Guideline for Positive Pressure Biogas Cover Systems

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1. Disclaimer

The contents of this guideline reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of any organization, entity, or company and this guideline does not constitute a standard, specification, or regulation. Biogas covers should be designed by an appropriately qualified and experienced engineer.

Trademark or manufacturer's names may appear in this report only because they are considered essential to the object of this document and do not constitute an endorsement of product by the FGI or any other organization, entity, or company.

2. Purpose of Guideline

The purpose of this guideline is to help Anaerobic Digester (AD)/Biogas System Operators design, select, install, and maintain geosynthetics used to create AD cover systems to collect and utilize biogas. The guideline is also intended to assist in the prevention of common difficulties and challenges with biogas cover systems that can lead to community odors and system shutdown. This guideline is intended to be a resource for AD operators that are interested in a long-lasting (at least ten years) cover system to collect biogas to maximize profitability and minimize operations and maintenance (O&M) expenses. Because the cover systems are collecting explosive gas, the guideline also presents safety and best practice recommendations for operation of these cover systems.

3. Positive Pressure Biogas Cover Systems

Anaerobic digestion (AD) and biogas systems are designed to convert biodegradable organic materials into recoverable methane (CH_4)-rich gas and a stabilized digestate that can be discarded or put to a beneficial use, e.g., land application. The conversion process uses a biological process that is widely cited (Agstar, 2020) to generate methane. A successful AD/biogas system creates a favorable environment to maintain a stable population of microorganisms that can efficiently convert the biodegradable organic materials into recoverable CH_4 gas. The microorganisms can convert the biodegradable organic materials into biogas, which can be captured by an impermeable geosynthetic cover system and then utilized or sold. More importantly, the cover system prevents the release of methane to the environment, which reduces available greenhouse gases and odors.

This guideline is not intended to serve as a fully comprehensive standalone reference guide for design, geosynthetic selection, installation, operation, and maintenance of a positive pressure biogas floating cover system or provide regulatory guidance for an AD. Each facility is different and site-specific design, geosynthetic selection, installation, operation, and maintenance should be developed. In particular, the site-specific O&M manual should at least address the following topics: (1) specific O&M requirements for each portion of the cover system, (2) an operation plan discussing the operating sequence for pressurizing the cover system, (3) as-built drawings, schematics, and diagrams for the cover geosynthetics and anchorage system, (4) clear instructions on any automated system, e.g., pressure relief system, including descriptions of the automated functions and related operating procedures, (5) general daily functions and (6) a project installation safety plan.

While negative pressure biogas cover systems are also used in the industry for AD, this guideline only references positive pressure biogas covers. Negative pressure biogas cover systems will be the subject of an upcoming guideline.

4. Biological Conversion Process

The biological conversion process described above involves anaerobic (no oxygen present) microbes present within the AD degrading or breaking down the agricultural organic matter (i.e., manure) to obtain energy and nutrients for growth and reproduction. Biogas is a byproduct of this conversion process and is composed primarily of CH_4. Biogas also includes carbon dioxide (CO_2) as well as some hydrogen sulfide (H_2S) and ammonia (NH_3), which must be removed for certain biogas end uses (Agstar, 2020). When using a gas generator to produce electricity in this application, it is important to eliminate H_2S gas because the H_2S gas can cause corrosion, and reduced service life, of the generator.

The AD system creates a controlled environment that efficiently converts biodegradable organic materials into biogas and produces a stabilized residual effluent (digestate) that can be used for fertilizer, i.e., land application. The primary responsibility of the AD/biogas system is to maintain process stability and capture the byproduct gases. To capture the produced gas, a geosynthetic cover system is recommended due to its flexibility, impermeability, chemical resistance, longevity (at least ten years), and low cost.

5. Geosynthetic Cover Systems

Geosynthetic cover systems have been used for a number of years to control odors from liquid manure ponds and capture biogases. Nicolai et al. (2004) and Bicudo et al. (2004) conclude that geosynthetic cover systems reduce odors from manure ponds by 95%. This value is below 100% because pond covers can be removed periodically for agitation and manure pump out but 95% capture is still a great advance for livestock farms and the environment. Geosynthetic covers have been used for a number of manure storage applications including ponds with constant liquid levels (biogas collection) and ponds with variable liquid levels (slurry storage), which are discussed separately below.

i. Biogas Collection

Biogas collection refers to a pond that is used to create an anaerobic digester for treatment of intensive livestock production including the dairy and beef industry manure contaminated liquid. In this application, 90 to 95% of the solids are separated out before the contaminated liquid is placed in the AD. Because significant quantities of biogas can be generated after placement in the AD, the geosynthetic cover system can often lift off the surface of the pond due to the stored gas underneath the cover (see **Figure 1**). The most successful AD covers are operated at a constant liquid level and not opened for agitation or pump-out. Key factors in the design of an AD cover system are the efficient movement of biogas and development of tensile stresses in the cover to resist internal pressures from gas generation and prevent wind damage after inflation as well.

Figure 1. In-service positive pressure biogas cover systems.

ii. Slurry Storage

Slurry storage refers to a pond that primarily contains liquid waste and it is open to the atmosphere. As a result, a geosynthetic cover system can reduce evaporation and odors. In this application, most of the solids are not placed into the storage pond, i.e., not separated out like with a biogas pond. The air space underneath the geosynthetic cover system becomes saturated with water vapor and other gases due to the low transmissivity of the geomembrane. The accumulated gas is removed via vacuum, which also keeps the cover system nearly flat on the liquid surface so a large "head space" does not develop. A slurry storage system is typically used for swine operations and gas destruction is metered for carbon credits in some countries. Key factors in the design of this geosynthetic cover are the cover needs to be flexible to rise and fall with the manure level and accommodate the annual agitation and pump-out of manure.

iii. Factory Fabricated Geosynthetics

The geosynthetics used in these cover systems can be pre-fabricated before arriving at the project site. The constant and favorable factory-controlled environmental conditions yield higher quality, such as, better seams between individual geomembrane rolls, than field fabricated geomembranes and fewer opportunities for damage by field activities and personnel. Stark et al. (2020) compare factory and field welded thermal geomembrane seams for a large off-stream water reservoir project. This comparison shows that factory welded seams exhibit higher seam peel and shear strengths at yield, less variability, and more consistency than field welded thermal seams. The compiled test results show that factory seams are about 10% stronger than field seams in shear strength and about 9% stronger in peel strength at yield. More importantly, the higher seam strengths resulted in 100% of the factory welded seams passing the project seam strength requirements even though the factory welding speed was 1.1 to 1.6 times faster than the field welding speed. Conversely, about 25% of the field welded seams did not pass the seam shear strength requirement, which caused significant delays, scheduling, patching, re-testing, costs, lower overall quality, and other construction issues. Because the geomembrane was primarily factory fabricated, there were about 78% less field seams on this project (Stark et al. (2020) than if the geomembrane was entirely field fabricated, which allowed the challenging project schedule to be achieved. The use of factory fabricated geosynthetics also allows modular construction, which yields a smaller carbon footprint because electrical power generated from renewable sources or less carbon intensive sources than hydrocarbons can be used for 80 to 100% of the geomembrane and geotextile seaming instead of hydrocarbon energy source(s) used for field fabrication. In summary, factory fabrication results in high quality, sustainable, innovative, efficient, lower cost, and shorter time for completion of geosynthetic installations (Silva et al. 2021).

Because factory fabricated geomembranes and geosynthetics are recommended for positive pressure biogas cover systems due to the pond sizes and need for quick installation, high density polyethylene (HDPE) geomembranes are not included in this guideline. The main reasons for this exclusion include:

a. Cannot fold and transport without inducing stress cracking and permanent deformations so they cannot be factory fabricated,
b. Exhibit low strains, i.e., yielding, to the peak tensile resistance,
c. Exhibit poor dimensional stability, i.e., wrinkles significantly due to changes in temperature, and
d. Are susceptible to fatigue cracking, which is not desirable because positive biogas cover systems are subjected to repeated cyclic loads.

Prefabricated cover panels should be fabricated to FGI guidelines by an experienced fabricator. For biogas and slurry storage applications, fabricated geosynthetics are typically fabricated into panels with an area of 2400 m^2 (25,824 ft^2) or about half an acre in size. If needed, these panels can be welded together in the field to create even larger panels. Prefabricated geomembrane panels are shipped to the project site in time for the planned installation. These panels can be shipped in advance and stored if required, however, they should be stored in a suitable location and environment (see ASTM D7865 for storage recommendations). Other site preparation may be needed, such as installation of specific gas piping, during the installation.

The factory welding of multiple rolls of geomembrane into a fabricated panel results in a panel much wider than the initial roll widths. This wider panel can either be rolled "as is" (rolled panel), or accordion-folded and then rolled or double accordion folded for transport. Rolled panels are typically 10 m to 13 m (32 ft to 42 ft) wide because it is difficult to physically handle wider rolls without damaging them. Most fabricated panels are accordion-folded to a narrower width of between 1.7 to 4.0 m (5.5 ft to 13ft) and then rolled.

For a fabricated panel to be properly used it must be adequately identified and packaged (see ASTM D7865 for more details). It also must be handled and stored in such a way that its physical property values are not degraded. Failure to follow the best practices may result in the unnecessary failure of a fabricated panel in a properly designed application (see ASTM D7865). Additional details on proper transportation and handling of geomembrane panels are discussed in Section 11 below.

For installation of the geosynthetics, two or more skilled installers are on the project site and approve the deployment area's subgrade before geosynthetic placement. Local equipment and laborers stage the geosynthetics, fill sandbags for ballasting and wind safety (see **Figure 2**), place gas collection piping, and rig pulling ropes for deployment of the cover system across the filled pond.

Typically, cover membranes are installed in a process whereby accordion folded panels or roll stock is un-wound on a deployment berm that is perpendicular to the long axis of rectangular ponds. They will be pulled onto and across the pond with ropes to the opposite embankment. This design orientation ensures that all seams span the minimal length possible. Site layouts will often need flat unobstructed deployment berms that are 15'-20' wide and extend 6'-10' beyond the cover terminations along the tops of the longitudinal embankments. The opposite embankments were the covers will be pulled from will typically require the same clear footprint area.

Once weather permits the prefabricated panels are unrolled and welded together, if necessary, to create a panel large enough to cover the entire pond in one deployment.

After the panel(s) are ready for deployment, a leading edge float is inserted into a pocket on the leading edge of the geomembrane panel and pull ropes are attached to the leading edge to pull the geomembrane across the liquid. Pull-on operations are typically done in incremental indexing movements. Pauses are made in the pull on process to weld additional

The rear edge of the geomembrane is placed in the anchor trench with the appropriate slack so the entire geomembrane is not pulled across the pond only the leading edge. If a new pond is being constructed, the cover system can be deployed and finalized on the bottom of the new pond and then the pond is filled. Once the geomembrane is installed and the anchor trench backfilled with soil, biogas safety valves are adjusted as needed and the gas collection tube is connected to the gas collection system to ready the system for operation.

iv. Costs

The cost of a geosynthetic cover includes factory fabrication, freight costs to ship the geosynthetics to the project site, and one or two or more skilled people to perform field welding and direct the installation because the majority of the fabrication is performed in a factory. Freight costs can be significant depending on the distance from a fabrication location to the project site. The smaller the project the higher the unit per area costs rise and the more difficult it becomes to provide budgetary costing. For example, the unit cost of freight on o full truck is much lower than the unit cost per a partial load. The unit cost of a stormwater removal pump on a small cover is just as much as the cost of a large cover but costs are amortized over very different areas which really impacts unit area costs. Cost for the supply and installation of a biogas or slurry storage cover system is between \$16 m2 and \$21 m2 (\$1.50 ft^2 and \$2.00 ft^2) of surface area before the pandemic and associated inflation depending on project specifics.

Typical cost for these covers is independent of whether the cover is used for biogas collection or slurry storage. Anchor trench excavation and backfill are not included in the cost range above but an estimate of \$8 m2 to \$10 m2 (\$2.50 ft2to \$3.00 ft2) is appropriate in most locations. Most projects will take two days to install but will require good weather for those two days (no precipitation and wind under 12 km/hour [7 mph]). Other materials required to be supplied on site are a quantity of sand for making sandbags (wind safety) and the necessary piping.

Figure 2. Geosynthetic biogas cover system experiencing uplift due to wind loads.

6. Safety

This guideline does not purport to address all of the safety concerns associated with its use, especially in the environment in and around biogas cover systems. It is the responsibility of the user of this guideline to establish appropriate safety. In farm environments, winds can be so strong that work in the area is often interrupted. Appropriate safety measures should be implemented in strong winds.

The installation of positive pressure anaerobic digesters requires a site-specific safety plan addressing safety training and equipment including fire prevention and protection. Specifically, the following inspections should be conducted before starting installation:

a. Conduct a thorough safety analysis of the site conditions before commencing any work.
b. The safety analysis must consider the proximity to clean water and if effluent is

present, the additional hazards associated with physical contact and the likelihood of biogas creating an explosive environment during installation should be evaluated.

c. A system to vent excessive gas generated under the geosynthetic cover is required to avoid excessive stress developing in the geosynthetics and explosive conditions. Emergency release vents may be positioned at various locations on the cover to release pressure or at a gas takeoff point(s).
d. A site-specific safety plan is required that addresses safe work conditions including fire retardant clothing, fire suppression equipment, non-sparking equipment, evacuation routes, nearby medical facilities and contact information, and overall safety training.

Proper safety procedures should be observed at all times when inspection, operation, or maintenance work is being performed around a biogas collection pond or slurry storage. Specifically, the following minimum safety rules should be adopted and enforced by the owner and installer:

a. No fewer than two workers should be present at a location when work of any nature is taking place around a biogas cover.
b. Due to the methane content of biogas, no smoking of any kind is permitted.
c. The installation technicians, and any support crew must at all times, be ready to deal the treat of a spontaneous fire.
d. Sharp knives should be properly sheathed and secured to prevent personal injury and damage to the geosynthetics/geomembrane.
e. All individuals accessing the top of a geomembrane should be advised that the geomembrane may be slippery when wet.
f. As much as possible, all workers should walk on access pathways where provided.
g. Electrical tools used to facilitate repairs to the geomembrane while it remains in service must be protected by an appropriate ground fault interrupting (GFI) device at the source of power and be certified non-sparking

7. General Best Practices for Installers

This section provides some best practices for installers of positive biogas cover systems. The following best practices should be considered/used by installer personnel:

a. Do not use equipment or tools that are sharp or bring sharp objects onto the deployed geomembrane panels.
b. Smoking on the geomembrane is prohibited.
c. Avoid shoes that can damage the geomembrane and other geosynthetics.
d. No chemicals can be left on top of the geomembrane.
e. Whenever solvents are used, they must be capped immediately after use. While not in use, solvents should be stored in their original packaging and in a protected location.

f. Geomembrane welding personnel must be informed of the risks of using a solvent and use appropriate personal protection equipment (PPE), such as gloves and masks during the operation.

8. Terminology

Some terms related to this guideline are defined within this section. Additional terms may also appear in ASTM D 4439 and D7865.

Fabricated panel**:** refers to a geomembrane panel fabricated at a manufacturing facility into a larger panel than the original roll stock material. A fabricated panel may be a larger rectangular panel of geomembrane or may be a specific fabricated shape or may contain special job-specific detail work.

Rolled panel**:** refers to a fabricated panel that is rolled from one end or in some cases from both ends to the middle.

Accordion-folded panel**:** refers to a fabricated panel where the material is folded back and forth in a "Z" formation in the same principal direction as the seams. This folding takes a wider panel of material and makes it into a narrow stack. For example, a 30 m by 30 m (98 ft x 98 ft) prefabricated panel could be accordion-folded into a 3 m (9.8 ft) wide stack of material 10 layers deep and 30 m long.

Accordion-folded and rolled panel**:** refers to an accordion-folded fabricated panel that is first accordion-folded to the desired width and then rolled to form a finished, rolled bundle for transport.

Double accordion-folded panel**:** refers to an accordion-folded fabricated panel that is accordion-folded to the desired width and then accordion-folded in the length direction onto a pallet (or into a container). Double accordion-folded panels typically appear as a "cube" of material with square corners.

Fabricator**:** the person or organization by whom the geomembrane material is fabricated into a fabricated panel.

Anaerobic digestor**:** a pond used to create an anaerobic digester for treatment of dairy and beef industry manure contaminated liquid with less than 10% solids.

Aerobic digestor**:** a pond that primarily contains liquid waste and it is open to the atmosphere primarily for swine operations.

9. Geomembrane Selection and Testing

This section provides guidance on geomembrane selection for positive biogas covers and the associated testing to demonstrate the desired properties. Given the demanding requirements of a positive biogas cover, the design engineer/owner should work with the geomembrane manufacturer to select geomembrane best suited for this application to ensure long-lasting, i.e., at least ten years with an expectation of twenty years, performance. This longevity will enable collection of the biogas over a long period, which will help defray the initial capital costs of the cover system.

The following table presents some of the important properties, e.g., UV, chemical, elevated temperature resistance, , for a positive biogas cover system and the recommended test procedure(s) to evaluate the property. All geomembrane cover materials need to be suitable for prefabrication including sufficient yield and flexibility properties. Finally, the table presents a minimum value for some of the desirable properties for the biogas cover application. The geomembrane can be reinforced or monolithic (unreinforced). Both types of products will need straps to hold down the geomembrane when it is under positive pressure. Generally, geomembrane materials used for biogas covers require a minimum 10 year manufacturer's weathering warranty.

Table 1. Important geomembrane properties for positive biogas cover systems.

UV resistance

Test	Test Method	Acceptance
Accelerated UV exposure for 10,000 light hours.	ASTM D7238	
Inspect for crazing, cracks, and surface degradation	GRI GM16	Pass
Retained strength	ASTM D751 grab tensile	80% (minimum)

Elevated Temperature Resistance

Test	Test Method	Acceptance
Oven aging at 85C for 90 days	ASTM D5721	
Inspect for crazing, cracks, and surface degradation	GRI GM16	Pass
Retained strength	ASTM D751 grab tensile	80% (minimum)

Chemical Resistance

Test	Test Method	Acceptance
Resistance to Methane Gas	TBD	TBD
Resistance to Hydrogen Sulfide GAs	TBD	TBD

Methane Permeability

Test	Test Method	Acceptance
Methane Gas Permeability (34.5 kPa / 100% RH / 25C)	ASTM D1434	1,000 ml/m^2/day (maximum)

10. Fabrication (In-Factory) Thermal Welding

Geomembranes sheets are manufactured and transported in individual rolls, i.e., rolled goods. The rolls are shipped to a geomembrane fabricator. The fabricator cuts the rolls to desired lengths and welds them together to create large panels. As individual rolls are unwound, they shall be visually inspected for possible defects or damage. The welds are tested for seam integrity by the fabricator before shipping to the project site. The typical minimum seam width for welding is a normally 50 mm (2 inches).

Seams typically represent the weakest areas of a biogas cover. It is critical that geomembrane panels have seams orientated to align the short axis of a lagoon or digester to minimize stress along them. Cross seams should be avoided. Welding techniques in the factory may include radio frequency welding, solvent, hot air welding, and wedge welding. In the field, typical welding techniques are solvent, hot air welding, and wedge welding. Different materials material may require more specific welding methodologies.

Radio frequency welding, also known as and high-frequency welding and dielectric welding, is a process that utilizes high-frequency electric fields to induce heating and melting of thermoplastic based materials. This process requires repeated clamping of the overlapped materials between a conductive sealing bar and platen that passes the radio frequency field through the material in incremental steps to advance from one end of seam to the other. The method is only practical for factory welding and can be utilized for materials that have dipoles, such as, PVC, most EIA's (Elvaloy®), and polyurethane based geomembranes.

Hot air welding is mostly used in conjunction with scrim reinforced membranes and it may otherwise cause deformation in un-supported or unreinforced materials. This method typically involves the introduction of hot pressurized air through a nozzle between two overlapped sheets of geomembrane quickly followed by pinch rollers that press the heated sheets together as welding progresses.

Thermal wedge welding is a process utilizing a heating element that makes intimate contact with the surfaces of overlapped geomembranes being welded. This method of welding is typically usually applicable to all geomembrane types either monolithic non-supported or supported with a reinforcing scrim fabric layer.

Geomembranes requiring taped or solvent welds are not recommended for positive pressure gas covers based on the high operational pressures involved and requirement for high factory and field seam strengths.

i. *Testing Factory Welds*

Testing should be in general accordance with ASTM D 7982, D7747 (reinforced geomembranes), D6392, D6214, D882 (unreinforced geomembranes), or other relevant test method. Trial welds should be evaluated prior to starting any panel fabrication. The trial welds must pass all seam peel and shear strength testing requirements before any panel production starts. Welder(s) should be retested at 4-hour intervals. Using trial seams. In addition, it is recommended that all seams, and patches, be 100% air-lance tested per ASTM D-4437. The results of all testing must be documented and available to the owner and/or engineer responsible for the project.

ii. *Geomembrane Repair and Patching*

This section provides some techniques for repairing and/or patching geomembranes before and after installation. Typically, no more than two patches are allowable for every 30 m (100 ft) of weld.

To patch a biogas cover geomembrane, use the same material as the original geomembrane, e.g., polypropylene, LLDPE, PVC, etc., prepare/clean the area to be patched, use a patch with a minimum of 150-mm (6 inches) overlap extending beyond the damaged area, and then apply the patch via suitable means, e.g., heat air or solvent. The patch material should have rounded corners. The patch should be continuously welded in place flat over the damaged area with roller pressure applied to the two surfaces to achieve a thermal or solvent bond between the geomembrane surfaces. The welded or bonded area is normally 2.5-cm (1-inch) minimum wide. If the geomembrane is scrim reinforced, the full perimeter edge of the patch should be sealed via heat gun capping with an unsupported film version of the geomembrane or extrusion welded to prevent wicking of moisture. No exposed scrim areas should be allowed if a reinforced geomembrane is used for the patch. In addition, the edges of all patches with reinforced materials should also follow manufacturer recommendations for sealing.

The various patching techniques include:

i. The edges of all patches used made with reinforced materials that are sealed per manufacturer recommendation.
ii. **Table 1** presents type of patching that should be used for a given geomembrane type. Note that reinforced materials are subject to moisture wicking and require re-sealing around their edges when cut to seal the reinforcing scrim.

Table 1. Patching technique for different geomembranes.

Geomembrane Polymer	Patch Application Technique	Comments
Elvaloy®	Heat gun for mechanical bond and extrusion welding or heat fused tape for exposed perimeter scrim encapsulation	Extrusion welds are not recognized as structural welds in the context of reinforced membranes.
PVC	Heat gun and/or solvent. Use a bodied solvent adhesive to encapsulate perimeter exposed scrim if material is reinforced	
Polypropylene Reinforced	Heat gun for mechanical bond and extrusion welding or heat fused tape for exposed perimeter scrim encapsulation	Extrusion welds are not recognized as structural welds in the context of reinforced membranes.

Unsupported LLDPE is not included in **Table 1** because it is not a suitable candidate for pressurized digesters due to creep and constant elongation with poor elastic memory. In addition, reinforced LLDPE exhibits creep within the seams and also should not be used in pressurized digesters. Unsupported HDPE is not included in **Table 1** because it cannot be factory fabricated, which is important because of the limited access and difficult field conditions around a biogas pond. Unsupported polypropylene also creeps and exhibits constant elongation with poor elastic memory so it is not included in **Table 1**. CSPE is not included in **Table 1** because of high cost and limited repairability over time.

Cap stripping is another patching method that involves bonding a separate strip of the parent geomembrane over an original seam to repair an extended length of seam found to be unsatisfactory. A cap strip can be applied using a hand-held heat gun and thermally welding the cap-strip patch to the original geomembrane. Cap strips should extend a minimum of 150-mm (6 inches) beyond the limits of the nonconforming seam and all corners shall be rounded. The bonded area of the cap-strip perimeter should be a nominal 2.5-cm (1- inch). A cap-stripped section must be nondestructively tested by air-lance testing around its full perimeter. After testing, if the cap strip geomembrane is reinforced the edge of the patch should be re-encapsulated via heat gun application of a non-supported material version or via extrusion welding to prevent wicking. Extrusion welds on any flexible membrane are for sealing purposes only and are not a structural seam component. Furthermore, extrusion welding can weaken flexible materials due to excessive heat build-up during the welding process so the heat gun temperature should be carefully selected. As a result, it is typically more desirable to re-encapsulate exposed scrim by cutting and applying non-reinforced or supported geomembrane over the exposed scrim area of the patch.

It is recommended that all patches be 100% air-lance tested per ASTM D-4437. The results of all testing must be documented and available to the owner and/or engineer responsible for the project.

11. Geomembrane Handling and Transportation

Proper care and handling of transportation is important to ensure all fabricated geomembrane panels are shipped and arrive at the project site without damage. ASTM D7865 provides suggestions for handling and transportation but some of the key points include:

i. Fabricated panels should be transported directly to the project site without being shipped by means of intermodal freight reducing double handling and potential freight damage.
ii. Proper packaging of panels is required including good conditioned custom sized wood pallets. The pallets should be wider than rolled or folded panel so the entire is supported. These pallets also require a protective wear strip between the panels and the top of the wood pallet.
iii. Fabricated panels need to be packaged with a durable outer wrap protective layer sufficient for abrasion prevention and weather proofing. The panels need to be tensioned strapped to the pallets and provide lift straps for loading and unloading. Panels need to be properly labelled for size, unfolding instructions, and with panel numbers associated with the specific MQA roll stock manufacturing and fabrication records.
iv. Equipment for unloading and handling of the fabricated panels should be evaluated and

approved for compatibility with the panel sizes, configuration, and weights before it is used. Panels should not be dragged at any time and should be properly lifted by a pallet jack or forklift. Lifting slings may be used to secure the panels during transportation and handling.

v. All fabricated panels should be inspected at the time of delivery to the site. The receiving inspection should also verify the quantity received and condition of the panels at arrival matches the shipping documents.

vi. Fabricated panels should be stored on site in a secure and properly compacted area allowing for adequate equipment access for loading and staging of installed panels. Moving of fabricated panels to the deployment and field fabrication area requires suitable lifting equipment following all site safety requirements. Equipment for moving and deploying panels must be evaluated and checked with packaging requirements including sizes and weights of panels.

12. Geomembrane Deployment and Installation

This section outlines some of the standard practices for preparation, deployment, and installation of factory pre-fabricated geomembranes for biogas cover applications. In positive pressure AD applications, the cover system is normally floated into place.

i. Field fabrication and deployment area requires a sufficient sized workspace for staging, unrolling, field welding if needed, and deployment of the factory fabricated geomembrane panels. The fabrication and deployment area needs to be dry, flat, compacted, and free of rocks, stones, sticks or any other debris that could damage the geomembrane as shown in **Figure 3**.

Figure 3. Deployment and fabrication area of geosynthetic biogas cover with the geomembrane panel being unfolded.

ii. The fabricated biogas cover panels need to be installed in good weather conditions, which includes low wind conditions. The project owner and installer must verify satisfactory weather conditions before scheduling the installation. The biogas cover should not be installed during excessive rain or wind conditions. It is recommended that installations not take place when wind speeds exceed 12 km/hour (7 mph) and in gusty wind conditions. The planning of the geosynthetic cover installation should avoid pulling the cover into the direction of prevailing winds if possible, to reduce uplift.

iii. Each fabricated geomembrane panel needs be placed in the correct starting point, which is normally located at a specific corner of the pond at the designated deployment and fabrication area. It is recommended that a panel layout diagram be prepared to ensure the panels are placed in the correct position before deployment. All fabricated panels should be labelled and marked to indicate the direction of the deployment and the sequencing order of the installed panels in accordance to the final site drawings and installation plan. The fabricated panels need to be unrolled in the principal direction on top of the berm area across the width of the pond. The panels need to be accordion folded and rolled in the factory so the material can be unfolded from the top layer during installation.

iv. The leading exposed edge of the first geomembrane panel being deployed needs to have extra reinforcement to prevent the geomembrane from tearing and provide sufficient strength for pulling the panel across the pond. The leading edge of the geomembrane can be reinforced by means of wrapping the exposed edge around wood beams (10 cm x 10 cm or 4"x4") as shown in **Figure 4(a)**. The wood beams need to be equally spaced out across the leading edge to function as the main pull points. The leading edge should also incorporate expanded polystyrene planks. The wood beams and foam planks ensure the leading edge has adequate strength and buoyancy.

v. Depending on the size of the fabricated panels, it is recommended that a 2.0 cm or 2.5 cm (¾" or 1") diameter polypropylene rope (see **Figure 4(b)**) be attached to both berm ends of the reinforced leading edge to pull the cover into place on top of the wastewater. Additional pull points equally spaced out across the leading edge are required and these should be pulled in a parallel straight direction from the opposite berm. The ropes need to be securely attached to the wood beam sections of the leading edge. The ropes then need to be attached to motorized equipment used to be pull the fabricated panels across the top of the pond. This can include heavy duty trucks, backhoes or onsite tracked lifting equipment such as forklifts. In addition to equipment, three to four field technicians should be located and spaced out on each side of the pond to assist with directing the cover into place. Under proper supervision, the cover should be pulled slowly and evenly in sections across the surface area of the pond ensuring the leading edge does not become submerged. Vehicles should be operated in lowest gear possible. Best results are achieved by utilizing excavators supporting the leading corners of the cover using their booms to lift the leading edge clear of side batter slopes.

(a) (b)

Figure 4. Photographs showing: (a) wood wrapped at the leading edge of the geomembrane (see yellow arrow) and (b) biogas cover geomembrane being pulled into place by yellow ropes and equipment.

vi. On larger projects, multiple prefabricated geomembrane panels may be required so the factory fabricated panels can be welded together on site and then floated into place. The fabricated panels need to be properly positioned and unrolled parallel to the prior uninstalled panel edge remaining on top of the berm deployment area to allow welding. The panels then need to be properly overlapped and prepared for welding. This process of welding additional panels is required until all panels are installed ensuring complete coverage of the pond surface area.

vii. Pending material type, typically the floating cover geomembrane panels should be deployed and welded when the ambient temperatures are between 4.4°C and 40.6°C (40°F and 105°F). The panel edges being welded need to be dry and cleaned prior to welding. All field welding should be performed by thermal bonding and tested in accordance with the appropriate requirements, e.g., GRI GM 19 (a or b). Welding in colder temperatures may require preheating of the geomembrane prior to welding. Welding in temperatures above 40.6°C (105°F) may require performing field welding in early morning hours or non-peak daylight hours. A proper safety and installation plan is required for both cold temperature and extreme hot temperature installations. Additional prequalification of the welding equipment is often required by the welder operator before starting any primary welding in both extreme cold and extreme hot installations. The resulting welds should be tested using a calibrated tensiometer to determine if the seam shear strength and peel strength meet project specification.

viii. Once the cover geomembrane is pulled into place, the cover needs to be adjusted to ensure sufficient material is distributed across the surface area including adequate material to be placed in the anchor trench. The anchor trench then requires immediate backfilling to prevent movement of the cover system. Anchor trenches for biogas covers should be designed to be larger in size than none pressure applications to ensure the cover and liner are securely anchored (see **Figure 5** for typical anchor trench dimensions). Before final anchor trench backfilling occurs, the cover should be temporarily secured in the anchor trench using sandbags or other acceptable types of weights. During backfilling operations, care must be taken to ensure uneven tension in the geomembrane does not develop. Special precautions need to be made if biogas is already being produced by effluent during installation, which could cause positive pressure to develop under the geomembrane.

ix. In addition to using anchor trench backfilling to secure the geomembrane cover, the geomembrane could be welded around the perimeter area of the pond to the geomembrane in the bottom liner system for restraint and containment of biogases. The type of welding used to weld the cover to the bottom liner system depends on the geomembrane used and can vary from hot air, wedge, and extrusion welding. Different materials material may require more specific welding methodologies to ensure a proper sealed and strong connection welding connection.

Figure 5. Photograph showing a 0.6 m wide by 1.1 m deep (24” wide x 45” deep) anchor trench to secure the geosynthetics after installation.

x. Once secured in place, the installation of ballasting weights on top of the geosynthetic cover is required. Ballasting weights are typically installed across the narrower width dimension of the pond at intervals determined by the project engineer. The ballasting weights are required to control the ballooning of the cover caused by the internal biogas pressure and to ballast the cover against wind loads. There are different methods for ballasting the cover system including the use of 15 cm (6”) diameter polyethylene pipe filled with structural grout (see **Figure 6(a)**), sand tubes, sandbags, or heavy-duty webbing material with a tensioning system. All ballasting should include welded support straps to keep the ballast secured to the cover geomembrane and preventing it from moving laterally (see yellow arrows in **Figure 6(a)**). Ballasting with structural grout filled pipes or webbing should also include securing the ballasting object outside of the pond surface area either by ground anchors(see **Figure 6(b)**), weights, or other mechanical means.

(a) **(b)**

Figure 6. **Photographs showing: (a) 15 cm (6”) diameter ballasting pipe filled with structural grout concrete and ballast straps (see yellow arrows) holding the pipe to the geomembrane and (b) ground anchoring of the pipe outside of the containment area (see yellow arrow).**

xi. Hatches required for aeration mixers or maintenance entry into the cover system should be prefabricated using a foam supported base system required to provide additional buoyancy above the wastewater. These prefabricated hatches should be installed on site in the berm fabrication and welding area prior to pulling specific cover sections into place (see **Figure 7(a)**). The hatches may need extra buoyancy so foam base (see yellow arrow in **Figure 7(b)**)) may be required.

(a) **(b)**

Figure 7. Photographs showing: (a) floating mixer hatch opening during installation and (b) hatch with an elevated foam base (see yellow arrow) required for additional cover buoyancy.

xii. All pipe penetrations and cover appurtenances that penetrate the cover geomembrane (see **Figure 8(a))** need to be installed by methods including welded pipe boots and mechanical anchorage in accordance with recommended FGI typical installation details and industry standards. These geomembrane penetrations include gas transmission piping, (see **Figure 8(b))**, emergency relief vents, gas vents, and sludge sampling ports. These penetrations should all be welded in place once the cover is pulled into place and secured as shown in **Figure 8(a)**. Depending on the geomembrane material type, welding and attachment of these various appurtenances should be performed by either thermal wedge, hot air, solvents, or adhesives.

(a) (b)

Figure 8. Photographs showing: (a) installed gas vent in cover geomembrane and (b) and gas recover piping system.

13. Environmental Loads, Ballasting, and Anchoring

This section provides basic guidance regarding structural design of bio-gas cover systems in positive pressure applications. Historically, design and structural detailing of these covers has been experience-based and proprietary to companies involved in their installation. However, regulatory drivers and interest in using the retained gas as renewable energy is dramatically increasing the size and frequency of bio-gas cover projects. Therefore, it is prudent to apply sound engineering principles to ensure safe and efficient operation of these systems because of gas flammability and potential environmental impact. The following engineering parameters must be established to complete the structural analysis and design the cover system:

i. *Design Operational Pressure* – the operator and gas process flow designer should provide this information. Otherwise, the safe operational limit must be specified by the cover designer, which cannot be exceeded by the operator.

ii. *Design Life Expectancy* – Where not provided by code or government regulation, the operator should provide the design life expectancy and of the cover system. In practice, most positive pressure biogas covers are designed to last 10 to 20 years with routine maintenance. Longer design life expectations and/or design for little to no routine maintenance will increase the initial construction cost and may not provide the best value.

As with engineering any structure, the risk of failure and life expectancy (based on proximity to human population and cost of repair/replacement) should be considered and weighed against initial and ongoing maintenance costs to develop the most efficient design combination.

iii. *Design Environmental Loads* – wind, snow, ice, rain, and any other anticipated environmental loads and load combinations that could be imposed on the cover system must be estimated. This information may be specified by code (ASCE 7 - *Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-22; https://www.asce.org/publications-and-news/asce-7*), government regulation, or provided by the operator based on risk tolerance. Otherwise, the maximum design wind velocity must be specified by the cover designer based on local conditions.

iv. *Dimensions and Geometry of the Cover System* – the operator or site Civil Engineer should provide dimensions and geometric details for the proposed biogas cover system. From a structural standpoint, a rectangular (long & narrow) impoundment allows for more efficient cover design compared to a square, circular, or irregular shaped structure.

v. *Geotechnical Site Parameters* – The site Geotechnical Engineer should provide the engineering characteristics, e.g., insitu and remolded undrained shear strength, plasticity, and moist unit weight) for foundation soils around the impoundment perimeter. Otherwise, minimum soil properties for use in cover and cover ballast anchorage must be specified by the cover designer.

Primary structural design considerations for positive pressure biogas cover systems include consideration of the tensile strength of the cover geomembrane, ballast requirements for the geomembrane during construction, and anchor trench dimensions and construction. The following paragraphs summarize the analysis for each of these items.

i. *Geomembrane Strength* – the flexible geomembrane cover system must be able to resist environmental design loads (wind, snow, ice, rain, etc.) while safely containing the design maximum operating (gas) pressure without seam or panel failure, excessive gas leakage, or permanent deformation. This analysis should include comparison of anticipated operational pressure stress/strain to be carried by the cover system to yield and/or ultimate stress/strain of the geomembrane forming the cover to ensure tolerable deformation. The anticipated stress/strain to be carried by the cover system depends on a number of factors including the operational pressure, environmental loads/load combinations and desired safety factor, unsupported span length of the geomembrane, geomembrane ballasting, and elastic properties of the geomembrane. Methods to evaluate anticipated stress/strain of geomembranes under pressure using both linear and stress-dependent moduli of elasticity is presented in Giroud et. al., 1995 (Giroud, J.P., Pelte, T. and Bathurst, R.J., 1995, "Uplift of Geomembranes by Wind", Geosynthetics International, Vol. 2, No. 6, pp. 897-952; https://www.researchgate.net/publication/284368677_Uplift_of_Geomembranes_by_Wind_-_Extension_of_Equations). Elastic beam theory has also been used to approximate stress/strain in a geomembrane in the linear or elastic deformation zone.

ii. *Geomembrane Cover Ballasting and Anchorage* – the cover geomembrane must be sufficiently ballasted and anchored to resist environmental and operational loads without rupture, excessive deformation, or detachment from the lagoon. Typically, perimeter anchorage is accomplished through an earthen anchor trench or mechanical attachment to a concrete ring wall (Koerner, R.M. (2012). *Designing with Geosynthetics*. 6th Edition, Xlibris Publishing Co., New York). Perimeter anchorage is normally designed to withstand the full rupture strength of the cover system where practical. Cover ballasting is often accomplished by end-anchored, grout filled pipes that run perpendicular to the long dimension of the lagoon. Other types of ballast may be used, e.g., sandbags, water tubes, etc., provided they are anchored to the geomembrane to resist sliding off during cover inflation or operational uplift. The size, layout, spacing, and anchorage of the ballast must be designed to maintain the desired shape of the cover, limit uplift of the cover, and resist environmental and operational loads without damaging the cover geomembrane. Ballast system design is best completed in conjunction with the cover strength design in the prior paragraph to ensure a balanced and efficient system design. It is important that the designer have a good working knowledge of structural and geotechnical engineering to properly consider stresses in and anchorage of the ballast system.

14. Venting and Emergency Gas Release Vent Systems

Positive pressure gas covers need to include gas cover vents and an emergency gas release venting system to prevent over inflation and potential rupture of the cover. Various systems are used in the industry including burping vents as well as both manual and automated emergency relieve venting systems. Manual emergency release vents typically use a manual open and close valve. The more automated systems include GPS systems which monitor the vertical cover inflation height and pressure sensors which monitor and vent the cover based on reaching specific water column pressures . Based on the size of the project, venting systems may be required in multiple areas of the cover as determined by the project engineer (Krohn, J. 2022).

i. Venting systems need to be properly attached to cover system including by welding and mechanical attachment.

ii. Gas release systems and vents need to be properly designed and approved by a licensed engineer and comply with the project safety plan as outlined in section 6.

iii. Gas release systems and cover vents should be regularly inspected and maintained

(a) (b)

Figure 9. Photographs showing: (a) manual valve emergency gas release system and (b) gas burping vent.

15. Biogas Operation and Maintenance

This section provides recommendations and guidelines for the operation and maintenance of positive pressure biogas cover systems. In positive pressure biogas applications, the cover is typically exposed to continuous fluctuations of gas pressure under the cover. This constant movement along with other environmental factors such as UV radiation, wind, rain, snow, and ambient temperature variances can result in accelerated wear and tear on the cover system resulting in potential performance issues. Based on this, it is important that a regular preventative maintenance and inspection program is developed for all biogas cover systems.

i. It is recommended that the cover system is inspected by a qualified geomembrane inspection company and inspector with adequate prior experience in biogas cover installations.
ii. The inspecting company needs to properly document and record all relevant visual observations and site details following a proper inspection and maintenance checklist.
iii. Visual observation should include all geomembrane cover panels inspecting for punctures, tears, cracks, and any areas of potential leakage. All field seams need to be closely observed to ensure their weld integrity. In addition, all cover appurtenances and mechanical points should be visually inspected for seam quality, pullout, and leakage. All cover patches and repairs during the initial installation or subsequent inspection and repairs should be visually inspected and documented. The cover ballasting system including strap attachments and anchor system should be closely inspected. It is also important that the perimeter cover anchoring system whether using mechanical anchorage or an earth anchor trench be closely inspected for leaks or areas of concern.

iv. All identified areas of concern captured in the inspection report should be repaired and verified on a timely basis by a qualified geomembrane installer.
v. Proper safety procedures are required for both the cover inspection and any required repairs as outlined in section 2 of this guideline.
vi. As part of preventative maintenance schedule for the cover system, it is recommended that biogas covers undergo an inspection on an annual basis.
vii. It is suggested that the biogas cover inspection follow the recommendations and procedures outlined Fabricated Geomembrane Institute Operation and Maintenance Guideline for Geosynthetic Lined Water Reservoirs.

16. References

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