CONSERVATION INNOVATION GRANTS

Final Report

Grantee Name: Manure Energy Research Corp (MERC)	
Project Title: Cropland Loading Reduction Through Pyrolytic Nutrient Conversion	
Project Purpose: Demonstrate A Cost Effective Way To Reduce Cropland Loading From Poultry Operations	
Agreement Number: 69-3A75-10-145	
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Period Covered by Report: 9/10/10 through 3/10/13	
Project End Date: 3/10/13	
Submitted on: March 25, 2013	

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Executive Summary

The Chesapeake Bay Stewardship Fund (CBSF) has previously supported work at Virginia Tech to explore the feasibility of pyrolyzing poultry litter into salable products. The initial research demonstrated the ability to consistently produce oils that may have potential as a bio-fuel and nutrient rich, easily transportable chars. Through the effort of this grant, the Manure Energy Research Corp (MERC), a non-profit research entity, proposed to take this work further to determine whether this technology can be brought to a point that private entities would begin to fund the effort 100%, to understand the likely speed of such investment and to determine the impact on cropland loading and regional benefits. To do this MERC intended to focus on three main efforts:

1. Work with industry stakeholders to evaluate whether pyrolysis outputs (bio-oil and bio-char) could be converted into quality products that could be sold at sufficient margins to sustain operations.
2. Develop a refined pyrolysis equipment design that may be manufactured and operated inexpensively to support business viability.
3. Refine the financial model based on the results from the above two efforts, raise sufficient funds to build and deploy two pyrolysis units and demonstrate the viability of the pyrolytic nutrient conversion method to reduce cropland loading from poultry operations.

Originally, the project asked for the overall amount of $2 million on a 1:1 cost share basis of which $600,000 was sought from CBSF and $400,000 from NRCS CIG 2010. MERC received the NRCS grant but CBSF decided to reallocate the money to other purposes at the last minute. In addition, the pledged co-funding was reduced to $90,000 versus the originally pledged $400,000 due to the unexpected changes in the funders' financial situations.

Despite these occurrences, MERC proceeded with the project while MERC's team was continuously looking for matching funds to support the completion of the overall project deliverables.

The project was based on considerable initial positive feedback from the industry partners about the value of the pyrolysis products. However, as the project progressed, a number of issues were uncovered about the possibility of pyrolysis products to be sold "as is" at sufficient margins. The project team worked closely with the partners to understand and resolve these issues. It was concluded that the outputs of the pyrolysis process require significant post processing in order to convert them into salable products. Furthermore, the pricing that could be obtained for these products even after post-processing was lower than was expected.

The initial feedback from the design and manufacturing community about the ability to develop a low cost and effective pyrolysis unit were positive. However, under close examination in working with design and manufacturing partners and obtaining several detailed quotes, MERC concluded that the unit cost of a 10 ton per day pyrolysis unit was significantly higher than expected.

Given these findings, MERC updated the financial model and evaluated the situation before proceeding with the main efforts mentioned in item #3 above, namely raise additional money and build two pyrolysis units.

In the fall of 2011, given the overall negative situation in the financial markets, the reduction of funds available and the technical learnings resulting from the work to date, MERC's team reevaluated the overall approach and asked for a twelve-month extension of the project and a change in the deliverables. At that time only about 20% of the grant money had been spent.

The team proposed to focus on identifying higher value products from the original pyrolysis outputs and on developing the overall equipment design that would support business viability. Based on the feedback from the engineering community, it was proposed to build a smaller unit to test the new design rather than the original two larger units. The effort of building the unit was to be undertaken only in the case when the new results supported further commercialization effort. The extension and the new direction were approved by NRCS.

Since September 2011, rather than spent time on raising additional money, the team focused on identifying higher value products and developing a streamlined equipment design.

An exciting higher value product that can be produced out of the pyrolysis BioChar was identified – an Hg sorbent for stack injection applications. Commercial Hg sorbents sell at prices 10-20 times the value of the char as commercial fertilizer feedstock.

Our team is convinced that this result is an exciting step on the path to the successful commercialization of the pyrolysis technology that can convert hazardous poultry litter into useful and high value products. An opportunity exists to demonstrate a similar level of value increase with the bio-oil by refining it into phenols or high temperature plastic (HTP/UTP) feedstocks. Finally we believe that frugal innovation techniques can be applied to the equipment design to decrease its cost. Successful completion of these actions can potentially enable a profitable business model. Unfortunately, the project ran out of time to complete these actions.

From the overall findings to date, the original economics of the business as were envisioned by the project are not sustainable. As a result, MERC did not proceed with building a commercial unit even of the smaller size. An opportunity exists, however, to continue on the technical path that was laid out by the project to improve the profitability of the business.

Recommendation: The profitable solution for the treatment of poultry litter has not been created yet and this market opportunity is large. Only about 35% of the grant money was spent in this project versus allocated funds. NRCS might want to consider approving the follow-on project to complete the above actions. It is recommended that the new project not be required to obtain matching money based on the feedback that our team received from investors. Investors consider this project to be in an early stage of development and require the above-discussed actions to be completed before a serious investment in technology commercialization can be made.

Introduction

In 2009, Manure Energy Research Corp (MERC) proposed to NRCS to advance initial development work on the pyrolytic processing of poultry liter begun at Virginia Tech to determine whether this technology could be brought forward to a point where commercialization of the technology could be demonstrated as feasible and its market introduction be funded by private funding.

The project came to NRCS on the recommendation from CBSF that intended to co-fund the project. Originally, the project asked for the overall amount of $2M on a 1:1 cost share basis of which $600,000 was sought from CBSF and $400,000 from NRCS CIG 2010. MERC received the NRCS grant but CBSF decided to reallocate the money to other purposes at the last minute. MERC decided to proceed and raise additional money as the project progressed.

The project was led by a group of experienced business and academic leaders (see brief bios below) who believed that given the potential of the project, the funding can be managed.

Unfortunately, as the project started, co-funding partners informed MERC that due to the unrelated financial issues, the funds allocated to the project would be reduced to $90,000 versus the original $400,000 pledged.

The overall “belt tightening” situation in financial markets at the time did not help the project and put a strain on the project’s leaders who were under the constant pressure to raise additional funds.

An experienced team that had previously commercialized innovative technologies and brought them to market managed the project. The principal team, their relevant education and experience as well as their contribution to the project are detailed below.

a. Foster Agblevor. At the start of the project Dr. Agblevor was a Professor of Bioprocess Engineering in the Department of Biological Systems Engineering at Virginia Tech. He is currently a Professor of Biological Engineering Department at Utah State. His post doctoral research conducted both at the University of Hawaii and at the National Renewable Energy Laboratory (NREL), was in the area of biomass conversion to fuels and chemicals. He started his professional career as Staff Chemical Engineer at the Center for Renewable Chemicals and Materials at NREL, Golden, and Colorado and was a Senior Chemical Engineer when he left in 1996. Dr. Agblevor received his BS from Kwame Nkrumah University of Science and Technology, Kumasi, Ghana and PhD from University of Toronto, Toronto, Canada both in Chemical Engineering. Dr. Agblevor is the creator of the technology that this project is based on and has been advising the team on the overall technical direction.

b. Luda Kopeikina. A successful serial entrepreneur. Prior to her entrepreneurial endeavors, Ms Kopeikina served in senior executive positions at General Electric for six years before becoming CEO of Celerity Solutions, a public software company. She is also Lead Catalyst at the MIT Deshpande Center for Innovation. She received her BS in Mathematics, a Master's Degree and completed PhD in Computer Science, all from St. Petersburg University, Russia, as well as a Master's in Management from the Sloan School at MIT, where she also served two Visiting Scholar appointments. Ms Kopeikina led the project and was engaged in the fund raising initiatives with investors.
c. Poonam Narula. Dr. Narula received her BS in Chemistry in 1988 and MS in Physical Chemistry in 1990 from University of Bombay, Mumbai, India and PhD in 1997 from Wake Forest University, Winston-Salem, NC in Inorganic Chemistry. Dr. Narula is a six sigma green belt, also holds a certificate in process improvement from Worcester Polytechnic Institute and has recently completed her MBA in June 2009 from MIT Sloan school of Management. Dr. Narula oversaw the technical development of the technology and managed the operations of the sites.
d. Derek Grysk graduated from Virginia Tech and had been operating the prototype before the project started for eighteen months. Mr. Grysk's role was in operations and site management.
e. Noah Bullock. Noah Bullock earned an AB from Boston University. He has worked extensively in modeling and verification of biofuel systems and market development. In addition, he has done extensive modeling and market analysis both for biofuels and renewable energy. His professional experience has been with Deerpath Energy, a community wind developer, and GreenFuel Technologies, an algae to biofuels company. Mr. Bullock's role was to work with commercial partners on product testing and pricing.

MERC and NRCS agreed on the following project objectives in NCRS Grant Agreement #69-3A75-10-145 dated 9-10-10.

DELIVERABLES

1. Demonstrate the installation and operation of two commercial poultry littler pyrolyzation units, one in the Shenandoah Valley and one in the Delmarva Peninsula. The units should have a combined litter conversion capacity of 3,150 tons/year.

2. Develop an Operation and Maintenance Manual for a commercial poultry litter pyrolyzation unit.

3. Measure and document the quantity and quality of oil and BioChar produced from the commercial unit per ton of input poultry litter. Provide an analysis of poultry litter throughput as well as the oil and BioChar monitoring result.

4. Provide an analysis of the input litter and pyrolyzation products including carbon, nutrient and energy values per ton of litter processed.

5. Provide a report of the marketability, economic viability, and market sustainability of the pyrolyzation of poultry litter in the Chesapeake Bay watershed.

6. Provide a tour of the commercial poultry littler pyrolyzation unit near the end of the project for producers, researchers, USDA-NRCS and extension personnel to visit the unit for a personal inspection.

7. Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.

8. Semi-annual performance progress report and a final report that includes a description of the project and lessons learned and including a presentation of the data collected from the commercial unit including the quantification of litter processed, the quantity and quality of oil and BioChar produced per ton of input poultry litter, the analysis of carbon, nutrient, and energy values per ton of litter processed. The final report should also include a description of the cost of a commercial poultry litter pyrolyzation unit, as well as the analysis of marketability, economic viability, and market sustainability of the pyrolyzation of poultry litter in the Chesapeake Bay watershed.

9. Fact sheet describing the new technology or approach.

Based on its interim findings, in September of 2011 MERC requested the following changes to the agreement which were approved:

1. An extension of the project for an additional twelve months.

2. Modify Deliverable 1 to be: Demonstrate the installation and operation of ***one small scale commercial*** poultry litter pyrolyzation unit in Shenandoah Valley with the conversion capacity of 910 tons per year.

3. Change the key personnel to include Tim Brown and Martin Goldenblatt, both experienced executives who have previously successfully run businesses and commercialized new technology. Their relevant experience and education as well as their contribution to the project are detailed below.

   Tim Brown brings deep experience to the project in the worldwide components and materials markets that spans his 35 year career in industry. He worked in Engineering, Marketing, Sales, Operations and General Management roles in various size companies. Tim began his career in Engineering at Corning Glass Works and later managed Sales and Marketing at the Murata, Sprague Electric, and Morgan Crucible corporations. Most recently Tim was Vice President of Marketing at Ark-les Corporation. He also ran two successful businesses, one at Morgan and the other at Ark-les. Mr. Brown successfully repositioned several mature companies helping them return to growth and profitability. He assisted in the financing, scale up and sale of several start-ups. In addition to his knowledge of North American markets, Tim successfully established and managed organizations in Asia and Europe. Tim has a BA in Physics from Hamilton College and a Masters Degree from the University of Massachusetts. He is a Thomas Watson and NDEA Fellow. Tim oversaw the work with the engineering and manufacturing firms as well as the operations of the unit.

Mr. Goldenblatt brings to the project over 30 years of experience in the fields of consulting, sales and marketing for the energy markets. He has played an integral part in the success of multiple start-up companies. Mr. Goldenblatt's experience spans the entire spectrum of utility needs including plant operations, planning, maintenance, renewables, biomass and back office applications. Mr. Goldenblatt was a founder and Board member of LODESTAR. In addition, Mr. Goldenblatt was Vice President of Sales at GreenFuel Technologies. Mr. Goldenblatt holds a B.M.E. Degree in Mechanical Engineering from the City College of New York and an M.S.M.E. Degree in Mechanical Engineering from Northeastern University. Mr. Goldenblatt worked with off-take partners on end products testing and pricing.

While obtaining the extension, MERC discussed with the NRCS CIG personnel that in order to demonstrate the viability of the pyrolysis technology for poultry litter processing, the project needs to focus on validating three major aspects of the business model: markets and pricing for end products, manufacturing cost of a commercial size pyrolysis unit and operational model and costs.

The scope of the project included:

- Direct contact with potential off-take partners in the Energy and Fertilizer industries to determine product needs and price levels.
- Both laboratory and customer testing of off-take samples (Bio Oil and Bio Char).
- Direct contact with local farmers to obtain feedstock, provide site services for the prototype pyrolyzer.
- Continuous fundraising with potential investors/grant partners.
- Development and testing of a detailed business model including a financial package.
- Development of a cost-effective pyrolysis unit that can efficiently process poultry litter into quality products.
- Identifying a suitable manufacturer to manufacture and install the unit.
- Demonstration of feasibility of cropland loading reduction through pyrolytic nutrient conversion.

Background

The Wall Street Journal article "*Chicken Litter: The Aerial Hunt for Poultry Manure*," defined the problem that this project set out to address in the following way: "Livestock and poultry operations generate about 500 million tons of manure each year, or about three times the amount of human waste in the U.S., according to the Environmental Protection Agency. Much of that waste goes untreated and sometimes can make its way into public waterways. Among other contaminants, manure contains nitrogen and phosphorus that in large quantities can cause algae blooms -- green, gooey splotches on the water surface that can deplete the water's oxygen, killing fish and other organisms. And in some cases, the runoff, which can contain E. coli and other bacteria, can threaten human health."

Currently, the problem of poultry litter disposal is dealt with in several ways. Farmers are free to use the litter as fertilizer provided that the amount used per acre is within pollution regulations. In some regions, such as the Chesapeake Bay, where this project resided, the amount of litter produced is much higher than can be applied as fertilizer. As a result, farmers often sell the remainder to brokers that truck the litter to the neighboring regions where the amount of litter applied as fertilizer is less. Many farmers produce compost and sell it in bulk or bags locally or through distributors elsewhere. Due to the increasing amounts of poultry produced in the region, these disposal methods are not sustainable and still carry environmental risks.

The second well recognized method of litter disposal is incineration to produce electricity. Even though this method is used in a number of regions, it has been proven to be not sustainable without government subsidies and fierce lobbying efforts are underway to tighten regulatory controls. Political action has blocked several proposed installations.

Several new technologies, such as bio-digestion, gasification and others, are being experimented with in various parts of the world. However, none have demonstrated a scalable model that can address the problem in a profitable and sustainable way.

MERC's proposed vision was to solve this pressing environmental problem of nitrogen and phosphorous pollution caused by the disposal of poultry litter by converting it into energy using fast pyrolysis. Using small pyrolysis reactors MERC intended to pyrolyze the litter into Bio-Oil on or near the producing farms, consolidating the off-take products and then selling them to commercial partners. Commercial partners included local as well as multi-national oil and fertilizer companies. The environmental value proposition was to turn a waste stream into an energy source and reduce the pollution caused by litter disposal at the same time. This vision was expanded to include capturing value from the Bio-Char produced while manufacturing the Bio-Oil.

MERC's proposal included two major innovations that were intended to produce a profitable and scalable model:

1. An innovative distributed business model that minimized transportation costs and
2. A proprietary additive that eliminated odor and was critical in ability to condition the feedstock and the pyrolysis process to enable a more consistent bio-oil output in order to avoid post-processing.

MERC's innovative business model was built upon the creation of a distributed network of small pyrolysis reactors embedded in local farming communities. This distributed manufacturing concept was developed to lower the significant cost of raw material (feedstock-litter) transportation incurred by centralized processing models making them unprofitable. MERC's model also included a provision to minimize the transportation cost of finished goods (Bio-Oil and Bio-Char) by collecting end products into sizable transportable tankers that could be directly sent to the off-take partners. Additionally, MERC believed that manufacturing locally would build local farmer loyalty to the business through direct participation in its financial success and the creation of new jobs in the local farming community.

The business model was leveraged on four factors:

1. Market acceptance of the BioOil and BioChar at prevailing prices without additional processing,
2. Capital cost of the small reactors (CAPEX) being in a certain range,
3. Litter (feedstock) availability and stable cost,
4. Local labor cost at stable and reasonable rates and other operational considerations in range.

The model assumed that raw material transportation costs would be minimal and that off-take transportation costs would be at least at parity with competing products.

Please see Financial Impact Analysis Section of this report for specific assumptions that were made for the above factors in the original model.

Review of methods

The project proposed an innovative adaptation of a well established fluidized bed pyrolysis technology to reduce a environmentally hazardous organic process waste (chicken litter) into saleable products. The process was designed for a minimum emissions footprint and to generate the bulk of the energy needed for the conversion of the waste. The primary technology was developed at Virginia Tech.

Innovativeness: This project is innovative in several ways. First, the pyrolysis of litters in a way that eliminates odors and produces a PH neutral, near ash-free oil has not been done by others. Moreover, the project proposed the use of a proprietary additive that was believed to be valuable in the process of producing bio-oil consistently. Based on the tests that were performed before the start of the project, the team believed that the operational techniques could be varied so that the process produced oil consistently that met or exceeded the requirements of ASTM D7544, the Standard Specification for Pyrolysis Liquid Biofuel. To our knowledge, this has not been achieved by others using poultry litters. Second, we developed a unique method of adjusting the feedstock input to our specification and separating the output from pyrolysis in such a way that the output products can be made consistent and their valuable characteristics are maximized.

From the start of the project until the fall of 2011, the project utilized the following approach that included the following tasks:

b. Operate the current prototype at the Riverbank Farm located in Rockingham County, Virginia, in the heart of the Chesapeake watershed, to produce sufficient daily volumes for off-take partners' assessment. Partners included fertilizer and oil companies.
c. Work with off-take partners to determine product suitability and confirm product pricing.
d. Document refinements that might be made to reduce manufacturing costs and/or improve operating efficiency.
e. Develop refined design that could be manufactured and operated inexpensively.

Due to a number of unexpected challenges that the project encountered during this period that will be discussed later in the report and the results achieved, the team reassessed its approach and received support from NRCS CIG in September 2011 to proceed. The interim project update and direction are stated below and highlight two critical areas that the project focused on after September 2011.

1. Cost reduction. The project was successful in documenting unit operating costs by running the current prototype. The project was also successful in identifying refinements needed in the prototype design. The next step was to design a new and

improved pyrolysis unit that addressed issues that were encountered in the running of the prototype and then confirm that the estimate for manufacturing costs is within a viable range for proceeding with the commercialization process. MERC intended to find the right combination of engineering and manufacturing resources to make this possible.

After September 2011, MERC worked with Hazen Research, the original designer and manufacturer of the prototype, to develop a new design that took into account lessons learned from operating the prototype. It became clear in discussions with Hazen before September 2011, however, that Hazen could not provide a critically needed part of the design, namely, the required process control instrumentation and software, and could not cost optimize the unit to bring the manufacturing costs in line with our requirements. To address these issues MERC planned to prepare an RFP for selected manufacturers with Hazen's input and consultation. The selected manufacturer was intended to complete the design and manufacture the unit.

2. Value received from products. The project was successful in confirming that the pyrolysis technology can convert poultry litter into useful end products that are of interest to off-take partners.

   - MERC intended to evaluate Bio-Oil as a product for the following markets: industrial heating, oil refinery feedstock and lubricants. MERC was working with companies in each segment on further defining requirements and pricing. Such work required a number of iterations. For example, industrial heating and transportation vendors have stringent requirements for sulfur in the oil products that they use. Our process can adjust the amount of sulfur in oil but this path requires experimentation in the lab and then production of samples accordingly.
   - MERC intended to evaluate Bio-char as a feedstock for fertilizer companies and as a stand-alone organic fertilizer product. Several concerns were raised during this evaluation. One of the concerns that potential off-take partners voiced related to the fact that the char was dusty. MERC planned to address this concern by potentially adding granulation capability to the unit among other options.

After September 2011 MERC continued to work with off-take partners to determine the range of likely prices for the products.

In parallel, MERC planned to conduct two projects that could potentially position the off-take as higher value products:

- Evaluate Bio-Char for carbon activation. From the academic literature and consultations with experts, MERC believed that this approach would be successful. As a result, our bio-char could be positioned in markets with prices five to ten times higher than in the fertilizer market. AFR (Advanced Fuel Research) was expected to perform this work since this company was recognized as an expert in this area.

- Evaluated Bio-Oil for the extraction of phenols. Prior experiments by Dr. Foster Agblevor in this area were successful. Provided that phenols can successfully be extracted out of Bio-Oil, the oil derivative phenols could be priced at over ten times current oil pricing. Utah State University under direction of Dr. Agblevor was expected to perform this work.

It was agreed with NRCS CIG that the effort of building a new unit was to be undertaken only in case when the new results from the above methods supported further commercialization work.

Discussion of quality assurance

The project maintained high quality standards in all its work internally and with outside partners. Below is the list of partners that worked on the project and the discussion how the quality assurance was maintained.

- University laboratory work was done at Virginia Tech and the University of Utah under the supervision of a faculty member, Dr. Foster Agblevor. Work was performed to the research standards set by the universities and Dr. Agblevor.
- Outside design engineering work was performed by Hazen Research in Golden, Colorado by degreed engineering professionals. Hazen maintains an internal quality control system and engineering standards.
- Outside laboratory work was performed by Energy & Carbon Materials Advanced Fuel Research, Inc. (AFR) in East Harford, CT. The work was completed under the direction of Marek Wójtowicz Ph.D. AFR maintains its own internal quality standards.
- External customer product characterization was performed in the laboratories of such companies as Chevron and Anderson Fertilizer that maintain their own quality systems. Both companies are ISO 9000 2000 certified.
- Market and pricing information was taken from direct customer and/or stakeholder comments during interviews or conferences and published materials from government, corporate and private sources.

Findings

The project yielded valuable technical and commercial insights into technological improvement, process control and cost, and the current market and future potential for commercialization of the pyrolysis process for the processing of poultry litters.

An exciting new higher priced product potential was demonstrated for the Bio-Char.

In summary, given the results available to date, MERC discovered that although the technical hurdles identified so far could likely be addressed with significant additional investment, the economics of the business as we envisioned it do not support proceeding with the commercialization effort.

It is recommended, however, to support the continuation of the effort of investigating pyrolysis as a potential method of processing poultry litters into energy as discussed later in the report, addressing the economics with more research into higher value products from bio-oil and bio-char and the utilization of frugal design methodologies to bring down the capital investment costs.

Key Learnings/Accomplishments

As was mentioned previously, the original business model was leveraged on four areas stated below in the order of importance. The assumptions in the model were based on the initial inputs from partners and industry. The project intended to obtain confirmations on these areas utilizing the existing prototype and then proceed with building commercial units.

1. Market acceptance of the BioOil and BioChar at prevailing prices without additional processing,
2. Capital cost of the small reactors (CAPEX) being in a certain range,
3. Litter (feedstock) availability and stable cost,
4. Local labor cost at stable and reasonable rates and other operational considerations in range.

The overall findings summarized below as well as the lack of sufficient funds precluded MERC from proceeding to build the commercial unit.

Below are key lessons-learned related to the above areas.

1. Market acceptance of the BioOil and BioChar at prevailing prices without additional processing.

   Bio Oil Merchantability: Bio-oil was tested in independent labs as well as by potential commercial partners such as Chevron. The initial interest in the product was confirmed. In addition, companies like Chevron were willing to pay 10-20% premium above regular oil prices provided that the product was REN certified. However, several parameters were identified in the testing of Bio-Oil such as higher than expected levels of nitrogen, sulfur and water. Bio-Oil required either pre-processing or post-processing in order to produce an acceptable product. Test results can be found in Appendix 1 Bio-Oil Analysis.

MERC's proposed solution was to bind the nitrogen through the addition of a litter amendment and add a distillation step to remove or adjust other chemicals. Unfortunately, these steps increase the cost of the oil and increase the required capital investment. Please see Financial Impact Analysis Section of the report for the discussion of the impact of these findings on the economics.

Bio Char Merchantability: The initial interest in the bio-char as fertilizer was confirmed. Customers were highly interested in the material being organic due to an increasing expansion of the organic fertilizer market.

However, MERC uncovered two issues that were not as apparent in the initial discussions.

The first issue was pricing that was lower than expected. Commercial customers were only willing to pay for the material at the fluctuating material pricing based on the combination of NPK in the material. The pricing had to also include transportation costs.

The second issue was OSHA driven handling concerns about tiny quartz particulates in the Bio-Char that were thought to represent a silicosis risk. The concern can be easily addressed by pelletizing Bio-Char during the manufacturing process and implementing breathing protection (masks) during processing at the fertilizer company depending on how successful the pelletizing was in binding the quartz.

MERC considered several solutions for char pelletizing. Appendix 2 has a schematic of one of the processes that were considered for Bio-Char pelletizing. MERC eventually decided on the method to combine the hot char coming out of the pyrolysis process with lignin and press the mixture through a die and a mechanical cut off blade combination.

However, after careful research into the costs of pelletizing, the cost of lignin and taking into account the drop in Bio-Char pricing, MERC concluded that it is more economical to sell Bio-Char "as is" at the price offered by off-take partners than to pelletize it. Please see Financial Impact Analysis Section of the Report for the impact of these findings on the economics.

Value of the Bio-Oil and Char: In summary, commercial partners confirmed the initial interest in both products.

Customers confirmed that if quality requirements were met, and a REN number obtained for the product, the Bio-Oil could be sold at a premium (10-20%) to the prevailing price for equivalent grade material. In discussions with large oil companies such as Chevron MERC confirmed that each one of them would be able to consume our entire forecasted annual output of Bio-Oil. Fertilizer companies also confirmed that Bio-Char could be sold at the prevailing market pricing for its assayed amount of nutrient weight.

However, customer testing uncovered parameters that required attention related to both, the Bio-Char and the Bio-Oil. Both products could not be sold at the prevailing prices without additional processing. The pricing offered by partners for "as is" products reduced the initially estimated revenue and post-processing requirements increased the needed capital equipment cost.

As was mentioned before, in September 2011, having evaluated these intermediate findings, MERC decided to identify higher value products that can be produced from Bio-Char and Bio-Oil to increase the overall value proposition of the business. The results of this effort are discussed later in this section under Higher Value Products.

2. Capital cost of the small reactors (CAPEX) being in a certain range.

The project intended to document lessons learned from operating the original prototype at the Riverbank Farm, create an improved design, find a manufacturer to produce it and produce commercial units.

Design Improvements: MERC relied on the original prototype developed by Virginia Tech to produce samples of pyrolysis products for off-take partners as was discussed in other parts of this report. MERC discovered that the prototype required a number of significant improvements such as:

- The capacity of the chilling system needed to be improved to produce quality Bio-Oil.
- The feedstock airlock needed to be redesigned to eliminate blowback.
- The fluidized bed required additional insulation.
- The feedstock needed additional drying before the pyrolysis process could be effective which necessitated adding a pre-pyrolysis drying step.
- A special mixer needed to be added to better control ash content and final water content in the Bio-Oil.
- Electrostatic precipitator/baghouse required a different design for more efficiency.
- Process stability improvements.
- A software system for process control.

Design: In concert with Hazen Research, MERC created the improved design of a robust process based on the laboratory-developed key process control model (specifically feedstock residual ash control). An improved and scalable conceptual design for a commercial plant was created incorporating lessons learnt from the operation of the prototype listed above. These design improvements increased the CAPEX and the unit complexity. A high-level conceptual design can be found in Appendix 4.

As was mentioned earlier in the report Hazen could not provide a critically needed part of the design for the required process control instrumentation and software, and could not cost optimize the unit to bring the manufacturing costs in line with our requirements. To address these issues MERC prepared an RFP for selected manufacturers with Hazen's input and consultation. The selected manufacturer was intended to complete the design and manufacture the unit.

After rigorous bidding process in which seven pre-selected vendors participated, MERC discovered that the cost of manufacturing of the first pyrolysis reactors would be approximately one million dollars. The exact quoted cost for a skid mounted version of this reactor from Biomass Engineering in the UK, the most qualified builder since they have direct experience in building a similar unit for chicken litter feedstock, was $1,166,261.81 USD (£742,700.00 GBP) ex works. Based on manufacturing experience in the group with similar reactor systems MERC estimated that at high quantity manufacturing, the pricing might drop to $600,000 per rector. Changes in the design to take into account the resolution of issues encountered in the original prototype and adding the process control hardware and software contributed to the higher than estimated costs. Added to this investment were unforeseen capital requirements for meeting the needs of Bio-security and feedstock mixing that will be discussed later in this section.

MERC believes that this level of investment for pyrolysis reactors is too high to produce a reasonable return on investment in the business.

MERC recommends, however, that frugal innovation methodologies can be applied to streamline the design or potentially rethink the design concept to take the costs down to the originally estimated level. However, at this point in the project, the capital equipment costs are too high to proceed with the step of building even the smaller size commercial unit per the updated on September 2011 Deliverable 1 since the project does not have this level of budget allocated for this step.

Process Emissions: Theoretically, pyrolysis systems are discussed in the literature as closed loop systems since the output gases are not significant and can be put back to fuel the system. However, in reality, MERC discovered that some amounts of VOCs are produced as a result of the process. The original prototype was developed without the necessary treatment of the air exhaust. MERC had to spend a significant amount of time to adjust the design of the prototype and take these lessons learnt into account in the design of the commercial unit. These changes certainly added to the unit manufacturing cost. Although a prototype unit of 10 tons pre day capacity would likely not require permitting, MERC believes that some EPA approvals would be needed depending on the final emissions profile. The potential need for EPA approvals may add additional expense to the operating model.

3. Litter (feedstock) availability and stable cost.

   Since the start of the project the price of poultry litter in the Rockingham County, Virginia, has risen from $10 per ton to $20-30 per ton and is still rising. MERC's original model estimated to pay at the maximum $15 per ton for poultry litter based on the discussions with farmers in the area. This pricing constitutes almost double increase in costs. MERC believes, however, that even though the price for poultry litter is a critical component of the model, this price increase can be accommodated, provided higher value products are produced from the original Bio-Oil and Bio-Char.

   Our original vision was to deploy units nationally by replicating the same local production model regionally. Since the start of the project the availability of litter diminished and the costs increased across US regions. One of the factors driving these changes is the competitive demand for the litter from operations such as Fibrowatt that is forecasted to increase average feedstock costs since litter production is essentially inelastic.

4. Local labor cost at stable and reasonable rates and other operational considerations in range.

   Production Model: The original model assumed 24x7 operations with three shifts operating each unit. Due to the additional post and pre-processing requirements more people per each shift were required thus increasing labor costs by almost 50%-100% depending on the capacity installed. The most significant variable cost in the business is labor and so the impact of this change was large. MERC conducted a cost benefit analysis between placing a smaller number of larger reactors versus using 10-ton per day reactors as was originally planned. The scenario with a smaller number of reactors of larger size used labor more effectively but increased litter transportation costs. The net result is that both scenarios increased costs.

   Bio-security: During the duration of the project the poultry industry intensified the regulations of Bio-security. Evaluating these requirements, MERC concluded that each production site would have to implement unanticipated Bio-security measures that at a minimum would require wash down of all incoming and outgoing traffic and safe disposal of the wash down effluent. This requirement further increased capital investment pre installation and added unanticipated labor to the model. Please see Financial Impact Analysis Section of the report for the impact of these findings on the economics.

Economic Viability of the Original Model: The above-discussed lessons learned in categories 1-4 converted the originally profitable model into an unprofitable one with no payback. Based on the knowledge obtained to date by the project, the original business model was found to be not sustainable. Please see the Financial Impact Analysis Section of this report for a more detailed view into the business economics.

Higher Value Products: As mentioned earlier in the report, since September 2011, MERC focused the project on identifying and developing alternative higher value products from Bio-Char and Bio-Oil. The results of these efforts are documented below.

Higher Value Bio-Char: MERC's market research determined that various activated carbons used for heavy metal sorption have sales values between $1000 and $2000 per ton with the industry benchmark pricing at $1300 per ton for activated carbon sold as mercury sorbent. In comparison, char sold as a fertilizer feedstock has a value of $200 per ton. If Bio-Char could be converted into this higher value product it could significantly enhance the potential profit margins as well as shorten the project's payback period.

A test protocol to determine the effectiveness of activated Bio Char made from litter feedstock as mercury sorbent was defined in cooperation with an outside expert, Clean Energy & Carbon Materials Advanced Fuel Research, Inc. (AFR). The sample preparation methods (activation and washing) incorporated into the test matrix were chosen using the results of a joint survey of the scholarly work done in this area to date. Unmodified chicken litter pyrolysis Bio-char made under MERC's current process conditions was supplied to AFR from the University of Utah. Five char samples representing a target range of expected favorable process conditions based on the literature survey and initial physical characterization of the char were prepared by AFR using a steam activation process. The various samples were then subsequently sent to an independent outside lab, URS, for mercury sorption testing.

The URS laboratory tests compared MERC's samples to a standard commercially available activated carbon. A final report was issued by AFR incorporating the URS sorption testing results which show that two of the five sample lots performed very well against the commercial control for direct injection sorbent applications. See Appendix 3 for additional information. MERC and AFR believe that the properties of the two best sample lots in the test results would be commercially saleable as tested.

These results indicate that our char can be used for heavy metal sorption in stack injection applications. This is a significant breakthrough for this project since the increase in char value could have a significant positive impact on the business case.

Additional work is required to build a fully informed business case for this potential new product. Please see the Financial Impact Analysis Section of this report for a very preliminary estimate of these findings on the business case economics.

MERC's recommendation is to pursue this path of development since the initial business indications are positive.

Higher Value Bio-Oil: The project started working with Utah State University (Dr Foster Agblevor) to evaluate the production of phenols from Bio-Oil. The initial results were promising. However, the project was not completed due to internal issues at Utah State. Phenols can be sold as a product at a value of $1000-2500 per metric ton depending on the grade. More importantly MERC discovered that the phenol fractions can be further refined into high value High and Ultra High Temperature Plastics (HFT/UTPs). From discussions with researchers MERC received indications that the temperature range reachable by UHT's made from Bio-Oil could exceed the currently available commercial range. Ultra High Temperature plastics (UHT) can sell as high as $24/kg. Please see the Financial Impact Analysis Section of this report that presents a very preliminary view on how these finding can impact economics.

Recommendation: In summary, MERC believes that in order to commercialize pyrolysis as a method of processing poultry litter, the original pyrolysis products, Bio-Oil and Bio-Char, have to be converted into higher value products. The pricing estimates for such potential products are high enough to change the economics of the business and position it for sustainability. MERC recommends pursuing the development of such high value products.

Financial Impact Analysis

Appendix 5 Progressive Financial Impact Analysis shows a simplified financial model that reflects MERC's findings during the course of the project. It shows the economics of one pyrolysis unit installation with the assumptions listed under Major Assumptions. ***The model does not include corporate costs of the business.*** This Appendix demonstrates in numbers that in order to develop the pyrolysis technology into a viable business for processing poultry litters, the products produced by pyrolysis have to be upgraded into higher value products per the above recommendation.

The Appendix presents six columns with six economic scenarios reflecting project progression as new information was discovered during the project. The cases reflect the lessons learned in the above sections of the report:

Base Case presents the original project assumptions at the start of the project. Litter price was assumed to be $10 per ton, crude oil price was pegged to $84 per barrel, capital investment for one pyrolysis unit installation of 10 tons per day capacity was assumed to be $500,000. The base case was profitable with the payback period of two and a quarter years.

Additional Oil Processing presents the economics of one pyrolysis unit with the same assumptions as in the Base Case plus three additional assumptions:

1. Bio-Oil was REN certified and pricing for Bio-Oil increased by 15% versus the Base Case;

2. Includes costs of an additive to improve Bio-Oil parameters as was discussed in Section Bio-Oil Merchantability above. The additive was estimated at $10 per metrics ton.
3. Additional costs for the distillation step were estimated at $100,000 per installation.

Due to the increase of oil pricing, this case was slightly more profitable than the Base Case but the payback increased to almost two and a half years due to the increase in investment costs.

Char Price Lower presents the economics with the additional assumption (versus the Addition Oil Processing column) that the price for the Bio-Char reduced in half - to $100 per metric ton - due to the logistics costs and the average NPK based pricing as discussed in the Bio-Char Merchantability Section above. The case is still profitable but the payback period increased to four years.

Op Costs Increased column presents the economics based on the lessons learned discussed in the Sections 3 & 4 above. This cases uses the assumptions of the Char Price Lower column and reflects the increase of litter pricing to $20 per ton, increase in the variable cost of labor, and the increase in capital equipment per installation to reflect the Bio-security requirements. Bio-security capital equipment requirements were estimated to be an additional $50,000 per installation. This scenario becomes unprofitable with no payback.

Product Unit Cost Higher column reflects the higher costs of the pyrolysis unit manufacturing. This is additional assumption to the prior Op Costs Increased case. In addition to the prior column, this case assumes that manufacturing in quantity can take the manufacturing cost from the currently estimated $1.1 million to $600,000 per 10 tons per day unit. This scenario demonstrates the challenge of making this business sustainable in the long run without upgrading Bio-Oil and Bio-Char to higher value products.

Sales of Higher Value Products column estimates a scenario when Bio-Oil and Bio-Char can be converted into higher value products as discussed in the Section Higher Value Products above. As we discussed above, there are many unknowns on this path and this scenario has not be researched fully. More research and market testing is required to confirm this case. This case is shown here to contract it with the prior column and to show that in order to make the business case viable, more revenue is required to be obtained from the products produced.

It is assumed that the activated char can be sold for $1,300 per ton and the phenols at $1,500 per ton. The conversion throughput was estimated at 80% for Bio-Char and 60% for Bio-Oil. It is further assumed that the investment required for processing is $2.5 million dollars – an additional investment for Bio-Oil and Bio-Char conversion. All these numbers require validation. However, under these assumptions, the case is profitable with a reasonable payback of two and a quarter years.

Deliverables

This section discusses each deliverable that is listed in the contract.

Original Deliverable 1: Demonstrate the installation and operation of two commercial poultry littler pyrolyzation units, one in the Shenandoah Valley and one in the Delmarva Peninsula. The units should have a combined litter conversion capacity of 3,150 tons/year.

In September 2011, based on the reduction of actual funding to $400,000 vs. our original proposal of $1,000,000 and findings to date discussed in this report MERC requested that this deliverable be changed to the construction of a single smaller scale commercial unit.

Modified Deliverable 1: Demonstrate the installation and operation of one small scale commercial poultry litter pyrolyzation unit in Shenandoah Valley with the conversion capacity of 910 tons per year.

An overview of the conceptual design for an improved 2.5T commercial production unit was produced under contract by Hazen Engineering and can be found in Appendix 4.

The conceptual design formed the basis of a formal quotation. Seven companies in the US and Europe were solicited for bids. We discovered in the bidding process that the manufacturing costs of this improved design were higher than $1.1 million. This amount exceeded MERC's available funds and as a result a production unit was not commissioned.

Deliverable 2: Develop an Operation and Maintenance Manual for a commercial poultry litter pyrolyzation unit.

A manual was prepared for the prototype but not for a production unit since none was produced.

However, MERC invested in laboratory experiments targeted at developing operating procedures that would improve the consistency and robustness of the process output in any future production unit. The major learning that arose from these studies was that for a steady state process where feed rate, reactor temperature and filtering were well controlled and available chilling capacity was sufficient, the ash content of the incoming feedstock was the critical parameter in determining the quality and consistency of the Bio-Oil and Bio-Char produced. A method of blending multiple feedstock batches of varying ash levels with dry material on site using a common feedstock mixer was devised and verified in simulated lab tests.

Delieverable 3: Measure and document the quantity and quality of oil and BioChar produced from the commercial unit per ton of input poultry litter. Provide an analysis of poultry litter throughput as well as the oil and BioChar monitoring result.

Since a commercial unit was not available, MERC conducted studies using data from the Virginia Tech prototype unit that was similar in its throughput to the first planned 2.5T production unit. The data was combined with expectations from planned improvements found in the new conceptual reactor design and used to generate a set of mass balance equations for the new design (see Appendix 6). In steady state operation in the 2.5T commercial reactor design operating with a reactor temperature of 450º C the model predicted a daily production average of .33T of Bio-Oil, .33T of Char and .16T of Syngas produced per wet ton (20% moisture) of feedstock. Through experimentation MERC found that these relative percentages could be changed to increase either char or oil output by varying process temperature.

The Bio-Oil was classed into two types that were produced at different stages of the process chilling of the pyrolysis gas stream. The first was oil with a very high water content that without further processing had little commercial value. The second was oil with commercial fuel value but significant levels of impurities directly related to feedstock composition and processing. One of large oil companies, a potential off-take partner, analyzed this oil in their lab. A detailed analysis of this Bio-Oil can be found in Appendix 1.

The analysis discovered that the oil evidenced unacceptable levels of Nitrogen (50,900 ppm vs. 1000 ppm target) and a very high pour point (temperature at which the oil will not flow or pour) of 18º C.

In practical terms, a pour point of 18º C means that the untreated oil would not flow on a typical cool summer evening. In comparison, typical Biodiesel fuel has a pour point between -12º and -33ºC while standard untreated diesel fuel exhibits a pour point between -9º and -6º C. Left unaddressed, a pour point of 18º C (64.4º) would severely limit potential applications for the oil in most of the US and Canada.

Nitrogen is a catalyst poison. The nitrogen present in the oil is the direct result of the nature of the chicken litter itself. Chicken litter is rich in nitrogen urea that breaks down during pyrolysis. A large percentage of the nitrogen produced in the process remains in the Bio-Char and supports its fertilizer value. However, some of this nitrogen is captured in the oil during condensation. Technically MERC believes that with additional research into feedstock modifications with additives and/or processing changes a significant portion of the nitrogen found in the oil could be eliminated. However, given the large amount of nitrogen present in the gas stream there was no certainty that nitrogen levels could be reduced to the 1000ppm target that was established for Bio-Oils. Dr Agblevor conducted several experiments at Utah State in this regard. The results were encouraging but more work is required to obtain a firm method that can economically reduce the nitrogen levels.

MERC believes that there are several ways to decrease the pour point: a) processing changes; b) the identification of new surfactants and c) commercially available additives.

Given the results of the analysis, MERC concluded that without adding additional cost to the process either in process and materials changes or in the addition of downstream processing steps it would be difficult to address the above listed Bio-Oil impurity concerns. In any case solving these problems would add significant cost to the final product.

Bio-Char was analyzed internally and by the Anderson Fertilizer company. The analysis can be found in Appendix 7. The Anderson analysis indicated high quartz content in the char that in Anderson's view represented a silicosis risk. Discussions with Anderson indicated that the risk could be partially mitigated by post process pelletizing the char but that OSHA regulation would likely require some level of respiratory precautions be implemented in production. They expressed a clear preference for material that did not require precautions. A pelletizing concept was developed which would have used waste heat from the process to activate a biodegradable binder (lignin) which mixed with the char would have been extruded under low pressure through a die and then cut off by a rotating blade.

Deliverable 4: Provide an analysis of the input litter and pyrolyzation products including carbon, nutrient and energy values per ton of litter processed.

MERC found that process off-take was strongly dependent on input feedstock composition. The strongest determinant in predicting the production behavior of a given feedstock lot was its preprocess ash content as determined by a simple test burn of the material.

One ton of wet feedstock produces on average .82T of off-take divided between Bio-Oil, Syngas and Bio-Char. In our experiments the relative % distribution of the off-take varies between these three commodities depending on the pyrolysis temperature and the moisture level of the feedstock. Actual production ranges for several feedstock lots are shown below for a pyrolysis temperature of 500ºC:

Production Fraction	wt% min	wt% max
Char	29.2	46.8
Gas	7.9	30.0
Oil	35.6	48.6

Analysis detail of the feedstock (input litter), products yield, bio-oil properties depending on the input, pyrolysis gas composition, nutrient composition of bio-char, PH level and a particle size distribution of pyrolysis chars can be found in Appendix 8.

The char composition was analyzed and contained approximately 25% mineral content with the balance (75%) being various forms of carbon. Typical nutrient values contained in the mineral fraction for broiler char were: 2.8% N (total), 2.7% P_2O_5, 4.2% K_2O.

The Bio-Oil produced from chicken litter feedstock had an average heating value of 28.59 MJ/Kg.

Deliverable 5: Provide a report of the marketability, economic viability, and market sustainability of the pyrolyzation of poultry litter in the Chesapeake Bay watershed.

Please see the Key Findings section of this report that provides insights into this item. MERC considered this item the most critical objective of the project. Most of the work in the project revolved around marketability of pyrolysis products, verifying and validating operating costs and other requirement that have a direct bearing on the overall economic viability of the project. Unfortunately, based on the findings to date, MERC found that the actual production economics of the original business plan did not support an economically viable business in the Chesapeake Bay watershed at this point.

However, the project identified several ways to change this result as discussed in the Recommendations section of this report.

Deliverable 6: Provide a tour of the commercial poultry littler pyrolyzation unit near the end of the project for producers, researchers, USDA-NRCS and extension personnel to visit the unit for a personal inspection.

As explained above for business and lack of funds reasons a production unit was not manufactured. However MERC made the prototype unit available for visits by a number of stakeholders including the following:

Pat Stuntz, Cambell Foundation

Joan Hollen, Marketing Specialist
Shenandoah Valley Partnership

Bobby Clark
Agriculture Extension Agent
Shenandoah County

Cary Bullock,
CEO
Thermo Energy Inc.

Deliverable 7: Attend at least one NRCS CIG Showcase or comparable NRCS event during the period of the project agreement.

MERC presented at the Virginia Cooperative Extension Poultry Litter to Energy Seminar in July 2011.

Deliverable 9: Fact sheet describing the new technology or approach.

A pictorial representation of MERC's distributed model versus the commonly used centralized approach can be found in Appendix 9.

Conclusions and Recommendations

The profitable solution for the treatment of poultry litter has not been developed yet and this market opportunity remains large. The project yielded valuable technical and commercial insights into technological improvement, process control and cost, and the current market and future potential for commercialization of the pyrolysis process for the processing of poultry litters.

Even though from the findings available to , pyrolysis reactors are not ready to be put into the field to process poultry litter, MERC believes that the technical hurdles identified could likely be addressed with additional projects and investment as follows:

Conclusion/Recommendation One:

The advantage of the pyrolysis process is that the reactor can be small and be used on site in the distributed poultry litter processing model. Provided that the reactor can be operated profitably, this is the easiest way to eliminate the problem at the source and create valuable products. MERC's recommendation is to continue to fund projects using pyrolysis technology for this purpose.

Conclusion/Recommendation Two:

The project confirmed that both outputs from the pyrolysis process were welcome in the market by commercial users. However, they required additional processing. Given this fact, the project shifted into identifying higher value products and demonstrated that with additional processing one of the outputs can be sold for 10-20 times more than the originally planned product (fertilizer). The initial results for converting the second product into a higher value product are positive as well. It appears that a 10 times more value can be achieved. MERC's recommendation is to fund a study, if possible, to pursue this experimentation further to determine specific costs of conversion and test the higher value products with commercial users.

Conclusion/Recommendation Three:

The project developed a conceptual design of a pyrolysis reactor that can process poultry litter and take into account the lessons learned from the earlier operation of the original prototype. The cost of building this reactor is currently too high. Due to the history of the original prototype development, Hazen Research was the only vendor that can produce the updated design. However, Hazen Research by its own admission, designs equipment for research purposes and not for field uses. As a result, our collective recommendation is to fund a project, if possible, to apply frugal innovation methodologies to the current design. It has been demonstrated that these approaches can produce equipment at one tenth of the original cost.

MERC believes that the above projects can change the economics of the business and make pyrolysis a viable technology for processing poultry litter.

Only about 35% of the grant money was spent in this project versus allocated funds and considerable progress was made both in market understanding and technology. NRCS might want to consider approving the follow-on project to complete the above actions. It is recommended that the new project be not required to obtain matching money based on the feedback that our team received from investors. Investors consider this project to be in an early stage of development and require the above-discussed actions to be completed before a serious investment in technology commercialization can be made.

Appendices

Appendix 1
Bio-Oil Analysis

Analysis of Pyrolysis Oil Samples

	Bio-Oil received on December 1, 2011
Description	Bio-Oil Sample 12/1/2011
Source	BioEnergy Planet (on behalf of MERC)
Date received	12/1/2011
FILTERED ID	
Date filtered	
Identification	TGQ4162
Solids, ppm	
API Gravity (10508)	7
Pour Point, °C (10603)	18
Viscosity	
cs at 40°C	
cs at 100°C	
Karl Fischer Water, ppm (20715)	
Karl Fischer Water, wt%	11
Sulfur, ppm	1583
Nitrogen, ppm	50900
Total	
Basic	
Carlo Erba (31319)	
Carbon, Wt%	60.25
Hydrogen, Wt%	9.59
Nitrogen, Wt%	5.07
Oxygen, Wt%[1]	25.09
[1]By Difference	
Oxygen, Wt% Tx A&M	
Bromine Number (20406)	43
Acid Number	99.7
MCRT, Wt% (10315)	8.32
Chlorides, ppm (Modified D4929)	
Organic	

Inorganic
ENSYN NAA
T A&M NAA

<u>ICP Metals, ppm</u>

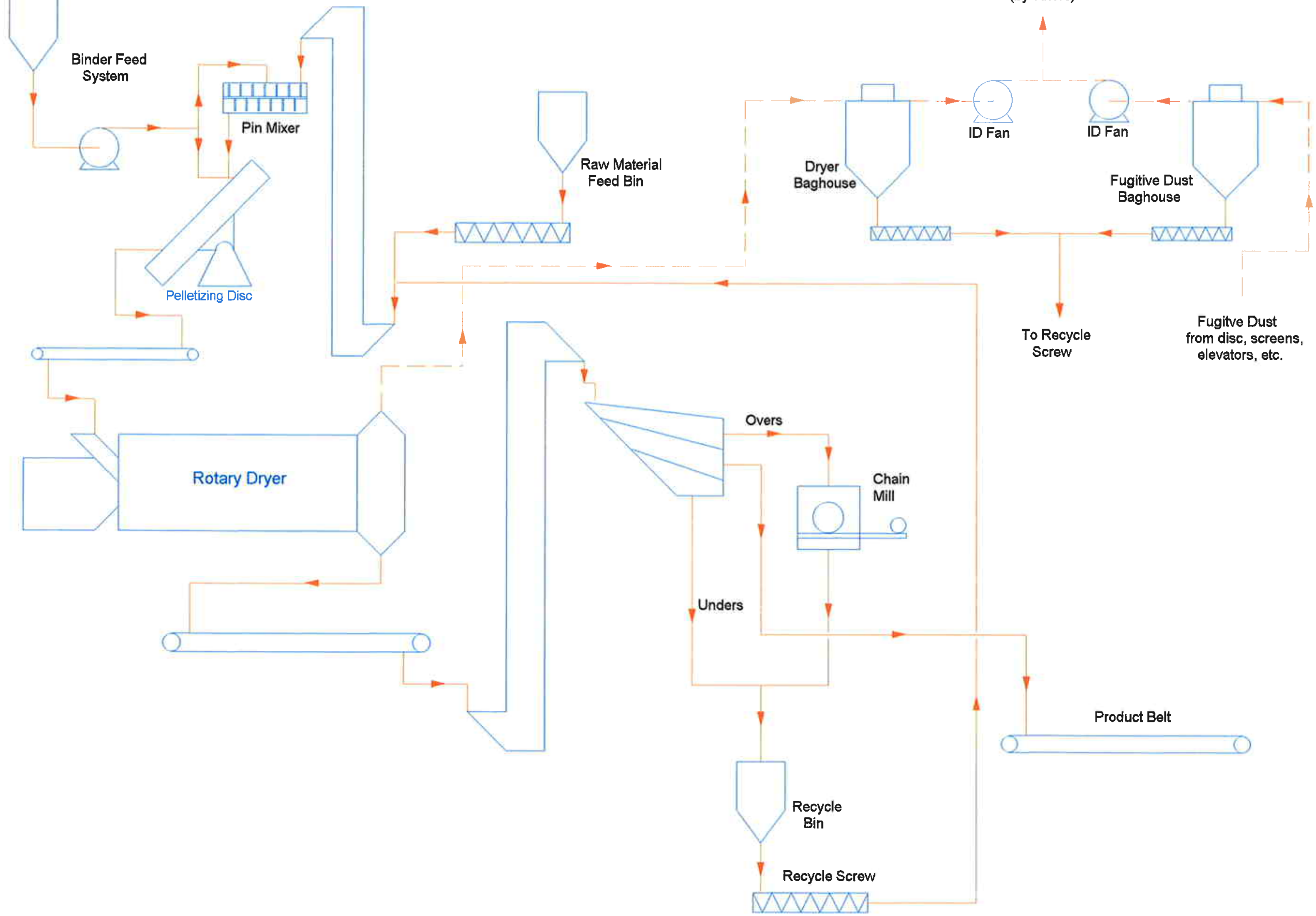
Al	10.4
As	40.8
B	11.6
Ba	<0.96
Bi	<1.0
Ca	<2.89
Ce	
Co	<0.5
Cr	<0.96
Cu	7.2
Fe	50
K	16.8
La	
Li	<1.0
Mg	2.9
Mn	<0.9
Mo	<0.5
Na	6.8
Nd	
Ni	1.1
P	<0.96
Pb	<1.92
Pd	
Pr	
Pt	<2.9
Si	10.2
Sn	<1.92
Ti	<0.96
V	<0.96
Zn	25.2

<u>SimDist, °F</u>

St	28
5	80
10	385
30	560
50	651
70	710
90	859
95	903
EP	1005
Rec, %	

Appendix 2
Char Pelletizing
Flow Diagram

Pelletizing Plant Flow Diagram



Appendix 3
URS Report Summary
Char Activation

Advanced Fuel Research, 87 Church Street, East Hartford, CT 06108 USA

AFR

POULTRY LITTER CHAR ACTIVATION AND MERCURY-SORPTION TESTING

Marek A. Wójtowicz and Michael A. Serio

Advanced Fuel Research, Inc.
87 Church Street
East Hartford, CT 06108-3728

Final Report - Revision 1
Adsorption Testing
Results for Activated
Char Samples

Prepared for Timothy J. Brown of MERC/BioEnergy Planet, Inc.

May 15, 2012

URS

Mercury Adsorption Test Results for AFR Sorbent Samples in Simulated Flue Gas

Introduction

This technical note describes tests to evaluate mercury adsorption by AFR sorbent samples (FB460, FB464, FB465, FB467 and FB469) in simulated Western Coal flue gas at 300ºF. URS performed the tests at the URS Sorbent Testing Laboratory in Austin, TX. The test procedures used and results obtained are described below.

Test Procedures

Mercury adsorption tests were carried out on a URS mercury bench-scale test unit (Figure 9). The test conditions are listed in Table 1. Tests were performed at a temperature of 300°F. To perform the tests a simulated flue gas is prepared by mixing known volumes of various reagent gas streams. Moisture is added to the reaction gas by flowing a known volume of nitrogen gas through a temperature-controlled saturator. Mercury is added to the gas by flowing a nitrogen carrier stream through a temperature-controlled permeation chamber containing the desired mercury species; in these tests, elemental mercury was used.

Table 1. Flue Gas Condition 1

Flue Gas Parameter 1	Targeted Test Value
SO_2 (ppm)	400
NO_x (ppm) [95% as NO]	200
HCl (ppm)	2-5
H_2O (%)	7
CO_2 (%)	12
O_2 (%)	6
Hg^0 (µg Hg/Nm^3)	~48
Nitrogen	Balance
Temperature (°F)	300°F
Flow Rate (L/min @ 70°F)	1.0

To perform the mercury adsorption tests, the sorbent sample was mixed in a sand diluent (white quartz; -50+70 MESH) at a sample loading of 2 mg/g. This loading represents a "standard" concentration used by URS for most carbon sorbents. Prior to adsorption testing, each sorbent-sand mixture was loaded into a quartz tube (0.5-inch ID) and heated to the desired temperature (300°F) for at least 30 minutes. During this period, the simulated flue gas was measured for "inlet" mercury concentration. Tests were started by flowing simulated flue gas downward through the sorbent bed at a flow rate of 1.0 L/min (actual flow rate at 70°F). The effluent gas stream was flowed through heated lines to a semi-continuous mercury analyzer for analysis. The mercury analyzer has been described previously[1]. Tests were allowed to proceed until adsorption equilibrium was reached.

URS

The percent breakthrough is determined as a function of time by normalizing the measured mercury concentration at the outlet of the sorbent bed to the inlet mercury concentration. The area between the breakthrough curve and 100% breakthrough represents the total mass of mercury adsorbed as a function of time. The adsorption capacity of the sorbent (µg Hg adsorbed/g sorbent) at time *t* is determined by summing the total mass of mercury adsorbed through time *t* (area above the breakthrough curve) and dividing by the sorbent mass. The 100% breakthrough (equilibrium) capacity is defined at the time when the outlet mercury concentration is first equal to the inlet concentration.

Because it is not possible to precisely control the inlet mercury at specific levels and because mercury adsorption is affected by mercury concentration, results for different sorbents cannot be directly compared without correcting for differences in concentration. To do this, URS corrects all lab and field measurements to an inlet mercury concentration of 50 µg Hg^o/Nm^3 by assuming a linear dependence of capacity on concentration. This is a reasonable estimate for Norit's FGD carbon based on the laboratory results but may not be valid for all sorbents at all conditions; this value was chosen since a large number of previous laboratory tests were conducted at a concentration close to this.

<u>Results and Observations</u>

Table 2 lists the AFR sorbent test results for elemental mercury adsorption along with the results of a quality control samples tested by URS. The quality control sample is a commercially available non-treated activated carbon (shown as QC PAC in Table 2). All breakthrough curves are shown in Figures 1-8. The calculated sorbent capacities for QC PAC tests are within normal operating range of previously performed QC PAC tests. Sample FB460 was run in duplicate to confirm the lack of adsorption observed.

Table 2. Equilibrium Elemental Mercury Adsorption Capacity of AFR Sorbent Samples

Figure #	Test Date	Sorbent	Temp (°F)	Inlet Hg^0 Concentration ($\mu g/Nm^3$)	Initial Hg^0 Adsorption Capacity[a] (µg/g) @ 50 $\mu g/Nm^3$	Equilibrium Hg^0 Adsorption Capacity (µg/g) @ 50 $\mu g/Nm^3$	Slope of Breakthrough Curve (%/min)	Hg^0 Oxidation at 100% Breakthrough[e] (%)
1	3/23/2012	QC PAC	300	58.4	1089	1260	0.67	99.9
2	3/24/2012	FB464	300	51.1	317	460	0.83	-
3	3/25/2012	FB460	300	54.7	NA[b]	NA[c]	NA	-
4	3/26/2012	FB460 dup	300	49.4	NA[b]	NA[c]	NA	-
5	3/27/2012	FB465	300	53.6	NA[b]	300	NA	93.6
6	3/27/2012	FB467	300	51.4	NA[b]	320	NA	38.9
7	3/28/2012	FB469	300	55.0	123	370	0.65	42.0
8	3/29/2012	QC PAC	300	55.4	1120	1232	1.19	98.6

Note[a] Initial adsorption capacity is defined as mercury adsorption capacity calculated up to 5% breakthrough.
Note[b] Initial Hg^0 adsorption only calculated for sorbents that reach 95% adsorption.
Note[c] Equilibrium Hg^0 adsorption capacity could not be determined, Hg^0 concentration remained within ±10% of the inlet Hg^0 concentration.
Note[d] Slope is defined as the rate of change in the % breakthrough from 5% to 100% breakthrough vs. cumulative elapsed time.
Note[e] Hg^0 oxidation at inlet was 1.4% (98.6% elemental Hg determined from inlets run on 3/29/2012).

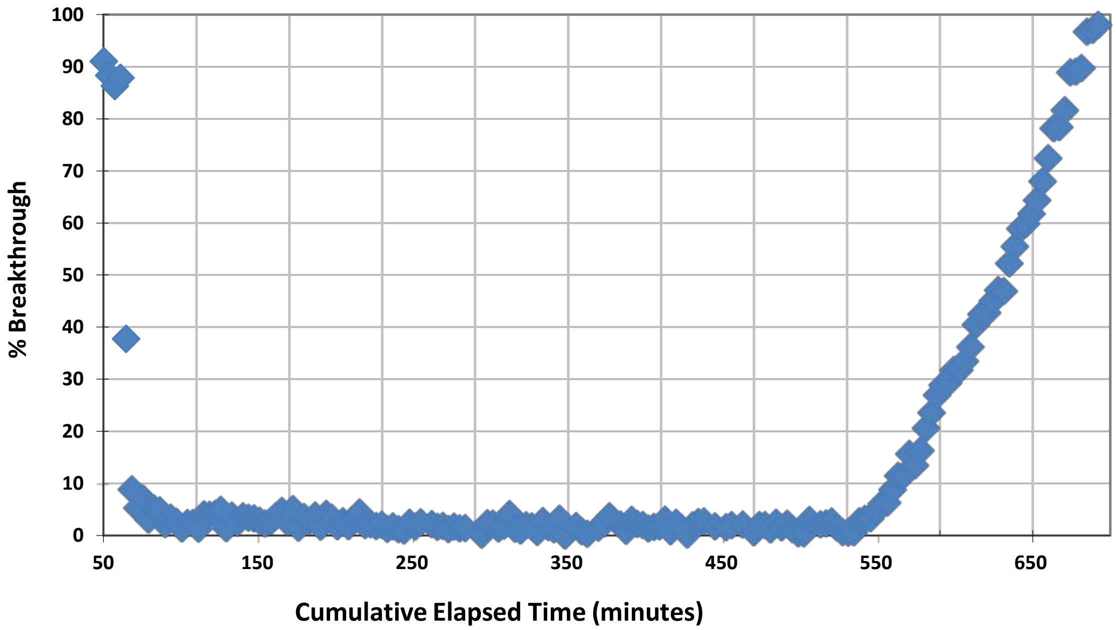


Figure 1. QC PAC (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities are 1089 µg/g and 1260 µg/g, respectively.

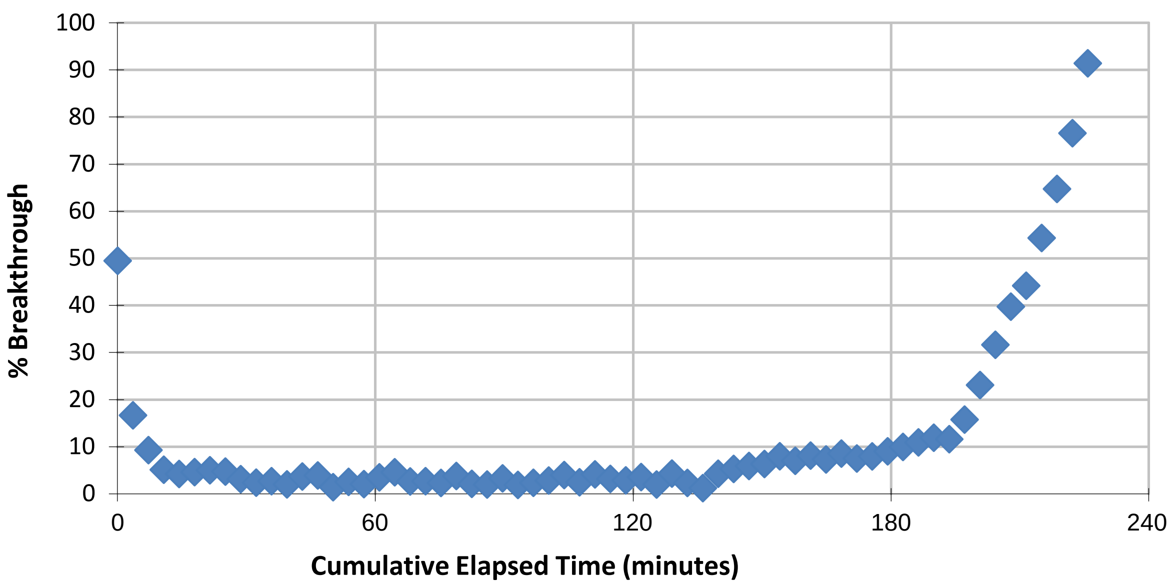


Figure 2. FB464 (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities are 317 µg/g and 459 µg/g, respectively.

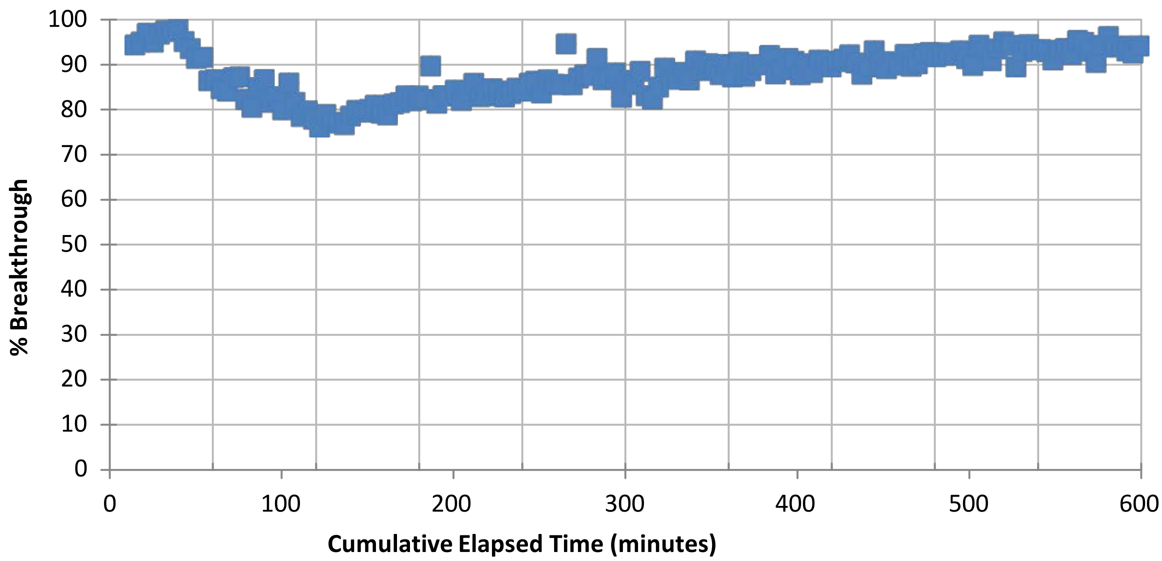


Figure 3. FB460 (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities could not be calculated due to lack of adsorption onto material.

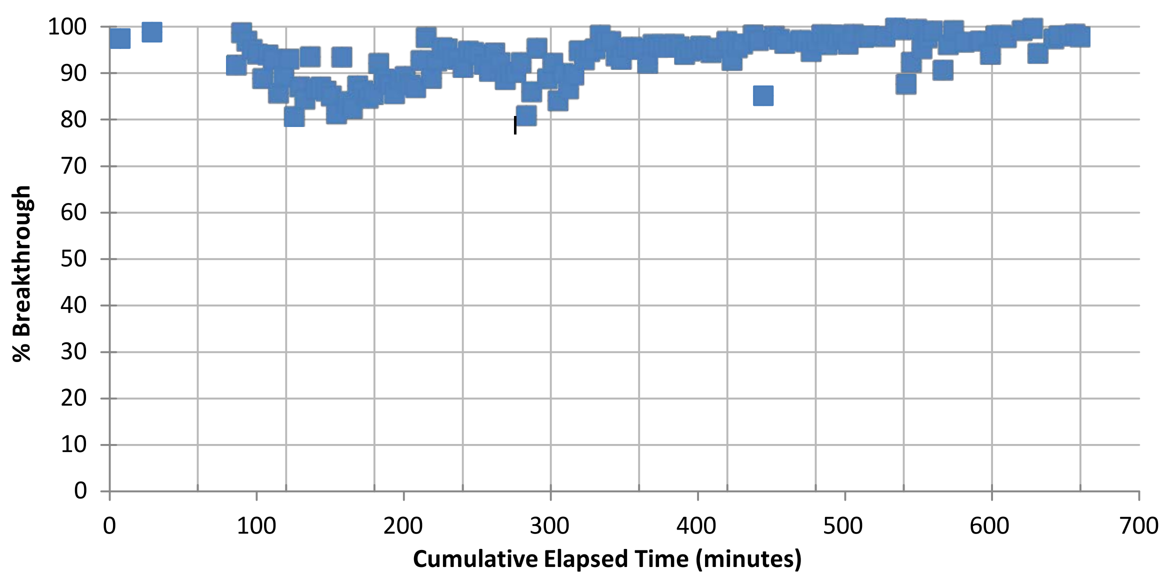


Figure 4. FB460 Re-run (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities could not be calculated due to lack of adsorption onto material.

URS

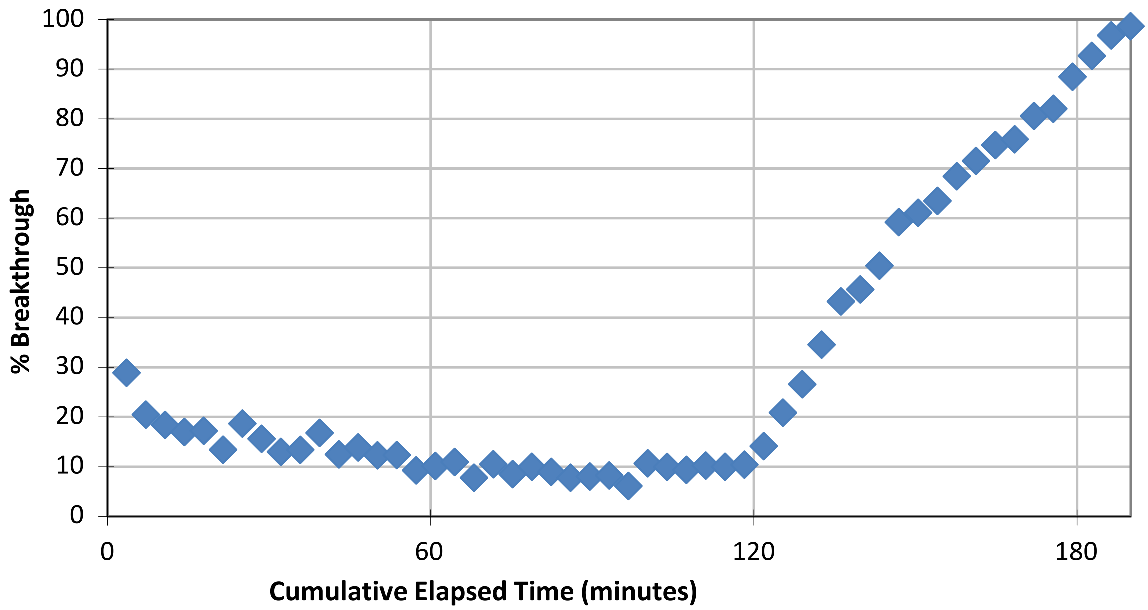


Figure 5. FB465 (2mg/g) Hg Adsorption Breakthrough Curve. The equilibrium Hg^0 adsorption capacity is 295 µg/g.

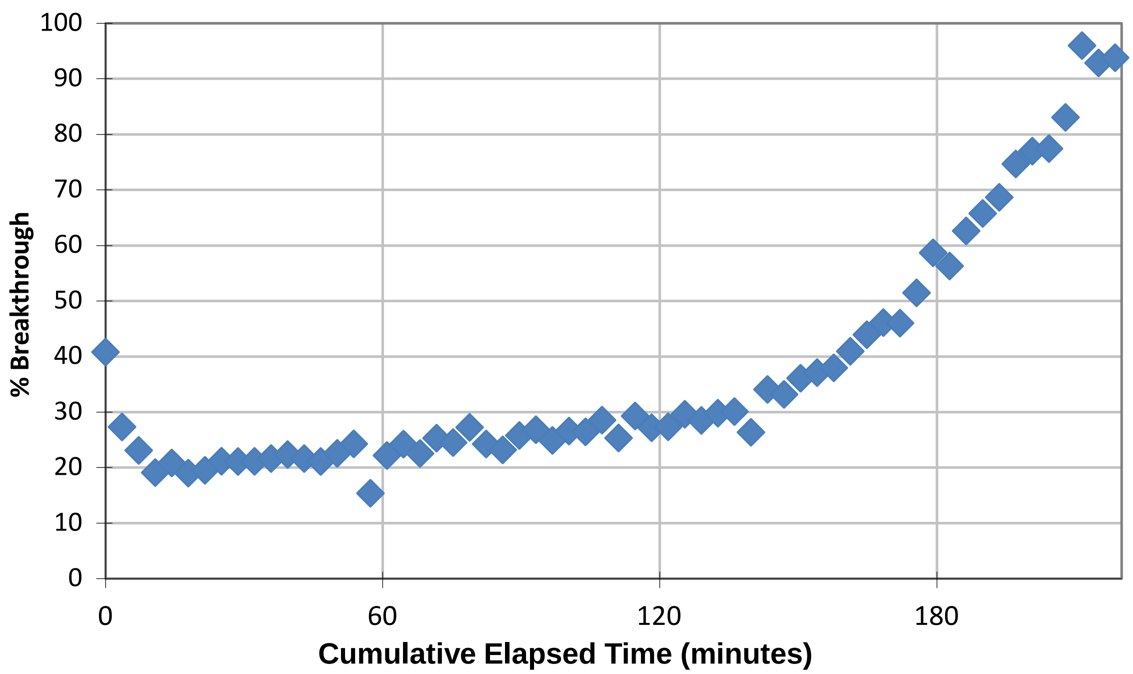


Figure 6. FB467 (2mg/g) Hg Adsorption Breakthrough Curve. The equilibrium Hg^0 adsorption capacity is 320 µg/g.

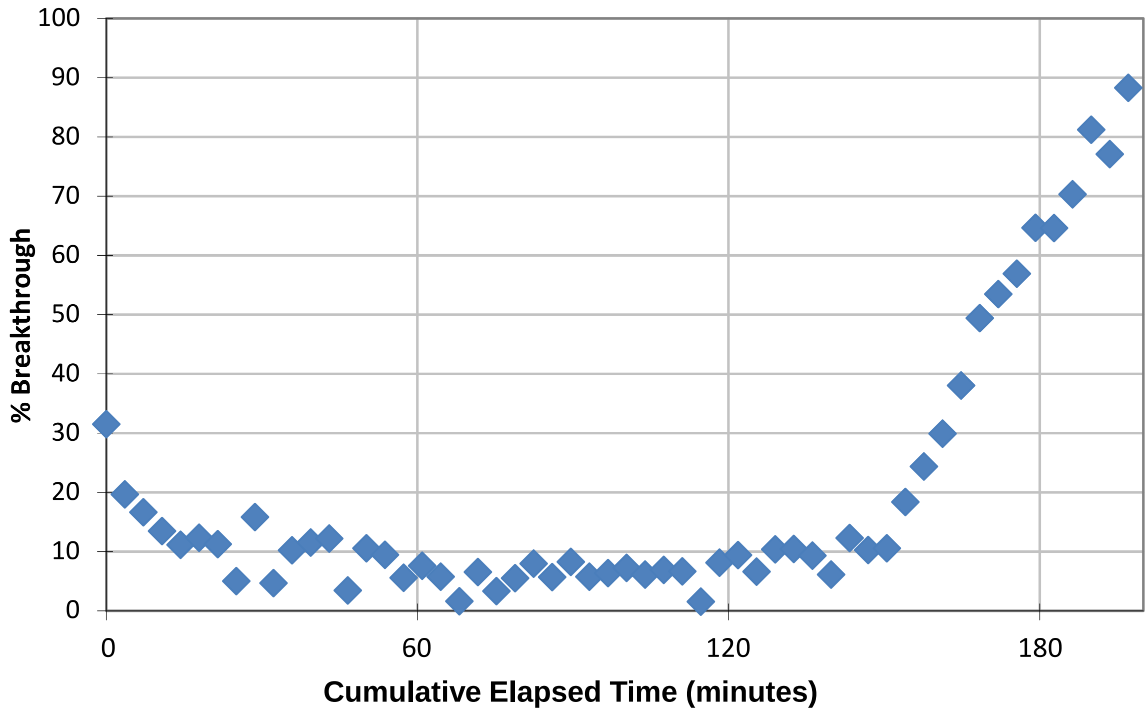


Figure 7. FB469 (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities are 123 µg/g and 370 µg/g, respectively.

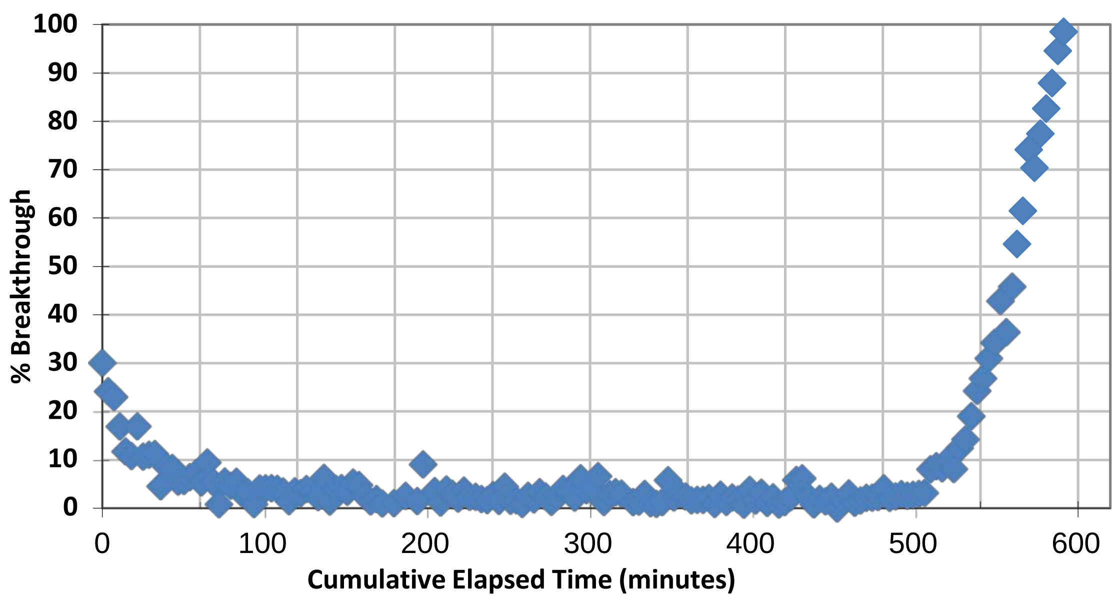
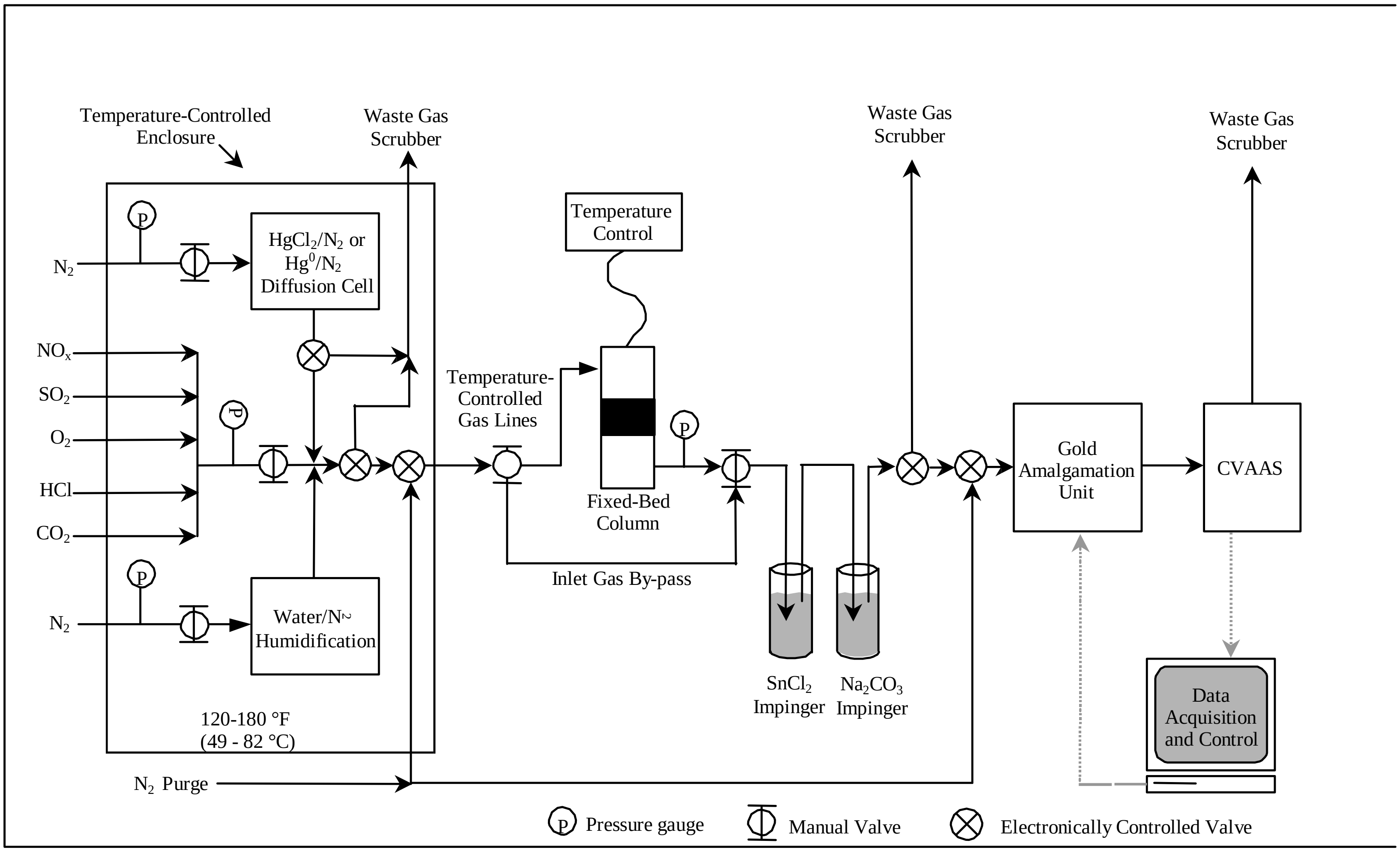


Figure 8. QC PAC (2mg/g) Hg Adsorption Breakthrough Curve. The initial and equilibrium Hg^0 adsorption capacities are 1120 µg/g and1232 µg/g, respectively.

References

1. Carey, T.R., O.W. Hargrove, C.F. Richardson, R. Chang, and F.B. Meserole, “Factors Affecting Mercury Control in Utility Flue Gas Using Activated Carbon”, J. Air & Waste Mange. Assoc., 48, 1166-1174, 1998.

Figure 9. Bench Scale Mercury Adsorption Test Unit



Appendix 4
Commercial Reactor Design

Poultry Litter Pyrolysis Unit Block Flow Diagram

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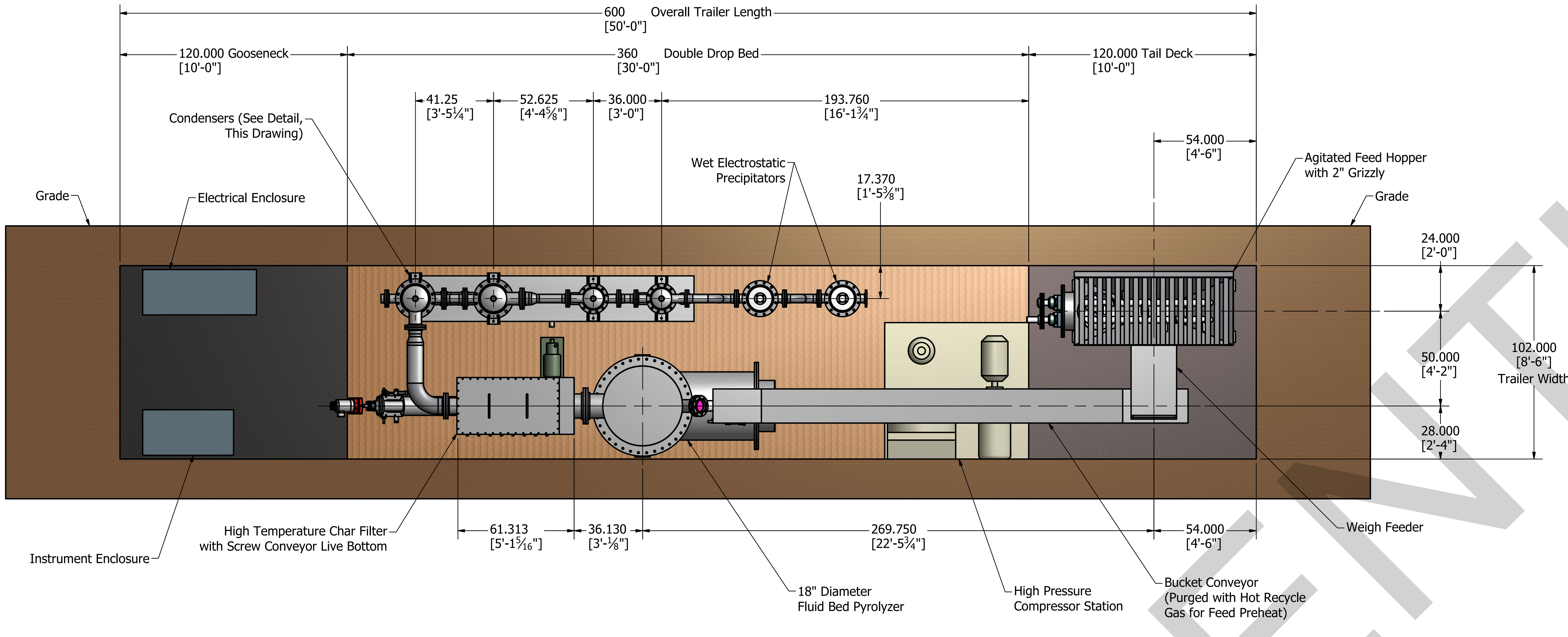
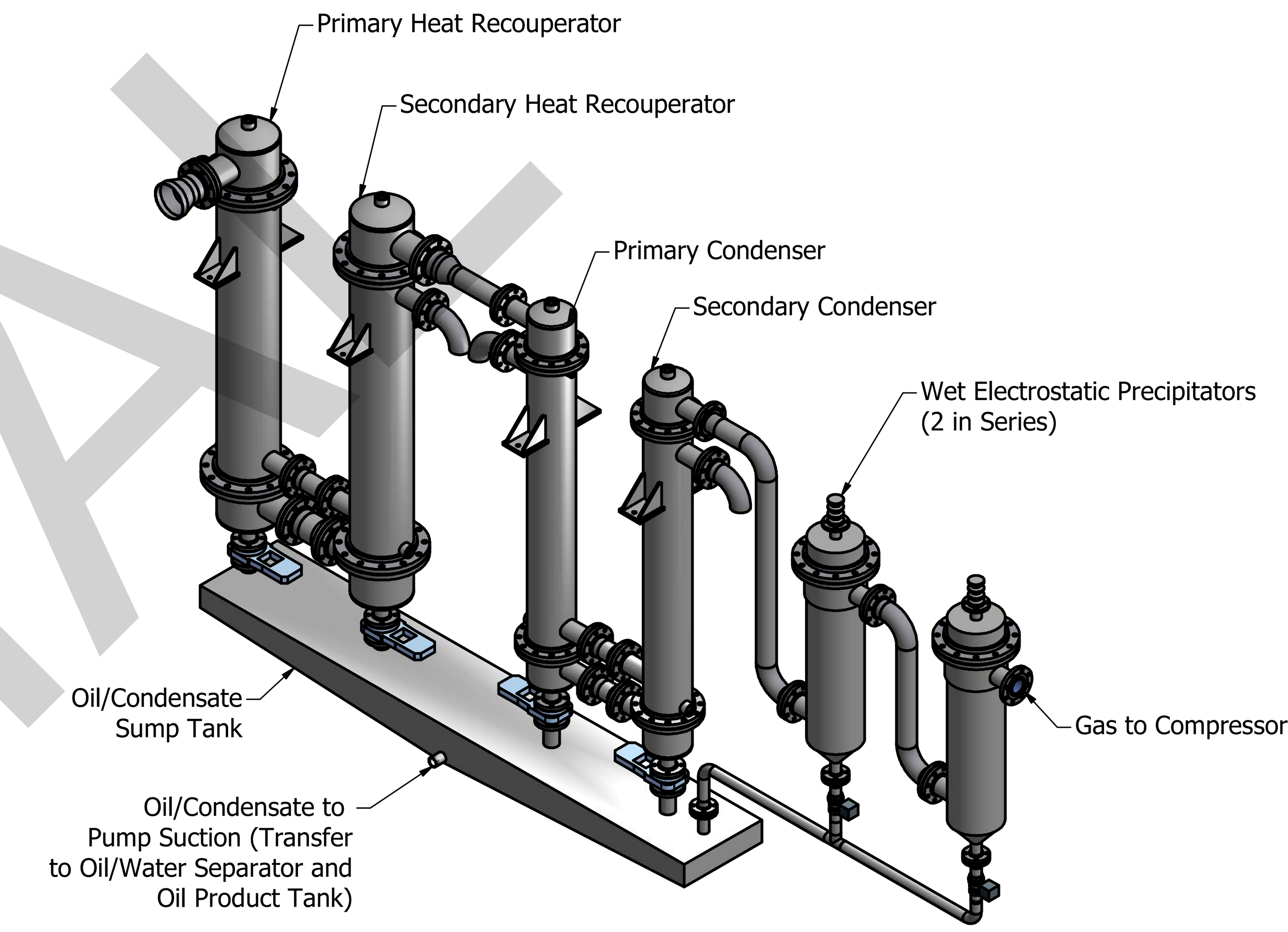
DRAWN DWC Designs	10/27/2011	**Hazen Research, Inc.** 4501 Indiana Street, Golden CO, 80403
CHECKED		**Poultry Litter Pyrolysis Unit Overall General Arrangement Model Views**
QA		
MFG		
APPROVED		DWG NO 11400-0201-1 / REV A
		SCALE / SHEET 1 OF 1

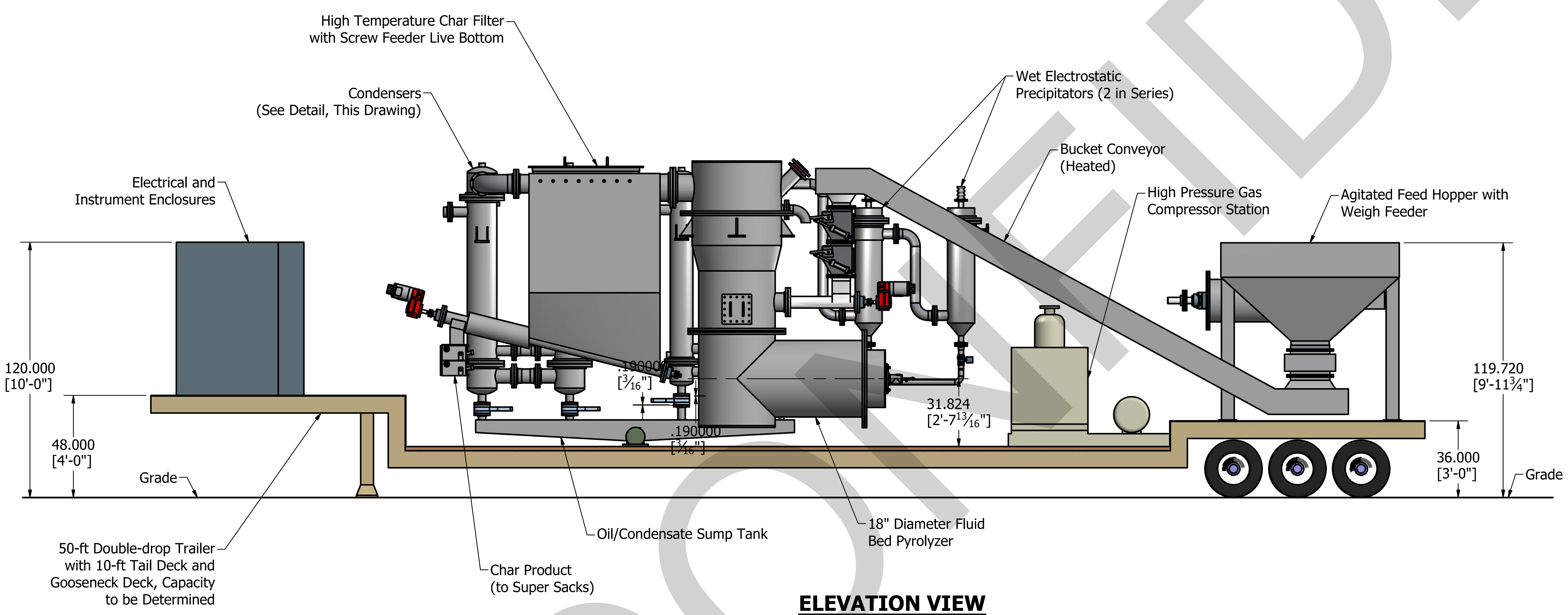


PLAN VIEW
SCALE 1"=3'-0"

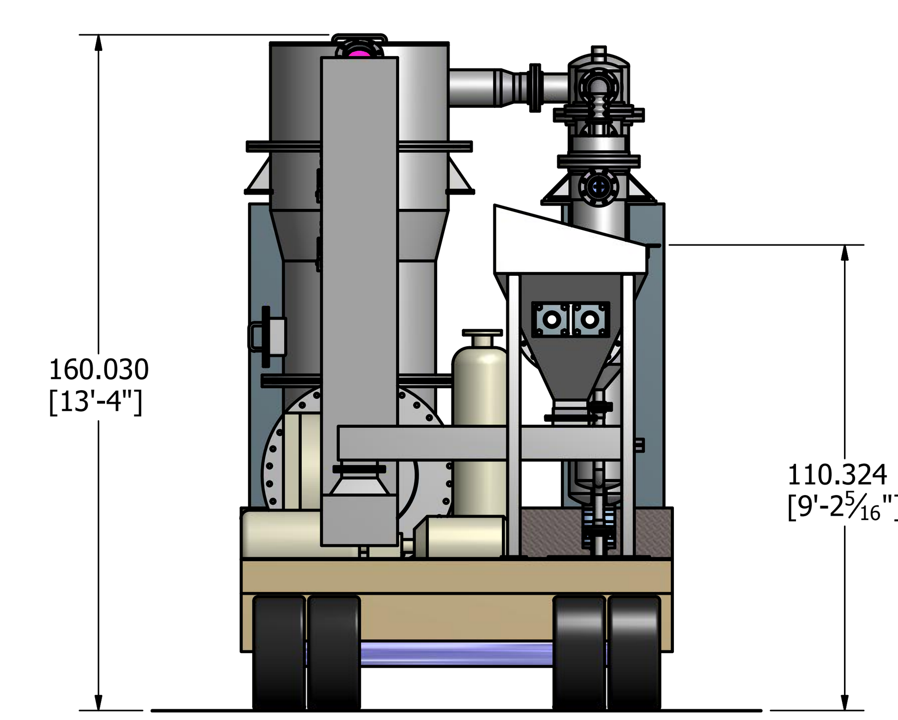


PRIMARY AND SECONDARY CONDENSERS

Equipment To Be Determined (Not Shown):
Combustion Air Blower
Burner Control Instrument Station
Oil Product Tank and Pump
Process Water Tank and Pump
Gas Treatment Station
Chiller Station
Pressure Blower Station



ELEVATION VIEW
SCALE 1"=3'-0"



END VIEW (FBR FEED END)
SCALE 1"=3'-0"

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4501 Indiana Street, Golden CO, 80403

Poultry Litter Pyrolysis Unit
Overall General Arrangement
Plan and Elevation Views

DWG NO 11400-0202-1 REV A
SCALE SHEET 1 OF 1

Appendix 5
Progressive
Financial Impact
Analysis

Progressive Financial Impact Analysis

Economics of One Pyrolysis Unit Operations
(without corporate costs)

Major Assumptions	Base Case	Additional Oil Processing Required	Char Price Lower	Operating Costs Increased	Production Unit Cost Higher	Sales of Higher Value Products
Litter Price ($/ton)	$ 10	$ 10	$ 10	$ 20	$ 20	$ 20
Crude Oil Price ($/barrel)	$ 84	$ 84	$ 84	$ 84	$ 84	$ 84
Bio Oil Price ($/gallon)	$ 2	$ 2	$ 2	$ 2	$ 2	$ 2
Bio Char Price ($/ton)	$ 200	$ 200	$ 100	$ 100	$ 100	$ 100
Pyrolysis Unit Cost ($/unit)	$ 350,000	$ 350,000	$ 350,000	$ 350,000	$ 600,000	$ 600,000
Capital Investment ($/installation)	$ 500,000	$ 600,000	$ 600,000	$ 650,000	$ 900,000	$ 900,000
Processing Capacity/day	10	10	10	10	10	10
Additive for Oil Quality ($/ton)		$ 10	$ 10	$ 10	$ 10	$ 10
Post Processing of Products ($/unit)						$ 2,500,000
Activated Char Price ($/ton)						$ 1,300
Phenol Price ($/ton)						$ 1,500
Revenue						
Bio-Char Sales ($/year)	$188,160	$ 188,160	$ 94,080	$ 94,080	$ 94,080	$ 978,432
Bio-Oil Sales ($/year)	$ 383,673	$ 441,224	$ 441,224	$ 441,224	$ 441,224	$ 1,128,960
Total Revenue ($/year)	$ 571,833	$ 629,384	$ 535,304	$ 535,304	$ 535,304	$ 2,107,392
Costs						
Raw materials ($/year)	$ 36,400	$ 36,400	$ 36,400	$ 72,800	$ 72,800	$ 72,800
Fixed Costs ($/year)	$ 199,800	$ 199,800	$ 199,800	$ 372,300	$ 372,300	$ 372,300
Variable Costs ($/year)	$ 113,316	$ 113,316	$ 113,316	$ 113,316	$ 113,316	$ 113,316
Quality of Oil Cost ($/year)		$ 36,400	$ 36,400	$ 36,400	$ 36,400	$ 36,400
Total Costs ($/year)	$ 349,516	$ 385,916	$ 385,916	$ 594,816	$ 594,816	$ 594,816
Unit Profitability ($/year)	$ 222,317	$ 243,468	$ 149,388	$ (59,512)	$ (59,512)	$ 1,512,576
Payback Period (years)	2.25	2.46	4.02	none	none	2.25

Appendix 6
Mass Balance

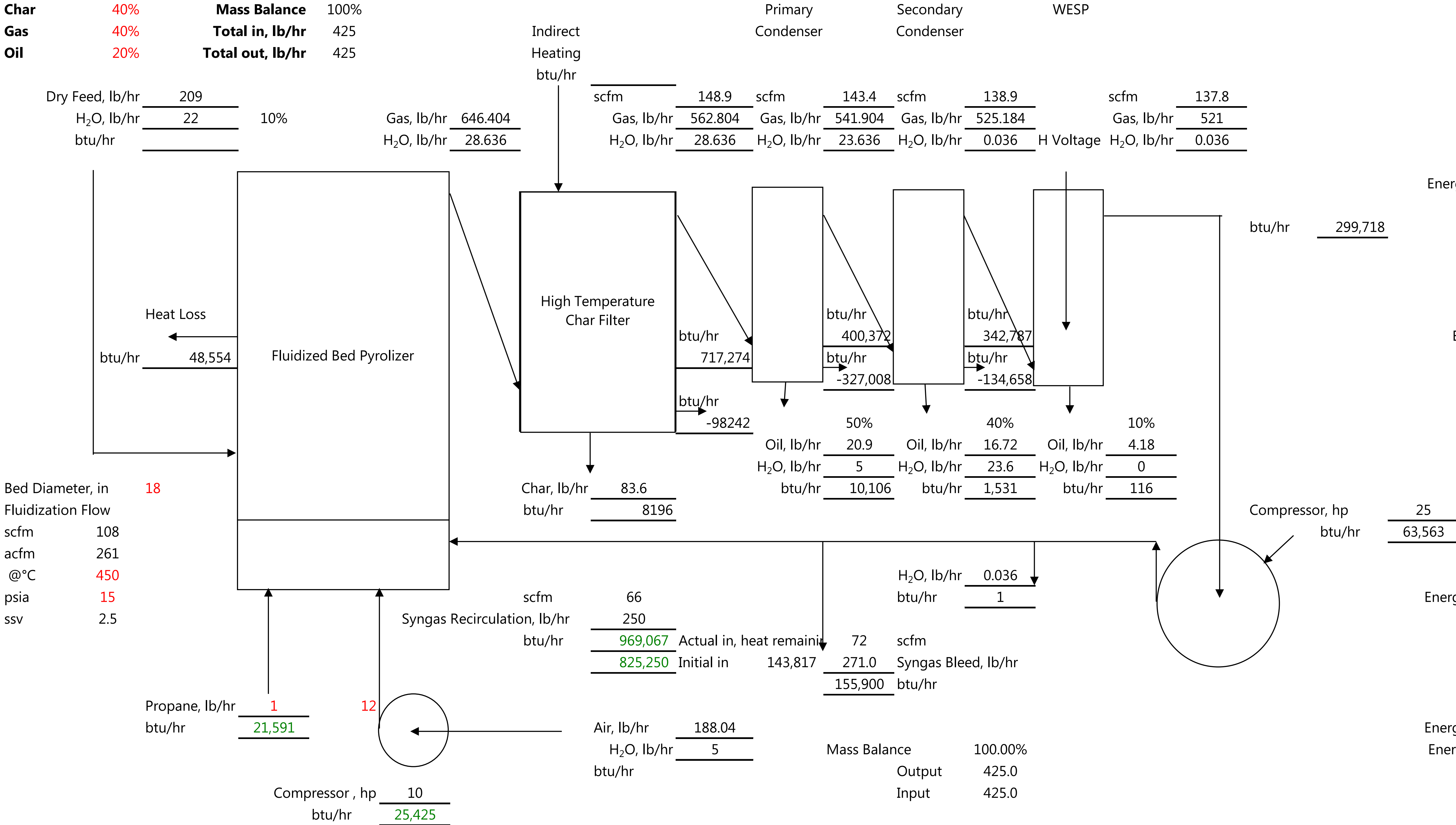
Confidential

Hazen Project 11400

Poultry Litter Pyrolysis Process
Mass and Energy Balance

Product Distribution

Char	40%	**Mass Balance**	100%
Gas	40%	**Total in, lb/hr**	425
Oil	20%	**Total out, lb/hr**	425



Overall Energy Balance

Total in	872,266	btu/hr
Total out	827,265	btu/hr
Balance	95%	
FBR		
Energy in	872,266	btu/hr
Energy loss to envierment (est 5%)	48,554	btu/hr
Energy out	823,712	btu/hr
Balance	100	%
Filter		
Energy in	823,712	btu/hr
Energy loss to cooling	-98,242	btu/hr
Energy removed with char/ash	8196	btu/hr
Energy out	717,274	btu/hr
Balance	100	%
Condenser 1		
Energy in	717,274	btu/hr
Energy Loss to cooling	-327,008	btu/hr
Energy removed with oil	10,106	btu/hr
Energy Out	400,372	btu/hr
	103	%
Condenser 2		
Energy in	400,372	btu/hr
Energy Loss to cooling	-134,658	btu/hr
Energy removed with oil and water	1,531	btu/hr
Energy Out	342,787	btu/hr
Balance	120	%
WESP		
Energy in	342,787	btu/hr
Energy loss to cooling	-42,952	btu/hr
Energy removed with oil and water	116	btu/hr
Energy out assoicated with syngas	299,718	btu/hr
Balance	100	%
Bleed		
Energy in	363,280	btu/hr
Energy removed with Bleed	155,901	btu/hr
energy remaining in recycle	207,379	btu/hr
Balance	100	%

Confidential

Appendix 7
Bio-Char Analysis

Confidential information Manure Energy Research Corp (MERC)

Analysis of bio-char:

Nutrient	%
Total Nitrogen	2.79
Water Insoluble N	2.02
Water Soluble N	0.77
Nitrate N	BDL
Ammonical N	0.01
Available Phosphate	11.89
Soluble Potash	9.15
Calcium	8.64
Magnesium	1.88
Sulfur	1.3
Aluminum	0.49
Boron	0.01
Iron	0.57
Manganese	0.13
Sodium	2.03
Heavy Metals: (ppm)	
Cadmium	3
Nickel	51
Lead	14
Arsenic	
Mercury	BDL
Selenium	1.5
Molybdenum	
Cobalt	5
Copper	0.11
Zinc	0.13

ANALYTICAL RESULTS

Date: ***10-Mar-10***

Client: ANDERSONS INC.

Work Order No: 10030071

Project:

Client Sample ID: BIO CHAR

Matrix: BULK

Lab ID: 10030071 001A

Collection Date: 1-Mar-10

Analyses	Result	Reporting Limit	Qual	Units	DF	Date Analyzed	Analyst
NIOSH7500							
Cristohalite	ND	*0.50*		wt"A>		3/9/2010	NMB
Quartz	0.86	0.50		wt%		3/9/2010	NMB
Tridymite	ND	*0.50*		wt%		3/9/2010	NMB

Qualifiers:

ND- Not Detected at the Reporting Limit (RL).

J - Analyte detected below the Reporting Limit

B - Analyte detected in the associated Method Blank

* -Value exceeds Maximum Contaminant Level

S - Spike Recoveryo.utl!il!.e.P.cc.e.P!c::d recioY&cyJimitS

R - RPD outside .accepted recovery limits

E Value above quantitation range

T- Tentatively Identified Compoun(TIC)

ANALYTICAL RESULTS

Date: ***01-Nov-10***

Client: ANDERSONS INC.

Worl{ Ordel' No: 10101078

Project:

Lab ID: 10101078 001A

Client Sample ID: BIOENERGY PLANET/MERC BIOCHAR

Matrix: BULK

Tag Number:

Collection Date: 10/15/2010

Analvses	Result	Reporting Ib......	Oual	Units	DF	Date Analvzed	Analvst
NIOSH7500							
Cristobalite	ND	0.50		wt"A>	1	10/28/2010	'NMB
Quarlz	0.72	0.50		wt"/o	1	10/28/2010	NMB
T;ridymite	ND	0.50		wt%	1	10/28/2010	NMB

Qualifiers:

ND • NotDetected at1he Reporting Limit (RL).

J • Analyt_e detected belo"'.the ReportingLimit

B • Analyte detected in the associated Me1hod Blank

* • Valqe exceeds Maximum Contaminant Level

S • Spike Recovery outside accepted recovery limits

R.: RJ!I?._tside

B · Value above quantitation range

T -Tentatively Identified Compound (TIC)

Appendix 8
Feedstock and Off-take Analysis

Feedstock analysis (dry basis)

Sample	C (%)	H (%)	N (%)	S (%)	Cl (%)	Ash (%)	HHV (MJ/kg)
Chicken bedding	47.24	5.94	**<0.5**	<0.2	82 ppm	**1.36**	19.25
Broiler litter-1	34.05	4.42	**2.89**	0.63	0.74	**15.33**	15.47
Broiler litter-2	36.84	5.00	**3.94**	1.02	1.14	**16.05**	15.65
Broiler litter-3	35.33	5.40	**4.10**	0.70	n/a	**21.17**	14.37
Starter turkey litter	43.65	5.71	**2.57**	0.36	0.20	**5.42**	18.47

Products yield from fluidized bed reactor

Sample	Temperature, ℃	Yield, wt%		
		Oil	Gas	Char
Chicken bedding	500	63.3±11.3	n/a	12.7±
Broiler litter-1	500	45.7±2.9	13.6±5.7	40.6±6.2
Broiler litter-2	500	36.8±1.2	22.3±2.5	40.8±1.9
Broiler litter-3	500	43.5±5.1	23.6±6.4	32.9±3.7
Starter Turkey litter	500	50.2±1.6	21.7±1.9	21.7±1.9

Bio-oil properties

Sample	C (%)	H (%)	O (%)	**N (%)**	S (%)	Moit (%)	**pH**	Ash (%)	**HHV (MJ/kg**
Chicken bedding	55.25	6.54	37.58	**<0.5**	<0.05	5.3	**2.7**	<0.08	**22.64**
Broiler litter-1	63.24	7.22	23.89	**5.05**	0.46	4.6	**6.1**	<0.09	**28.25**
Broiler litter-2	64.06	8.14	22.27	**4.94**	0.41	4.6	**6.3**	<0.09	**28.0**
Broiler litter-3	62.84	8.31	20.72	**7.23**	<0.9	4.0	**6.3**	0.17	**29.57**
Starter turkey litter	64.90	8.44	20.31	**5.60**	0.4	3.7	**4.2**	0.10	**29.76**

Pyrolysis gas composition

Component	Concentration	Mass rate (lbs/h)
CO	1414 ppmdv	1.10
Filterable Particulates	0.0106 (g/dscf)	0.02
NOx (as NO_2)	19.2 ppmdv	0.02
NH_3	942.8 ppmdv	1.86
VOC (as propane)	5300 ppmdv	6.50
Phenol	8.73 ppmdv	2.53E-02
Formaldehyde	0.05 ppmdv	4.34E-05
HCl	3.65 ppmdv	0.004
H_2S	0.00 ppmdv	0.00
Naphthalene	1.29 ppmdv	5.06E-03

Particle size distribution of pyrolysis chars

Mesh Size	Size (µm)	Char Mass fraction (%)	
		Poplar wood	Broiler litter
-18/+20	917	0.17	1.44
-20/+35	667	2.63	2.29
-35/+45	428	3.02	0.29
-45/+100	253	**61.89**	11.32
-100/+115	137	9.29	4.24
-115/+200	100	11.89	3.80
-200/+230	69	3.76	19.43
-230	32	7.28	**57.29**
Total		100	100

Nutrient Composition Broiler-3 char

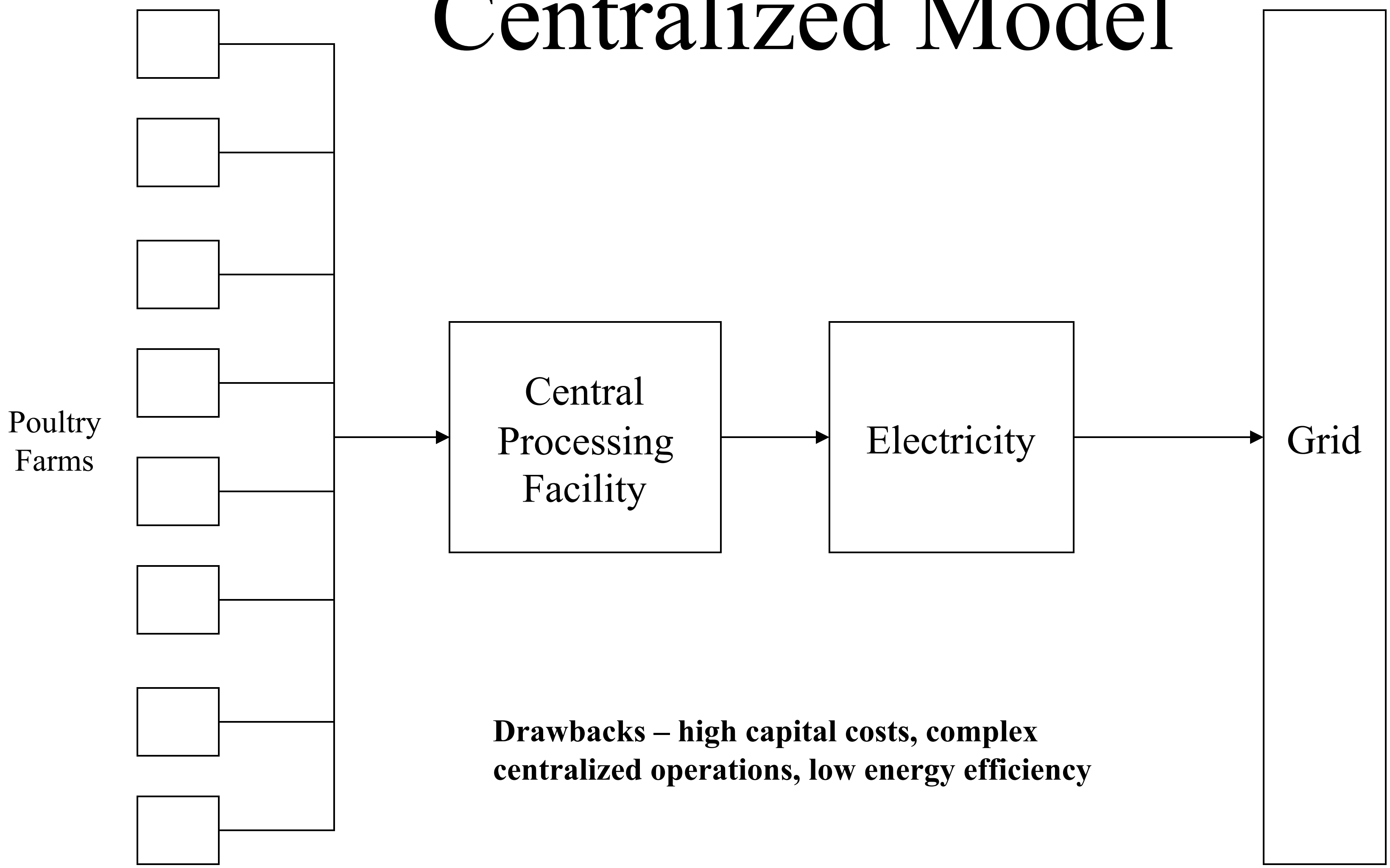
Element/Compound	Wt%
Total N	2.84
P_2O_5	2.68
K_2O	4.19
Ca	7.5
Mg	1.54
S	0.99
Al	0.54
B	0.01
Cu	0.11
Fe	0.54
Mn	0.12

Element	
Na, (wt%)	2.05
Zn, (wt%)	0.1
Cd, mg/kg	1.0
Ni, mg/kg	40.0
Pb, mg/kg	37.0
As, mg/kg	42.5
Hg, mg/kg	DL
Se, mg/kg	1.9
Mo, mg/kg	16.0
Co, mg/kg	5.0

Pyrolysis char sample	pH
Broiler-1	9.6
Broiler-2	9.2
Broiler-3	9.7
Switchgrass	9.7
Poplar wood	7.9
Oak wood	6.6
Pine wood	7.1

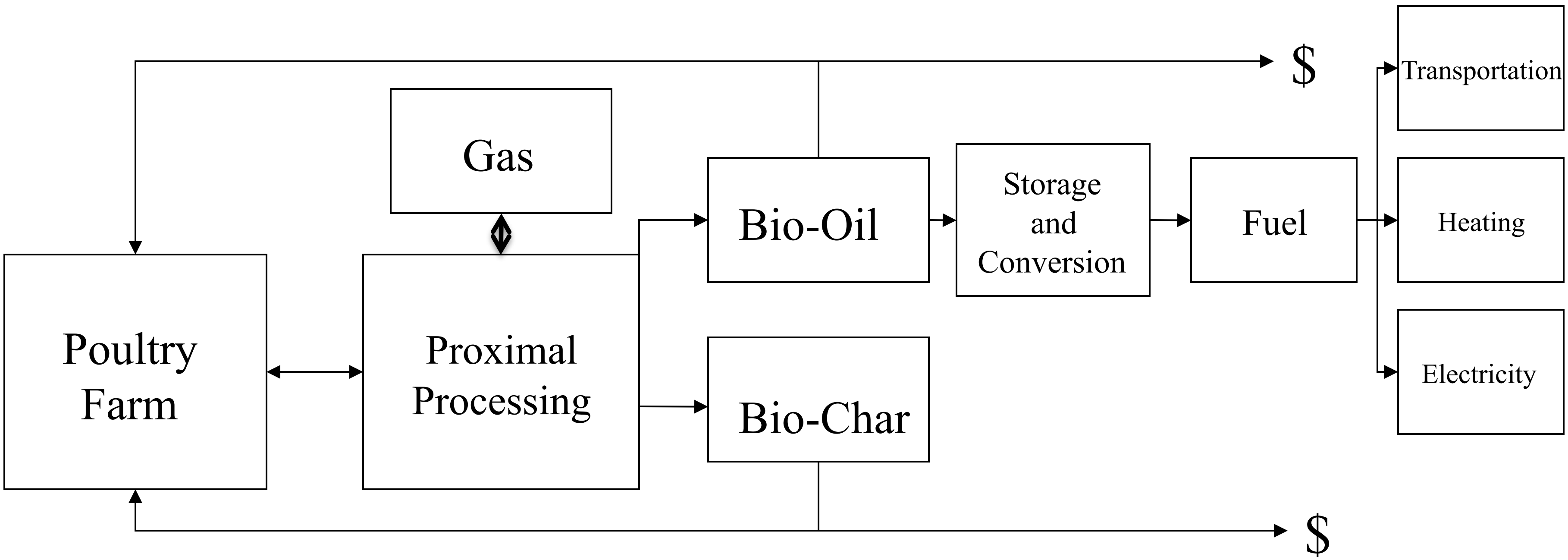
Appendix 9
MERC Business Model
Distributed versus Centralized

Commonly Used Centralized Model



Drawbacks – high capital costs, complex centralized operations, low energy efficiency

MERC Distributed Model



Benefits – low capital costs, distributed operations, relatively high energy efficiency