Title: Mass depopulation of swine facilities via on-site generation of carbon monoxide – **NPB#21-072**

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Introduction

A foreign animal disease (FAD) outbreak would be truly devastating to all aspects of the US swine industry. African Swine Fever (ASF) is a highly contagious virus of paramount relevance that causes high morbidity and mortality (USDA APHIS, 2019). By February 2019, an estimated 45M pigs had been culled in China due to ASF with an economic loss of nearly \$8.5B (estimated at 100 kg hd^{-1} at 13.5 RMB kg^{-1}; Zhang et al., 2019). Comparatively, a FAD outbreak in the US could cost upwards of \$50B over 10 years (Carriquiry et al., 2020). While extreme prevention measures can be deployed and enforced, a confirmed ASF outbreak would force instant response to limit the viral spread. This will require mass pig depopulation, which must be performed humanely, timely and reliably, while simultaneously upholding personnel safety and limiting psychological impacts (AVMA, 2019). Depopulation needs to be done rapidly to limit the potential for disease spread as well as low cost, enabling a faster return to production, ultimately boosting the competitive advantage of US producers. Thoroughly considered, evidence-based strategies are needed for successful depopulation.

Approved methods to achieve mass depopulation goals are detailed in FAD PReP/NAHEMS (2015). The recent 2014-2015 Highly Pathogenic Avian Influenza (HPAI) outbreak demonstrated the need for alternative methods of rapid depopulation and the critical need for evidence-based, best management practices (Gingerich, 2015). If

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a FAD outbreak occurs, the depopulation approach must be rapidly implemented with the goal to decrease the amount of virus in the environment. Other depopulation methods can create delays, as was found during the HPAI outbreak, due to a lack of material, device availability (CO_2, foam, euthanasia devices, etc.) and high labor input needed to perform the depopulation. Delays in depopulation would increase the amount of virus shed over time, which would amplify total virus shed in the environment, and increase the probability of transmission to other herds. Gerritzen et al. (2006) describe the use of compressed CO for depopulation poultry in the Netherlands and targeted 1.5% to 2% (15,000 to 20,000 ppm) CO concentration inside a 35,000 bird barn. There was limited information presented on the gas source and flow, but results indicate 100% mortality and challenges associated with execution and mixing.

Carbon monoxide is a colorless, odorless gas that is primarily produced from the incomplete combustion of hydro-carbonaceous fuels, such as propane and gasoline. It is slightly less dense than air (air = 1.29; CO = 1.25; CO_2 = 1.98 kg m^{-3}) and is toxic to animals when exposed to concentrations greater than 35 ppm. It is highly toxic because CO binds to the site in hemoglobin, that would normally carry oxygen, to produce carboxyhemoglobin, thereby rendering hemoglobin ineffective for delivering oxygen to bodily tissues. For humans, symptoms are characterized by dizziness, nausea, fatigue, shortness of breath, loss of consciousness and death (Mayo Clinic, 2021). Each year, approximately 50,000 people in the US seek emergency medical care due to accidental CO poisoning from exposure to fumes from home furnaces, gas appliances, gas heaters, etc. (CDC, 2021). Accidental CO poisoning results in 350 to 500 deaths on an annual basis (CDC, 2021). The (2010) reports lethal concentration-time exposure levels for CO of 40,000 ppm for 2 min, 16,000 ppm for 5 min, 8,000 ppm for 10 min, 3,000 ppm for 30 min, and 1,500 ppm for 60 min. The desired CO concentration reported by Gerritzen et al. (2006) is ***five times greater*** than the lethal dose for humans after 30 mins of exposure. This strongly indicates poor distribution and mixing; thus, warranting further investigation. Also, with respect to pigs, literature is scarce on lethal concentrations and no such concentration-time relationship exists.

Carbon monoxide is produced industrially in US by a limited number of firms via partial oxidation of hydro-carbonaceous gases. Most industrially derived CO is used immediately downstream of manufacture for chemical synthesis (Wilbur et al., 2013). Carbon monoxide is considered a "chemical of concern" by the EPA and requires approval of any use application prior to purchase. Due to the liability associated with its use on-farm, it is unlikely that the sale of CO for depopulation would be approved without significant use restrictions and a lengthy approval timeline for individual end user. Onsite production of CO, in concert with strict safety protocols and necessary safety equipment (i.e., CO monitors) minimizes the liability associated with the use of CO for depopulation. Carbon monoxide can be produced by means other than the partial oxidation of hydrocarbons; however, these methods require specialized reactants and specific reaction conditions (i.e., temperature, etc.). In this proposal, we will use partial oxidation, that is, combustion under oxygen-limiting conditions of natural gas and liquid propane gas to produce CO with additional CO-enrichment by conversion of CO_2 in the combustion stream to CO with heated activated charcoal.

Specific objectives are:

1. Develop a CFD model to quantify dispersion of CO in a typical deep pit building that has been sealed to the extent practical under real-world conditions to determine time to reach lethal CO levels at animal-level throughout the building under differing environmental conditions.

Design, construct, and commission a turnkey, mobile platform for onsite production and dispersion of CO using liquid