Worker Health and Safety in Concentrated Animal Feeding Operations

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ABSTRACT. *A trend in consolidating livestock and poultry operations into concentrated animal feeding operations (CAFOs) potentially increases farm worker exposure to the hazards associated with high animal density conditions. The two main contributors of documented injury (fatal and non-fatal) are related to accidents with machinery and animals. Tractor rollovers are the leading accident in the area of farming machinery issues; kicks, bites, and workers being pinned between animals and fixed objects are non-machinery issues typically caused by inadequate precautions taken in the vicinity of livestock. These types of accidents are well documented; however, recommended safety strategies continue to be studied to reduce the risks and numbers of injuries associated with both machines and animals. Unlike accidents involving machinery and animals, air emission exposure and potential health effects from CAFOs are not well documented. CAFOs have the potential to show higher gaseous and particulate matter emissions compared to smaller farms. Pollutants like hydrogen sulfide, ammonia, volatile organic compounds, particulate matter, and endotoxin are emitted on CAFOs and can potentially affect worker health. These specific air emissions, their sources, and some of their harmful capabilities have been identified, and regulations have been implemented to create improved work environments on CAFOs. Despite such precautions, farm workers continue to report respiratory health symptoms related to their work environment. Air pollutant exposure and its health effects on farm workers require focused research to arrive at improved safety strategies that include mitigation techniques and protective gear to minimize adverse effects of working in CAFOs.*

Keywords. *Agriculture, Air pollutants, Concentrated animal feeding operations, Machinery safety, Occupational injuries, Protection, Respiratory health, Safety with animals.*

Concentrated animal feeding operations (CAFOs) make up only 5% of all livestock farms in the U.S. but raise approximately 54% of the nation's livestock (APHA, 2003; IATP, 2006). Because the U.S. follows a "cheap food policy," the demand for economic efficiency in animal production results in livestock and poultry facilities becoming larger and more concentrated. Consequently, the numbers of animal units per worker and the mechanization rate increase and management practices change (e.g., farrowing or finishing swine production), which might result in altered exposure to health risks for this industry's working population.

Although the work in CAFOs has not been reported to have introduced new disease or injury outcomes in workers, one can anticipate that the concentration of exposures and tasks enhance the probability of health problems. This article discusses the possible

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consequences of increased exposure to livestock waste and related air pollution, mechanization, and noise levels.

Livestock production requires tasks that include not only animal handling but also intensive use of machinery. The maintenance, transport, and processing of crops/feed require the use of machinery, as does maintaining cleanliness and effective waste management throughout the facility. Machine-related tasks spatially and temporarily overlap the contact with animals, specifically when moving, feeding, treating, and/or obtaining products from those animals. In addition, there is the potential for increased exposure to air pollutants that are resultant of the type of task performed. Working in the agricultural industry continues to rank among the most hazardous occupations in the U.S. (Layde et al., 1996; Osorio et al., 1998; May-Lambert et al., 1998; McCurdy and Carroll, 2000; Hendricks and Adekoya, 2001). The two main contributors to worker injury in farming operations are machinery- and animal-related accidents, which are documented as the leading sources of farm worker injury overall (Von Essen and McCurdy, 1998; Browning et al., 1999; McCurdy and Carroll, 2000; NASD, 2002a 2002b; Thomas and Buckmaster, 2003; NASD, 2005). Accidents with machines include tractor rollovers, being snagged and entangled into a rotating tractor mechanical shaft (so-called power take-off (PTO) driveline), being injected with industrial fluids under high pressure, being run over, and electrocution. Animal-related injuries involve workers being kicked, bitten, stepped on, or pinned between animals and a permanent object. These two main types of accidents have been documented and investigated thoroughly, but they may be expected to occur more frequently on CAFOs because of increased workload stresses. However, work on protection and prevention strategies to educate and train workers, as well as the development of protective gear and engineering solutions, are still at a nascent stage.

Aside from the hazards of machine- and animal-related injuries, increased air pollutant concentrations are a second area of potential major health effect of concentrating animals. Most of the air emissions that are harmful to human health arise from the handling of feed, movement of animals on manure, and the storage and removal of manure. CAFO air pollutants include hydrogen sulfide, ammonia, volatile organic compounds, particulate matter, and endotoxins. Because the composition of these emissions differs according to farm layouts, region, and species of animals housed, there is a large variability in emission rates and farm practices across all types of livestock operations. This variability makes it difficult to identify and correct implicated agricultural practices for the purpose of improving the health of farm workers.

The present review focuses on accidental injury and air pollution as the areas of major concern to the health and safety of farm workers as the nation's livestock farms converge into CAFOs.

Concentrated Animal Feeding Operations

There are approximately 238,000 animal feeding operations nationwide, producing 575 million tons of manure each year (Federal Register, 2003). Since 1960, there has been a 59% reduction in cattle operations, a 94% reduction in dairy operations, and a 95% reduction in hog farms in the U.S. (Centner, 2003). Concomitantly, there has been a consistent and increasing growth in the number of CAFO operations since the early 1980s (table 1).

The current U.S. EPA definition of a CAFO (EPA, 2006a) is an animal feeding operation where livestock are confined and fed for at least 45 days per year. The EPA uses the definition of number and type of animals reported in table 2 (large CAFOs). A second definition includes smaller operations also listed in table 2 (small and medium CAFOs),

Table 1. Change in CAFO operations from 1982 to 1997 (source: EPA, 2004).

Animal Type	Size Class (animals/CAFO)[a]	1982 (CAFOs)	1997 (CAFOs)	Percent Change (CAFOs)
Milk cows	300-999	3,385	4,534	+34
	>1,000	456	1,303	+186
Other beef and dairy	150-299	34,370	36,421	+6
	300-999	16,827	19,541	+16
	>1,000	2,524	3,008	+19
Swine	150-299	4,730	5,726	+21
	300-999	1,432	4,134	+189
	>1,000	103	1,011	+882
Poultry	150-299	3,175	6,129	+93
	300-999	1,786	3,312	+85
	>1,000	362	688	+90

[a] All smaller size classes decreased in number.

Table 2. Animal distribution for CAFO size (source: EPA NPDES, 2006).

	Size Thresholds (animals/CAFO)		
Animal Sector	Small CAFOs	Medium CAFOs	Large CAFOs
Cattle or cow/calf pairs	less than 300	300 - 999	1,000 or more
Mature dairy cattle	less than 200	200 - 699	700 or more
Veal calves	less than 300	300 - 999	1,000 or more
Swine (weighing over 55 lbs)	less than 750	750 - 2,499	2,500 or more
Swine (weighing less than 55 lbs)	less than 3,000	3,000 - 9,999	10,000 or more
Sheep or lambs	less than 3,000	3,000 - 9,999	10,000 or more
Turkeys	less than 16,500	16,500 - 54,999	55,000 or more
Laying hens or broilers (liquid manure handling systems)	less than 9,000	9,000 - 29,999	30,000 or more
Chickens other than laying hens (other than liquid manure handling systems)	less than 37,500	37,500 - 124,999	125,000 or more
Laying hens (other than a liquid manure handling systems)	less than 25,000	25,000 - 81,999	82,000 or more

due to their discharge of pollutants into navigable waters, but again this definition requires that livestock be confined and fed for at least 45 days per year. We would expect different exposure concentrations to be experienced by the worker in each of these confinement categories, with increasing specialization and degree of concentration from small to large CAFOs. The focus of this article will be on issues related to large CAFOs, which are increasing in number throughout the industry.

It is economically beneficial for farmers to concentrate animals from smaller operations into large CAFOs. CAFOs consolidate numbers of facilities, operators, expertise, and equipment, thus reducing production costs (Centner, 2003). For this reason, large animal farm units have the potential to be more cost and operationally efficient than many small farm units (EPA, 2004). The number of animals per facility can range from 200 to 125,000 animal units (table 2) depending on animal species. Nationwide, CAFOs alone produce 288 million tons of manure annually (APHA, 2003; IATP, 2006), which leads to manure disposal issues. It therefore becomes imperative to investigate the potential exposure impacts of emissions from animal waste, to identify vulnerable worker groups, and to identify mitigation options.

Worker Demographics

Concurrent with increasing CAFO size is a trend toward increasing number of animals per farm worker, with an overall decrease in worker numbers per operation. The USDA-NASS (2006a, 2006b) reports annual U.S. demographics for farm worker populations, as well as animal inventory of all farms and ranches. Between 2000 and 2005, there was a 12% decrease in the number of workers employed on U.S. livestock farms (952,000 vs. 840,000, respectively). During the same period, national livestock animal inventories increased by 3% (600 million to 619 million animals for 2000 vs. 2005, respectively). An increase in animal units per worker may lead to greater work and exposure risks.

The U.S. Department of Labor (USDOL, 2006) surveyed all types of farm workers over the age of 14 years between 1994 and 1995. Farm workers were young overall, with two-thirds of these workers under the age of 35, and more than one-fourth 21 years old or younger. A total of 15% of the farm workforce worked past the age of 44 years, and only 6% worked past 55 years of age. Figure 1 provides the average ages of farm workers in the U.S.

The USDOL (2006) stated that approximately 70% of all farm workers were foreign-born (of which 94% were born in Mexico), and 30% were U.S.-born. Among the U.S.-born population, 59% were non-Hispanic whites, 32% were Hispanic, 8% were African American, and 1% were from other ethnic groups. A comparison of ethnicity and place of birth for farm workers is shown in figure 2.

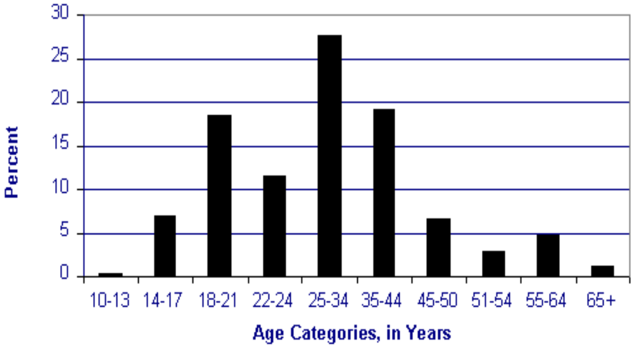

Figure 1. Farm worker distribution across age categories (source: USDOL, 2006).

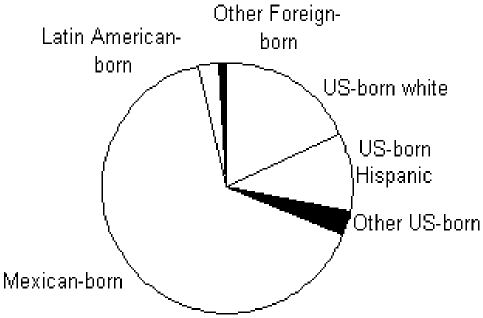

Figure 2. Farm worker ethnicity and place of birth (source: USDOL, 2006).

Foreign-born workers who are increasingly less likely to migrate on a yearly basis dominate the current agricultural work force. Most are unable to read or speak English, have low levels of education, and have family incomes below the poverty level. They lack access to many basic health care services (Mobed et al., 1992; Schenker, 1998) and are susceptible to injury because of lack of communication or educational skills as well as long work hours (Khan et al., 2003; Maloney and Grusenmeyer, 2005).

Health and Safety

An average of 21.3 fatalities occur per 100,000 U.S. farm workers annually, making agriculture the second most dangerous occupation behind mining (NSC, 2002). In 1995, the National Institute for Occupational Safety and Health (NIOSH) documented the numbers and rates of injuries among farm workers in the nation. An injury, as defined by epidemiologists, is "physical damage occurring to an individual due to an acute exposure to energy levels outside the normal tolerance bands for human tissue," and requirements of injuries can include medical attention, lost time from work, restriction from work or school, or loss of consciousness (McCurdy and Carroll, 2000).

It was reported that 196,000 lost-time work injuries occurred on U.S. farms, with the greatest number of injuries occurring at beef, hog, and sheep operations (43.3% of all farms) (table 3). The leading causes of lost-time work were from machinery (21.3%) and livestock injuries (20%). McCurdy and Carroll (2000) reported a range of machinery-related injuries of 18% to 35% of all cases, and for animal-related injuries a range of 12% to 33% of all cases. Generally, agricultural survey-based studies identified machinery as the leading source of injury, while other studies investigated in operations with high animal numbers (such as in CAFOs) identified inadequate precautions taken around animals as the leading source of injury (Miller et al., 2004).

Farm workers are considered a vulnerable population because of the hazards present in their workplace. They endure twice as many work-related injuries and are six times more likely to suffer fatal injuries than the average American worker (NSC, 2002).

Safety around work with machines and animals is an important workforce concern. However, because machinery- and animal-related accidents have been well reported in the literature, they will be discussed briefly here. The harmful effects of air pollutants emerging from CAFOs will be discussed in greater detail.

Machinery Safety

Today, farm machinery is considered the leading cause of injury and death on farms (Layde et al., 1996; NASD, 2002a, 2002b; NSC, 2002). Increasing mechanization of farms over time has been associated with increased rates of injury and fatality. Although

Table 3. National estimates of lost-time injuries by farm type, 1995 (source: NIOSH, 1995).

Farm Type	Frequency	Percent	Rates per 200,000 Hours Worked
Cash grains	33480.8	17.1	7.6
Field crops	12403.6	6.3	5.8
Vegetable, fruit, nuts	21406.0	10.9	3.8
Nursery	15260.9	7.8	7.3
Beef, hogs, sheep	84735.5	43.3	10.2
Poultry	2903.4	1.5	4.0
Dairy	17122.2	8.7	4.4
Other farms	8512.2	4.3	5.6

there is a paucity of documented machinery injuries from CAFOs, similar machines are used on both CAFOs and crop farms

On newer CAFOs built specifically to house livestock for specialized sector markets, facilities are highly mechanized with electronic monitors, and injury rates and types are not yet well documented. With fewer workers per animal unit, and more machinery in use, it could be argued that there is increased potential for injury. On the other hand, newer equipment may be safer. Older CAFOs and those operations modified to increase animal numbers and density will more likely exhibit injury rates closer to traditional livestock farms. In the past, farm vehicle accidents, and more specifically tractors, have been the largest contributors to fatal injuries (Myers and Snyder, 1995; May-Lambert et al., 1998; Browning et al., 1999). The National Safety Council (NSC, 1995, 1997, 2002) reported that an overall tractor fatality rate of 8.2 deaths occurred per 100,000 tractors, with 2,191 deaths resulting from rollovers in an 11-year period (this is on all farms, not just livestock operations).

In 1985, rollover protection (ROPS) became standard (following voluntary ASAE Standard S318) on new tractors. Furthermore, all modern tractors include seat belts, power take-off shields (required on new tractors since 1977; Maher, 1997), and enclosed cabs, which greatly reduce injury risk when used correctly (www.cdc.gov/mmwr/preview/mmwrhtml/00049301.htm). Older, unmodified tractors without these protections still pose major injury risks on farms without the economic ability to upgrade or modify existing equipment (Myers and Snyder, 1995; Browning et al., 1999). Currently, it is estimated that more than half of the approximately 4.7 million tractors used on U.S. farms still do not have ROPS (Reynolds, 2006). Although the larger and newer CAFO facilities are likely to be able to replace older tractors, this may not be true of the smaller categories of CAFOs.

Tractor power take-off (PTO) drivelines are another hazard to farm workers. Without a workable shield, workers risk entanglement of hair or clothing, which is often fatal as the shaft rotates 9 to 17 times per second (Thomas and Buckmaster, 2003). In addition, PTO drivelines attached to equipment (e.g., augers, elevators, post-hole diggers, and grain mixers) cause about 50% of PTO-related injuries (Schwab et al., 2000; Ingram, et al., 2003; Freeman et al., 2003; Harshman et al., 2004).

Additional forms of vehicle-related injury include being run over or pinned by tractors, front loaders, fork lifts, etc. (McCurdy and Carroll, 2000). Other machinery-related devices found to cause work injuries include electrocution (Von Essen and McCurdy, 1998) and high-pressure injection from devices like grease guns, paint guns, and diesel engine injectors (Thomas and Buckmaster, 2003). Power washers are high-pressure spraying tools used to clean housing structures for animals on farms and have also been reported to cause injuries and fatalities (CDC, 1993; NASD, 1993; CDC, 1995). Risks associated with power washers on farms include serious wounds from the spray (leading to infection or amputation if not treated), striking objects that may injure others close by, electric shock, and carbon monoxide poisoning (CDC, 2006). The risk of carbon monoxide poisoning from the exhaust of gas-powered pressure washers is greatly increased inside buildings. Since carbon monoxide gas intake can vary among people, the level of carbon monoxide poisoning can result from the combination of several environmental factors: the air concentration of the work area, the level of exertion and ventilation rate, and the duration of exposure (CDC, 1995). It is important to note that although carbon monoxide is potent, a passive ventilation rate (vs. active ventilation rate) would be very hazardous when inhaling this asphyxiant. Therefore, improved ventilation in indoor facilities can reduce the risk of carbon monoxide exposure (CDC, 1995) if gasoline-powered power washers are being used. If the machines cannot be placed outside with hoses running into the building, then the exhaust fumes should be vented to the outdoors to prevent CO poisoning (CDC, 1995).

It must be noted that the actual injury rate on CAFOs has not been studied in comparison to less intensive operations. Purpose-built livestock facilities (e.g., finishing pig buildings) may actually demonstrate a decrease in injury rates for specific, specialized tasks that are highly mechanized and electronically controlled. Instead, the worker may now be at higher risk of musculoskeletal problems due to repetitive motion or awkward posture, or noise-related hearing loss.

Safety with Animals

Work at CAFOs involves the interacting, restraining, sorting, and loading of animals. Documentation of injuries or fatalities from animal handling specifically on CAFOs does not exist; however, CAFO workers deal with the same hazards as small livestock farms when handling similar animals and may have an even higher risk for injury because they work with a larger number of those animals. On the other hand, it is also possible that newer CAFOs' livestock facilities may encourage a decrease in injury rates for specific, specialized tasks, such as milking, where although there are more livestock units, the interface between animal and human may be reduced with modern facilities and machinery. In the absence of studies on CAFOs, the following findings are used to describe the animal sources of injury reported on animal feeding operations in general.

Close handling of animals makes farm workers vulnerable to animal-related accidents, causing injuries or in some cases fatalities. Milkers on dairies spending more than 30 hours per week interacting with cows can have up to a 20-fold increased risk for injury (Boyle, et al., 1997). Roughly one out of four injuries on farm operations involve animals, and such injuries include animals stepping on handlers, animals slipping and falling on handlers, animals biting or kicking handlers, and animals squeezing or pinning handlers against a permanent object (NASD, 2002a, 2005). Animal-related injuries can lead to considerable loss of money, time, and productivity (NASD, 2002b).

Iowa's Department of Public Health reported more than 500 animal-related accidents, and found animals to be the leading cause of farm injuries in 1995 (NASD, 2002a). In central Wisconsin, 71 animal-related injuries were identified from a farm worker population of 3,186 adults over the age of 18 years (Layde et al., 1996). Utah studies show that animals were the primary source of injuries, with horse injuries accounting for 42.3% and cattle injuries accounting for 7.7% (Miller et al., 2004). Studies in Vermont demonstrated that a large proportion of injuries involved cattle, with one-third of all injuries occurring in dairy barns and 5% occurring to youth under 15 years of age (Hendricks and Adekoya, 2001).

NIOSH (1995) estimated that 105,000 lost-time injuries occurred annually in livestock and poultry operations in the U.S. Of those injuries, 65,000 occurred from livestock handling, and 10,000 resulted in permanent disability. Lost-time injuries mostly involved impairment to the leg, hip, and knee, followed by the arms, shoulders, and fingers. It is imperative to train farm workers in the proper care and handling of livestock species for injury prevention purposes. Furthermore, facilities require careful design planning and investment in appropriate restraint gear, not only for the safety of farm workers and animals but also for efficiency of animal handling and production.

Other Occupational Health Issues

Workers on CAFOs may also be at higher risk for noise and musculoskeletal problems. The average as well as acute noise level is likely to increase concomitantly with animal number and density, especially in enclosed spaces. The increased occupational noise burden has only recently been studied in detail. Humann et al. (2005) found in a swine confinement facility that all dosimeter assessments of workers exceeded the 85 dBA NIOSH recommended exposure limit (REL) (ISO, 1999). If unprotected, this would put workers at increased risk of developing noise-induced hearing loss over time.

The noise level can be generated by a combination of mechanical and animal sources. Mechanical causes on farms include fans, auto-feeders, power washers, vacuum pumps, tractors without cabs, chainsaws, augers, workshop tools, harvesters, bulldozers, and vehicle engines. Animal sources include the increase in noise level at feeding time, which is especially noisy in swine production, and other activities, such as heat checking and testicle removal (Beckett, et al., 2000; Depczynski et al., 2005; Humann et al., 2005). Possible solutions include engineering controls, earplugs, or modification of work practices, e.g., rotating employees who perform the tasks that generate the most noise, or mechanical feeding where possible (Humann et al., 2005).

Musculoskeletal disorders (MSD) are common in labor-intensive agriculture (Davis and Kotowski, 2007), and at least two studies have confirmed an increased risk for workers on larger dairy and pig farms (Thelin et al., 2004; Kolstrup et al., 2006). A Swedish study found that 86% of the dairy workers and 78% of the pig workers reported at least one musculoskeletal disorder in the previous 12 months. The most common symptom was pain in the upper extremities, especially the shoulders and the lower back, with short stature, repetitive work, working in awkward positions, and being exposed to dust as risk factors for MSD (Kolstrup et al., 2006). A case-control study found increased risk of osteoarthritis of the hip in “larger” dairy and swine barns, as compared to operations with larger acreage (less dense livestock production) or without livestock (Thelin et al., 2004). However, the size of the facilities was not large in comparison to most U.S. CAFOs. Ergonomic studies of CAFO production methods are needed for evaluation of the problems and intervention, as the proportion of the workforce affected is so large (Meyers et al., 1995).

Air Pollutants

The air-emission exposure of workers in the U.S. has been characterized for swine, poultry, and cattle operations, and the presence of approximately 150 potentially toxic gases has been documented to arise from the management of animals, feed, and manure. Exposures to pollutants are associated with inducing cellular and immunological responses that result in respiratory diseases (Omland, 2002). In many cases, mitigation of emission of one pollutant compound might bring about the emission of another (Amon et al., 2001). While the effects of air pollutants have not been documented from CAFO sources, common air pollutants found on CAFOs and their exposures will be discussed in this section, followed by their effects on worker health.

Description and Exposure of Air Pollutants

Hydrogen Sulfide (H_2S)

Hydrogen sulfide is a colorless gas that has cyanide-like properties, which inhibit mechanisms in the oxidative phosphorylation and aerobic metabolism of the cytochrome oxidase systems in cells, causing oxygen deprivation or asphyxia (Gerasimon et al., 2007). Its production occurs anaerobically in CAFOs through the presence of bacteria that can decompose sulfur-containing organic matter found in manure and reduce sulfate in feed and water (Arogo et al., 2000; NRC, 2002). Mineralization transformation of organic compounds containing sulfur is the primary route of hydrogen sulfide formation (Clanton and Schmidt, 2000).

Manure stored in anaerobic lagoons or storage pits typically causes hydrogen sulfide production and emissions (Xue and Chen, 1999). Arogo et al. (2000) determined that in swine confinement operations manure storage pits are stratified and can produce different rates of hydrogen sulfide throughout the depth of the pit. The authors demonstrated that hydrogen sulfide concentrations are highest during the first five to ten days of storage for liquid swine manure. The settling of manure into storage pits, where solid content increased progressively with depth, also affected hydrogen sulfide production. Although sulfide production was higher in the top layers of the pit, low pH levels in the bottom layers caused greater molecular concentrations of H_2S and a greater potential for H_2S release than in the top layers. Arogo et al. (2000) concluded that maintaining a pH >7 in the surface liquid of the pit would reduce H_2S release because manure with a lower pH and higher manure solid content would result in higher H_2S production. Initial sulfate concentrations influenced hydrogen sulfide production positively, and thus hydrogen sulfide emissions can be controlled if sulfate concentrations are minimized in manure storage. Current studies are identifying and using sulfate-reducing bacteria in acid mine drainages and stored livestock manure to minimize the levels of sulfate and reduce microbial H_2S emissions (Tsukamoto and Miller, 1999; Pikuta et al., 2000; Cook et al., 2004a; Cook et al., 2004b).

Ammonia (NH_3)

Symbiotic bacteria have developed metabolic mechanisms to fix nitrogen gas (Galloway and Cowling, 2002) and break down digestible proteins (Bussink and Oenema, 1998), producing biologically active reduced forms of nitrogen, such as ammonia. Emissions of reactive nitrogen take part in a series of processes called the "nitrogen cascade," whereby ammonia is emitted when the nitrogen in animal urine and feces is mineralized, hydrolyzed, and volatilized (NRC, 2002; Omland, 2002).

Nitrogen is mainly excreted as urea in urine and as organic nitrogen in feces; however, urea is more rapidly converted to ammonia because of its high potential for volatilization (Bussink and Oenema, 1998; Kulling et al., 2001). In ruminants, the major source of ammonia emission arises from hydrolysis of urea in urine (Bussink and Oenema, 1998; Swensson, 2003). Microorganisms secrete enzymes in the rumen that degrade digestible proteins to ammonia, and use this ammonia to synthesize new proteins or transform it to urea that is excreted in urine (Bussink and Oenema, 1998).

Crook et al. (1991) found that levels of airborne contaminants like ammonia were higher in swine facilities during the fall and winter seasons, when less ventilation was provided and temperatures were higher within confined structures. Thus, concentrations vary according to environmental conditions. Ammonia emissions require several factors for release into the environment, including air speed, ventilation rate, temperature, water content in manure, type of manure, areas exposed with manure, storage time, spreading technique of manure, types of feeds, and feeding routine (Frank et al., 2002). Approximately 20 teragrams (Tg) of ammonia per year are emitted to the atmosphere by CAFOs, potentially causing respiratory effects and decreasing pulmonary function in exposed workers (NRC, 2002). Local atmospheric concentrations of ammonia in areas where animal populations are dense have been reported to range between 0.28 to 88 ppm (ATSDR, 2004). NIOSH recommends that the time-weighted average of ammonia exposure for up to a 10-hour workday during a 40-hour work week should not exceed 25 ppm, while the Occupational Safety and Health Administration (OSHA) follows a permissible exposure limit of 50 ppm during any 8-hour work shift of a 40-hour work week (NIOSH, 2005; OSHA, 2006a).

Volatile Organic Compounds (VOCs)

Volatile organic compounds are defined as any compound of carbon that participates in atmospheric photochemical reactions (CARB, 2004). The definition goes on to exclude several compounds, including methane and chlorofluorocarbons (CFCs). Volatile organic compounds include a wide array of chemicals emitted as gases from certain solids or liquids. These gases vary in toxicity levels, and their impact ranges from short- to long-term health effects (EPA IAQ, 2006). Air samples from North Carolina swine facilities have revealed 331 VOCs, of which 157 are known as airway irritants (IATP, 2004). VOCs are also precursors to particulate matter ($PM_{2.5}$) formation, which is harmful to worker and public health (NRC, 2002).

Particulate Matter (PM)

Particulate matter has a broad size scale and a composition that consists of very small solid and liquid particles suspended in the air (CARB, 2003). In 1987, the EPA specified the maximal ambient levels allowable in a 24-hour period for inhalable particulate matter with an aerodynamic diameter less than or equal to 10 μm (PM_{10}) (Li et al., 1997; Harrison, 1999; Samet et al., 2000; Dockery, 2001; Alexis et al., 2002; EPA, 2004). In 1997, the EPA implemented new standards for fine respirable particulate matter that is less than or equal to 2.5 μm in diameter ($PM_{2.5}$) (Harrison, 1999; Dockery, 2001; Alexis et al., 2002; EPA, 2004). This regulation is critical in that it covers the size of components that can penetrate the airways and alveoli of the lungs, potentially causing harm to human health (Samet et al., 2000; Alexis et al., 2002). In December 2006, the EPA revised the national ambient air quality standards for PM to increase the protection of public health and welfare (EPA, 2006b; Rom and Samet, 2006). The revisions revoked the previous standard, which was 50 $\mu g\ m^{-3}$, as the EPA claimed that there was not sufficient evidence to show a connection between health effects and long-term exposure to PM_{10}. In contrast, the $PM_{2.5}$ 24-hour standard was reduced from 65 to 35 $\mu g\ m^{-3}$ to better protect against health effects related to short-term exposure. These changes, however, have elicited great debate by the American Thoracic Society and other health organizations, which declare for more stringent standards (Rom and Samet, 2006). They recommend that the average 24-hour $PM_{2.5}$ standards be 25 $\mu g\ m^{-3}$ and that average annual $PM_{2.5}$ standards be 12 $\mu g\ m^{-3}$. The current national PM standards are shown in table 4.

The components of PM in CAFOs include soil particles, bedding materials, fecal matter, litter, and feed, as well as bacteria, fungi, and viruses (EPA, 2004). Bioaerosols are defined by the EPA (2004) as particles of biological origin that are suspended in the air. They are documented as the main contributors of PM in CAFOs because of the feed, fecal, and bedding material used. PM from all sources are often found in concentrations in excess of the air quality standards, and even above the suggested maximum levels of air pollutants in animal confinement facilities (Donham, 1991; Kullman et al., 1998; Iowa Study Group, 2002). Ammonia can also react with oxides of nitrogen to form fine PM (Morawska et al., 2004). Animal confinement facilities have been shown to generate particles smaller than 3 μm in greater numbers than larger particles (Lee et al., 2006).

Table 4. National air quality standards for particulate matter (source: EPA, 2006b).

Particle Size	Standard ($\mu g\ m^{-3}$)	Averaging Period
PM_{10}	Revoked	1 year
	150	24 hours
$PM_{2.5}$	15	1 year
	35	24 hours

Dusts originating from the soil or crops tend to have a different distribution of particle size, with more coarse particles.

Endotoxin

Endotoxins are heat-stable protein complexes composed of lipopolysaccharides (LPS) and are a component of the outer membrane of gram-negative bacteria (Kullman et al., 1998; Kline et al., 1999; Omland, 2002; Mueller-Anneling et al., 2004; Heederik et al., 2006; Kujundzic et al., 2006; Madsen, 2006; Schulze et al., 2006). They are liberated during cell lysis and are associated with the development and progression of respiratory diseases in agricultural workers (Kullman et al., 1998; Kline et al., 1999; Mueller-Anneling et al., 2004; Heederik et al., 2006; Madsen, 2006; Schulze et al., 2006). Endotoxin is found where organic dust is produced and distributed into the air by animal or human activities (Kirkhorn and Garry, 2000). Animal feces and bacterial-contaminated plants are the major contributors to endotoxin-contaminated organic dust (Schenker, 1998), largely affecting workers exposed to agricultural environments (Radon, 2006). Kujundzic et al. (2006) also demonstrated that determining endotoxin toxicity and health effects requires establishing an approximate aerodynamic particle distribution for airborne endotoxin. They reported that airborne endotoxin is associated with airborne PM greater than 1 μm.

Inactivation of the ability of endotoxin to stimulate the immune system only occurs at extremely high temperatures (160° for 4 hours); therefore, endotoxin has the potential to provoke a harmful response as it accumulates in a facility, only diminishing with its physical removal or by ventilation. In contrast, live bacteria are viable and potent for a much shorter period (Radon, 2006).

Effects of Pollutants on Worker Health

CAFO airborne exposures are complex mixtures of gases and PM, including allergens, microorganisms, antibiotics, and pulmonary irritants. The interactions of these mixtures are poorly understood and will vary from facility to facility depending on the type of livestock, the animals' stage of life (in specialized operations), and individual management practices. The following section summarizes information known about individual air pollutants, acknowledging that effects can be additive and synergistic.

Hydrogen Sulfide (H_2S)

Recommendations issued by NIOSH (1997) suggest that exposure to hydrogen sulfide not exceed 10 ppm for up to a 10-hour work shift in a 40-hour work week. OSHA permits a general industry ceiling concentration of 20 ppm for 15 minutes, or a maximum allowable peak of 50 ppm for 10 minutes (OSHA, 2006b). Areas with hydrogen sulfide concentrations higher than 50 ppm should be immediately evacuated. H_2S has a low odor onset, with the characteristic "rotten egg" smell present at 0.13 ppm, and no odor detected at levels over 150 ppm (Kirkhorn and Garry, 2000). Employers must keep exposures to hydrogen sulfide below the prescribed limits by using engineering controls and safe work practices.

Exposure to H_2S may not present significant risks as an irritant to the lungs at ambient concentrations measured in livestock facilities, but it can pose serious health effects and even sudden death if experienced under anaerobic conditions (Omland, 2002). Schenker (1998) described numerous reports of fatalities in liquid swine manure agitation (in storage facilities) where hydrogen sulfide concentrations measured between 150 and 1000 ppm. The author also described measurements of chicken manure slurry at concentrations of 200 ppm, and cattle manure storage facilities with concentrations between 60 and 500 ppm. Kirkhorn and Garry (2000) reported that the agitation of manure in manure pits could release concentrations of H_2S up to 1,000 ppm in areas where workers and animals breathe. Within a few seconds of manure agitation, H_2S levels can rise from 5 ppm to more than 500 ppm, and because H_2S accumulates above the liquid level of manure in manure pits, workers can quickly be affected by the gas when doing maintenance or taking a manure sample (NASD, 2002c). Case studies indicate that farm workers are at high risk for chemical toxicity and death pertaining to manure pits and the high levels of H_2S associated with them (Morse and Woodbury, 1981; MMWR, 1993; NIOSH FACE, 2005).

Ammonia (NH_3)

The ATSDR (2004) has documented the toxic effects of ammonia emissions. When ammonia dissolves in the water present in tissue, the effects include necrosis of cells, inflammatory responses, and other tissue damage. Ammonia may also affect the respiratory tract by causing significant airway obstruction by damaging the cilia and the mucosal barrier to infection. Potential outcomes include secretions, edema, and reactive smooth muscle contraction. Respiratory symptoms can include inflammation, shortness of breath, wheezing, coughing, bronchial reactivity/hyperresponsiveness, and/or a decrease in pulmonary function. Reynolds et al. (1996) demonstrated that ammonia can irritate airways by adsorbing onto respirable particulate. Consequently, farm workers who raise livestock and poultry are at risk for these effects when they work with or apply ammonia-containing fertilizers to fields (ATSDR, 2004).

Volatile Organic Compounds (VOCs)

Health effects from exposure to VOCs include headaches; nausea; loss of coordination; eye, nose, and throat irritation; and damage to the liver, kidney, and central nervous system (EPA IAQ, 2006). The NRC (2002) states that some VOCs may irritate the skin, eye, nose, throat, and mucous membranes on contact if inhaled. Exposure to VOC pollutants can also have additive effects and cause airway irritation when individual VOCs are combined (IATP, 2004). Other VOCs are carcinogenic or can cause central nervous system disorders (such as drowsiness and stupor) at high levels of exposure (NRC, 2002). Because CAFO workers are exposed to a complex mix of gases and particles, they are more likely to experience synergistic effects of VOCs and other pollutants (e.g., ammonia and PM) than from exposure to VOCs alone.

Particulate Matter (PM)

The size of PM that is of greatest concern to worker health is that which is small enough to be inhaled into the lung, i.e., less than 10 μm in diameter (PM_{10} and $PM_{2.5}$) (CARB, 2003). PM_{10} contains both coarse and fine particles that are described as thoracic and respirable particles, while $PM_{2.5}$ is a smaller particle size capable of penetrating the alveolar regions of the lungs (Harrison, 1999) and is thought to be the most injurious to human health (Derwent, 1999).

Numerous studies have shown that elevated ambient PM is associated with increased morbidity and mortality (Burnett et al., 2000; Morris, 2001; Hoek et al., 2001; Dominici et al., 2003). PM is implicated in the onset of asthma, bronchitis, and chronic obstructive pulmonary disease, as well as the development of pneumonia (Li et al., 1997; Imrich et al., 1999; Imrich et al., 2000; Soukup and Becker, 2001).

Fine (particles 2.5 μm or less) PM pollution is associated with increased heart rate, decreased heart rate variability, and increased cardiac arrhythmias (Monn and Becker, 1999; Samet et al., 2000; Dockery, 2001). Particulate matter is linked to heart disease by the direct effects on the cardiovascular system, blood, and lung receptors, as well as indirectly by initiation of pulmonary oxidative stress and inflammatory responses (Brook et al., 2004). There are significant short- and long-term health effects on the cardiovascular system from PM exposure. A PM analysis of 90 U.S. cities reported associations between mortality and long-term $PM_{2.5}$ pollution in cases not confounded by weather and independent of other co-pollutants (Samet et al., 2000; Dockery, 2001). In addition, an extended eight-year follow-up on the same study showed that there was a significant and consistently positive association between $PM_{2.5}$ and total mortality, cardiovascular mortality, and lung cancer mortality (Laden et al., 2006).

Long-term health effects studies have shown that lasting exposure of $PM_{2.5}$ is associated with overall cardiovascular mortality (Pope et al., 2004) and with increases in all-cause, cardiopulmonary, and lung cancer mortality (Pope et al., 2002) for every 10 $\mu g\ m^{-3}$ increase in $PM_{2.5}$ annual concentrations. Reduced levels of fine PM were also associated with reduced mortality risk in these updated findings.

In concentrated animal operations, organic dusts (particulate matter of biologic origin) are by nature very heterogeneous and may contain inorganic components. Examples are animal feed, microorganisms, allergens, toxins, animal dander, urine, and feces (Schenker, 1998). Using personal monitors, concentrations of inhalable dust may be found to exceed 10 mg m^{-3}. OSHA has a non-specific dust standard of 15 mg m^{-3} for total particulates that are not otherwise regulated, and 5 mg m^{-3} for respirable dust (approx. 4 μm aerodynamic diameter and smaller; NIOSH, 1994). The level at which acute effects are felt in humans is thought to be around 2.4 mg m^{-3} (IOWA Study Group, 2002), and the level would be lower for chronic effects.

The forced expiratory volume in one second, known as FEV_1, represents the standard measure of pulmonary function and is often linked with PM exposure. Pulmonary function decreases with obstructive lung disease, and such decreases have been linked to agricultural dust exposures (Reynolds et al., 1996; Iversen et al., 2000). Decreased FEV_1 has often been observed in animal confinement facilities and in CAFO workers. Iversen and Dahl (2000) demonstrated that over a longitudinal seven-year exposure and health study, the loss of FEV_1 was higher for pig farmers than for dairy farmers. Reynolds et al. (1996) also found that the degree of decrease in FEV_1 corresponds to a dose-response relationship of personal exposure to airborne endotoxin and ammonia in dust. This agrees with similar findings by Vogelzang et al. (1998), who found an association between decreased FEV_1 and long-term exposure to endotoxin. Acute bronchitis may occur in up to 70% of swine CAFO workers, and as many as 25% were shown to have developed chronic bronchitis in a study conducted by Donham (2000). As reviewed by Kirkhorn and Schenker (2002), chronic cough, chronic phlegm, and persistent wheeze have been observed in CAFO workers and in a dose-response fashion with PM. These problems are likely to be exacerbated if the CAFO worker smokes. There is potential for a synergistic effect of elevated PM exposure and tobacco use in the way that smoking in asbestos workers increased the prevalence of pulmonary fibrosis (Kilburn et al., 1986). In 2000, approximately 25% of all farm workers in the U.S. smoked (NHIS, 2000; Senthilselvan, 2007), and in dusty environments, a synergistic effect has been noted with respect to occupational lung disease (Lee et al., 2007).

Specific Components of Particulate Matter

Microorganisms are present in CAFO air in high concentrations, including viable bacteria, molds, antigens, glucans, endotoxins, and antibiotics (Kiekhaefer et al., 1995). Many viable gram-positive bacteria are aerosolized, such as coliform bacteria and other human pathogens. For example, inhalation of thermophilic bacteria and actinomycete spores can cause a very serious allergic reaction called hypersensitivity pneumonitis, or farmer's lung (Schenker, 1998). Microorganisms including molds, predominantly *Cladosporium*, *Alternaria*, *Penicillium*, and *Fusarium*, have been identified in CAFOs (Kiekhaefer et al., 1995). Other allergens can be abundant in CAFO air and include grain dust and pollen, animal dander, dust mites, and fecal particles, which may cause or exacerbate atopic asthma in susceptible individuals (Schenker, 1998). Recent research has challenged the prevailing assumption that exposure to bioaerosols increases the risk of all types of respiratory illness (Douwes et al., 2002; Heederik and Sigsgaard, 2005). Early life exposure to bioallergens appears to reduce the incidence of atopy and atopic asthma; conversely, similar exposures as an adult may increase the risk of non-atopic asthma (Madsen, 2006; Schulze et al., 2006). In a study of Norwegian farmers, although the rate of asthma was less than in the non-farmers, 80% of the asthma was non-atopic (Eduard et al., 2004). However, further analysis indicated asthma was increased specifically in cattle and pig farmers, and non-atopic asthma increased in pig farmers and farmers with two or more types of livestock. Non-atopic asthma is thought to be more irritant-based from exposures to chemical agents, e.g., diesel exhaust, pesticides, and other irritants including endotoxin, fungal spores, and ammonia (Schenker, 2005). How this plays out in CAFOs is yet to be studied.

Endotoxin has strong pro-inflammatory effects (Heederik et al., 2006; Madsen, 2006; Schulze et al., 2006), and genetic variations in individuals may be responsible for variation in susceptibility to health effects from endotoxins (Radon, 2006). When inhaled, endotoxins stimulate the release of cytokines (chemoattractants that initiate inflammation) from alveolar macrophages and respiratory epithelial tissues (Mueller-Anneling et al., 2004).

Longitudinal studies have shown that an accelerated decline in lung function occurs at endotoxin concentrations less than 100 ng m^{-3} (approx. 800 EU m^{-3}) (Reynolds et al., 1996; Vogelzang et al., 1998; Iverson et al., 2000). High concentrations of 100 to 200 ng m^{-3} are reported to cause bronchoconstriction in exposed workers, and concentrations of 1,000 to 2,000 ng m^{-3} may result in organic dust toxic syndrome (ODTS), the symptoms of which are fever, muscle aches, chest tightness, headache, coughing, and fatigue(Kirkhorn and Garry, 2000). Long-term respiratory effects are airway inflammation and dysfunction, which result in asthma-like syndrome (Iversen et al., 2000), and chronic obstructive pulmonary disease (Madsen, 2006; Schulze et al., 2006). Asthma-like syndrome is an acute, reversible airway reaction of exposure to organic dust, and its symptoms consist of inflammatory events that do not involve persistent airway hyperreactivity (Schenker, 1998).

Exposure to endotoxin may result in a more dynamic inflammatory response for patients who have pre-existing inflammatory diseases, such as asthma (Imrich et al., 1999; Heederik et al., 2006; Vogelzang et al., 1998; Kline et al., 1999). Asthma is a disorder characterized by variable airflow obstruction, airway hyperresponsiveness, and airway inflammation (Schenker, 1998).

Other human exposure-response studies report declines in airflow, development of neutrophillic alveolitis (Mueller-Anneling et al., 2004), and chronic bronchitis (Radon, 2006). As CAFOs grow larger, their high concentrations of endotoxin and other health hazardous bioaerosols make it imperative to find ways to lower the agricultural dust in the facilities.

Health Protection

Numerous sources of potential injury exist within CAFOs. Because CAFO workers are exposed to such risks daily, it is crucial to take the appropriate precautions in safety training and preventive protection for all workers. Although there has been a decline in numbers of reported agricultural injuries, there is still a great interest in developing and implementing safety strategies to continue to reduce these injuries. To date, more and more studies are focusing on identifying the factors that contribute to injuries to improve current forms of protection or incite future research studies. DeRoo and Rautiainen

(2000) reported there have been two approaches taken in farm safety interventions. One approach is to use education to increase knowledge, awareness, and attitudes for safer behaviors while working. The second strategy includes the modification of the environment and/or equipment so that better protection is provided while hazards are removed altogether. It has been argued that modifications are more effective than educational strategies (DeRoo and Rautiainen, 2000); however, new interventions for the current multitude of hazards found on farms today will also require the assistance of better organization and management of farms (Rautiainen et al., 2004). In addition, another alternative approach is regulation. Although very effective in Sweden, regulation is not highly favored by the vast majority of U.S. farmers and large farm organizations, making it difficult to pass legislated regulation of farming (Thu et al., 1998). Therefore, while regulations have been implemented to decrease the emissions of air pollutants, there are no laws that regulate the farm work environment to protect workers from hazards in machinery use, on-site dust levels, and animal handling.

We are unaware of any published reports that provide evidence of the specific interventions that could be most effective in reducing the common injury types found on CAFOs. Several forms of health protection available today for CAFO workers are discussed briefly in the following section.

Training and Education: Injuries

Many agencies have various forms of training and education available for owners, supervisors, and workers in all types of operations. The Federation of Animal Science Societies (FASS) has developed farm worker training materials for animal care and use practices of all livestock species (https://ecomm.fass.org/publications). The U.S. National Pork Board has developed a distance learning course to provide interactive training in animal management, people development, and decision tools as refresher courses for producers or to train workers with little or no experience (www.pork.org/Producers/DistanceLearning/DistanceLearning.aspx). Use of such modular training can teach species-specific information that could greatly decrease the likelihood of injuries or fatalities on CAFOs. Machinery safety instruction is available to workers directly through the manufacturers of purchased machines. Public occupational safety agencies, such as NIOSH, the USDA National Resources Conservation Service (NRCS), NSC, the National Agricultural Safety Database (NASD), and OSHA also provide current publications on injury statistics, hazard profiles, and prevention. Unfortunately, these reports are rarely designed to be understood by the average farm worker.

On a more local level, cooperative extension programs in each state provide continuing education training for all types of farm and ranch workers. Simplified informational pamphlets, videos, and training sessions are often produced in a variety of languages. However, with the dispersed nature of livestock premises and few workers on each CAFO, enforcement of training and education is not common. In a California-based survey, only 70% of injured workers had received training for the job duties related to their injuries (Osorio et al., 1998). This is despite Cal-OSHA requirements in the California Code of Regulations, Title 8 (Cal-OSHA, 2007), which states that employers must always provide training for their supervisors and other employees, and inspect work areas/ machinery regularly. This includes agriculture and operations with fewer than ten workers, and there are specific training requirements for use of agricultural equipment, tools, personal protective equipment, and chemicals. Compounding the lack of enforcement by regulatory agencies are the conditions of the workers themselves. Most of these individuals are foreign-born, poorly educated, and illiterate both in English and their native language (Mobed et al., 1992; Schenker, 1998). Thus, most written information, the primary form in which instruction regarding proper machine and animal handling is provided and pollutant exposure is discussed, is inaccessible to these individuals.

Research and Emission Control Strategies

Research findings are becoming increasingly vital to CAFOs by advancing knowledge about existing conditions, testing new or proposed methods, and providing economically feasible solutions that will improve worker health. Protective structures, such as ROPS on tractors, have been widely examined to prevent occupational injuries. Myers and Pana-Cryan (2000) demonstrated that there are three approaches to preventing tractor-related injuries: (1) do nothing, (2) install ROPS, and (3) replace the tractor. Method 1 would result in 3,256 fatal or non-fatal injuries, while method 2 would prevent 2,133 fatal or non-fatal injuries, and method 3 would prevent 2,155 fatal or non-fatal injuries. Thomas and Buckmaster (2003) also determined that factors such as lack of adequate shielding, protrusions on the driveline, and victims in close proximity during PTO accidents yield severe injuries causing death (3%), amputation (26%), and fractures (32%). These findings provide means and effectiveness of improving or influencing the development of protective gear with great potential to reduce work-related injuries. Nonetheless, absent or inadequate evaluations of safety interventions and the difficulty in monitoring trends in injury rates makes it difficult to determine the success of particular studies on worker safety (DeRoo and Rautiainen, 2000). Additionally, much relevant literature exists outside the peer-reviewed scientific journals, and retrieving full-text documents can be both very time consuming and expensive (Beahler et al., 2000).

Research is also playing a major role in developing preventative strategies to protect workers from harmful air pollutant exposures. Reducing emissions and exposure levels are two strategies currently under investigation. Farms are abiding by regulations based on initial emission rates and are aiding researchers in finding alternatives to reduce emissions and health effects for workers. NIOSH (1990), for example, issued recommendations in order to prevent chronic exposure to ammonia concentrations. These include decreasing the levels of ammonia exposure by increasing ventilation, reducing the number of animals per unit area, increasing the frequency of manure removal, employing sensors to alert workers of elevated ammonia levels, and using full-face respirators with ammonia cartridges. Amon et al. (2001) states that for dairy barns, certain manure treatments can drastically change emissions of ammonia, such as switching from aerobic composting of farmyard manure to stacking and storing manure anaerobically without manipulation (also called anaerobically stacked farmyard manure). Other manure storage systems could include the use of straw to absorb ammonia in manure, fast removal of liquid slurry to closed pit, dilution with water, using acidification cation, or by adding salts to lower ammonia emissions (Bussink and Oenema, 1998; Kulling et al., 2001; Ross et al., 2002). Alternatively, there are also studies focused on nutrition. They demonstrate the importance of formulating diets that provide cows with the optimal percentage of protein, which minimizes unwanted nitrogen excretion, thus reducing unwanted ammonia emissions (Kulling et al., 2001; De Boer et al., 2002; Frank et al., 2002; Monteny et al., 2002; Kulling et al., 2003; Swensson, 2003).

Wenger et al. (2005) designed a personal environmental sampling backpack for exposure monitoring of swine workers in an effort to build monitoring instruments that measure air emissions accurately for the purpose of establishing consistent emission standards and corresponding regulations. If engineering changes and management practices are not sufficient to reduce PM levels below concentrations thought to produce long-term respiratory health effects, then the alternate is personal protective equipment

(PPE). However, Carpenter et al. (2002) found that although PPE was readily available to Midwestern farmers, fewer than 3% of workers reported wearing PPE most or all of the time. PPE usage by workers was determined by personal preference and not heavily influenced by personal desire, current health problems, ease of use, personal appearance, time required, cost, government regulations, and concerns from family members. In a study of California farmers, consistent PPE use when exposed to dust was at most observed by 20% of the cohort (Mitchell and Schenker, 2008). Long-term consistent PPE use was associated with an expressed concern about respiratory problems and being an ex-smoker, but not associated with educational level or age and did not increase with time. Disincentives to the use of masks and respirators include claustrophobia, and such equipment can be uncomfortable in hot, humid areas where heavy exertion is needed. The effectiveness of the equipment may be compromised if improperly used, or by failing to clean or maintain the equipment. The proper design and fit testing of respiratory protection equipment is essential, and agriculture has a poor track record in providing and monitoring the effect of related programs.

A cultural shift is needed to recognize that dust exposure in these facilities is more than a nuisance issue; the exposure to dust has long-term health implications that require engineering and management solutions to keep dust emissions as low as possible. Examples of engineering modifications are the use of misting with canola oil, and less effectively fogging with water, changing livestock diet, or using deep wood shaving litter (Pedersen et al., 2000). For noise abatement, newer construction could better make use of designs and materials that are less noise reflective. Changes in management practice could involve alternating tasks so the same people are not exposed to the same pollutant for their entire work shift, and increasing the frequency of flushing or ventilation. During work situations where dust levels are unavoidably high, the wearing of new and user-friendly PPE should become an expected and rewarded behavior. The increasing trend for CAFO numbers and size does not seem to be slowing down; as chronic health problems do not generally show up immediately in younger working populations, proactive changes in the design and management of CAFOs are needed to ensure the health of this sector of the agriculture community.

Conclusions

CAFOs emit an array of substances that challenge regulatory agencies charged with setting standards designed to protect the workforce within the livestock industry. Workers are vulnerable to pulmonary diseases, and to the main contributors of injury and death on livestock operations, i.e., improper handling of animals and machinery. Protecting worker health proves to be very difficult with the large variability of farm practice, layout, region, and species of animals housed across all CAFOs in the U.S. Workers exposed to high levels of hydrogen sulfide, ammonia, VOCs, particulate matter, and endotoxin exhibit signs of respiratory inflammation and/or obstruction, asthma, pneumonia, bronchitis, damage to the central nervous system, and cardiovascular complications. In addition, the mix of emissions at each facility is affected by the management practices characteristic to a particular feed operation. Complex mixes of different airborne substances pose a challenge to regulation, particularly when the ability to state the effect on health of individual contaminants is incomplete. The science of the interaction of gaseous and particulate mixtures on biological systems is still in its infancy. Thus, which levels of emission concentrations to regulate is in itself an issue of debate.

It is therefore impossible in most cases to attribute the influences of worker health to a specific setting or work environment. To improve the health and regulation of these workers and their working environment, it is imperative that scientists and agencies focus on the characteristics that are common to this working population in order to find appropriate linkages between exposure and disease manifestation in CAFOs.

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