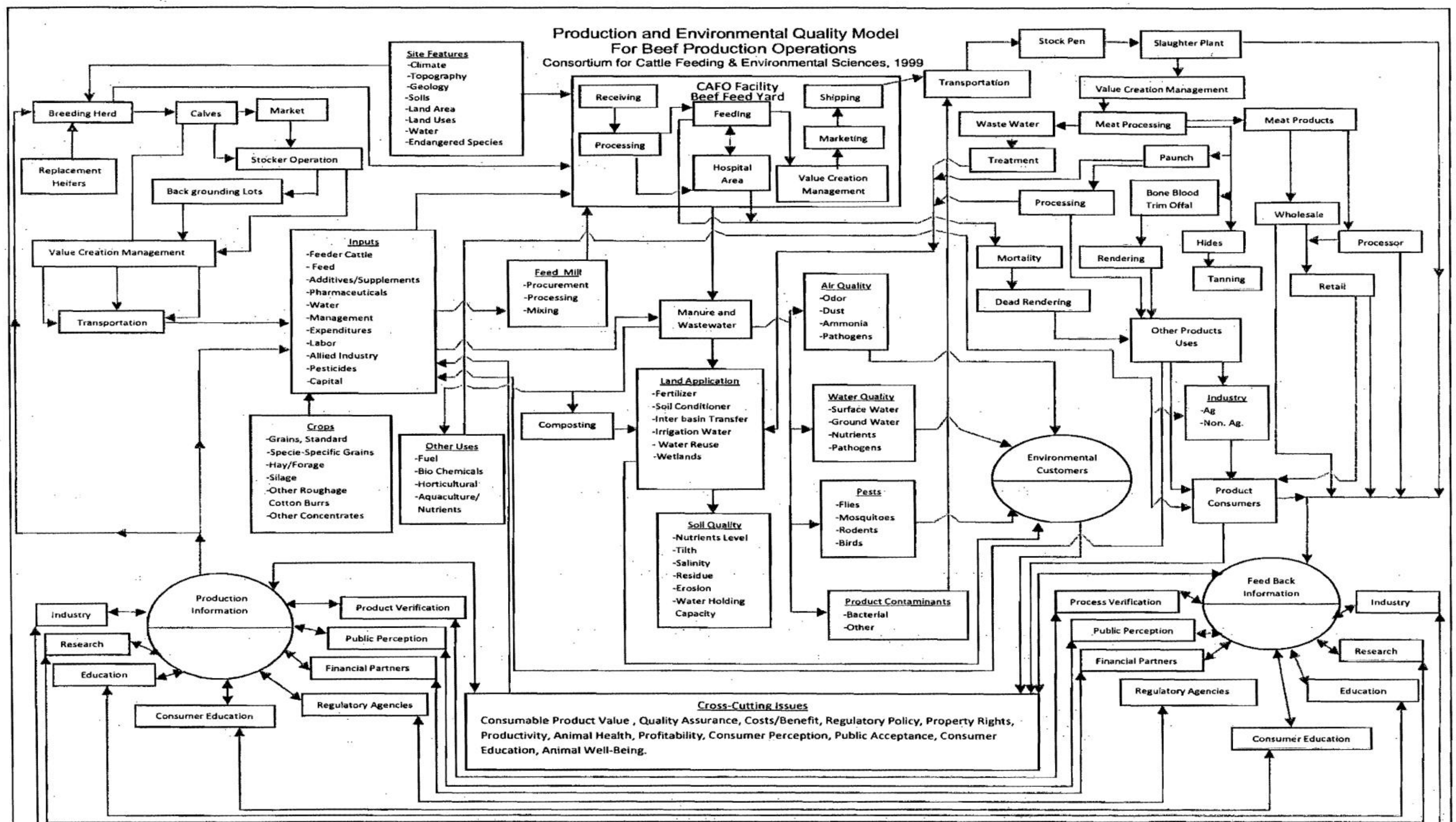
> Goodrich, B.L., S. Mukhtar, and S.C. Capareda. 2008. Characterization and Transport Analysis of Dairy Biomass for Co-firing in Coal-Based Power Plants. Technical Paper #084068, presented at the 2008 ASABE Annual International Meeting, Providence, Rhode Island. June 29 to July 3. Meeting sponsored by the Society of Agricultural and Biological Engineers (ASABE), St. Joseph, Michigan.

Extension Publications prepared for dissemination:
Auvermann, B.W. 2010. "Stock-and-Flow-Modeling of Solid Manure of Variable quality in a Competitive Biofuel and Land-Application Market", fact sheet published under a USDA-CSREES/NIFA National Facilitation Project, National Livestock & Poultry Environmental Learning Center, University of Nebraska, Lincoln, NE.

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.

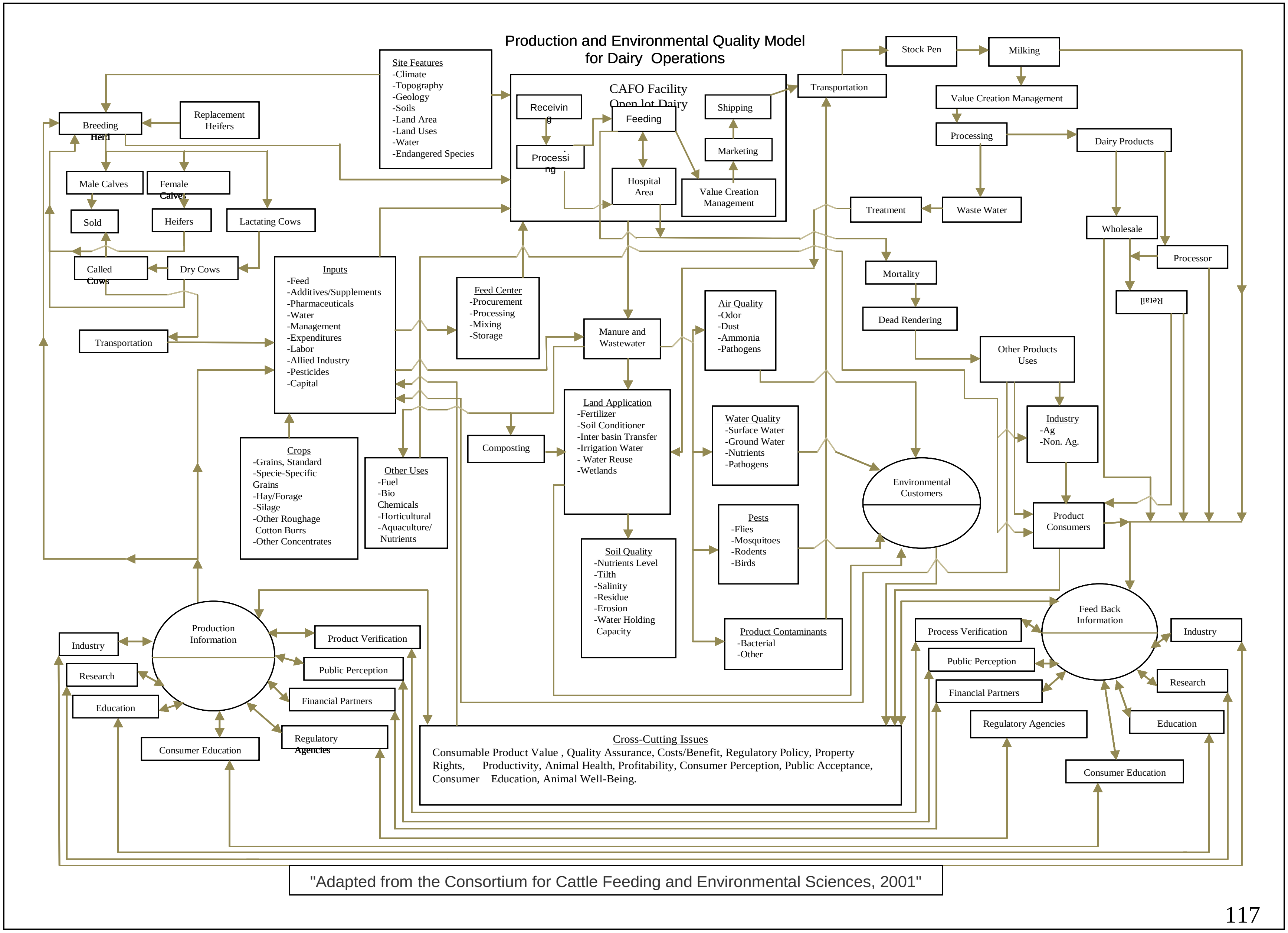
Mukhtar, S., L.B. Goodrich, C. Engler, and S.C. Capareda. 2008. Dairy Biomass as a Renewable Fuel Source. Texas Cooperative Extension Publication # L-5494. February, 2008. Texas A&M University System, College Station, TX.

Figure E.4. Production and Environmental Quality Model for Beef Production Operations



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

Figure E.5. Production and Environmental Quality Model for Dairy Operations



Task F – Sensitivity analysis of CAFO energy systems (BA, SC, SM, WH)

Task F.1. (SC, WH): Feasibility work.

Task F.2, (BA, SM, SC): Developing strategies for a efficient utilization of manure.

Task F.3. (BA, SM): Addressing engineering and on-farm issues arising from manure-to-energy projects.

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 outlined 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.

Objectives:
1) Develop baseline data needed for economic evaluation and analyses (e.g. transport and fuel costs) followed by model development and analysis. (Task F.1.)
2) Develop criteria and standards for CAFO producers to follow in order for their manure to be of marketable value. (Task F.2.)
3) Evaluate engineering and other on-farm issues associated with manure-to-energy projects (Task F.3.).

Approach & Methods:
The feasibility work (Task F.1.) was designed to provide baseline data and information needed for economic evaluation and analysis (e.g. transport and fuel costs), to be carried out in Tasks E and H. This task was closely aligned with concurrent efforts of Task E.1. Work on this task began in January, 2006, with data gathering phase from Texas Agricultural Statistics Survey (TASS) and TCEQ databases. The information was continually updated by working closely with TCEQ and TASS livestock producers in the state, and power plant owners to establish CAFO locations and sizes. The information was to be shared with other institutions in need of such valuable data in spatial and electronic form. New GIS software was acquired with updated roadmaps to use with GIS transport analyst.

The preparatory work included calculating transport distances from power plants in the state to regional CAFO's of record; gathering transport cost variables within the sampling area/region; and gathering other economic variables and indicators such as competing cost of fossil fuels as well as biofuels.

New GIS software which had updated roadmaps for transport analysis, including road distances was placed with biomass inventory tonnages for state of Texas. A survey of manure hauling companies in the region was conducted to gather data on manure harvesting and transportation costs. These results were analyzed and correlated with the results from Task E.1.

The proposed manure sources and management practices were further described in Appendix D, provided in Volume III of this report.

The general procedure for the feasibility study was as follows:

a. A typical dairy farm and a beef cattle feedyard was selected whose management practices represents the majority.
b. Transportation costs were assumed based on the survey and the results of GIS study for this project.
c. For the centrally located energy conversion facility, a proposed site was assumed which was equidistant from the facilities selected. For co-firing project, the results of previous GIS transport routes were used.
d. The magnitude of monthly and yearly cattle biomass wastes produced was estimated and projected for annual distribution.
e. 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).
f. The fixed and variable costs for the operation of the conversion facilities were determined based on current available data for the feasibility studies.

For dairy manure, the most nearly 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 process, one system could take advantage of the other to improve the system operation synergistically. The manure could be used directly in an anaerobic digester simply by adjusting the moisture content to that which is 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 given population greater than 500 head. Figure F.1. shows an example of a thermal conversion system in a dairy facility.

Beef cattle feedlot manure is characterized by having relatively low moisture but higher ash content depending upon the frequency of harvest cycle. Harvesting at frequent intervals could capture relatively fresh organic matter, but if excessive, could result in scraping of the soil layer resulting in too high ash content, which is to be avoided. 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 1,000 head.

The task relied on the development of software for feasibility analysis using them most common spreadsheet software (MS Excel). Input parameters included the following: cattle population; CB heating value; moisture and ash content of manure; recommended size of conversion facility; and fixed costs and variable costs

Output parameters included the following: internal rate of return (IRR); net present value; benefit cost ratio; power output; sale of electricity; and production/sale of char among other minor outputs.

Developing Strategies for Efficient Utilization of Manure as Biofuel (Task F.2.). This task involved the development of critical strategies for animal producers to follow in order for their specific bioconversion process as manure to be of marketable values for the stated purpose. Assuring a central conversion plant model, the premise was that once the manure requirements for each coal power plant are set, the collection efficiency for each producer contributing DB or FB will also be established to sustain the requirements of each power plant. The minimum and maximum transport distances to sustain the delivery of manure to each power plant considering a reliability factor of the DB or FB can also be established. Changes in those minimum and maximum transport distances that would result from method or efficiency changes related to the collection, storage and transport of CB can also be estimated.

This task was heavily dependent on timely completion of several prior tasks, including Tasks C and E. The plan was to incorporate results of FB or DB characterization to begin development of utilization strategies. Accordingly, there were delays in beginning Task F.2.

An improved spreadsheet simulation model was developed. The model capabilities could perform the following types of analyses:

a. Evaluate biomass energy resource availability in CAFOs in Texas;
b. Investigate the heating and power potential for on-site conversion/utilization systems; centrally located conversion facility; or as biofuel for co-firing in power plants;
c. Evaluating the potential emissions reduction and/or carbon credits through conversion of animal manure (DB or FB) as biofuel for heat and power purposes; and
d. Perform sensitivity analysis for the different inputs of the spreadsheet simulation software.

Addressing Engineering and On-Farm Issues (Task F.3.)

The purpose of Task F.3. was to address engineering and other on-farm issues arising from manure-to-energy projects. The plan was to evaluate contemporary norms for engineering design of CAFO facilities and propose new design features for dairy and beef CAFOs to accommodate renewable energy considerations related to CB quality. Biofuel considerations should include ease and flexibility of harvesting, collection, storage, processing and transport of DB or FB.

Results:

Preliminary results of Task F.1.analysis generated the following conclusions:

a) The three conversion options evaluated can be economically feasible **if** the initial capital cost for the conversion units are low. For example, the current capital cost for gasification systems are in the order of between $2,000 to $4,000 per MW. Within this range, the gasification systems may have a longer payback period. However, if the initial capital cost is reduced to less than $1,000 MW the economic indicators become attractive.
b) Economic indicators (e.g., internal rate of return or payback period) of the energy conversion facilities are dependent upon the sale of other by-products of the conversion systems such as char and carbon credits. Thus, characterization of char for fertilizer use may need to be made including its value for carbon sequestration.

Task F.2 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) would need to have an on-site drying and storage facility.

b. Each farm would need to 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-located 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%.

Analytical results of FB and DB analysis as well as supplying large bulk samples for test burns were incorporated into laboratory-based pilot plant research on combustion, reburn, pyrolysis and gasification performed by Dr. Annamalai et al. The results of these experiments were presented and discussed in-depth in Volume I of this final report. Additionally, these analytical results were utilized in transportation system/economic analysis discussed pursuant to Tasks E.1. and F.1. above. In this way, progress under Task F.2. fostered the analysis and development of utilization strategies.

Task F.3. was promulgated based on the premise of a) completion of, or substantive progress on prior tasks in a timely fashion, and b) adequate funding released from other Tasks or new project funding, which was not realized. Many of the prior tasks were late in reaching fruition, and the premise of subsequent funding or co-funding was not realized. Therefore, progress under Task F.3. was minimal. Nevertheless, it is a continuing need and worthy project should subsequent funding become available.

<u>Summary and Conclusions:</u>
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 head and feedyard facilities with population greater than 1,000 head. The most likely revenue would come from the sale of power to local utilities and the sale of char as soil amendment.

The feasibility study showed that it was possible to develop on-site conversion facility in animal feeding facilities 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 would be enhanced if the power plant could take advantage of generating more power at peak load conditions (summer months and during peak irrigation schedules). The spreadsheet model can be adapted to other industries, such as for power production and generation in a cotton gin.

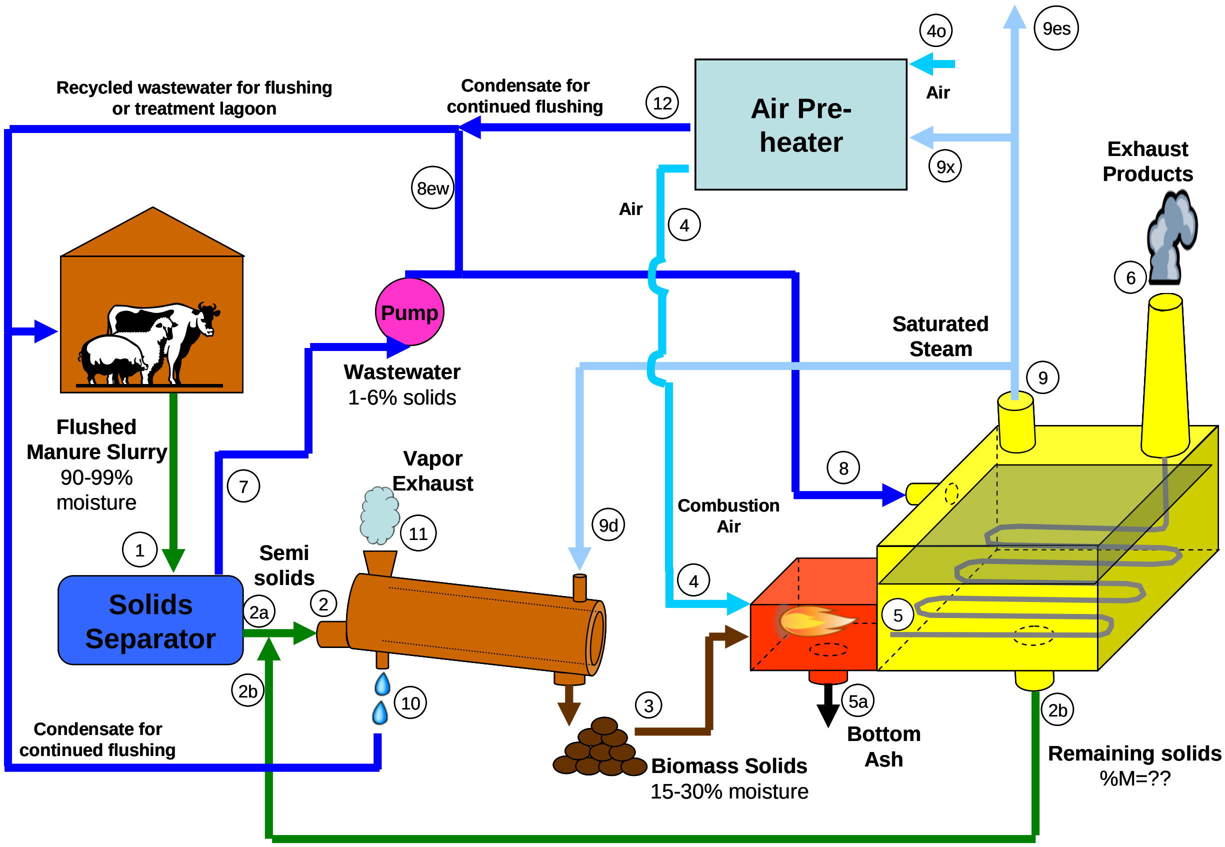


Figure F.1. Small Scale Manure Conversion System in a Dairy Facility. Adapted from: Carlin, N. T. 2009. Optimum Usage and Economic Feasibility of Animal Manure-Based Biomass in Combustion System. Ph.D. Dissertation, Texas A&M University, May 2009.

<u>Task G. (JS) Industry input into energy-systems model development.</u>

Task G.1. (JS, KA): Establishment of a project Industry Advisory Committee (PIAC).

Task G.2. (JS, KA) Utilization of feedback from PIAC.

<u>Introduction:</u>
An important component of this project was to develop a strong interactive connection with potential users of the research being developed, conducted and reported under this project. Conversely, the wealth of knowledge which existed in the private sector could provide a valuable framework and source of essential perspectives to the research scientists/engineers engaged in this project. Finally, a greater sense of prioritization could be gained from stakeholder feedback. Accordingly, a robust Project Industry Advisory Committee (PIAC) was organized early in the project.

The PIAC was constituted so that it represented both (a) the beef cattle-feeding industry and the dairy industry as potential suppliers of biomass energy resources; and (b) the coal-fired electric utility industry as potential users of biomass energy. Other entitles were added as appropriate.

<u>Purpose and Objectives:</u>
1. Develop an interactive relationship with stakeholders to exchange ideas and knowledge among researchers and private sectors potential users of research outputs;
2. Provide a forum and coordinating mechanism to determine progress on fulfilling the research goals, objectives and tasks;
3. Gather and assimilate stakeholder feedback into research priorities, protocols, and interpretation of results as appropriate;
4. Encourage private-sector adoption of relevant findings of the research team.

<u>Methods and Protocols:</u>
Initial members of the Project Industrial Advisory Committee (PIAC) members were identified by the investigators and were asked to participate in a telephone conference call on Nov 21st, 2005. The purpose of the conference call was to introduce the project purpose and scope, project overview, the investigators (PI's) involved and their respective roles; consider adding other members; and to discuss Project Goals, Objectives, schedules and Tasks. The initial participants included: Cliff Clark, TXU (later Luminant), Dallas; John Cowan, Texas Assn. of Dairymen, Grapevine; Ned Meister, TX Farm Bureau, Waco; Paul Joiner, Panda Energy Group, Dallas; Ben Weinheimer, TX Cattle Feeders Assn., Amarillo. They were provided with a 4-page summary of the full 61-page Work Plan, along with a preliminary schedule.

The PIAC members were made aware of project structure with two research agencies lead the project: Texas Engineering Experiment Station (TEES), and Texas AgriLife Research (formerly the Texas Agricultural Experiment Station; the agency name was changed January 1, 2008) of the Texas A&M University System. Faculty from the following research Units were receiving first-year funding to perform specific work plan elements: Department of Mechanical Engineering/TEES, College Station--Dr. Kalyan Annamalai; Biological and Agricultural Engineering Department/Texas AgriLife Research, College Station--Drs. Saqib Mukhtar, Sergio Capareda, & Cady Engler; Texas AgriLife Research-Amarillo--Drs. Brent Auvermann & John Sweeten; and Texas AgriLife Research -Temple--Dr. Wyatte Harman. Other cooperating faculty involved subsequently included Dr. David Parker and Dr. Robert DeOtte, WTAMU, Canyon, and Dr. Don Cawthon, Texas AgriLife Research -Stephenville.

Two additional candidates were nominated as PIAC members: Dr. Dave Hutcheson, Animal Agricultural Consulting, Inc. - a retired Professor of Animal Science, formerly at Texas AgriLife Research (AREC-Amarillo); and Mr. Olan Plunk , VP of Environmental Services, XCEL Energy (Utilities), Golden CO.

Following the initial conference call, formal letters appointing the members to the Project Industry Advisory Committee were sent and acceptances were received. A complete list of PIAC members is shown in Appendix E.1.

The project IAC (PIAC) was briefed regularly and PIAC members provided researchable ideas, suggestions for in-kind support or co-funding as appropriate, and progress evaluation and feedback. Several began to incorporate project outputs into their private-sector work during the course of this project

Seven meetings were conducted involving both the investigator team and the PIAC members, or their designees. These meetings were rotated among locations at the invitation of PIAC members or investigators. Dates and locations of these meetings were reported in the following results section, along with key feedback provided by the PIAC members.

<u>Results and Feedback:</u>

The *first meeting* of the investigators and Project Industry Advisory Committee was held on January 27th, 2006 and hosted by John Cowan at the Texas Association of Dairymen, Grapevine TX. Agenda consisted of primarily of PI's presentations of Work Plan elements (Goals/Objectives/Tasks), and early progress. Feedback from the PIAC during this meeting would help refine and guide the project toward positive outcomes. The DOE/Golden Field Office project officers (Kevin Craig & Becky Wall) were invited to join these meetings as appropriate or available, but were unable to attend. A synopsis of feedback from the first Industry Advisory Committee follows:

- PIAC appreciated the opportunity to participate.
- Intense focus should be on-farm efforts.
- Develop technologies that are very scaleable, large to small.
- Feedyards – Keep dry fuel dry; no wet systems.
- Develop models for field-scale systems (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.
- Improve quality of raw material. What can be done with fuel to improve quality (e.g. ash separation).

The *second joint* meeting of the project investigators and Project Industry Advisory Committee (PIAC) serving the USDOE-funded project "Renewable Energy and Environmental Sustainability Using Biomass from Dairy and Beef Animal Production Facilities", was held on May 31, 2006 at the Texas A&M University System Agricultural Research & Extension Center (AREC) in Stephenville (see Appendix E.2.). The meeting consisted of a field tour to a commercial-scale dairy farm with a covered-lagoon type anaerobic digester. The tour was followed by the joint investigator/advisory meeting to gather updates, feedback, suggestions and comments, and to identify future emphasis and plans. Key points made by PIAC included:

- Need to document feed ration composition in order to understand mineral composition of FB or DB (Hutcheson).

- Need to develop an understanding of problems of low gas productivity with the Broumley Farm digester project in order to provide guidance on how to avoid it in future projects. This includes variable electrical generation tied to gas output and composition (Plunk).
- Need to place more focus on technologies for removing ash from HA-FB, rather than relying on feedlots to pave feedpens. What are the financial tradeoffs? (Weinheimer).
- Should keep in mind that concrete pens caused lower feedlot cattle production in the 1960's-1970's, according to research at Bushland and elsewhere. (Hutcheson).
- This project team should provide technical advice/trouble shooting to Broumley Dairy before the opportunity is lost. (Caldwell). Evaluate net benefit/cost relationships. (Weinheimer).
- Technology transfer from this project should extend to revising the TCFA feedlot energy management guidelines using new project knowledgeable. (Weinheimer).
- All scalability factor costs and environmental benefits should be addressed in our investigations to include biofuel requirements and costs, and product streams from alternative technologies. Make sure the variables in the experimental design should include only feasible circumstances and not those that are not technically feasible. (Plunk).
- Trend toward increasing sulfur in feedlot rations (Hutcheson) is going to be problematic to power plants, which already face major cost of removal. (Plunk)

The *third joint meeting* of Investigators and Industry Advisory Committee was held on Sept. 28, 2006 at the Texas AgriLife Research and Extension Center in Amarillo, TX. The meeting agenda and PIAC feedback provided are summarized in Appendix E.2. Some key PIAC recommendations or comments were:

- Reburn results on NOx reduction using FB as reburn fuel appear exciting. (Plunk). Make sure our numbers are correct (Plunk).
- Greater emphasis is needed on "designer" biomass fuel to the utilization application, including a classification or grading system for fuel classifications in-situ or upon collection. Appears bulk density can become reliable guide to ash and moisture to avoid transportation and handling of FB with low energy density. (Joiner).
- Develop reliable ash utilization strategies. Phosphorous or odor chemical extraction could be explored (Joiner).
- Cattle feeding infrastructure is not likely to change in a 10-20 year time span. Must develop systems to deal with the fuels produced today. (Weinheimer).
- Cannot afford to put much energy or cost into biofuel promotions. Should look at net energy value at the point of utilization. (Weinheimer).
- Scaleable systems to on-site or nearby utilization should receive greater attention. (Weinheimer).
- Should look at environmental as well as energy footprints of complete systems. (Weinheimer).
- Supply of low ash manure is very limited and unlikely to increase. Ash removal could recruit more higher ash FB to simulate lower ash content supplies. (T. McDonald).
- Development of gasification systems at feedlot level to use high-ash FB was encouraged (T. McDonald), as a more practical approach to transport to central conversion facilities.
- Grinding of FB adds value to the fuel, but obviously adds an expense we should evaluate (Plunk). Ash removal would be added benefit.
- Activated charcoal is becoming a valuable product that can result from gasification of FB. (Plunk).
- Chlorine is a real negative in combustion systems unless it can be off-set value-wise by potential mercury capture, which would add value. Looking forward to the Hg-capture results. (Plunk).

- We cannot add a lot more cost to manure handling; the cattle have already extracted (90%) of the carbon in the feed, so FB contains the last 10% of carbon. (Hutcheson).
- Phosphorous and zinc have value if they can be extracted from the ash as useable minerals from cattle nutrition. (Hutcheson)

The *fourth joint* meeting of investigators and the PIAC was hosted by TXU, and was held at their TXU Big Brown Power Plant, Fairfield, TX on December 12, 2006. Again, the meeting agenda and the PIAC feedback is provided in Appendix E.2. PIAC comments and recommendations included the following:

- The research team needs to devote more effort on using high-ash feedlot biomass, which is real-world condition. (Weinheimer).
- The chemical analysis of FB ash is appreciated. Need better analytical tools. (Hutcheson). Soluable phosphorous is more important than total P.
- Great progress was shown on the systems analyses model (by Carlin & Harman) for the liquid manure thermochemical utilization. A water treatment mode should be added. (Hutcheson).
- Trace mineral values have increased (viz. zinc selenium, phosphorous); greater research attention is needed on extracting them from ash. Wet distillers grains have concentrated P relative to whole corn, and more will be excreted as manure and hence higher P concentrations present in ash or residue. (Hutcheson and J. Johnson).
- Most appropriate technological scale will be on-site (i.e. feedlot or dairy), rather than power-plant scales. (Weinheimer). A science review panel was recommended to guide a mid-course correction to shift project focus toward the most fruitful areas.
- Net energy considerations must be established for complete systems. (Weinheimer).
- More data is needed on value and uses of anaerobic digestion residue. (J. Johnson).

The *fifth joint meeting* of the PIAC and investigators was held on April 13, 2007 at TAMU, College Station, hosted by TEES and the Department of Mechanical Engineering. Key points of feedback from the PIAC included the following:

1. The proposed tasks use several different paths to achieve energy conversion until one or more "catches fire". It is for the industry to adopt the technology suitable to their need and suitability of their feedstock. High ash FB is suitable for gasification while low ash FB is 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 in sufficient quantities. Researchers should develop technologies for high ash FB or for ash removal if that is necessary; need scalable technologies. Needs small scale on-site energy conversion systems as well as technologies for utilities-scale.
5. DB consulting company feedback: Much more progress has been made since last meeting. There was a lot of interest in Carlin's model (Task A.8). 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? We should give that greater attention.

The *sixth meeting* of investigators and IAC was held on Dec 10, 2007 at Waco, hosted by the Texas Farm Bureau. The agenda and feedback provided by the PIAC is shown in Appendix E.2. The PIAC attendees were Ben Weinheimer, TCFA; Paul Joiner, Panda Energy; Cliff Clark, TXU/Luminant; and Ned Meister, TFB. A summary of key points made in the PIAC response to presentations and discussions was as follows:

a. PIAC members were happy to be part of this group; they understand the quality of research and trust our results. Investigators are addressing both pollution control and renewable energy production; both beneficial endeavors. The project has come a long way and we must interpret what we have learned and relate to the feedyard industry in a practical way.
b. For technology transfer, the feedlot operators will not go out and pave their pens to improve manure quality for bioenergy unless there are economic returns to justify. Hence, we should put greater focus on improving high-ash or upgrading manure from current types of feed pens (e.g. solid surfaced).
c. Density gradient could perhaps be used to improve FB quality e.g. 100 vs. 62.4 vs. 20 lbs /cu.ft. for soil, water, and FB organic matter, respectively. The data obtained by investigators show the HHV benefits and hence, it may be possible to develop a system. Steps are needed to preserve C in order to enhance HHV, and vice versa.
d. Reducing carbon loss will solve 2 or three other environmental problems at once. Pathogen loss is also a concern.
e. Even though it is a limited resource, manure is an "opportunity fuel" and needs sound business plans for showing it as beneficial resource.
f. One concern is that the costs of using FB are only estimates and not very well refined. The supply of FB and DB are probably insufficient to support a 600 Megawatt plant as stand-alone fuel; hence, co-firing is a better alternative. The investigators must estimate the minimum amount of manure that can make an impact on coal plants. Need to determine whether manure can replace 1-5% of coal at some locations using co-firing technology. One must make sure that there is large scale success.
g. Carbon credits can become a large benefit if they can be well documented. Look at both NOx and carbon benefits of FB/DB. Industry needs the best intellectual advice.
h. Power industry will be required to have more and more renewables in their portfolio. Therefore crops, animal wastes, others will be considered. These factors could help stimulate funding or adoption of technology.
i. At some point, industry including TFB (Texas Farm Bureau) needs to take the lead in going to the policy sector and help get some additional longer term research and development funding.

A *seventh and final meeting* of the PIAC and investigators was held in Grapevine, TX on May 22, 2009. An agenda, participants and meeting summary are shown in Appendix E.2. Presentations were made by PI's/Co-PI's Annamalai, Sweeten, Capareda, Engler, and graduate students regarding project and tasks completed. Project wrap-up was also discussed.

A guest speaker, Gerry Greathouse, Pecos Valley Dairy Co-Op, Roswell, NM discussed the new Pecos Valley Biomass Initiative (funded by a $2.3 million DOE grant) in which manure from local dairies totaling 50,000-65,000 cows will be pooled and converted to energy. A main dirver is water quality protection. They have hired a consulting firm that is looking at alternative conversion technology. He was gathering information on what we have found out on dairy manure quality logistics and conversion technology. What we are learning here has bearing on their project. Right now, they are leaning toward anaerobic digestion technology. Dairy biomass quality and quantities for conversion are especially interesting in implementing manure harvesting technologies to maximize value which will be important using the existing dairy facilities. The value of what he has learned from the investigation at this meeting will be valuable to implement, viz. harvesting practices to maximize quality and write operating practices to create incentives. Another value-added proposition will be harvesting nutrients and fiber from digested slurry.

C. Clark, Luminant, recommended that remaining investigations and attention focus on distributed energy conversion, which is different from an original central power plant focus of the project originally because our data now shows the delivered cost of DB or FB can exceed the value relative to coal. We should also focus more on anaerobic digestion, as a means of producing methane, which can be transported for used on-site or on gasification or pyrolysis, which can produce combustible gases and/or char.

Olon Plunk, Xcel Energy, believes our co-firing at less than 5% of fuel has been well-targeted research toward power plant application and recommended we take additional steps toward technology commercialization. The economic component needs to encompass potential cap-and-trade policy effects on FB or DB harvesting or utilization practice as additional income.

Ben Weinheimer (TCFA) recommended we apply remaining efforts on using high-ash manure and adopting appropriate conversion, logistics, and economic efforts to that reality. Also, the industry needs for us to package our information we have gained into complete-systems ready for adoption and involving simple operations and inexpensive enough for a $2 million feedlot to afford to build and operate. Our expertise can help the industry steer away from unrealistic schemes.

Meister (TFB) showed the high value of this research project to industry and will lead to new uses for manure and contribute toward GHG/air quality emissions reductions, as well as carbon credits which we can help industry get a grip on soon. We should focus remaining attention on packaging our results, recommendations, and technology transfer.

Cowan (TAD) asserted the project has positioned the dairy industry better than it was previously. A main benefit of our findings is showing how to improve manure quality and value. We need to package the findings and technology better so it is useful when needed. Right now dairies are in an economic survival mode, and profitability must return before they make changes such as renewable energy, which provides additional benefits of water and air quality management also being forced by the industry, which is mutually beneficial.

Paul Joiner encouraged us to maintain this form of industry integration into the process, including carbon trading which can help or hurt, depending on how configured. We can help industry with the policy side through injecting technology. Industry needs complete systems, not piecemeal knowledge/technologies, so our challenge is to keep working with industry. Access to data bases is another way research can help industry. It all has to be affordable.

Cliff Clark summarized these PIAC points by an emphasis on putting the technological tools we have developed here to work through saleable products.

Other individual industry briefings were held during the course of the project that included project results. These meetings included the following:

a. Presented technical information to Panda Energy, Du Pont, and Frito Lay representatives at meetings in Amarillo on FB as potential biofuel, among other domestic and foreign companies.
b. Conducted site visits and briefings to discuss additional research co-funding opportunities with private industry. These included an office meeting with TXU (viz. Luminant) officials at their Dallas Headquarters, January 25, 2007.

Task H – Economic modeling of cattle biomass energy systems (WH)

Task H.1. (WH, KA, JS): Economic analyses of co-firing, reburning and gasification of CB in the production of energy, including benefit/cost analysis for using CB as biofuel with or without coal.

Task H.2. (WH) Estimate the opportunity cost (per unit of energy produced) of using non-renewable energy sources.

Task H.3. (WH) Adapt and utilize the IMPLAN Economic Model to analyze community-level economic impacts of generating energy from CB.

Introduction:

Dr. Wyatte Harman, Professor of Agricultural Economics, Texas AgriLife at Blackland Research Center, served as economics team leader for this Task. Other task participants were: Nick Carlin, PhD student, Mechanical Engineering; Dr. James Richardson, co-Director and agricultural economist, Agriculture Food and Policy Research Center, Department of Agricultural Economics; and Melanie Magre, Research Associate.

Costs associated with FB and DB collection/harvesting, transportation and processing are integral to conversion system economics. In this DOE funded project, Co-PI Wyatte Harman (WH) reviewed previous economic analysis spreadsheets which proposed a method of calculating transportation costs associated with CB acquisition.

Annamalai et al. (2005) showed that based on pilot plant tests at USDOE Pittsburgh, PO, coal plants that reburn with feedlot biomass (FB) could reduce NOx emissions by up to 90%. A U.S. patent was issued describing this process (Annamalai and Sweeten, 2005). Reburn with FB if locally available could save on coal purchasing costs. The purpose of this study was to estimate the emission variations and compute the annualized cost of installing and operating a FB reburn system retrofit to a plant currently with primary NOx controllers. As FB supplies a greater percentage of the overall heat rate of the coal-fired unit, the amount of coal required for fueling the plant decreases; however, due to lower heating values of FB, the overall required amount of fuel mass would increase with biomass heat contribution. Major obstacles could include ash content, cost and available supply of FB or DB. Moreover, CO2 emissions from non-renewable sources are expected to decrease while the overall amount of ash production would be expected to increase when reburning with FB or DB.

An economics literature review focused primarily on secondary nitrogen oxide (NOx) technologies such as selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and reburning (commonly with natural gas or micro-ionized coal). This information was geared toward developing the economic models which could a) compare a FB reburning system to more common technologies such as SCR and SNCR; and b) estimate the net present value and payback period of a FB reburn system installation on an actual coal-fired power plant. Information was also obtained about primary NOx controllers such as low-NOx burners and air staging. Moreover, there has been some research on how these NOx control technologies affect other emissions, aside from NOx, such as CO2 and ash.

Objectives:

1) Conduct an economic comparison of conversion alternatives on the basis of cost per unit energy produced. (Task H.1.);

2) Provide benefit/cost estimates for using DB or FB biofuel source. (Task H.1.).
3) To estimate the opportunity cost (per unit of energy produced) of using non-renewable energy sources such as coal or natural gas. (Task H.2.).
4) Adapt and utilize the IMPLAN Economic Model (University of Minnesota) to analyze community-level economic impacts of generating energy from CB. (Task H.3.).

Approaches, Methods and Materials:
The economics studies were planned to evaluate economics of dairy or cattle feedlot manure conversion using available research proven conversion process data. Using the current, best estimates of construction costs for transportation, storage, handling and energy-conversion facilities, those costs were amortized over the expected life of the facility. Labor, energy and other costs related to unloading, processing and handling of the CB at the conversion facility will also be estimated.

The economic modeling tasks began with a review of literature concerning the development of alternative DB and FB technology utilization costs. Co-investigators determined the economic data needs and deliverables needed to achieve the stated objectives. Dairy farm energy use surveys were completed in the Bosque River Watershed and analysis was commenced. The total energy loads on a typical dairy were found to be 22% hot water thermal and 78% electric for cooling, milking, and lighting. A small 60° kW internal combustion (IC) engine could satisfy all of the hot water (thermal) load with a heat recovery water heater. Additionally 60 to 80% of the electrical load could be satisfied by the engine.

Economics of Co Generation:
An economic study was conducted for the possible savings of installing a co-generation system, fueled by natural gas, on a typical dairy farm. Co-generation systems are designed to generate both electrical and thermal energy simultaneously so that savings on electric utility bills may be made. As dairies herd sizes increase, opportunities to save money on energy costs through co-generation systems may become significant due to additional operation costs inherent in keeping more animals.

Since most dairies currently use electric water heaters to meet hot water thermal loads, it is easier for such a co-generation system to be profitable. However, other factors such as discount rate and down time may have critical impacts on the success of the co-generation system. Low electrical rates and high fuel costs will also play roles in determining the profitability of this system. Yet the low fuel requirement to meet relatively small hot water loads on the dairy minimizes the impact of high fuel costs. Financing and maintaining the co-generation system may be the greatest obstacles.

Results:
Co-Generation with natural gas or biogas was examined for a 900-cow dairy, the net present value (NPV) of a proposed co-generation system was found to be $76,900 with a simple payback of three years. Installing an engine with a rating that is larger than the required electrical load allows for greater payback when more animals are added to the farm, assuming that energy consumption is proportional to the number of animals on the farm. Moreover, in sensitivity studies of the NPV, the proposed co-generation system was shown to be profitable for dairies with 700 to 1,400 cows. Many of the large dairies with freestall operations are within this size range or larger.

A co-generation system may be used in conjunction with an anaerobic digestion system since the IC engine can be driven by biogas produced from manure waste streams. Economically, it must be determined whether the capital, operation and maintenance costs of a digester can become lower than the cost of purchasing natural gas. The intention was to use the data and outputs of the Broumley Dairy anaerobic digester in the Bosque River watershed to evaluate the biogas option. Unfortunately, this digester system was closed down before the evaluation could begin.

Economics of Reburn with FB and DB:

Feedlot biomass (cattle manure) has been proposed as a reburn fuel to reduce NOx emissions in coal-fired units. Two major obstacles of reburning with cattle biomass were identified as ash production and transportation distances/costs.

Coal plants that reburn with feedlot biomass (FB) can reduce CO2 emissions, and save on coal purchasing costs while reducing NOx emissions by up to 90%. The purpose of this study was to estimate the savings on emissions, compare the annualized cost to that of other NOx control technologies such as selective catalytic reduction (SCR), and to compute the approximate net present value (NPV) of installing and operating a FB reburn system retrofit to a plant currently with primary NOx controllers.

When looking at the specific NOx reduction cost, it was found that for equal annual NOx reductions, SCR was less cost effective at $8,298/ton NOx removal than low-ash FB reburning at $7,150/ton NOx. Selective non-catalytic reduction (SNCR) seems to be the poorest option with a specific NOx reduction cost of $10,614/ton. However, SNCR requires the lowest investment cost, which may make it favorable to smaller plants (<200 MW). Possible future CO2 penalties, increased coal cost, lower distances between plant and feedlot, and longer operation hours of the reburn system are all favorable to the value of a FB reburn system.

For a coal plant (500 MW, 9,750 Btu/kWh, and 80% capacity factor), the annualized cost of reducing NOx through FB reburning was found to be approximately $57.7 million per year. The analysis included O&M costs, biomass and coal delivery costs, ash disposal costs, ash revenues, and annualized capital costs. Possible future CO2 penalties, increased coal cost, lower distances between plant and feedlot, and longer operation hours of the reburn system are all considered favorable to the value of a FB reburn system [Carlin et al, 2006b].

The economics team computed the overall net present value of installing and operating a biomass reburn system in a coal-fired plant and performed a sensitivity analysis by varying several parameters such as transportation distances, coal cost, hours of operation, etc.

A preliminary analysis compared dairy manure as reburn fuel at a level of 10% DB:90% coal in a coal-fired plant verses a plant using selective catalytic reduction (SCR) technology for reduced NOx emissions. Based on a 50-mile transport distance of DB and $0.12/ton-mile hauling charge, annual cost of generating electricity for a 500 MW plant could be reduced about 10%. A similar economic comparison was planned with a more commonly used coal generating plant that uses low-NOx emission control technology instead of the more expensive SCR technology.

DB & FB Cost of Supplies:

The Panhandle survey was conducted and analyzed from a list of contract manure collectors/truckers. Input from Texas Cattle Feeders Association and selected feedyards & dairies were used as well. The economics of hiring contract haulers to transport cattle biomass fuel versus a scenario in which the power plant would purchase its own trucks and hire its own drivers to transport the biomass were evaluated.

The economic model developed in this task involved a detailed algorithm for computing FB transportation costs. Loading speed, average truck speed, truck gas mileage, diesel fuel cost, truck capacity, hauling cost, hauling schedule, maintenance cost, and labor, were added as parameters to the transportation cost calculation. Before the modification, the only input for transportation cost was a simple "$/ton/mile" number that was largely assumed. Drying and grinding costs for FB reburn fuel were investigated also. Cost estimates for anaerobic digestion facilities similar to that at the Broumley Dairy in Erath County were explored as well.

Alternative NOx Reduction Technologies Costs:
A comparison was made of capital, O&M, and fueling costs of three secondary NOx control technologies: (1) selective catalytic reduction (SCR) systems, (2) selective non-catalytic reduction (SNCR) systems, and (3) biomass reburn systems for coal-fired power plants. The economics of three NOx controls to find the most cost effective option for coal plants were compared as well.

The economics model may be used to compute annual costs for several alternative or secondary NO_x control technologies such as selective catalytic reduction (SCR) as well as cattle biomass reburning. Additionally, the spreadsheet model can compute the net present worth (NPW) and the simple payback period for a cattle biomass reburn system retrofit on an existing coal-fired power plant. A base case computation, using nominal inputs found from literature review, was conducted to serve as reference values. Several input parameters such as coal price, value of NO_x credits, reburner heat rate, and biomass transportation distance were varied to show how sensitive the NPW would be to these parameters. Calculations such as estimated NO_x credits earned for reductions beyond NO_x levels achieved by primary controls (low-NO_x burners), were included in the economics spreadsheet model.

A journal paper on the economics of reburning coal with cattle biomass in existing coal-fired power plants was completed. USEPA [2007] capital cost estimates that were included. A discussion of cattle biomass feedstocks, common NO_x control technologies, modeling equations, and computational methodology were provided in the paper: Carlin, N.T., K. Annamalai, W.L. Harman, J.M. Sweeten. 2008. "The economics of reburning with cattle manure-based biomass in existing coal-fired power plants for NO_x and CO_2 emissions control". *Journal of Biomass and Bioenergy*, 33 (2009); 1139-1157.

Cofiring Systems Economics:
The reburn economics model (discussed previously) was successfully converted to a simple co-firing model. In practice, only up to 15% biomass on a mass basis is co-fired with coal mostly due to biomass's inferior heat value in which DB or FB would be blended with coal or lignite at low ratios e.g. 5:95%; 10:90%, etc. As expected, the overall economic outlook for co-firing does diminish for co-firing *retrofit* projects, because there is little or no revenue from *avoided* NOx emission allowances. However, it is easier to scale down co-firing applications, because unlike, reburning, which requires at least 5-10% heat input from the biomass reburn fuel, cofiring can be conducted at any heat input level [DOE, 2004]. Even without revenue from avoided NOx emissions, co-firing coal with 1 or 2% manure-based biomass (by mass) may be more feasible than importing enough biomass to run a reburn system.

As expected, the economics of co-firing and reburning appeared to be similar with the exception of any cash flows involved with NOx reduction. NOx reduction is not expected to factor into the overall economics during cofiring, as experiments have shown that NOx is not significantly altered when blending coal with cattle biomass in primary burn zones in coal-fired boilers. More work is warranted to verify capital cost functions of installing biomass cofiring systems in

existing coal plants. The USEPA [2007] released new information about this subject that may be useful to the current research and future follow-up on analysis, should funding become available.
Drying Systems:
The variable O&M cost of either a biomass co-fired facility or reburn facility was found to be dominated by fueling costs for biomass dryers. Cost-related economics were developed on manure drying systems particularly focusing on the dryer fan's O&M costs. It is more expensive to transport raw manure, especially in humid climates or where cattle are fed in confinement buildings, which can be as high as 60 to 80% moisture, than by using relatively dry manure (<40% moisture) found in arid climates. To move smaller manure particles through a drying chamber, a high mesh screen conveyor belt may be required to dry the manure. However, this would increase the pressure drop in the drying chamber, and thus increase electricity consumption for the dryer fans. It may be necessary to consider rotary dryers instead of conveyor belt dryers for manure drying, and modify the economic model accordingly. The higher electricity consumption from the dryer's fans did affect the overall O&M cost of the drying facilities.

Currently, propane, natural gas or electric heaters are the means by which the biomass is dried before transport to the combustion facility. But given the high price of natural gas and petroleum fuels, using any of these methods to dry the biomass may be out of the question. There are two ways to address this problem (1) find cheaper ways to dry the biomass, or (2) use waste heat from the power plant operations to dry high moisture biomass fuel to an appropriate level for further processing, blending, or direct firing.

For the former option, solar energy dryers may be used, especially if the coal plant is relatively small (under 300 MW_e) and requires only 1 or 2% biomass. However, there is a high capital cost for solar energy applications, and it is not clear if this additional capital could be amortized by the incentive revenues from co-firing. Secondly, providing a consistent supply of biomass to the coal plant, year-round, may be more challenging using a solar-powered drying system.

The other option is using waste heat from the power plant to dry the biomass. However, this may not be possible if the power company or proprietor of the power plant has reservations of having raw manure at the plant site. Moreover, utilizing waste heat may interfere with some of the post-combustion controls at the power plant. For example, if the plant has a SCR system, which requires the flue gases to be over 600 K, there must be careful consideration of the placement of any heat exchanger for biomass drying. Since diesel prices are also high, this second option may only be suitable for cases in which the power plant is very close to the source of DB or FB.

Opportunity Cost Study (Task H.2.) (WH)

Introduction:
The economics research team met and developed improvements in the economic data and existing worksheets discussed under Task H.2. Using that information, they conducted an opportunity cost assessment.

Methods:
The methodology was reviewed for developing the opportunity costs of existing non-manure low-NOx technologies such as SCR and SCNR using standard fossil fuels, as a precursor to evaluating cattle biomass as a substitute to fuel. Improvements were made to the economic worksheet regarding costs and other parameters included in the economic analysis. By adding the common acquisition cost of CB (cost per unit of energy produced) to the unit costs of each process, the opportunity cost of generating energy from coal or natural gas was compared directly to manure.

The economic worksheet included calculating the opportunity cost of excluding cattle biomass and using only coal.

Improvements included expanding and itemizing costs involved with a manure drying system, including a heat supply boiler and air fan. Labor for operating the dryer system such as required employees per dryer, drying schedule, drying days per year, operating manure loaders, storage trailers, land costs, and natural gas costs were also explicitly written into the spreadsheet program. Transportation costs were also improved by selecting larger 40 yd^3 trailers pulled by truck tractors, which tend to be less expensive than the smaller volume dump trucks. To complete a full sensitivity and risk analysis for the reburn economics model, the economics team decided to use an add-on program for Microsoft Excel called SIMITAR.

Results:
The opportunity cost appeared to be a dominant part of the biomass reburn system analysis, and the predominant incentive for co-combustion with biomass. As the drying and preparation processes for manure combustion were itemized and investigated more fully, the cost of drying the biomass before reburn combustion in a way that would provide a homogenized and steady supply for a power plant, was found to be more exorbitant than previously thought.

Overall economic results indicated that cost-offsetting credits for potential reductions in NO_x and/or carbon emissions when utilizing 10% cattle biomass on a heat equivalent basis are likely to be needed to breakeven compared with a 100% coal, status quo, scenario. Break even credit values were calculated within the worksheet. ***The ability to forecast required emission credits for feasible cattle biomass combustion may ultimately prove to be the economic modeling spreadsheet's most significant contribution to the present research.***

The economic data improvements in opportunity cost phase were also used to enhance the accuracy of the subsequent regional IMPLAN analysis. To prepare for the IMPLAN analysis to follow, the economics team decided to adjust the economics spreadsheet program to model co-firing in addition to reburning.

IMPLAN Regional Economic Modeling to Predict Regional Impacts (Task H.3.)

Introduction:
An important factor in determining project feasibility of alternative thermochemical processes using FB or DB as biofuel to determine the project's advantages, and value to the community. Fortunately, a well-accepted means exists for such evaluations for an array of technologies. Dr. Harman and his economics team developed access to a well-regarded IMPLAN model for this evaluation. The team adopted and utilized this model to determine community economics impacts.

Methods:
The IMPLAN analysis model was used to provide economic impacts of utilizing cattle biomass in a reburning application for the Bosque River Watershed of Central Texas. The analysis included projected increases in employment due to the cattle biomass utilization in coal-fired utility plants. In view of the importance of the IMPLAN analysis for future adoption of CB as reburn or co-firing fuel, more work and revision to the economic modeling spreadsheet was warranted.

IMPLAN Training and Model Acquisition:
Dr. Harman and research associate Melanie Magre attended two IMPLAN workshops for introductory and advanced training in November, and December 2006, respectively, at the

University of Minnesota IMPLAN Group headquarters. Software for the IMPLAN computer model and the Texas database for 2004 county economic activity was acquired at the workshops. This database and training was utilized for future regional economic assessments of dairy manure utilization when replacing coal in coal-fired power plants near the Bosque River dairy industry. The IMPLAN Model considers employment, monetary flows, and other sector financial impacts based on use or non-use of CB as fuel source.

Economic IMPLAN Modeling of CB Energy Systems:
Subsequent to the IMPLAN model training, a preliminary economic impact analysis was made of reburning manure in a 10% replacement scenario for coal in six coal-fired electricity generating plants that are plants nearest to the dairy production areas of Bosque and Erath Counties in central Texas and the High Plains area with cattle feedlots as well as dairies. The transportation distances for hauling manure were estimated to be about 200 miles one-way in the dairy area and about 75 miles in the feedlot area as were developed in Task E. Several hundred trucks would be required to accomplish the task for each plant for which commercial hauling rates of $0.15 per ton-mile for 25-ton loads was expensed.

Preliminary Results:
The preliminary IMPLAN analysis of the 10% reburn substitution scenario indicated that direct employment would increase by over 2,000 people or about 340 employees per plant site, most of which are truck drivers. Total indirect and induced employment of the plants would match the direct employment making a total of 4,228 jobs, or over 700 jobs per plant. Direct economic activity was expected to increase over $100 million/year and over $183 million/year including the indirect and induced benefits to an area, according to the IMPLAN results.

Further research included refining the preliminary estimates as more data became available regarding plant investment and operating costs, especially for the FB drying and grinding operations which were not available at the time of this impact analysis. These refined estimates could have a large bearing on IMPLAN model results.

Refined IMPLAN Analyses:
A regional IMPLAN analysis was conducted to compare partial substitution of dairy biomass (DB) for coal as reburn fuel on a heat equivalent basis versus 100% coal for an electricity generating plant in central Texas. The coal-fired plant modeled was located approximately 135 miles from the heart of the Bosque and Leon River watersheds which contained about 150,000 head of dairy cattle. The plant was located in close proximity to lignite coal which is mined for the plant. The economic analysis was based on partially utilizing DB collected and transported to six drying sites from dairies and after drying, transported by truck-trailers to the plant for grinding and reburning with coal. Regional income and employment impacts were examined based on three DB reburn rates of 5%, 10% and 15%; lignite coal recovery costs of $2 to $20 per ton; and DB prices of $0, $5, and $10 per ton.

Results (Task H.3.):
Both regional economic activity and employment increased as the amount of DB increased in relation to coal. Based on $18 per ton^{-} mining cost of lignite coal and “free” DB, at the source dairy a 5% reburn rate was shown to increase economic activity by nearly $27 million and 280 jobs annually. A 10% DB inclusion rate would generate economic activity of about $29 million and about 500 jobs; and a 15% DB reburn rate approximately $30 million and over 720 jobs. Additionally, economic activity and employment were projected to increase as the cost of mining lignite coal increased.

The impacts of increases in the cost of mining lignite coal, was illustrated using a 10% reburn rate and free DB. A $2 per ton^{-} mining cost increase boosted economic activity nearly $18 million and job numbers about 490. Both economic impact measures increased steadily to $30 million and over 500 jobs using the higher cost of coal recovery of $20/ton. Likewise, both economic activity and employment increased as the purchase price of DB increased.

A 10% reburn rate, $18 per ton coal mining cost, and free DB at the source dairy could increase economic activity by about $29 million and employment by over 500 jobs, increasing the DB purchase cost to $10 per ton and increasing the predicted economic activity to approximately $39 million and employment of over 600 jobs!

<u>References Cited:</u>

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<u>Technology Transfer and Dissemination:</u>

A Ph.D. dissertation was completed by Nicholas Carlin, which contained all of the economic work documented under this task. The dissertation is as follows:

Carlin, N.T. 2009. Optimum Usage and Economics Feasibility of Animal Manure-Based Biomass in Combustion Systems. Ph.D. Dissertation, Department of Mechanical Engineering, Texas A&M University, College Station, TX.

Journal articles published or submitted pursuant to Task H included:

Carlin, N.T., K. Annamalai, W.L. Harman, J.M. Sweeten. 2008. The economics of reburning with cattle manure-based biomass in existing coal-fired power plants for NO_x and CO_2 emissions control. *Journal of Biomass and Bioenergy***,** 33 (2009); 1139-1157.

Carlin, N. T., Annamalai, K. T., Oh, H., Gordillo Ariza, G., Lawrence, B., et al. 2008, Co-combustion and gasification of coal and cattle biomass: a review of research and experimentation. Submitted to *Progress in Green Energy*.

<u>Publications / Presentations:</u>

- Discussions of the research under Task H were also included in the following publications that were written pursuant to other tasks:
  - Annamalai, K. T., Carlin, N. T., Oh, H., Gordillo Ariza, G., Lawrence, B., et al., 2008, "Thermo-chemical energy conversion of coal, animal waste based biomass, and coal: biomass blends", 19th National and 8th ISHMT-ASME, Heat and Mass Transfer Conference, JNTU Hyderabad, India. January 3-5, 2008.
  - Annamalai, K. T., Carlin, N. T., Oh, H., Gordillo Ariza, G., Lawrence, B., et al., 2007, "Thermo-chemical energy conversion using supplementary animal wastes with coal", Proceedings of the IMECE, 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, WA, November 11-15, 2007.

Task I. – Energy Analysis of dairy farms and feedyards (SM, SC, BA).

Introduction:

Energy usage on dairy farms and feedyards varies depending on size, conservation, feed handling methods, water use, equipment selection, operating patterns and seasonal considerations. Where on-site use of manure for energy conversion is considered, it is important to define the site specific as well as "normal" energy use patterns, in order to try to match energy needs with potential bioenergy production. Predicated on additional (3rd year) funding, the research team had planned to match energy requirements vs. potential energy production on-site using recorded usage of electricity or natural gas with HHV values, and the results of energy conversion experiments in previous tasks were available also. This task was added in Year 2 based on projected Year 3 funding to complete. It would utilize data from the twelve Texas dairies identified in the Year 1 DB biomass characterization study (see Task C.2) to evaluate energy usage.

Most of the progress under this add-on task was captured under preceding tasks. The HHVs from 'as excreted' dairy manure as scraped, vacuumed, separated, and aged DB solids were determined and reported under Tasks A.1., C.1., and C.2. Similar HHV characterization data were determined for FB in Task A.1. Completion of DB characterization work was included in preceding discussions of Task C.2. This analysis and data tables need not be repeated here.

Objectives:

1) To determine site-specific and average energy use requirements or patterns for selected dairies and feedyards.
2) To match energy requirements with potential energy outputs of thermochemical conversion or anaerobic digestion determined under other preceding tasks.

Methods:

The basic plan for this task was to utilize energy records from the 12 Texas dairies used for the DB characterization study under Task C. Seven additional dairies in California were available as data sources also, from a parallel study.

A survey of 14 dairies in Texas and California was conducted to determine their total energy use on an annual basis. The goal of the survey was to evaluate the effect of production and management processes on energy consumption.

The total energy used on facilities varied widely with the type of operation, e.g., pasture, open-lot, or hybrid (a combination of open-lots and free-stall) systems, as well as with the relative age of the facility. The on farm energy supply sources included electricity, gasoline, diesel, propane, and natural gas. Where possible, the electricity usage at the dairies was allocated to four main energy sinks: the milking parlor, the animal housing areas, feeding, and manure management.

Results:

Task I was partially completed.

Total energy usage on the 14 surveyed dairy farms ranged from 464 kWh/yr to 1,637 kWh/yr, for a pasture dairy (NE Texas) and a hydrid open-lot/free stall dairy in Central Texas, respectively. The largest energy user was milking parlors for all 14 dairies.

The estimated daily potential energy availability from harvested dairy manure (25 kWh/day/hd) was determined to be much greater than the average daily on-farm energy requirement (3.2 kWh/day/hd). This indicated the possibility of adopting on-site manure-to-energy conversion systems. Analysis showed that renewable energy conversion systems with more than 15% overall conversion efficiencies could be considered for on-farm energy production alternatives.

Additional funding was not received to hire a graduate student who would conduct the analyses necessary to match energy use with practical systems designs and bioenergy outputs. The feedlot energy use survey was not conducted due to lack of funding and manpower also.

Summary:

We have now a better understanding of the energy usage in dairy operations between facilities in Texas and California. Total energy usage ranged from as low as 464 kWh per year per animal (kWh/yr/hd) for a pasture dairy in Northeast Texas, to as high as 1,637 kWh/yr/hd for a hybrid facility in Central Texas.

Generally, milking centers and housing components dominated the electricity usage for hybrid dairies, with the milking parlor being the primary consumer of energy for the open- lot facilities. Newer dairies were more efficient in electrical energy use than older facilities. A significant amount of energy could be saved by upgrading facilities with newer and more energy efficient equipment.

The potential energy present in harvestable DB is nearly seven (7) times higher than the net composite energy use on a Texas or California dairy farm. Hence, on-site conversion of DB to meet energy needs appears theoretically possible, depending on realized efficiencies of feedstock conversion and utilization systems.

Technology Transfer and Dissemination:

A technical paper was written for presentation to the 2008 International Meeting of the American Society of Biological and Agricultural Engineering, Providence, Rhode Island, July 1-3, 2008. The dairy energy use survey was also summarized in a published refereed publication, as follows:

Capareda, S.C., S. Mukhtar, C. Engler, and L.B. Goodrich. 2010. Energy Usage Survey of Dairies in the Southwestern United States. Applied Engineering in Agriculture. 26 (4):667-675.

GOAL 4 – PROCESS SENSITIVITY ANALYSIS, INSTRUMENTATION AND INFORMATION TECHNOLOGY (BA, SM)

Task J. Process Sensitivity Analyses, Instrumentation and Information Technology (BA, SM)

Goal 4 – Process sensitivity analysis, instrumentation and information technology (BA, SM)*

Task J – Process sensitivity analysis, instrumentation and information technology (BA, SM)

Task J.1.: Effects of fuel preparation, including drying at lower and higher temperatures.

Task J.2.: Net energy budgets for dairy and beef production systems in relation to CB and energy production potential.

This Task J was an additional work plan element that was added in hopes of attracting sufficient funding in Years 2 and 3 of the grant cycles. It was partially influenced by wishes of the Project Industry Advisory Committee. However, when it became apparent that further DOE funding would not be available for Years 2 and 3, this Task J was not developed further.

Pursuant to Task J.1., Sharon Sakirkin (Research Associate) conducted with partial funding, a series of precise experiments to calibrate and validate a partial least squares (PLS) regression model relating near-visible infrared diffuse reflectance spectroscopy (NVIR-DRS) signals to ash content of cattle manure/soil mixtures having ash contents between 15 and 95% of dry matter. She prepared an M.S. thesis on this project, completed in 2008, plus two journal manuscripts. These results and the papers were reported previously under Task A.1., and will not be repeated here.

The energy budgets (Task J.2.), like several Tasks under Goals 3 and 4, were not explicitly funded under the Work Plan as Year 3 funding was not forthcoming. This analysis would have required a M.S. level graduate student, and since funding was not received, the planned work could not be undertaken. As such, progress toward meeting the aspirations implied in the Task J.2. was not available to report.

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ASTM E 1757-01, "Standard Practice for Preparation of Biomass for Compositional Analysis"

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Appendix A

List of Acronyms and Terminology Used in Volume II

Appendix A. Listing of Acronyms

AB: Agricultural Biomass
ARS: USDA-Agricultural Research Service
AWDF: Animal Waste Derived Biomass Fuels
CAFO: Concentrated Animal Feeding Operations
CB: Cattle biomass
CGT: Cotton gin trash
CO_2: Carbon Dioxide
DAF: Dry Ash Free
DB: Dairy Biomass
DBS: Dairy biomass slurry
DOE: U.S. Department of Energy
EPA: Environmental Protection Agency
FB: Feedlot biomass (Cattle manure or Cattle Biomass CB)
FC: Fixed Carbon
GIS: Geographic Information Systems
HA-FB-Raw: High Ash Feedlot Biomass Raw form
HA-FB-PC: High Ash Feedlot Biomass Partially Composted
HP: High Phosphorus
HHV: Higher Heating Value
HV: Heating value
IAC: Industry Advisory Committee
LA-FB-Raw: Low Ash Feedlot Biomass
LA-FB-PC: Low Ash Feedlot Biomass Partially Composted
LAHP: Low ash/High Phosphorus feedlot biomass
MAF: Moisture Ash Free, Dry Ash Free
mmBTU: million BTU
MMF: Mineral Matter Free
NETL: National Energy Technology Laboratory (USDOE)
N2: Nitrogen
NOx: Oxides of Nitrogen
O2: Oxygen
PC: Partially composted (45-55 days)
PIAC: Project Industry Advisory Committee
PM: particulate matter
RM; Raw Manure
S: Sulfur
SCR: Selective catalytic reduction
SGP: Sun Grant Program
SR: Stoichiometric ratio, Air: Fuel/ (Air: Fuel) $_{stoich}$
SS: Soil surfaced or high ash feedlot biomass
TAES: Texas Agricultural Experiment Station (name changed to Texas AgriLife Research, January 1, 2008) (Part of TAMUS)
TAMU: Texas A&M University
TAMUS: Texas A&M University System (includes 7 research and Extension agencies and 11 universities)
TCEQ: Texas Commission on Environmental Quality
TEES: Texas Engineering Experiment Station (Part of TAMUS)
TXU: Texas Electric Utilities (now Luminant)
USDA: US Dept. of Agriculture
VM: Volatile matter
VS: Volatile Solids
WTAMU: West Texas A&M University (part of TAMUS)

Appendix B

Partial Listing of Publications Generated as a Result of this Volume II

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Partial Listing of Publications Generated as a Result of this DOE Project

Refereed Journal Articles:

Anderson, Thomas, Robert P. Lucht, Soyuz Priyadarsan, Kalyan Annamalai, Jerald A. Caton. 2007. In situ measurements of nitric oxide in coal-combustion exhaust using a sensor based on a widely-tunable external-cavity GaN diode laser. Journal of Applied Optics. Vol. 46:3946-3957.

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Absorption Sensor for In Situ Measurements of Atomic Mercury in Coal Combustion Exhaust**.** Journal of Energy & Fuels, 22:3029–3036**.**

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Annamalai, K., A. Udayasarathy, H. Oh, J.M. Sweeten.2009. Mercury Emission And Control For Coal Fired Power Plants. pp 205-217. ISBN 978-81-8487-014-5, Book Edited by A.K. Agarwal, A. Kushari, S.K. Aggarwal, A.K. Ruchai. Narosa Publishing House, New Delhi,2009.

Annamalai,K., J.M. Sweeten, S. Priyadarsan, S. Arumugam. 2007. Principles Of Energy Conversion For Coal, Animal Waste, and Biomass Fuels. Encyclopedia of Energy Engineering and Technology. Edited by Barney Capehart, Tyler and Francis, ISBN # 978-0-8493-3653-9; pp 476-497.

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