Impermeable Covers for Odor and Air Pollution Mitigation in Animal Agriculture: A Technical Guide

AIR QUALITY EDUCATION IN ANIMAL AGRICULTURE

Mitigation Strategies: Covers - 2

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This publication discusses the types of impermeable covers for manure storage, including factors to consider when selecting an impermeable cover.

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Impermeable covers can nearly eliminate odor and gas emissions from manure storage facilities by creating a barrier that prevents gases from escaping the stored manure. Impermeable covers are made of materials that only allow gas molecules to pass through them at very low rates, such as plastic, concrete, or wood.

Livestock manure is commonly stored in tanks or lined earthen basins until it is applied to cropland at agronomic rates or removed from the site. Uncovered manure storage facilities release odorous, hazardous, and greenhouse gases, including hydrogen sulfide (H_2S), ammonia (NH_3), volatile organic compounds (VOC), methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). Odorous gases can cause nuisance complaints, and the other gases can contribute to air pollution and climate change.

In some locations, liquid livestock manure is fed to anaerobic digesters or covered lagoons to produce biogas (methane and carbon dioxide). The biogas can be flared or used to fuel a boiler or modified combustion engine to generate electricity and/or heat. Impermeable covers are used on anaerobic digesters and lagoons to create anaerobic conditions and capture the biogas.

Livestock producers currently use various materials, from straw to plastic, for either permeable or impermeable covers on manure storage facilities. The materials vary in cost, effectiveness, design, and operation considerations. This publication provides information on impermeable covers. Information on permeable covers is available in another fact sheet.

How Impermeable Covers Work

Impermeable covers are typically made from materials like plastic, concrete, or wood. For safety and longer life expectancy, the cover materials, structural members, and fasteners must be able to withstand exposure to moisture, corrosive gases, and manure.

Gases pass through impermeable covers at very low rates, less than 1 L/m^2 day (5.7 in^3/ft^2 day), given in terms of permeability. Covers create a barrier between air immediately over the stored manure and air flowing over the cover's top. Plastic covers can float on the manure surface or be held in place by gravity or suction created with fans. Plastic covers also can be inflated with air or stretched over a frame to form a dome over the manure storage facility. They are inflated by biogas over anaerobic digesters and lagoons. Plastic covers are usually sealed around the edges, where they come in contact with the manure storage facility or anaerobic lagoon to minimize emissions around the perimeter.

Concrete or wood covers can be built over concrete manure storage structures but not over lined earthen storages or anaerobic lagoons.

Impermeable covers reduce the amount of odor, NH_3, H_2S, VOC, CH_4, and N_2O gases emitted from livestock manure storage facilities. Impermeable covers trap gases emitted from the manure between the cover and the manure. As the gas

Rigid covers are commonly restricted to small manure storage facilities.

concentrations in the airspace under the cover and above the stored manure increase, the amount emitted from the manure decreases because the concentrations in the airspace under the cover and the dissolved gases in the stored manure come into balance. Gas concentrations increase under the cover and in the stored manure as bacteria in the manure produce and release more gaseous compounds.

Covers also reduce the effect of wind blowing across the manure surface of an uncovered storage facility or anaerobic lagoon. Wind whisks away gas molecules at the manure-air interface and brings in fresh air with lower gas concentrations. The imbalance between the low concentration of air and the dissolved gases in the manure increases the dissolved gases emitted from the manure into the air. The gases are emitted in an effort to balance the gas concentration in the manure with the air above the manure. Conversely, a cover keeps volatile compound concentrations near the manure surface high, which reduces gas emissions and keeps more of the dissolved gases in the manure.

Impermeable covers increase dissolved gas concentrations in the manure or anaerobic lagoon because fewer gas molecules are emitted. The airspace under the cover is limited, so gas concentrations build up quickly, resulting in more dissolved gases staying in the manure and fewer gases being emitted. The increased gas concentration in the manure or anaerobic lagoon needs to be managed to avoid excessive emissions during agitation, pump out, and land application.

Types of Covers

Rigid Covers

Rigid covers include concrete or wood roofs and plastic or vinyl-coated fabrics stretched over framing over manure storage facilities. Lightweight rigid covers for circular steel and concrete storage facilities are available from suppliers. Heavy-gauge polyester with a polyvinyl chloride (PVC) coating is available to retrofit existing aboveground storages.

Rigid covers are commonly restricted to small manure storage facilities. Covers, support materials, and fasteners must made of corrosion-resistant materials. Wind and snow loads, plus the weight of the cover material and supports, need to be considered when using a rigid cover. Rainwater falling on the cover and snowmelt must be directed off the cover and away from the manure storage structure, preferably to a well-drained, vegetated area. Traffic and equipment access to rigid covers should be discouraged to prevent puncturing plastic or vinyl coated fabric covers. Equipment should be kept off concrete or wood covers unless they were specifically designed and constructed to handle equipment loads.

Access for manure slurry agitation and removal or sludge monitoring in anaerobic lagoons must be built into cover systems. Aboveground manure storage facilities can be agitated and emptied from the bottom. Belowground covered manure storage facilities are usually agitated and emptied through the cover.

Gas concentrations within covered manure storage facilities can reach lethal levels. Extreme caution must be used when opening covers, agitating stored manure, and emptying the storage facility. People should never enter a covered manure storage facility (e.g., inflated dome or covered tank) without personal breathing protection and adequate safety lines and personnel.

Plastic Covers

Plastic covers include geomembranes and geosynthetic materials. Plastic covers can be made of High Density Polyethylene (HDPE), Linear Low Density Polyethylene (LLPDE), or Polyvinyl Chloride (PVC). Covers may be multilayered to reduce permeability, reinforce and strengthen the membrane, or provide ultraviolet or chemical protection. Membrane thicknesses typically range from 10 to 60 mils (0.01 to 0.06 in).

Figure 1. Positive air pressure covers are filled with air from a blower. (Source: Ted Funk, University of Illinois)

Plastic covers come in large sheets that are unfolded or unrolled and pulled over a manure storage facility or anaerobic lagoon. Avoid installing plastic covers in windy weather. When one or more sheets are needed to cover a storage facility or lagoon, the joints may be welded either chemically or thermally. Joints made where the two covers overlap need to be clean and dry and within manufacturer-specified temperatures to create a strong, non-leaking seam. Follow manufacturer instructions to minimize chances of seam failure.

Flexible impermeable covers include floating, positive air pressure, and negative air pressure systems.

Flexible Impermeable Cover Systems

Three types of flexible impermeable cover systems are discussed in this publication: floating, positive air pressure (PAP), and negative air pressure (NAP). PAP and NAP covers are alternatives for addressing wind and gas bubble problems for floating covers.

Floating impermeable covers can be stretched over manure storage facilities and allowed to lie on the manure surface. The cover may be partly inflated with gases that form large gas bubbles under the cover. The large bubbles can make a flexible cover vulnerable to high winds, which stress the cover fabric. A thicker plastic cover can solve the bubble problem but also is more expensive.

Floating impermeable covers also are used to cover anaerobic digesters or lagoons and collect biogas for flaring or feeding a boiler or combustion engine. The covers are sealed at the digester or lagoon perimeter to keep out oxygen, maintain anaerobic conditions in the digester or lagoon, and capture all the biogas produced. The biogas creates enough pressure to inflate the cover to withstand wind, rain, and snow.

Table 1. Percent reductions in odor, hydrogen sulfide, and ammonia emissions for impermeable covers, their life expectancies, and capital cost per square yard of cover.

Material	Emissions Reduction (%)			Life Expectancy	Capital Costs ($/yd^2)
	Odor	H_2S	NH_3		
Concrete	95 – 100 (a)	–	–	20 years (a)	–
Wood Lid	75 – 95 (a)	–	98 (b)	–	–
Floating	39 – 95 (a, c, d)	90 – 95 (e, c)	81 – 95 (b, d, e)	10 years (a, e)	4.5 – 9.00 (e)
Positive Air Pressure	95 – 99 (e, f)	95 – 99 (e, g)	95 (e)	10 years (e)	6.75 – 12.60 (e, f)
Negative Air Pressure	95 – 99 (e, h)	95 (e)	95 (e)	5 – 10 years (e, i)	3.15 – 3.60 (e, i)

Information Sources:

a. Mannebeck, 1985
b. Sommer et al., 1993
c. Clanton et al., 1999
d. De Bode, 1991
e. Bicudo et al., 2004
f. Zhang and Gaakeer, 1998
g. Funk et al., 2004a
h. Zhang et al., 2007
i. Funk et al., 2004b

Initial, operating, and disposal or recycling costs are key considerations when choosing a cover.

PAP (or inflated dome) covers usually have a central post and are filled with air from a blower. The blower air produces enough pressure under the cover to hold the plastic cover up and withstand forces from wind, rain, and snow *(Figure 1).* PAP covers are deflated for manure agitation and pumping, and the cover rests on the central post. Manure is agitated and removed through an opening in the deflated cover.

NAP covers use fans to pull air out from under the cover, creating a vacuum that helps hold the cover in place on the liquid surface. The small fan airflow helps keep gas emissions small. An effective suction system prevents large bubbles, which can be buffeted by wind, from forming under NAP covers.

Choosing a Cover

Initial, operating, and disposal or recycling costs are key considerations when choosing a cover. *Table 1* lists the percent reductions in odor, hydrogen sulfide, and ammonium emissions, life expectancies, and installation costs per square yard of cover (Note: 1 square yard = 9 square feet). Percent reductions reported were the reductions in emissions with a cover compared to an uncovered control. Other factors are effectiveness, service life, and maintenance requirements. The type and size of the livestock operation and manure storage system, available labor, proximity to neighbors and public areas, climate, and safety also should be considered.

Impermeable covers have longer service lives, typically 10 years, but are more expensive than permeable covers. The materials, extra equipment required, design complexity, installation, and maintenance make impermeable covers more expensive. Additionally, the removal and disposal or recycling of impermeable covers can be costly and may include landfill fees.

However, impermeable covers are effective at reducing odors and gas emissions — they can cut odor, hydrogen sulfide, and ammonia emissions by 95 percent. An impermeable cover system that is well-sealed and treats the vented air may achieve nearly 100 percent odor control. Livestock producers who want to reduce odor and gas emissions by 90 percent or more should use an impermeable cover system.

Design and Management

Impermeable cover effectiveness depends on the type of cover material, installation, and control of vented gases. Impermeable covers that only partially cover the surface or are not sealed around the manure storage edges will provide limited emissions control. Covers need to withstand wind damage, ultraviolet radiation, and other environmental effects. The corrosive action of water vapor, ammonia, hydrogen sulfide, volatile organic compounds, and acids should be considered when selecting cover materials and concrete coatings.

Plastic and vinyl-coated fabric cover selection depends on important physical properties, including tensile strength and resistance to stretching, puncture, corrosive gases, and ultraviolet light deterioration. Other factors to consider are attachment methods, long-term maintenance, repairability, useful life, and final disposal.

Most plastic and fabric covers have a life expectancy of about 10 years, although instances of failure within a couple years have been reported. Plastic and fabric cover vendors may offer 10-year warranties on materials but only two-year warranties on workmanship. Typically, plastic or fabric covers that fail within the first year fail because of workmanship.

Proper cover installation is required for maximizing cover life expectancy. Field-installed joints and seams must be done properly and cured to have good structural strength and produce a good seal. Avoid placing the cover on or dragging it over rough terrain, rocks, and building materials that can cause punctures or tears. Avoid walking on the cover material during installation or repair. Install and repair covers when ambient temperatures are within the range specified by the manufacturer.

Many impermeable cover systems have structural support systems under the cover. Select materials that can withstand exposure to moisture and corrosive gases.

Impermeable cover systems require a controlled exhaust system to avoid excessive pressure buildup under the cover due to gas production *(Figure 2).* Provisions

Proper cover installation is required for maximizing cover life expectancy.

Figure 2. Negative air pressure covers are held in place by a vacuum created by fans that pull air out from under the cover.
(Source: Ted Funk, University of Illinois)

Provisions for collecting and removing rainwater and snowmelt must be considered for both positive air pressure and negative air pressure cover systems.

to collect and remove gas can be made using perforated gas collection pipes and/or exhaust fans when installing a NAP. The collected gases can be directed to a flare, boiler, gen-set, gas-phase biofilter, or air treatment system before being discharged to the atmosphere.

Air treatment systems on manure storages with impermeable covers should be able to handle odorous air with corrosive and toxic gases. Hydrogen sulfide concentrations have been measured up to 1000 ppm. Flat, low-profile covers have an advantage because they minimize airspace and limit the volume of air that needs to be treated. Gas-phase biofilters are an air treatment option.

Impermeable cover systems should be designed to allow access for manure agitation and pumping from manure storage facilities and for monitoring sludge depth. Access is normally achieved by removing a portion of the cover, often at several points around the structure, or by installing permanent openings that can be sealed between pumpings. Individual cover system manufacturers have added flaps or lift systems to covers to make access easier. Custom manure applicators may charge a higher rate if conditions to agitate and pump are inconvenient or considered hazardous.

Provisions for collecting and removing rainwater and snowmelt must be considered for both PAP and NAP cover systems *(Figure 3)*. Excess rain and snowmelt that collect on a NAP cover can be drained through a series of perforated collection pipes laid on the cover surface and connected to a pumping system. PAP and NAP cover systems can collect rainwater and snowmelt in trenches made within folds in the cover surface and the water pumped out periodically. Rainfall management should ensure that rainwater does not get into a manure storage facility, anaerobic digester, or lagoon, or damage the storage foundation or lagoon bank. Cover runoff should be directed toward a vegetative infiltration area, a collection basin, or drainage ditch. Check state and local regulations for handling cover runoff.

Figure 3. Negative air pressure and floating manure storage covers require a system to collect and remove rainwater and snowmelt.

(Source: Ron Sheffield, Louisiana State University)

On large manure storage facilities, impermeable cover sections may need to be welded together with well-sealed joints to make a complete cover. Covers should be sealed around the storage edges. This is typically accomplished on earthen-embanked manure storages by fastening the cover fabric to the berm using anchor trenches. Embedded bolts, plastic fittings, rubber strips, and steel plates can be used to fasten fabric covers to concrete manure storage facilities. Avoid overhangs, ledges, or lips on the underside of covers where condensate may collect.

Recycling and disposing of plastic or vinyl-coated fabric covers can be costly. One producer paid $1,000 for picking up and hauling a 2,000 ft^2 geotextile cover, and an additional $800 in landfill fees. The disposal cost for a 2,500 yd^2 cover was estimated at $690 (25 labor hours at $10/hr, 8 tractor hours at $30/hr, and a $200 landfill tipping fee). Pickup, hauling, and landfill fees vary by location and hauling distance, and the above numbers may not be representative of service fees in your area.

The potential for increased nutrient concentrations in the manure may mean that more land is needed for manure application at agronomic rates. Impermeable covers will reduce liquid evaporation from the manure storage in dry climates and precipitation addition in wet regions, which may affect nutrient concentrations and manure volumes. These changes may require shifts in cropping systems to accommodate changes in pumping and application frequency. These and other system changes may impose additional financial and managerial requirements on the operation.

Impermeable covers are expected to increase the nitrogen and sulfur content of the stored manure and anaerobic lagoon due to reduced ammonia and hydrogen sulfide emissions. Phosphorus content does not change due to a cover because no volatile form is emitted. The volatile nitrogen and sulfur compounds can be lost during agitation or if anaerobic lagoon effluent is irrigated onto the cropland. Incorporation after land application helps reduce volatile nitrogen and sulfur emissions and retain the nutrients. Sampling and analysis are recommended to determine the stored manure or anaerobic lagoon effluent nutrient concentrations.

Safety

Rigid covers may be designed to structurally support equipment, animal, and human loads on top of the cover. Fences should surround manure storages and anaerobic lagoons to keep equipment, animals, and people off of rigid covers not designed and constructed to carry the load.

Plastic and fabric covers usually are not designed to support equipment, or animals or people walking on them. Manure storages and anaerobic lagoons should be surrounded by fences to prevent animals or people from accidentally walking onto and falling through a cover that appears to be solid.

Dissolved gas concentrations of hazardous gases such as ammonia and hydrogen sulfide accumulate in the manure under covers. These gases can volatilize quickly when the cover is removed for agitation, pumping, or inspection. Covers can create conditions with potentially high toxic gas concentrations near the inspection and agitation openings. Use extreme caution when accessing manure under a membrane cover through an access flap or cover lift system.

People should never enter a covered manure storage facility (e.g., inflated dome or covered tank) without personal breathing protection and adequate safety lines and personnel.

Greenhouse Gases

Since the impact of greenhouse gases — in this context as emitted from livestock and manure — on climate is relatively new, there is little research on the relationship between impermeable covers and greenhouse gas mitigation. Impermeable covers that capture and combust methane from stored manure, anaerobic digesters, and lagoons will reduce greenhouse gas emissions. Impermeable cover gas tightness, digestion completeness, and methane fate are important factors. Additional research is needed to clarify the conditions that may effectively reduce greenhouse gas emissions.

Never enter a covered manure storage facility without personal breathing protection and adequate safety lines and personnel.

Since the impact of greenhouse gases — as emitted from livestock and — manure on climate is relatively new, there is little research on the relationship between impermeable covers and greenhouse gas mitigation.

Case Studies

Earthen Manure Storage NAP (Zhang et al., 2007; Zhang and Small, 2008)

An impermeable NAP cover system was installed on a two-cell earthen swine manure storage basin (200-ft by 167-ft primary cell and a 200-ft by 510-ft secondary cell). A 20-mil reinforced polyethylene plastic membrane was used for the cover. The covers were anchored in trenches dug around the cells and backfilled with soil.

A system of perforated pipes was placed under the membranes. Air was removed through the pipes using eight ¼-kW fans (two on the primary cell and six on the secondary cell) running continuously. The fans drew air out at a rate of about 160 cfm per fan.

The storage had air-assisted manure agitation systems that allowed the manure to be agitated without removing the cover. Air was injected through a grid of diffusers and small air lines at the bottom of the storage. The air was injected by a blower at about 14.5 psi (100 kPa).

Capital cost for this type of NAP cover was between \$0.93 and \$1.39/ft^2. The covers had an expected lifespan of about 10 years.

Earthen-Embanked Lagoon NAP (Funk et al., 2004)

An impermeable NAP cover was installed on a 120-ft by 160-ft earthen-embanked swine lagoon. A 0.41-mm thick, flexible reinforced polyethylene membrane was used for the cover. A fan provided approximately 500 Pa of suction that secured the cover by burying its perimeter in a trench dug around the lagoon and backfilling with soil.

A loop of 4-in corrugated, perforated polyethylene field tile was placed around the lagoon's perimeter, under the cover. A centrifugal fan (Dayton Electric Model QBR137F) connected to the field tile loop removed air from under the cover to create suction and hold the cover in place. The exhaust fan's average static pressure was 2.3 in water (564 Pa).

Bubbles or bulges collected under the membrane but did not pose any problems. The expected cover lifespan was 10 years. Total installation cost was about \$8000 or \$0.41 per square foot. Electrical power costs for the fan were about \$36 per month (at \$0.10/kWh). No maintenance costs were incurred during the eight-month experimental period.

Concrete Manure Storage Tank PAP (Zhang and Gaakeer, 1998)

An impermeable PAP cover was used to cover a 75-ft diameter concrete manure tank for a 200-sow, farrow-to-finish production facility. The cover was a 36-mil roof-covering tarp (Spreers Petrochemicals Company, Winnipeg, MB). The tarp diameter was 1 meter larger than the tank diameter, allowing the cover to be inflated to a height of about 8 feet.

A 4-ft by 4-ft grid of ¼-in nylon ropes was laid across the tank's top and attached to the concrete tank rim to support the deflated cover in case of power loss or blower deactivation. Each rope and the cover tarp were fastened with plates to bolts anchored in the concrete every 2 feet.

The cover system included an air delivery system and a pressure controller. The air delivery system had a direct drive radial blade blower (0.37 kW, 1750 RPM) with a capacity of 848 cfm at 0 Pa and 191 cfm at 250 Pa. An anti-backdraft system helped keep air in storage when the blower was off. Air leakage was less than 127 cfm at the normal operating pressure of 0.4 in water (100 Pa). The cover remained inflated for about an hour with the blower off. The normal pressure (100 Pa) kept the tarp steady without flapping at winds of up to 56 mph.

The project's capital cost was about \$6,000 or \$1.4 per square foot. The tarp was a special order and more expensive than a mass-produced tarp. Operating cost only included the electrical energy needed to operate the blower (266 kWh or $27 per month at $0.10/kWh). The cover operated for three years with no maintenance. Manure removal was accomplished through a removable panel in a 4-ft by 6-ft frame attached to the tank rim and the cover.

Earthen-Embanked Lagoon PAP (Funk et al., 2004)

An impermeable PAP cover system was installed on a 120-ft by 160-ft earthen-embanked swine first-stage lagoon. A 14-mil vinyl-coated fabric was used for the cover. When inflated, the cover became an air-supported pneumatic structure 119-ft wide by 159-ft long (the perimeter trench dimensions) by 18-ft high. At normal operating pressures from 0.3 to 0.4 in water (80 to 100 Pa), air leakage was 120 cfm.

The cover was anchored using a perimeter earthen trench (2.5-ft deep by 2-ft wide) that was backfilled with soil from the site. On the trench's inside wall (lagoon side), a piece of 3-mil plastic was placed around the top edge to protect the cover fabric from sharp objects (e.g., plant roots and rocks). The outer edge of the vinyl-coated cover fabric was wrapped around treated 2-in by 4-in lumber, which held the tarp material against the outside wall and reduced material movement within the trench. The trench was backfilled to anchor and seal the perimeter. Soil outside the perimeter trench needs to be sloped away from the trench to allow good drainage.

Because the lagoon was already full at the time of cover installation, a 5-ft by 5-ft grid of ¼-in polypropylene ropes was tightly strung across the lagoon. The ropes were anchored inside the perimeter trench using soil anchors. The ropes supported the cover during installation, removal, and power outages or equipment failures.

The air delivery system was a spark-resistant centrifugal blower (Dayton Electric Model QBR137F), a variable-speed motor drive (Boston Gear Model BCX2003), and an anti-backdraft flap. The blower was direct driven (0.37 kW at 1530 RPM) and had a maximum capacity of 2610 cfm at 0 in water and 1590 cfm at 1 in water (250 Pa). The PAP cover's internal pressure was controlled by adjusting blower speed using a variable speed drive. A duct connected the fan to the cover. The PAP operating pressures ranged from 0.25 to 0.4 in water (62.5 to 100 Pa). During windy conditions, operating at 0.4 in water (100 Pa) created a steadier structure, reducing stress on the cover membrane at the perimeter.

The tarp design included five self-sealing drain holes to minimize rainwater accumulation on the tarp should the air supply fail and the tarp settle. During operation, the internal pressure sealed the drain holes. The supplier recommended a 14-mil thick membrane, based on strength requirements, cost, and handling during heat welding of the seams. The cover did experience a seam split when the operating pressure went to 1 in water (250 Pa). An overpressure cutoff switch on the blower or some other high pressure protection device probably could have protected the cover.

At $0.94/ft^2, the vinyl-coated cover fabric accounted for about three-quarters of the project's capital cost, which was about $21,000. The cost to power the blower was approximately $12.30 per month (at $0.10/kWh). Disposal costs totaled $690 and included 25 hours of labor ($250), 8 hours of tractor use ($240), and $200 for the landfill tipping fee. Based on a 10-year life of the material, the cover system's annual cost for the facility was $0.0125/ft^2.

Floating Covers on Anaerobic Lagoons and Digesters (Roos et al., 1999, Cheng et al., 2004)

Floating covers on anaerobic digesters and lagoons are inflated by the biogas. Suppliers install the covers. The cover material is usually 30 to 45 mils thick. Installation costs ranged from $0.37 to $5.81 per square foot. The covers completely span the digester or lagoon and are secured to the lagoon bank by burying the cover in a perimeter trench. Rainfall runoff management is important to avoid lagoon bank damage during heavy rains.

A modular, reinforced cover was installed on a 210 ft x 16 ft x 14 ft heated anaerobic digester on an 8,900-head swine finishing operation in Illinois. The cover was damaged in a wind storm that blew down a nearby building. A new 40 mil HDPE cover was installed and reportedly worked well (Roos et al., 1999).

A 20 mil floating cover was installed on a 300 ft by 300 ft anaerobic lagoon on a 4,000-sow, farrow-to-wean pig farm in North Carolina. The 20 mil cover was unsatisfactory. A 40 mil cover was installed and reportedly worked well (Roos et al., 1999; Cheng et al., 2004).

A 20 mil floating cover was installed on a 140 ft by 160 ft earthen storage pond on a 2,400-head pig nursery in Iowa. The gas is combusted by a flare (Roos et al., 1999).

Conclusion

Impermeable manure storage covers can be made using a wide range of materials. Each cover needs to be designed and installed with consideration for the unique characteristics of the individual site. Impermeable covers are a large capital investment, but are extremely effective at reducing odor and gas emissions.

Figure 4. This floating impermeable cover was installed over an existing earthen manure storage lagoon.

(Photo courtesy of the National Pork Checkoff)

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