

SWINE HEALTH

Title: Low Cost Mobile CO₂ Vaporizer System Prototype - 2020 – **NPB #20-146**

Investigator: Colin Gendre

Institution: Intricate Group Inc.

Date Submitted: 06/23/2021

Industry Summary:

Currently there is a lack of mobile, low-cost vaporizer systems readily available to provide CO₂ gas for large scale depopulation at swine operations. To better utilize CO₂ for depopulation, there is a need for a “right sized”, mobile, low-cost, easy to use vaporizer system. This system should accomplish the necessary flow rates (CFM of CO₂), to meet the AVMA guidelines for a 20% CO₂ displacement rate, for the most commonly available chamber sizes (e.g. dump truck box, roll off dumpsters). Ideally a “right sized” vaporizer should be portable, easy to set up, easy to use and not require many offsite resources to run. Flow rates (CFM of CO₂) should be easily adjustable to match chamber volume. The vaporizers should also be built for easy external cleaning and be able to withstand commonly used disinfectants in the pork industry.

Objective: Development of a low-cost, mobile CO₂ vaporization system prototype that can be used to meet the AVMA guidelines for depopulation of swine using CO₂. This vaporization system should be capable of working in most areas of the contiguous United States meaning it will need to operate in temperatures ranging from -30°F to 104°F. The following criteria were to be considered while developing the prototype:

1. Portability
2. Ease of setup and use
3. Level of training
4. On site resources to operate
5. Maximum chamber volume that the system can fill at the required 20% CO₂ displacement rate over 5 minutes
6. Ease of external cleaning and disinfection
7. Cost to produce is less than \$75,000 USD/unit.

Narrative on how research was conducted: A simple ambient air CO₂ vaporizer was utilized as the basis of this system to keep in alignment with low cost and simplicity to operate. Ambient air vaporizers utilize the ambient conditions to increase the temperature of the CO₂ to convert liquid CO₂ to gaseous CO₂. Liquid CO₂ is not typically available on farms but can be delivered through providers such as Air Liquide or Praxair.

The first phase in the research was to engineer the system and select appropriate equipment to meet the objectives of the project. Ambient air CO₂ vaporizer are designed for continuous use in a vertical orientation, typically in soda bottling facilities, applications that allows for various ranges of flow rates and ambient air conditions and the required horizontal orientation to properly fit on a trailer created challenges to source a vaporizer that would fit the application and still be able to be mounted on a trailer so it could be mobile.

Once the appropriate vaporizer was selected, the next engineering objective was to design the process to be both simple and functional. Vaporization of CO₂ is dependent on both temperature and pressure of the liquid/gas; vaporization can be achieved at lower temperatures if the overall pressure is decreased. A pressure

These research results were submitted in fulfillment of checkoff-funded research projects. This report is published directly as submitted by the project's principal investigator. This report has not been peer-reviewed.

For more information contact:

National Pork Board • PO Box 9114 • Des Moines, IA 50306 USA • 800-456-7675 • Fax: 515-223-2646 • pork.org

regulator was, therefore, installed upstream of the vaporizer to reduce the inlet pressure of the liquid CO₂ to help achieve the desired vaporization rates at low ambient temperatures. A regulator was also installed on the outlet of the vaporizer to maintain the outlet pressure to the depopulation chamber. A simple flow meter that runs on the trailer's 12-volt system was installed to provide real time flow rates to the operator.

Once design was completed, all necessary parts and materials were procured to build the prototype. Many of the items were long lead items as these are fairly specialized parts for this application. Once materials were received the system was constructed on a mobile flat deck trailer.

Research Findings: The last phase of the project was to test the system and validate any assumptions of the project. After completion of the initial testing, it was determined that the regulator located downstream of the vaporizer was insufficient to maintain pressure in the vaporizers. This resulted in dry ice formation in the system and a failure of all of the flow control equipment.

Based on this, it was determined that either a control valve or a back pressure regulator would be required to maintain a minimum of 80 PSI in the vaporizer, as lower pressures could result in dry ice formation and system failure. The manual control valve that was originally located upstream of the vaporizer was moved to a downstream location to act as the back pressure regulator since a regulator sized for this application would be price prohibitive.

The second testing event demonstrated that relocating this control valve maintained the required pressure in the vaporizer, which allowed the system to function properly. This allowed the system to be tested under the various flow rates required for the proposed depopulation chambers. Testing was completed on a relatively warm day (~80 °F) so the system will require further testing at lower ambient temperatures in the winter of 2021-2022 to determine the sizes of depopulation chamber that can be used at various low ambient temperatures.

Overall, the findings were that we were able to design, construct, and test a prototype system that met the seven requirements as listed in the summary above. The large majority of the costs of this prototype project were in the design, procurement, and testing of the system. Based on the materials and equipment selected it was determined that the system can be built for the required maximum cost of \$75,000 USD as set out in the budget objectives.

Standard operating procedures (SOP's) were developed to aid in the operation of the system and for the training of operators. To maintain a low cost and simple operation, the system is controlled and operated manually by valves, therefore training and operation are very simple. The entire system is mounted on an 18 foot flat deck trailer that can be pulled by a 3/4 ton or larger truck making it a very mobile system.

The vaporizer, piping, valves, and exterior equipment components are either aluminum or stainless steel that are suitable for outdoor use and storage, and cleaning with most industry standard cleaning products (Extreme bioshield, bleach, or hydrated lime **should not** be used on the equipment).

The system was designed with flow control to ensure flowrates and distribution pressures are sufficient for depopulation purposes, while not causing undue stress on the livestock. CO₂ flow rates will be monitored by an operator to ensure proper delivery rates are achieved based on the depopulation chamber size. The SOP includes a table that provides the conversion of cubic feet per minute (CFM) required for each standard depopulation chamber to standard cubic feet per hour (SCFH) that is read on the flow meter display. This will allow operators to ensure the proper volumes are provided based on the ambient temperature during depopulation events.

The system can be run by two people: one that operates the control valve and maintain the flow rate, the other to hook up/unhook the hose to the depopulation chamber.

Key Findings:

1. Simple, easy to operate system (No complex boiler, heating systems or electrical systems)
2. Portable, weighs less than 4,550 lbs. (Can be towed behind 3/4 ton or larger trucks)
3. Cost effective (Post prototype systems can be built for \$75,000 USD)
4. Flexible for various depopulation chamber sizes (The vaporizers are capable of providing a large flow rate for depopulation chambers in excess of 3,000 ft³)
5. Can be cleaned and disinfected by most industry standard cleaning agents

Contact Email: colingendre@intricategroup.com

Contact Phone: 780-231-6706

Scientific Abstract: CO₂ based depopulation of swine has been considered a viable approach for small animals, however the process is typically not used for large animals due to the availability of large volumes of gaseous CO₂ required for use in large depopulation chambers. The best option for CO₂ supply to these large chambers is on site liquid CO₂ vaporization, which is not a feasible expectation for swine operations. To overcome the drawbacks of fixed equipment on every swine farm, a trailer mounted CO₂ vaporizer system was proposed. This trailer mounted CO₂ vaporizer system was designed for low cost, to be easily transported between farms and easily setup and operated. To achieve all of these goals the system has limited electrical components with only one electronic flow and temperature meter that is connected to a digital readout and is powered internally off of the trailers battery (which is recharged during towing). The system is short (18 foot) lightweight (4550 lbs.) and can be towed easily with a 3/4 ton truck. The system is designed to be connected to a bulk delivery vehicle meaning that there is no need for any external infrastructure on the site. The system can be operated by two people with minimal training, during testing operators that had not operated the system before were capable of controlling the system within a few minutes of starting.

The system was designed and tested in Alberta, Canada with typical prototyping processes. There was design and construction, follow by testing and identification of system flaws. After a quick redesign the system operated as expected on the testing day. The testing demonstrated that the trailer mounted CO₂ vaporizer system was capable of providing the AVMA required flow of CO₂ for the proposed depopulation chambers:

- Dump truck (11.5'X7.2'X4') 67 CFM
- Dump Trailer (7.6'X18'X4') 110 CFM
- Roll off (20 yd -21.5'X7'X4') 121 CFM
- Semi (48 ft) (47.6'X8.2'X4') 313 CFM
- Semi (53 ft) (52.5'X8.2'X4') 345 CFM
- Custom (16'X48'X4') 615 CFM

Testing occurred on a warm day (approx. 80°F), and it will therefore require further testing and verification when the ambient temperatures are closer to the lower design temperature of -30°F. Modelling by both the vaporizer manufacturer and the design team indicates that the temperature will not be a concern, but this needs to be fully verified with testing.

Testing also demonstrated that the pressure in the vaporizer was able to be reduced from the supply pressure of 300 PSI to 80PSI in the vaporizer meaning that ambient air vaporization can be achieved at low ambient temperatures without dry ice formation.

Based on the testing conducted, the trailer mounted CO₂ vaporizer system prototype was considered a success meeting all design goals: it is easily transported, setup, and operated; it is capable of providing gaseous CO₂ for all proposed depopulation chamber sizes, it can be cleaned using most conventional cleaning solutions available at swine operations; and it can be constructed for \$75 000 USD.

Introduction: CO₂ is a commonly used gas for depopulation of livestock at many farm sites for any number of reasons. With respect to swine operations, much of the literature outlines that the use of CO₂ is typically only applicable to small animals. This limit has everything to do with the depopulation chamber size and

availability of gas in large enough quantities to provide the proper flow rates to large chambers, rather than an adverse reaction of large livestock to the CO₂ gas. This prototype trailer mounted CO₂ vaporizer system has been proposed to provide adequate gaseous CO₂ to large depopulation chambers by using large liquid bulk delivery vessels rather than small, pressurized CO₂ tanks.

There have been other proposed large scale portable units that have boilers or electric vaporizers to achieve rapid and efficient vaporization of the liquid CO₂, but these systems have high costs and external energy requirements. This trailer mounted CO₂ vaporizer system was designed to have a low cost and be self-contained by using ambient temperature vaporizers and connecting directly to CO₂ bulk delivery vehicles.

Objectives: The objective is to provide a low cost and portable solution for vaporizing liquid CO₂ to gaseous CO₂ to be used for depopulating animals when required. The design of the system will provide a mobile mounted system for CO₂ vaporization that can be easily transported from farm to farm as it will be constructed and mounted on a trailer that can be towed by a 3/4 ton pickup truck. The system will utilize an ambient air vaporizer so will not require any power or fuel to operate. Liquid CO₂ will be required to be delivered to the system from local suppliers. The system won't include the depopulation chamber as that will be provided by the end user.

The system was sized to be capable of providing the required CO₂ flow rates (20% of chamber volume/minute) for the 5 minute requirements of the following potential depopulation enclosures:

- Dump truck (11.5'X7.2'X4') 67 CFM
- Dump Trailer (7.6'X18'X4') 110 CFM
- Roll off (20 yd -21.5'X7'X4') 121 CFM
- Semi (48 ft) (47.6'X8.2'X4') 313 CFM
- Semi (53 ft) (52.5'X8.2'X4') 345 CFM
- Custom (16'X48'X4') 615 CFM

The following criteria were to be considered while developing the prototype:

1. Portability
2. Ease of setup and use
3. Level of training
4. On site resources to operate
5. Maximum chamber volume that the system can fill at the required 20% CO₂ displacement rate over 5 minutes
6. Ease of external cleaning and disinfection
7. Cost to produce must be less than \$75 000 USD/unit.

Materials & Methods: CO₂ vaporizer systems are conventionally made from two materials: aluminum for low pressure applications, and stainless steel for high pressure applications. These two materials were compared with the common cleaning solutions listed above (Table 1). Based on the material compatibilities alone, stainless steel was determined to be a better option for construction material since it is more compatible with the cleaning solutions. Stainless steel, however, will result in a far more expensive and heavy system (creating portability and cost issues). Aluminum has been, therefore, selected as the material of choice, with the caveat that some of the standard cleaning solutions used in the agricultural sector (Extreme Bioshield, Bleach, and Hydrated Lime/Whitewash) cannot be used to clean the system.

The trailer mounted vaporizer system (Figure 1) is built around two (2) 15,000 SCFH ambient temperature vaporizers in series. It was determined that this scenario provided the shortest possible trailer length while providing the required vaporization of the CO₂.

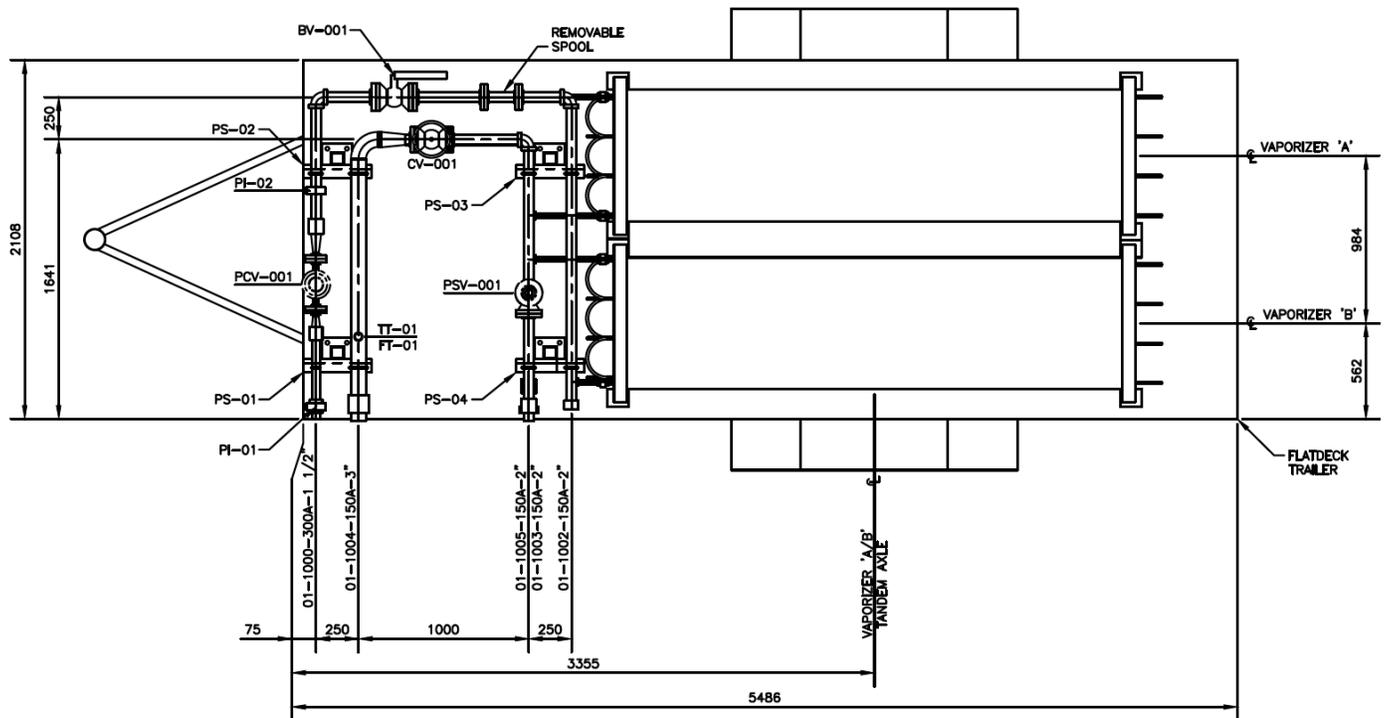


Figure 1 – Trailer Mounted CO₂ Vaporizer System schematic

The system was designed to attach (1 ½” truck in connection) to a standard hose provided by the bulk delivery vehicle. The bulk delivery vessel will provide liquid CO₂ at a pressure of approximately 300 PSI and a temperature of 0°F, which is a standard delivery temperature and pressure from bulk delivery vehicles.

A pressure control valve was included to reduce the bulk CO₂ delivery pressure (300 PSI) to a desired setpoint, not lower than 92 PSI, to maintain a vaporizer outlet pressure of 80 PSI. This lower pressure will optimize CO₂ vaporization at low ambient temperatures. This low setpoint pressure can be increased to ensure that the desired effluent flow rate is achievable. The 80 PSI vaporizer outlet limit is to ensure that there is no dry ice formation in the vaporizer that will adversely affect system operation.

Table 1 – Material Compatibility with Cleaning Solutions

Fluid	Stainless Steel	Aluminum	Source
anhydrous CO ₂	acceptable	acceptable	Praxair
carbonic acid (from moisture)	A - Excellent	B - Good	CP Lab Safety ¹
Synergize (or other "Quat")	acceptable	acceptable	Synergize list Aluminum and stainless steel as acceptable materials
Intervention/ Accel	A - Excellent	A - Excellent	https://www.contecinc.com/assets/dis035_preempt_material_compatibility_jpW9ryO.pdf similar AHP product
Virkon	care to be taken - short (<1 min contact time)	acceptable	Virkon background information: https://www.fishersci.co.uk/webfiles/uk/web-docs/SLSGD05.PDF Quote: "particular care is needed with acid sensitive metals, e.g. zinc, brass, copper, tin, aluminum, solder, mild steel"
Xtreme Bioshield*	B - Good	C - Fair	ratings (CP Lab Safety ¹) based on citric acid component vendor recommends rinsing aluminum after application
Bleach*	<20% C - Fair 100% D - severe	D - Severe	CP Lab Safety ¹
lysol spray	acceptable	acceptable	Scientific articles outline corrosion inhibition with benzalkonium chloride against strong acids
Tek-trol	acceptable	acceptable	Tek-trol data sheet corrosion testing showed no attack on materials
Hydrated lime/ Whitewash*	B - Good	C - Fair	CP Lab Safety ¹

¹<https://www.calpaclab.com/stainless-steel-chemical-compatibility-chart/>
<https://www.calpaclab.com/aluminum-chemical-compatibility-chart/>

* Not to be used with the vaporizer system

Should there be a blockage in the system or an overpressure event, a safety valve was located in the system to ensure that pressures do not exceed design pressures of the pipes and valves. At a pressure of greater than 200 PSI this system will release the CO₂ to a flexible hose that will be located away from the operator. A ball valve was installed for use during start-up to ensure the vaporizer is filled with vapor and the inlet is filled with liquid prior to the start of each operating event.

A drain valve was included to purge the hose from the bulk delivery vehicle to the trailer mounted CO₂ vaporizer system so that the hose can be safely removed by the bulk delivery vehicle operator. This valve was also designed to be used during start-up of operations to maintain pressure in the vaporizer and not trigger the pressure safety valve prior to opening the control valve to start flow.

A globe control valve was installed to be manipulated by the operator to provide the required flow of CO₂ through the vaporizers and then to the depopulation chamber. The operator will manually control the valve based on the required CO₂ delivery rate to the depopulation chamber. The operator will be required to tune this valve for the entire 5-minute depopulation to ensure flow rates remain as steady as possible. Minor environmental changes (shadows, wind, etc.) can change conditions in the system quickly.

A flow meter was installed to display the final gaseous CO₂ flow rate and temperature with the display located adjacent to the globe control valve for operator reference.

The CO₂ gas will be provided to the depopulation chamber using a hose.

The equipment was tested to determine:

- The maximum achievable flow rates (based on the desired depopulation chambers)
- The minimum operating pressure of the vaporizers
- The temperature of the effluent gaseous CO₂

All testing was conducted using a bulk delivery truck provided by Air Liquide in Fort Saskatchewan, Alberta (Canada) with three people present, the bulk delivery truck operator, and two trailer mounted CO₂ vaporizer operators. Testing of the equipment was conducted over 1 day during June in Alberta, Canada. During the testing the ambient conditions ranged from 79°F to 85°F.

Testing was conducted to determine operational conditions and parameters at ambient conditions.

The maximum achievable flow rates test involved the trailer mounted CO₂ vaporizer operators closing the effluent control valve on the system, then the bulk delivery truck operator filling the system with CO₂ vapor to a pressure of 150 PSI. The ball valve on the trailer was then closed and the bulk delivery truck operator started providing liquid CO₂ to the system. The trailer mounted CO₂ vaporizer operators opened the drain ball valve to ensure that liquid CO₂ was present, and then slowly opened the control valve as they closed the ball valve. The control valve was then manipulated to achieve the desired flow rates for a full 5 minute test, working up in flow rates. This test was continued until the highest desired flow rate was achieved.

The minimum operating pressure of the vaporizers was tested by maintaining the system at the maximum flow rate achievable and lowering the influent pressure by closing the pressure control valve in increments of 10 PSI. This was conducted until either a vaporizer pressure of 80 PSI was reached or a temperature after the regulator of less than -62°F, as these pressures or temperatures can indicate a risk for dry ice formation. Temperatures were measured using a Mastercraft Digital Temperature Reader (057-4544-4).

During all of the flow rate testing the influent and effluent temperatures were measured at the pipes using a Mastercraft Digital Temperature Reader (057-4544-4).

Results:

Table 2 outlines the flowrates achieved on the testing day, as well as the influent and effluent temperatures.

Table 2 – Flow rates and temperatures achievable by the system

Goal Flow Rate (CFM)	Measured Flow Rate (SCFH)	Inlet Pipe Temperature (°F)	Effluent Temperature (°F)	Ambient Temperature (°F)
67	4,020	3.2	51.8	82
110	6,600	-7.6	51.8	82
121	7,260	-4	86	82
313	18,780	-0.4	83.3	82
345	20,700	8.6	82.4	82
615	36,900	10.4	82.4	82

After the maximum flow rate testing, the influent pressure was reduced down to 91 PSI which resulted in a vaporizer pressure of 80 PSI. On the day of testing the regulator effluent temperatures were maintained at -25°F which is above the temperatures required for solid CO₂ formation.

The completed system was weighed after operation and it has a total weight of 4,550 lbs., meaning that the system is easily towed with a 3/4 ton truck. The equipment weight was distributed over the trailer to maintain an approximate tongue weight of 500 lbs. (11%), the operators delivering the system for testing said that it towed well. This meets the portability goal of the study.

The system was easily operated by personnel that had no prior experience. The SOP that was created was clear and there was very little learning curve required. Setup was simple, with the only requirements being to disconnect from the tow vehicle, ground the unit with the attached grounding spool, connect two (2) hoses, and have the bulk delivery truck operator connect the bulk delivery hose and any of their required grounding. This meets the goals of both ease of setup and operation as well as minimal operator training.

The trailer mounted CO₂ vaporizer system is self-contained and has only one (1) electrical component (flow and temperature meter) that is powered internally by the trailer battery. The battery is sufficient to operate the flow meter for more than a day and will recharge when connected to the tow vehicle for transportation. The only other components required are a bulk delivery truck and the depopulation chamber. There are no onsite resources required to operate the system, thereby meeting this goal.

Table 2 shows that the vaporizer is capable of providing the required flow of gaseous CO₂ for the “custom” depopulation chamber size, although this will need to be re-tested at cold ambient temperatures. This meets the 5-minute flow rates requirements.

The equipment is all exposed providing easy and quick cleaning and disinfection with most of the standard cleaning solutions (Table 1). This meets the “ease of cleaning and disinfection” goal.

Based on the equipment in the prototype, the systems can be built for \$75,000 USD each. This meets the cost goal.

Discussion:

During the testing it was determined that the trailer mounted CO₂ system could achieve the maximum desired flow rate of 615 CFM with an operating pressure of 190 PSI. This pressure is close to the setpoint of the pressure safety valve but is well within the pressure ratings of the equipment. This demonstrated that all of the desired flow rates were achievable at ambient temperatures of approximately 85°F.

During the temperature determination study (Table 2) the lower effluent temperatures from the first two flow rates (67 and 110 CFM) were attributed to additional cloud cover during these tests. This demonstrates the effect that ambient conditions have on the system and that effluent temperatures should be well monitored during calibration to ensure no undue stress is caused to the livestock during depopulation events.

The trailer mounted CO₂ vaporizer system was tested and achieved the required flow rates for all of the proposed depopulation chambers when ambient conditions were 80°F. The system was also capable of decreasing the pressure in the vaporizer, which gives a greater potential temperature range that it can be operated in, indicating that low temperature vaporization will be achievable. This does need to be verified at -30°F once the winter of 2021-2022 provides those ambient temperatures and further verification can be done.

When cost is one of the driving factors in system design, some flexibility must be maintained in operational goals. Given that the trailer mounted CO₂ vaporizer system is based on ambient temperature vaporization, there may be a risk that all flow rates are not achievable at low temperatures. Modelling conducted by both the vaporizer manufacturer and the prototype design team indicates the cold temperatures will not be an issue; however, this needs to be verified. The system should, therefore, be tested at the low temperature threshold of -30°F to see if the maximum design flow rate can be achieved. If this flow rate is not achievable at -30°F there may be a need to reduce the allowable depopulation chamber sizes at low ambient temperatures. If this is the case, the system should be tested at a range of ambient temperature to determine the maximum flow rate at each low ambient temperature until the maximum desired flow rate is achieved. This will provide a table of depopulation chamber sizes that can be used at various temperatures. This approach will allow for the trailer mounted CO₂ vaporizer system to be operated within the proposed temperature ranges, while limiting depopulation chamber sizes at lower ambient temperatures.

Based on this testing at high ambient temperatures (80°F), it was evident that the trailer mounted CO₂ vaporizer system was successful in delivering gaseous CO₂ to a variety of depopulation chambers. It was constructed and mounted on an 18 foot trailer that can be easily towed by a 3/4 ton pickup truck. The system utilizes an ambient air vaporizer, and all electronic equipment are powered by a self-contained system; there will be no requirement for additional power or fuel to operate the system. Liquid CO₂ will be required to

be delivered to the system from local suppliers, using bulk delivery vehicles that are then connected directly to the system. The prototype equipment procurement and construction process was also used to determine that multiple system could be purchased and deployed at a cost of \$75 000 USD each.

In all, all of the requirements for the design have been confirmed through this process, but the system will require further testing at cold ambient temperatures to ensure that all of the flow rates required for the various depopulation chambers can be achieved at lower temperatures. Should all of the flow rates not be achievable at lower ambient temperatures, the further testing will demonstrate the size limits of depopulation chamber based on low ambient temperatures.