# Progress Report: Transportable Gasifier for On-Farm Disposal of Animal Mortalities

**EPA/600/R-16/059**
**August 2016**

# Progress Report: Transportable Gasifier for On-Farm Disposal of Animal Mortalities

**August 26, 2016**

**U.S. Environmental Protection Agency**
**Office of Research and Development**
**National Homeland Security Research Center**
**Decontamination and Consequence Management Division**
**Research Triangle Park, NC 27711**

## NOTICE

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development's (ORD's) National Homeland Security Research Center (NHSRC), funded and managed the research described here through Interagency Agreement HSHQPM-11-X-00340 with The Department of Homeland Security and Contract Number EP-C-09-027 with ARCADIS US. It has been subjected to the Agency's administrative review and approved for publication. The views expressed in this report are those of the authors and do not necessarily reflect the views or policies of the Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Questions concerning this document or its application should be addressed to:

Paul Lemieux
National Homeland Security Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Mail Code E343-06
Research Triangle Park, NC 27711
919-541-0962

## TABLE OF CONTENTS

## List of Figures

## EXECUTIVE SUMMARY

A prototype transportable gasifier intended to process 25 tons per day of animal mortalities (scalable to 200 tons per day) was built as part of an interagency effort involving several federal agencies as well as the State of North Carolina. This effort is intended to demonstrate the feasibility of gasification for contaminated carcass disposal and to identify technical challenges and improvements that will simplify, improve, and enhance the gasifier system as a mobile response tool. Past testing of the prototype demonstrated partial success, in that the transportability and rapid deployment requirements were met, however, the throughput of animal carcasses was approximately 1/3 of the intended design capacity. Significant modifications were made to various gasifier components, including the burner system, feed system, control system, power distribution, and ash handling system in order to increase its operating capacity to the rated design throughput. A series of tests were performed in September 2015 to evaluate the effectiveness of the design modifications at increasing the system's throughput, as well as to demonstrate the unit's ability to operate around the clock for an extended period of time. These tests, once again, were partially successful, with the new burner system, feed system, control system, and power distribution systems all functioning in an acceptable manner. However, the ash removal system and the system to move material across the bed failed during the tests due to material issues. The test and evaluation showed that improved alloys would be needed in some of the parts to achieve the desired results. This report summarizes the results of the test and lessons learned from the modifications.

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| APHIS | Animal and Plant Health Inspection Service (USDA) |
| BGP | Brookes Gasification Process |
| DoD | U.S. Department of Defense |
| EPA | U.S. Environmental Protection Agency |
| LP | Liquified Propane |
| NHSRC | National Homeland Security Research Center (EPA) |
| ORD | Office of Research and Development (EPA) |
| PAC | Programmable Automation Controllers |
| PC | Personal Computer |
| PCC | Primary Combustion Chamber |
| RTP | Research Triangle Park, NC |
| SCADA | Supervisory Control and Data Acquisition |
| SCC | Secondary Combustion Chamber |
| TSWG | Technical Support Working Group (DoD) |
| USDA | U.S. Department of Agriculture |

## Acknowledgments

The authors would like to acknowledge the contributions of Lori Miller (USDA/APHIS), Michelle Colby (DHS S&T), Jim Howard (independent consultant), and Shannon Serre (EPA/CMAD) in the preparation of the testing protocols and performance of the testing. The authors would also like to acknowledge the contributions of ARCADIS, Ag Protein, Rendeq, and Joe Moore and Company to this effort.

# 1. INTRODUCTION

The U.S. Department of Defense (DoD) Technical Support Working Group (TSWG), in collaboration with the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (USDA/APHIS), built a transportable gasifier with the goal of processing large quantities of animal carcasses and plant materials resulting from agricultural emergency events. This unit may also be useful for other homeland security-related events involving contamination with biological agents as an on-site treatment/disposal process. This gasifier converts biomass material into an inert ash (although the ash may have to meet state disposal requirements) and a combustible synthesis gas that is burned in a secondary combustion chamber (1).

Performance testing on the prototype unit using a mixture of poultry and swine carcasses was performed in 2008 to evaluate the unit's potential throughput and environmental impact in terms of both air emissions and ash characteristics. The complete data set from the source emissions testing can be found in a published EPA report (2) and further analysis can be found in additional symposium papers (3-6). A second shorter performance test was conducted in 2010, mainly to evaluate material throughput issues. Based on shortcomings that were observed in those two tests, additional design modifications were made to the unit specifically to overcome the throughput limitations and operational difficulties. This report discusses the modifications made since the second test and the results of a test and evaluation exercise performed in 2015.

## *1.1. Gasifier Prototype Description*

The BGP-D1000 gasifier (BGP, Inc., Toronto, Canada) was designed to process 25 tons per day of feed material, using a series of chambers, each with different fuel/air stoichiometry. Two independent primary combustion chambers (PCCs), operating sub-stoichiometrically under natural draft, feed hot combustible vapors into two independent secondary combustion chambers (SCCs), thus achieving a quasi-steady-state operating mode. The PCCs serve to create the oxygen deficient atmosphere to gasify the carcasses. Heat from the SCCs provides the PCC hearth with thermal energy, and the SCCs provide for destruction of any combustible gases leaving the PCCs. The majority of the insulating refractory in the gasifier is composed of lightweight insulating wool refractory to minimize weight. Only the hearth and the load-bearing refractory components are composed of conventional firebrick and castable refractory. The thermal inertia of the hearth prevents significant PCC temperature loss when materials of high water content are charged onto the hearth. The unit operates on natural draft without requiring an induced draft fan. The commercial implementation of this design concept would allow manifolding up to eight gasifier units together with a pre-breaker and finer to achieve larger capacities, up to approximately 200 tons per day, which is comparable to other large capacity fixed-site incineration facilities (although this has not been demonstrated). The pre-breaker and finer are used to grind the animal carcasses into a size capable of being pumped to the feed distribution system and deposited onto the hearths. The pre-breaker is loaded using a "skid steer" or telehandler-type front end loader with a nominal bucket capacity between 500 and 600 lb. The gasifier is designed to operate 24 hours per day for an extended period of time before any maintenance shutdowns would be required, provided that the liquefied propane (LP) fuel tanks (for the burners) and the diesel fuel tank (for the generator) are refilled. Figure 1 gives a graphic depiction of the gasifier design concept.

Major components of the gasifier system include a pre-breaker (to reduce the size of the animal carcass to approximately 1.5 in), finer (to further reduce the size of the material to approximately 0.75 in), accumulator (to hold feed material until it is fed into the gasifier), transfer auger and pump (to move the ground animal carcass material to the accumulator), variable speed feed augers, carbon steel drag chain conveyors in each gasifier PCC (to spread the material on the hearth and to move it down the hearth), carbon steel ash auger (to move the ash to a bin for disposal), and exhaust stack. The gasifier control system is operated by two programmable automation controllers (PACs) connected to a personal computer (PC)-based Supervisory Control and Data Acquisition (SCADA) system.

The prototype gasifier was originally designed to be completely transportable. However, as the recent design modifications were introduced, in an effort to have a successful proof-of-concept of the main design changes, some of the transportability was sacrificed in an effort to reduce costs. These design modifications can be altered to be completely transportable once the proof-of-concept tests have been completed successfully.

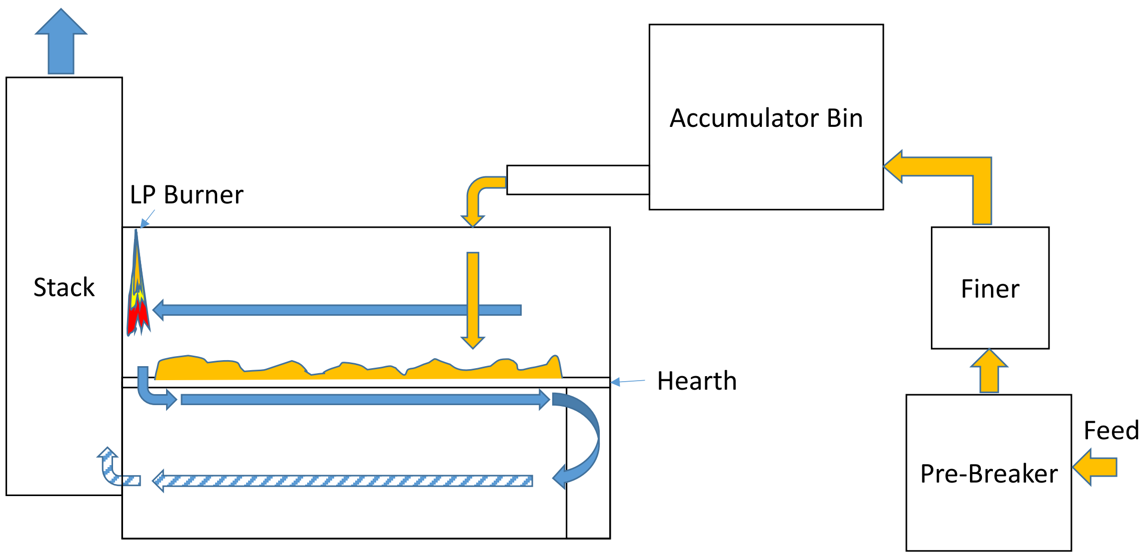


Figure 1. Gasifier Concept Schematic

The gasifier unit is equipped with a telescoping stack (34-inch diameter and approximately 12 feet high) projecting above the gasifier. A 34-inch diameter dilution air inlet at the base of the stack allows for control of the natural draft that draws the air through the PCCs and draws the combustion gases through the SCCs.

Two burners (2.15 MM BTU/h/630 kW), each capable of firing 20 gal/h of LP gas, are mounted in the duct between the PCC and SCC (i.e., one burner on each side). These burners provide initial heat to make the hearth hot enough to initiate gasification in the PCCs. The burners also provide process control to maintain predetermined temperatures in the SCCs based on a user-defined set point. The burners are fed from three 1,000 gallon LP fuel tanks mounted adjacent to the unit.

The gasifier unit is designed with a reservoir at the back end of the PCC to collect ash from the hearths. Once a substantial amount of ash accumulates, an ash removal auger continuously removes the ash to metal bins outside the gasifier. The ash removal process is manually actuated to initiate the motor, then runs continuously as the material on the hearths is gasified.

Photographs of the gasifier are shown in Figures 2 and 3.

Figure 2. Front View of Gasifier and Diesel Generator

Figure 3. Opposing Side View of Gasifier

### *1.2. Discussion of Previous Design Deficiencies*

Many aspects of the 2008 and 2010 performance testing satisfactorily met the required criteria for acceptance of the technology. Some of the successfully achieved requirements included:

- Transportability over primary and secondary roads;
- Ability to begin operations within 24 hours of arriving on site;
- Operation of the burner system; and
- Operation of the material feed system.

However a number of design deficiencies were not overcome during either the initial performance test in 2008 or the follow-on tests in 2010. These design and/or operational deficiencies included:

- The feed system was not able to handle equine or bovine carcasses due to feed hopper size and cost considerations when selecting the animal carcass maceration equipment when the prototype was built (this was an intentional design choice);
- The ash removal auger system failed during the 2008 performance test, although it was repaired for the 2010 performance test, also failed in the 2010 performance test. During the previous tests, the operating time was insufficient to provide enough ash to test the ash removal auger system;
- The material feed system introduced an amount of material into the gasifier equal to the amount of material fed into the macerator, making it difficult to control the distribution of mass onto the gasifier hearth;
- The oil-fired burners initially provided with the prototype (a design decision made to minimize the need for multiple types of fuel to be delivered in the field) offered poor flexibility regarding the range minimum and maximum fuel feed rates (turndown ratio) and difficult ignition. The oil-fired burners could not be replaced while the unit was hot;
- The electrical system of the gasifier was not effectively shielded from heat, resulting in damage to some of the wiring;
- A significant amount of manual labor was required both on the ground and on the top of the gasifier to feed a batch of material into the gasifier. The manual labor requirement not only complicated the feeding procedures but also made all-weather operation of the gasifier somewhat problematic due to the need for personnel to be on top of the unit potentially during inclement weather;
- No automated system for distributing the feed materials on the hearth was available;
- No automated system for pushing the combusted material back to the ash removal section of the gasifier was available; and
- No automated method was provided for controlling the throughput speed or volume of mass fed into the system.

These design deficiencies were noted and a new project was initiated to modify the existing configuration. These changes are discussed in the next section.

## 2. Implemented Design Modifications

Initial observations from the 2008 and 2010 performance tests highlighted potential system modifications needed for the prototype unit to meet the defined set of operational requirements that were specified. These proposed modifications were documented in a paper at the 2012 Carcass Management Symposium (5). These planned modifications were implemented, and proof-of-concept testing was conducted in September 2015.

### *2.1. Burners*

The oil-fired burner system was replaced with LP gas-fired burners (2.15 MM BTU/h) to improve the ability to control the temperature in the gasifier, offer improved turndown ratios (ability to operate at very low and very high firing rates), simplify the burner electronics, and allow for hot-swapping of burners in the case of a burner failure (increasing the reliability of the unit). The burners are Eclipse Ratiomatic 5 burners (Eclipse, Rockford, IL). Although use of LP will necessitate delivery of diesel fuel for the generator and LP fuel for the burners, delivery of two fuels to the site is not expected to unnecessarily complicate operational logistics and will increase the reliability of the unit. The burners are shown in Figure 4.

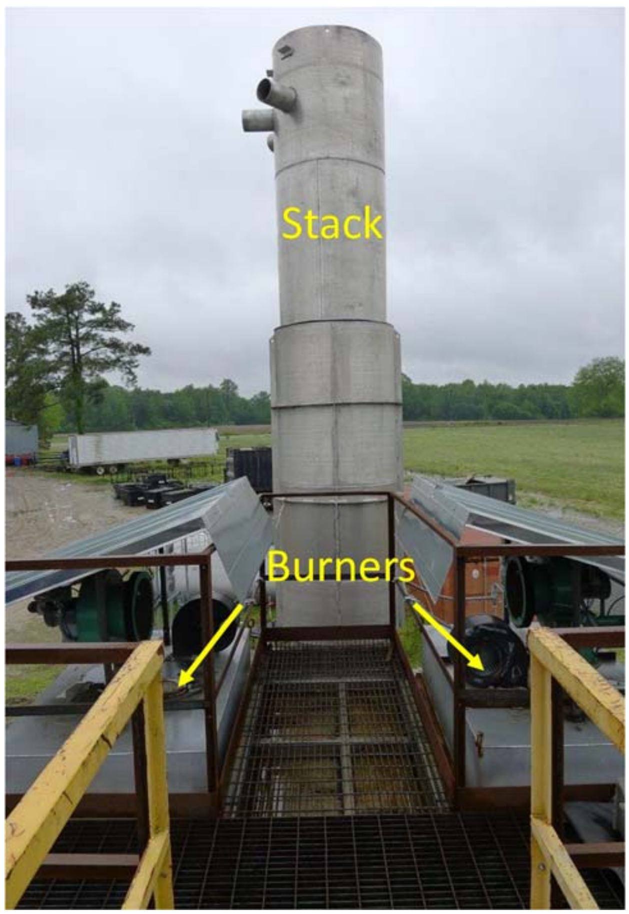


Figure 4. LP Burners and Exhaust Stack

### *2.2. Feed System*

The feed system was modified with a pre-breaker (Reitz PB-24, Hoexter, Germany) to allow for processing of larger animals, including bovine and equine carcasses. This will increase the ability of the unit to process a wider variety of animal carcasses. A finer (Weiller 1109, Whitewater, WI) was added to further reduce the size of the mass particles (nominally 0.75 inch diameter) to improve the efficiency and throughput of the system. The pre-breaker is shown in Figure 5. The material feed system was also modified to provide for more precise control over how much material is fed into each region of each hearth upon each feed event. Following the addition of the pre-breaker and finer, an accumulator bin (Rendeq, Burlington, NC) was installed. Material is pumped into the accumulator bin (about 3,500 lb capacity) after size reduction in the pre-breaker and finer, then the material is augered into the ports in the tops of the gasifier. This greatly improves the feed rate control of the unit. The accumulator bin is shown in Figure 6, and the material feed augers are shown in Figure 7.

Figure 5. Pre-Breaker and Finer

Figure 6. Accumulator Bin

Figure 7. Feed Augers

### *2.3. Internal Material Transport System*

Significant modifications converted the gasifier from a semi-batch feed system to a continuous feed system to minimize operational fluctuations that previously occurred due to intermittent feeding operations and to enable steady-state operation at a higher throughput rate. The hearth was modified with a set of drag chains (Rendeq, Burlington, NC) to improve material distribution across the hearth and to allow for continuous movement of the material across the hearth until it eventually reaches the ash removal reservoir. The drag chains and ash auger are shown in Figure 8.


Figure 8. Gasifier Chamber Showing Drag Chains and Ash Auger

### *2.4. Supervisory Control and Data Acquisition (SCADA) System*

The supervisory control and data acquisition (SCADA) system provides the human-machine interface (HMI) with the gasifier temperature, burner control, and feed control systems. In addition to providing the HMI, the SCADA system also electronically logs the system temperatures with timestamps for later retrieval and analysis. Alarm handling and recording is also built into the HMI package of the SCADA system.

The gasifier control system is operated by two programmable automation controllers (PACs) connected to the personal computer (PC)-based SCADA system. One is installed in the power distribution panel, and the other is in the main control panel. The power panel PAC is primarily responsible for controlling the pre-breaker, finer, and feed system components. A second PAC is installed in the main control panel. This PAC interfaces with the two burner management systems (BMSs) and also monitors the many thermocouples installed in the system. The two PACs are connected to the SCADA computer (Opto 22, Temecula, CA) by way of an Ethernet switch installed in the main control panel.

The following tests were performed in September, 2015:

- A throughput performance test to evaluate maximum material throughput and to identify appropriate operating regimes. These tests intended to determine the unit's nominal operating capacity for the second set of tests; and
- A long-term operation test where the unit is operated at its nominal operating capacity for 72 continuous hours.

Documentation of the operation of the gasifier, estimates of fuel usage and thermal efficiency, and development of training materials for operator and maintenance personnel were an additional goal of the 2015 tests.

# 3. Description of Testing

The unit began initial heating on September 10, 2015, with feeding of swine initiated on September 14, 2015.

## *3.1. Test Objectives and Results*

- **Objective 1**: Repair the components of the gasifier prototype which were damaged and deteriorated as a result of and since the 2010 test.

  Accomplished. Known areas of damage were the failure and seizure of the Ash Conveyor and the new Drag Chain on Side 1 and possibly on Side 2.

- **Objective 2:** Replace the oil-fired burners and associated equipment with gas-fired burners.

  Accomplished. New gas burners permitted better operation and control than oil burners and provided sufficient heat for the current design of the unit. There was some difficulty in dependability during the initial ignition, but much of this difficulty was caused by long periods between firings. Moisture and oxidation may have influenced the efficiency of the flame control system. The SCADA system provided significant benefit over the previous burner control system. Two spare burners were stored with the gasifier system.

- **Objective 3:** Modify the feeding system to accurately distribute desired quantities of macerated material onto specifically targeted locations within the gasifier.

  Substantially accomplished. The prebreaker, transfer screw, pump, finer, accumulator bin, bin screws, feed screws and feed valves (gates) operated well except for some balkiness of the feed valve limit switches due to corrosion from moisture infiltration of the whisker housing. Additional weather-proofing of the feed valve limit switches could serve to minimize potential corrosion. The SCADA made the operation of the feed system extremely user friendly.

  The height of the feed chute required the construction of a platform that allowed dumping of the carcass material, but with some difficulty. Large carcasses loaded horizontally were subject to bridging in the hopper. Plans to have a higher lift capacity were not accomplished because of time and funding limitations. A Telehandler with a grapple bucket and a quick release hook would be a solution for loading large animals such as cattle and horses. One steer was loaded vertically using a heavy duty forklift during the initial testing of the prebreaker in Burlington at Rendeq Inc., and it was ground without difficulty. Weighing the loader empty and loaded to track the mass being fed into the gasifier was burdensome. Either a full size scale or load cell on the loader would greatly simplify this process.

  As part of 2015 upgrades, an innovative feed component was installed in the gasifier primary chambers. The feed component consisted of a motor-driven drag chain assembly to transport the carcass material deposited on the hearth along the hearth at a speed that would permit gasification and then deposit the resulting ash at the ash auger for transport to the ash discharge chute. The drag chain operation was fully controllable in both speed and direction from the SCADA system. The drag chain units were approximately 43 inches wide and moved approximately 19 feet along the hearth, discharging approximately 4 feet from the ash auger, which is 9” in diameter and mounted about 3 inches above the hearth. The metals in the conveyor and frame were carbon steel and tested to approximately 750 °C. The actual operating temperatures were almost double the temperature for which the chain systems were designed. Despite repeated efforts by Rendeq Inc. the drag chains and their components were not able to withstand the heat. The graphite bearings failed, the rails warped, the sprocket welds failed, and the pins came out of the chain links.

The ash auger that had malfunctioned in the previous tests warped from the heat, the bearings failed, and the flight seized in the refractory openings between primary chambers.

Special high temperature materials such as cast iron or Inconel are needed for the feed and ash discharge systems. The systems themselves need to be redesigned and better coordinated, possibly using screw augers and carbon or ceramic sleeves. Additionally, the initial feed location of the carcass material should be moved to a point beyond the end of the hearth to allow for maximum residence time of the material on the hearth.

- **Objective 4:** Modify the macerator system to handle larger animals (e.g., bovine carcasses).

  Accomplished, but not demonstrated. The capability to handle larger carcasses was implemented with the PB-24 prebreaker, transfer screw, screw pump, finer, and accumulator as discussed previously, but the capability was not demonstrated during the 2015 test because a high lift loader was not rented for the activity and no bovine or equine carcasses were obtained due to time, contract, and funding constraints. The unit performed effectively using swine carcasses.

- **Objective 5:** Develop training materials for operational personnel.

  Accomplished, but not evaluated. Documentation related to operation of the gasifier system was prepared, but third party training and evaluation did not occur due to time, contract, and funding constraints. Actual operating personnel for the activities related to the gasifier system were intimately involved in the design, construction, and debugging of the system, so the documentation is believed to be complete and accurate, although not confirmed.

- **Objective 6:** Evaluate and modify controls for the macerator and gasifier to assure that the system can be operated properly and safely in all weather conditions.

  Accomplished. The SCADA internet-based electronic monitoring and control system provided outstanding capability to control, monitor, evaluate, and analyze the performance of the gasifier system, including remote control. Some period of operational familiarization is necessary for operation. A qualified SCADA programmer is required to debug, modify, or update the SCADA system.

- **Objective 7:** Conduct sufficient test runs to properly adjust the system, manage limitations, train sufficient personnel to safely and reliably operate it in the field, and to assure performance at the highest throughput possible.
- Attempted but not accomplished. The test and evaluation period was compressed and restricted due to contract, funding, and schedule constraints. The tests did confirm that the Gasifier System was operational, but the capabilities were limited by its current configuration. The tests revealed the inadequacy of carbon steel and low grade stainless steel to withstand the high operating temperatures required for prion destruction. In addition, the tests revealed that the transport system components required closer design tolerances to operate effectively. Another result was that the primary chamber temperature dropped by over 200 °C when carcass material was fed on the >450 °C hearth, while the secondary chamber remained at >850 °C. When the primary chamber temperature returned to about 325 °C+/-2C, the carcass material on the hearth flashed and the primary chamber temperature climbed steeply to over 1083 °C, exceeding the maximum set points for the primary chambers, causing both burners to shut down. This shutdown had no influence on the fire in the primary chamber, where the temperature remained above 1000 °C until the mass was consumed. Closing the vent ports had limited influence on quenching this uncontrolled heating. This uncontrolled heating resulted in the thermal damage to the ash auger and drag chains and bearings.

These problems may be able to be resolved by having higher temperature materials for the hearth transport system.

- **Objective 8:** Carry out a three-day Proof of Concept test at the highest throughput safely possible.

  Not Accomplished. The gasifier system components within the primary chamber failed due to the high operating temperatures encountered once the carcass feed was initiated. See Objective 3 above

- **Objective 9:** Clean and prepare the system for relocation.

  Accomplished. The unit was cleaned with crushed ice, disassembled, manually cleared, and pressure washed. All components were documented, packaged and transported by truck to a storage location at the EPA facility in Research Triangle Park, NC.

- **Objective 10:** Evaluate and document the system, its operation, its performance, its maintenance, and any modifications or improvements

  Accomplished. This report completes this objective.

### *3.2. General Observations*

- General

  The upgrades since 2010 provided significant improvement in the understanding, design, fabrication, operation, disassembly, capabilities, and challenges of mobile gasification technology. Things as simple as repairs by individuals who do not understand the operation of the system, influence of government shutdown and contract changes, and uncontrolled temperature spikes significantly influenced the system performance.

- Foundation and Containment-

  The upgrades required that a substantial concrete foundation was needed to support the feed system weight and to anchor the structural steel necessary to construct the feed system. Part of this need was caused due to budgetary constraints placing the proof-of-concept tests at a higher priority than having all components be transportable. For an operational unit, some sort of structure that would be operable in the universe of potential emergency sites would be needed. In addition, environmental containment was needed for the carcass materials and related runoff. Based on these needs, a 100 foot long x 30 foot wide x 7 inch thick concrete pad with a 30' x 30' containment area adjoining the end of one side was constructed to meet all the equipment mounting and carcass containment needs. Gravel was distributed along one end and both sides of the pad to provide access and support loaded vehicles in all weather. These site preparations proved to be extremely beneficial during all phases of the construction and testing, especially during severe weather periods.

- Generator

  The 250 kW, 230/460 V, three-phase diesel generator is capable of powering the continuous operation of the upgraded gasifier system as long as loads were added so that the starting current loads drop back to baseline. The generator must be run periodically and maintained in accordance with manufacturer's recommendations to prevent major repair costs.

- Material and System Compatibility

  Improved component materials are needed for better thermal resistance, strength, machinability, dependability, cost and availability so that the carcass material can be moved through the gasifier chamber at a rate that accomplishes the desired thermal destruction, whether that is 100 °C for Avian Influenza-contaminated birds or 1000 °C for prion-contaminated cattle or deer.

- Transportability

  The gasifier was originally intended to arrive at an affected premises within 24 hours of request and be ready to process materials 24 hours after that. The current system requires at least 120 hours to set up if an adequate concrete pad and traffic pattern is available. To meet the 24-hour objective, all major gasifier components would require dedicated trailers with jacks to be connected, erected, and operated in a manner similar to a mobile asphalt plant which can be erected in 24 hours or less.

## 4. RECOMMENDATIONS

The transportable gasifier prototype has been significantly improved since its inception a decade ago, but it requires additional improvements in order to be fully functional. The US has a continuing need for such a system, as evidenced by the 2015 HPAI outbreak, which was the largest animal disease outbreak in US history. It is recommended that the following actions be taken in order to leverage the investments to-date, and provide the needed capability to agricultural health emergency responders.

**Recommendation 1:** Partner with institutions, technology developers, emergency responders, and industry to improve this prototype to full functionality for production of units which can be maintained for deployment when needed.

**Recommendation 2:** Repair and reassemble the current gasifier system hardware for response to disease outbreaks such as Avian Influenza, Swine Flu, Exotic New Castle Disease, and similar diseases which can be destroyed with temperatures of 100 °C(7).

**Recommendation 3:** Make system improvements to reach higher temperatures for prion-infected carcasses, such as:

- A single hearth (10 feet wide by 3 feet high) with numerous channels (~13) for high temperature 9" screw augers feeding ground material (3/4" diameter) from a feed location outside the hearth, the full length of a longer hearth (at least 30 feet) to a ash discharge auger in a lower trench to a discharge chute.
- Select materials compatible with the high temperatures and materials being processed. Design temperatures for all internal components should be able to operate continuously at 800 °C.
- Permit mounting of screw auger bearing or graphite sleeves outside of the high temperature chamber.
- Control the air draft into the chamber into which the carcass materials is transported to minimize the turbulence and open flame production.
- Relocate the carcass feed to a point outside the end of the hearth to permit maximum residency time on the hearth.
- Install V-shaped lanes along the surface of the hearth, spaced to allow the installation and operation of high temperature 9-inch or 10-inch screw augers to move the carcass the length of the hearth.
- Install a similar V-shaped structure at the rear of the hearth to facilitate the operation of a high temperature 9-inch ash auger transporting the material to the ash discharge chute.
- Select either extremely high temperature bearings or graphite sleeves to permit unrestricted operation of the auger shafts, which will be controlled by the SCADA system. Ensure transportation, erection, assembly, operation and maintenance of the system components have maximum simplicity, flexibility, and efficiency.

**Recommendation 4:** Erect the gasifier under a suitable shelter with due consideration for process flow, vehicular access, operation, serviceability, and safety to minimize moisture problems for controls, motors, burners and refractory.

**Recommendation 5:** Ensure adequate trained personnel are available to assure safe and reliable system operation, even for the current system design.

**Recommendation 6:** Maintain, service, operate, and inspect gasifier and its components regularly so the prototype will be functional if additional improvements are initiated. This includes:

- Running the diesel generator at least monthly and treat the fuel to avoid separation, condensation, and gumming.
- Putting a load on the generator at least once a year to assure no loss of field. Rotate the motors to reduce the likelihood of corrosion. If they are stored outside they should be appropriately covered with plastic or other protective material. Secure all switch covers and seal the holes in the back of panels. Cover connector receptacles to prevent insect nesting. Protect cables and hoses from sun exposure and vermin such as mice and squirrels.
- Treat cabinets and storage containers with suitable vermin traps or poison. Keep the control computer up to date as far as operating system, security, and software updates and charge the battery regularly. Protect hardware components and structural steel from rust and corrosion as well as scrap hunters. Properly store project documentation and media to prevent degradation from moisture or vermin damage.

**Recommendation 7:** If there is benefit from future use of the current gasifier system or its components then the sooner action is taken the more benefit may be gained. Long term storage of the unit has in the past resulted in loss of components, moisture absorption, corrosion, component failure, contamination, and expensive repairs. Changes in technology will render many parts of the system out of date or impractical.

# 5. Conclusions

A prototype transportable gasifier, intended to thermally process contaminated animal carcasses, was constructed and tested, with some design requirements met and others not met.

A series of design modifications were completed, and testing was performed to address the effectiveness of the modified prototype so that this technology can be included in the toolbox of available technologies for mass disposal of animal mortalities.

These design modifications culminated in a series of tests to assess maximum throughput capacity, which was less than the target. Although a 72-hour long term operational test was also planned, it was not conducted due to inadequate characteristics of metals used in some gasifier components.

The throughput test was partially successful. Some design features worked as planned; others were somewhat less successful. A summary of the more successful and less successful aspects of the tests follows:

- LP gas-fired burners were easy to light and reliably adjusted their firing rate as temperatures in the primary and secondary chambers changed;
- The modified feed system using the pre-breaker, finer, and accumulation tank worked much better than the previously installed macerator system; it allowed consistent feed to be fired into the primary chamber;
- The modified control system enables automatic control of the gasifier without requiring any manual actuation of control valves; this will provide a significant improvement in all-weather operation; and
- The internal material transport system to move the burning material and ash across the hearth and to remove the ash from the inside of the gasifier failed due to inadequate materials of construction. The design itself appears to be functional for the purposes it was designed, but due to transient temperature fluctuations inside the gasifier, and non-uniform temperature distribution within the primary chambers, the temperatures that the components were exposed to were much higher than the design limits of the components. It is recommended that a high temperature alloy such as Hastelloy be used for these components.

## 6. References

1. BGP Inc. Engineering Report: Initial Shakedown And Testing Of Mobile Gasifier Prototype; DoD Contract Number: W91CRB-06-C-0007. 2008.
2. Lemieux P. Emissions Test Report: Source Sampling for Transportable Gasifier for Animal Carcasses and Contaminated Plant Material. RTP, NC: 2008 August. Report No.: EPA/600/R-08/127.
3. Lemieux P, Brookes D, Howard J, McKinney J. Transportable Gasifier for Animal Carcasses: Emission Test Results. Proceedings of the International Symposium on Management of Animal Carcasses, Tissue and Related Byproducts; July 21-23; Davis, CA2009.
4. Lemieux P. Gasification of Catastrophic Losses. Proceedings of the 2010 National Poultry Waste Management Symposium; October 26-28; Greensboro, NC2010.
5. Lemieux P, Serre S, Hall B, Sharpe B, Howard J. Transportable Gasifier for On-Farm Disposal of Animal Mortalities: Status Update. 4th International Animal By-Products Symposium; May 21-24; Dearborn, MI2012.
6. Lemieux P, Serre S, Hall B, Sharpe B, Howard J. Transportable Gasifier for On-Farm Disposal of Animal Mortalities: Status Update. 5th International Symposium on Managing Animal Mortality, Products, By Products and Associated Health Risk; September 28-October 1; Lancaster, PA2015.
7. Kansas State University. Carcass Disposal: A Comprehensive Review 2004 [cited 2013 May 29]. Available from: http://hdl.handle.net/2097/662.

## APPENDICES

APPENDIX A: Miscellaneous Operating Procedure: Operation of Transportable Gasifier

APPENDIX B: Transportable Gasifier Control Electrical Schematics

APPENDIX C: Grinding, Transfer, Accumulation and Feed (GTAF) System Manuals

APPENDIX D: Continuous Monitoring Data from September 2015 Performance Test

APPENDIX E: Manufacturer’s Documentation