Positive Pressure Anaerobic Biogas Cover Systems

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Positive Pressure Biogas Covers

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Positive Pressure Biogas Covers

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Guideline for Positive Pressure Biogas Cover Systems

Fabricated Geomembrane Institute

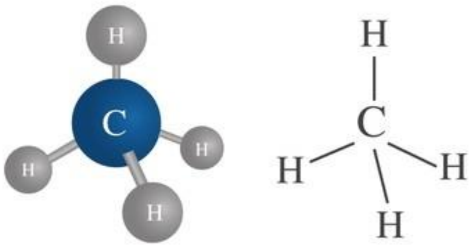
https://assets-global.website-files.com/5977726d80d12837b9592f43/635ab60264eaf33f6e8149c5_FGI-Biogas-Cover-Guideline-2022-9-29-22-Final.pdf

Presentation Outline

- Basics of Biological Conversion Process
- Main Functions of Biogas Cover Systems
- Design Considerations
  - Structural
  - Functional
  - Operational
  - Safety
- Geomembrane Material Selection
- Cover System Fabrication
- Geomembrane Installation Sequencing
- Biogas Operation & Maintenance Plan

Biological Conversion Process

- Anaerobic digestion is the process which micro-organisms break down organic matter in the absence of oxygen
- Anaerobic digestion converts organic material to biogas
- Biogas – CH4, CO_2, N2, H2, H_2S
- Lagoon Treatment - Solids are separated
- Biogas - electricity, heating, gas turbines
- Biogas Upgraders - remove $C0_2$, H_2S,
- Biomethane - Fuels for transportation
- Concentrated Animal Feeding Operations (CAFO), Food Processors, Municipal Waste



CH_4 Methane

Biogas Cover System

- Flexible Geomembrane Cover System
- Materials require adequate flexibility & tensile strengths in combination with ballasting & anchoring designs to withstand internal pressures
- Covers eliminate oxygen and enhances methane
- Methane is collected under the cover with a perimeter gas collection pipe
- Reduce odors and release of greenhouse gas
- Biogas cover – larger prefabricated panels joined by thermal welding on site and then floated into place

Biogas Cover System

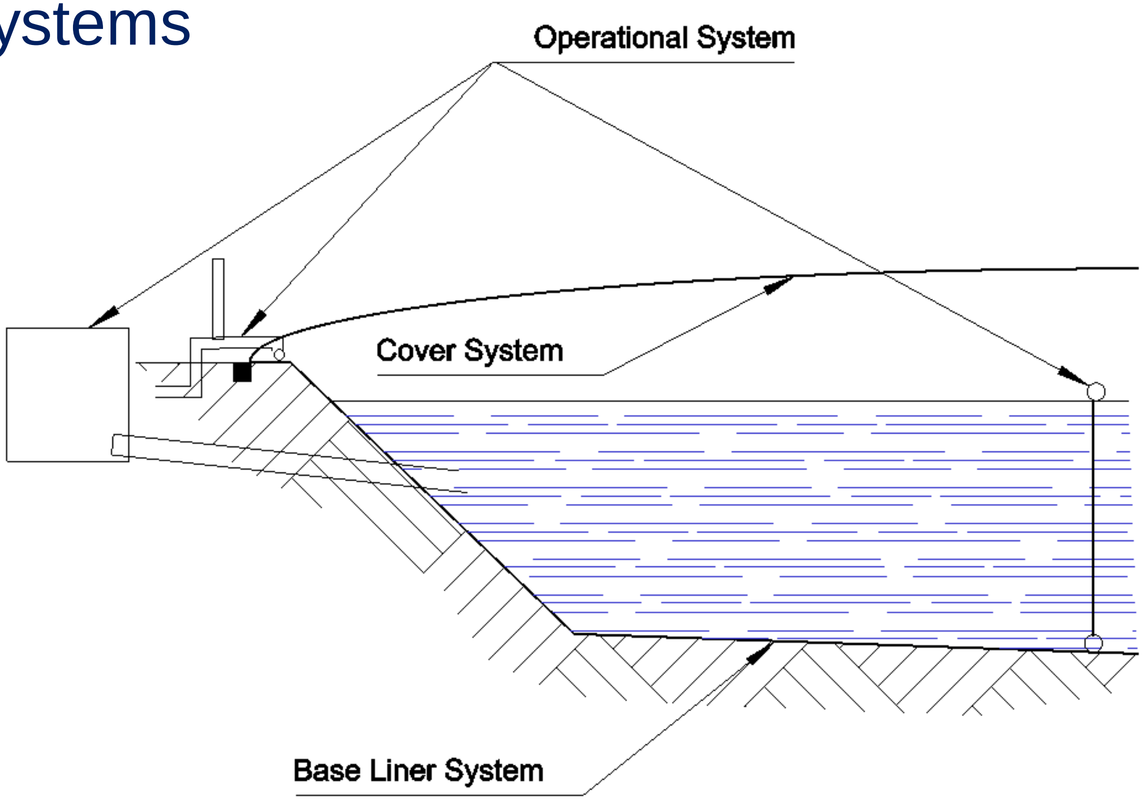
Photo showing perimeter gas collection pipe and baffle curtain being installed

Photo showing gas collection pipe and biogas cover being pulled into place

Design Considerations

Components of a Biological Digestor with a Positive Pressure Cover

- Base Liner System
- Operational Systems
- Cover System



Design Considerations

Cover System

FUNCTION

To capture digestor off-gas and route it to a collection system

STRUCTURAL PERFORMANCE REQUIREMENTS

- Contain off-gas without rupture or excessive deformation
- Resist external loads without rupture or excessive deformation
- Design is typically proprietary, and experience based – no regulatory or industry standard

PRIMARY COMPONENTS

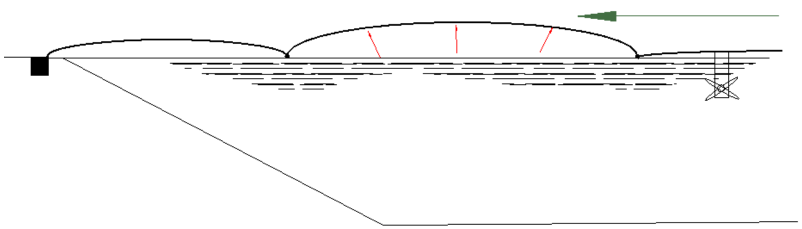
- Geomembrane
- Perimeter Anchorage
- Internal Ballast
- Mechanical Connections, Penetrations, etc.

RECOMMENDED ANALYSIS

- Define & estimate forces acting on cover
- Design and evaluate
    - Geomembrane strength and distortion
    - Perimeter anchorage requirements
    - Ballasting requirements
    - Functional requirements

Design Considerations

Estimating Forces



DYNAMIC

- Operational pressure (under cover) – significant, must be defined, operationally controlled and used in analysis
- Environmental forces – Wind, water, snow, ice, etc. – For positive pressure covers, wind is only significant environmental force due to ability to generate suction (uplift forces) in the same direction as operational pressure. Wind uplift must be estimated and considered in structural analysis
- Impact and abrasion – could be significant but rarely analyzed directly. Typically accounted for in material/load factors
- Personnel and Equipment – Relatively small and infrequent. Risk must be mitigated in Health and Safety Plan for Maintenance and Operations.

STATIC

- Uplift resistance of perimeter anchorage and ballast system – important, must be considered in analysis
- Self-weight– typically insignificant relative to operational pressure
- Weight of ancillary components within cover (mixers, electrical service lines, etc.) – typically insignificant relative to operational pressure. Attachment to cover, buoyancy during construction/ filling/ maintenance is generally considered in development of standard details but ignored in most project specific analysis
- Build-up of debris, soil, water, snow, ice, etc. on cover – Generally insignificant relative to opposing operational pressure, natural wind removal/evaporation and routine maintenance and cleaning – ignored in most analysis

Design Considerations

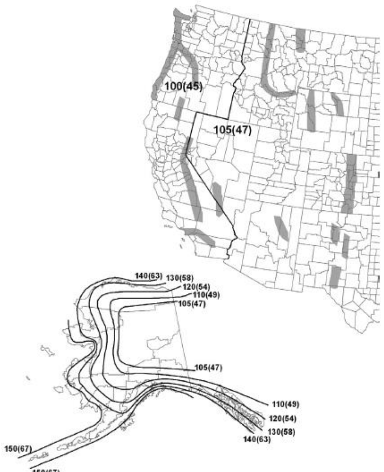


FIGURE 26.5-1C Basic Wind Speeds for Risk Category I Buildings and Other Structures

*After ASCE 7-16

$$\Delta p_R = \rho_o (V^2/2) e^{-\rho_o\ g\ z/p_o}$$

*After Dedrick (1975)

Estimating Forces

OPERATIONAL PRESSURE

- Generally, well defined by Owner (gas takeaway system) – must be monitored and controlled during operation. Typical value is ½-in W.C. (0.02 psi)

WIND UPLIFT

- No industry standard for estimate of wind uplift, method used up to designer
- Design wind speed must be defined by code, literature or Owner
- Several methods available for estimation of wind uplift force, all involve assumptions, uncertainty and modification to apply to digester cover application
  - ASCE 7-16 Method – apply appropriate factors for cost of failure and risk to humans, assume cover behaves like a dome or arch shaped roof structure with the spring line at grade – produces reasonable estimate
  - Li, C., et. al. 2020 – Covered in Recent FGI Webinar provides some additional considerations for customizing existing methods to more accurately model behavior of flexible exposed geomembranes.
  - Dedrick (1975) Method – applied by geosynthetics related publications (Wayne and Koerner, 1988; Giroud, et. al, 1995) – produces overly conservative estimate relative to application

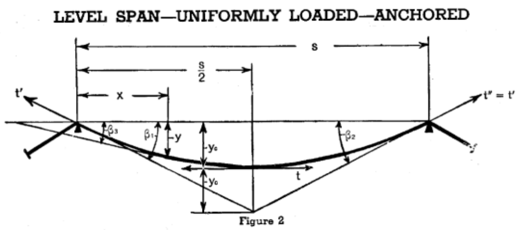
Design Considerations

Estimating Forces

<u>*UPLIFT RESISTANCE/ANCHORAGE*</u>

- Cover self-weight and ballast weight are well defined.
- Resistance to uplift provided through cover and ballast tension/anchorage is more complex due to relatively long spans, low modulus of cover and 3D interaction (load shedding) that occurs from the cover to the perimeter anchor trench – no standard approach
- Multiple methods (2D simplifications) are available to estimate uplift resistance provided through: Tension in the cover between ballast locations and/or perimeter anchorage; and Tension in the ballast lines between anchorage points
  - Tensioned cable method – approximates stress/strain and distortion in unit width of geomembrane using traditional tensioned cable theory but doesn't directly account for flexibility of materials, requires parametric analysis and iteration
  - Flexible Beam Model - approximates stress/strain and distortion in unit width of geomembrane by approximating geomembrane behavior as a simply supported low modulus beam
  - Normalized Tensile Stiffness Method, Giroud, et. al., 1995 – most commonly applied to geomembranes, pure form requires iterative solution
- All three methods produce comparable results if low modulus of cover/ballast materials is properly incorporated, flexible beam approach is the simplest

$$t = \frac{ws^2}{8y_0}$$



*Tensioned Cable Theory

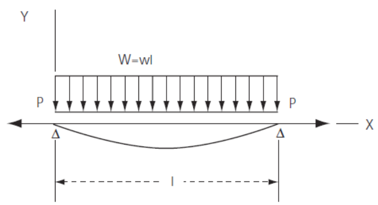


Figure 5. Flexible Beam Model.

$$P = \left[\frac{w^2 l^2 EA}{24}\right]^{1/3}$$

*Flexible Beam Model

$$\frac{S_e L}{2J\varepsilon} = \sin\left[\frac{S_e L}{2J}\left(1+\frac{1}{\varepsilon}\right)\right]$$

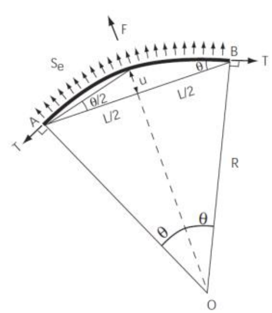
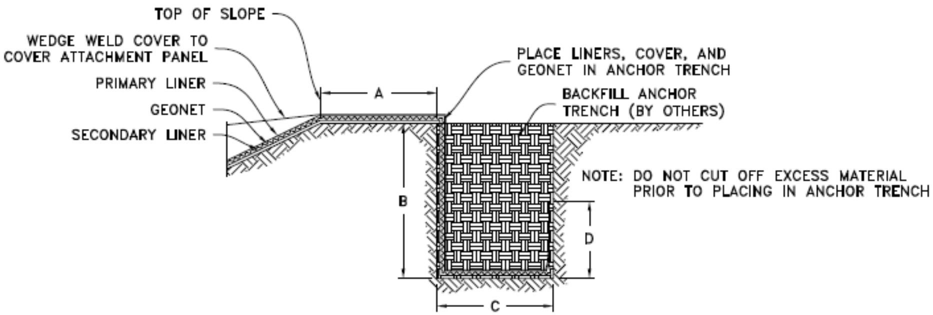


Figure 3. Giroud EGC Membrane Model.

*After Giroud, et. al, 1995

Design Considerations



DETAIL T3
SECURING LINERS AND COVER ATTACHMENT PANEL IN ANCHOR TRENCH

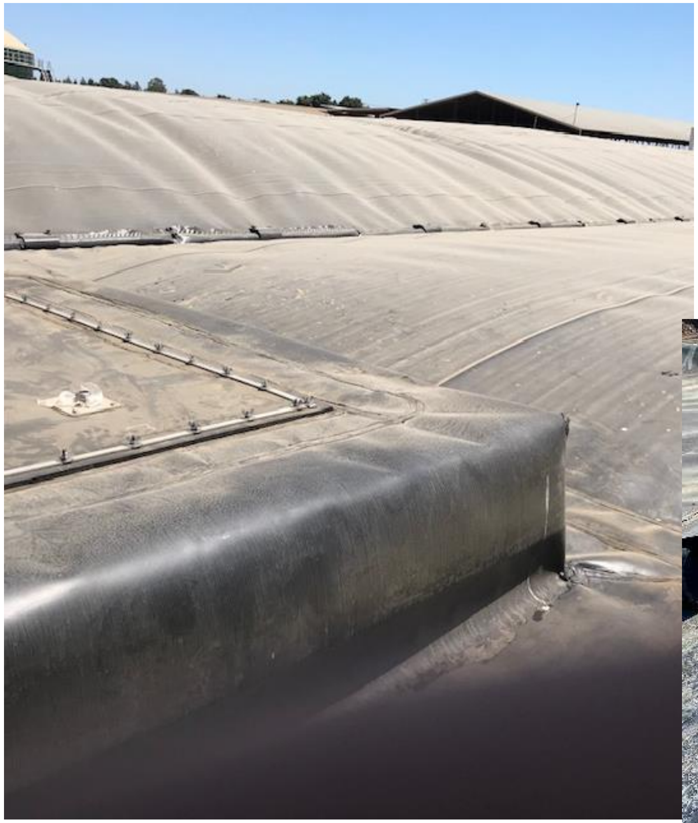
Perimeter Anchorage

COMMON METHODS:

- Concrete ring wall/foundation with post-installed concrete anchors and batten strips used to anchor the liner(s) and cover around perimeter –
  - Very effective & very expensive, mostly industrial locations
  - Requires structural design of wall to handle lateral loads at top
  - Requires structural and functional (seal) design of geomembrane connection to wall
- Anchor trench backfilled with compacted soil and/or concrete – liner(s) and cover placed in trench and secured via friction/weight of backfill
  - More common approach, mostly agricultural locations
  - Maximum load is produced by tension in the cover system (operational + wind loads), tension from liner(s) is generally much lower.
  - Load due to wind is highly uncertain – in order to reduce the risk of damage to the liner system (containment breach), the trench is designed to resist the full yield strength of the cover geomembrane – the cover would yield before pulling out of the trench and damaging liner(s)
  - Industry standard analysis is 2D, meaning the trench is designed to accommodate the design tension around the entire perimeter, applied at the same time – highly unlikely and conservative but justified – see ballast design…
  - Design Layout to avoid stress concentrations – radius corners
  - Engineering parameters of local soils must be estimated from experience or a Geotechnical Report to complete analysis
  - Mechanical anchorage may be added to reduce required size of trench

Design Considerations

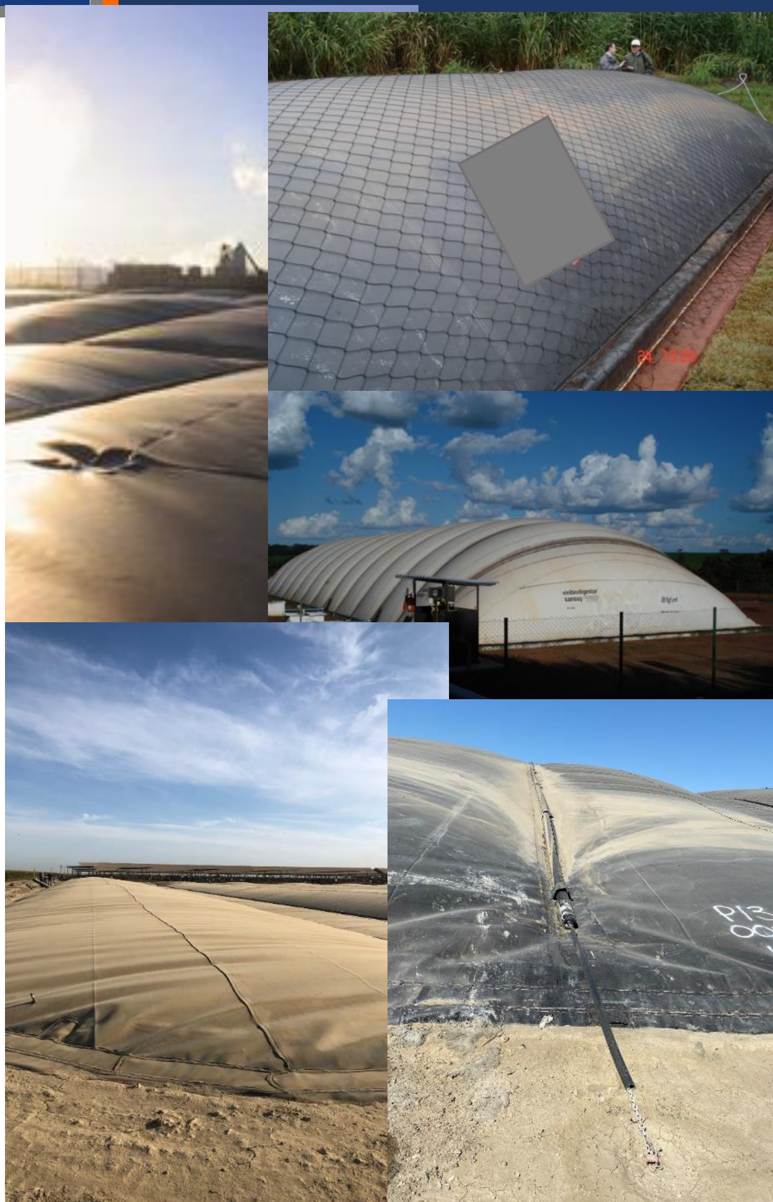
Mechanical Connections



Design Considerations

Penetrations and Seals

Design Considerations



Ballasting

<u>COMMON METHODS:</u>

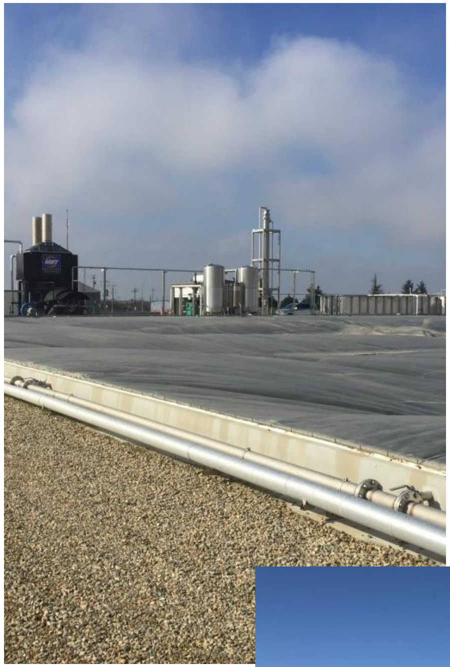
- Grid ballasting – Netting, steel or polymer Cables, Grout, sand or water filled tubes placed in a grid pattern over cover. Most include <u>end</u> anchorage to carry additional load through tension – more effective in regulating size and shape of cover "whales" and at countering uplift, but more expensive
- Perpendicular ballasting – Steel or polymer cables, Grout, sand or water filled tubes placed perpendicular to long dimension of lagoon at regular intervals. Most include <u>end</u> anchorage to carry additional load through tension – effective in regulating size and shape of cover "whales," not as effective at countering uplift
  - Analysis of this method indicates it is often not capable of resisting the full uplift forces created by design level winds (90 mph+)
  - Experience and performance monitoring of agricultural covers ballasted this way indicates "acceptable" performance… why?

Design Considerations





Design Considerations



Ballasting

RECOMMENDATIONS:

The following system layout recommendations improve ballast/cover system performance but are not always possible due to budget/space constraints

- Balance construction cost vs. risk/expense of failure
- Employ grid ballasting with concrete ring wall end anchorage
- When perpendicular ballasting is used
  - Layout lagoon geometry such that it is longer/narrower vs. square or irregular shape to minimize ballast line span
  - Create uniform cover spans where possible to limit differential horizontal stress on ballast lines (single, uniform spacing for mixer bays –if applicable, single uniform spacing for all other bays)
  - Minimize ballast line spacing to reduce cover span between lines
  - Add internal ballast weights to reduce ballast line span
  - Allow installation slack in ballast anchorage lines to increase deflection/decrease tension
- Design cover geomembrane to temporarily carry entire design load (operational + wind) without yield in the event of ballast line(s) failure – remember perimeter anchor trench should be designed for this load
- Engineer should provide Owner/Operator with maintenance "best practices" and inspection guidelines to monitor performance and correct issues before significant damage occurs
- Contractor should provide a warranty service contract option to ensure regular inspection and maintenance of system

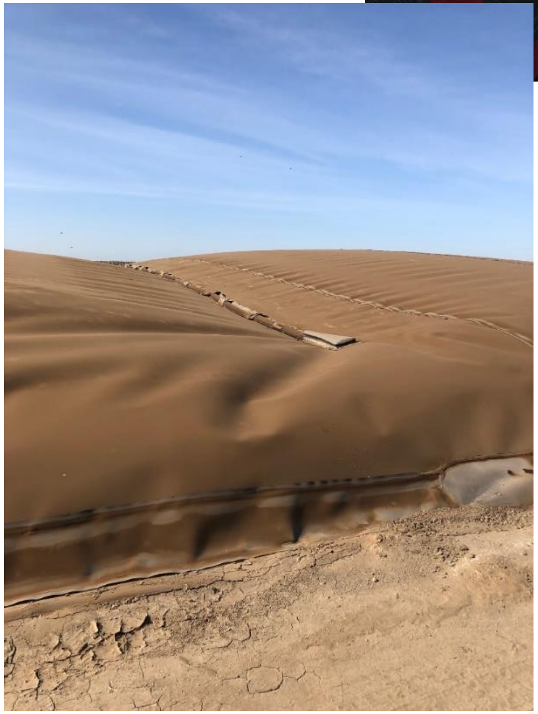
Design Considerations

Long-Term Performance, Maintenance & Monitoring

Environmental and Operational factors will have significant impact on longevity of the cover system

The Designer, Contractor, Supplier and Owner/Operator must consider the long-term impact of:

- Constant exposure to sunlight and then impact of UV degradation
- Elevated temperature impact on geomembrane relative to chemical degradation and mechanical properties
  - Internal due to digestion of waste
  - External due to sunlight
- Fatigue on cover material, welds and anchorage
- Abrasion and impact



Safety

- Positive pressure biogas covers can be very dangerous
- Project specific safety plans are required
- Safety Training including specific fire prevention
- Fire retardant clothing, non sparking equipment, ground fault, interrupting equipment, no smoking on site, fire extinguishers

Geomembrane Material Selection

- Common Materials
  - LLDPE, PVC, RPE, HDPE
- Life Expectancy – 10 to 20 Years
- UV Resistance
  - Geographical location & solar radiation levels
- Temperature Resistance
  - Ambient temperature, methane temperatures (85°F - 130°F)
- Chemical Resistance - CH_4, H_2S
- Low Methane Permeability Rate
- Adequate Weathering Warranty

Geomembrane roll stock

Geomembrane Material Selection

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)

Geomembrane Material Selection

GRI Method GM-35 QUVA Pressurized Test

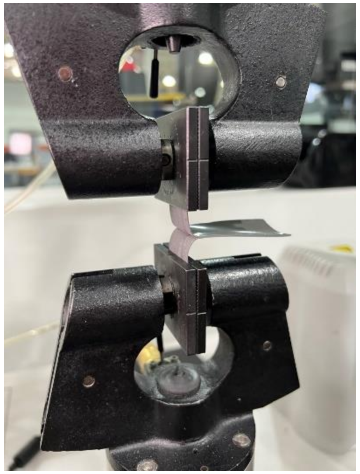
- 27 kPa (3 psi)
- UV Radiance
- Methane
- 70 deg C (158 F)

ASTM D7238 QUVA Test

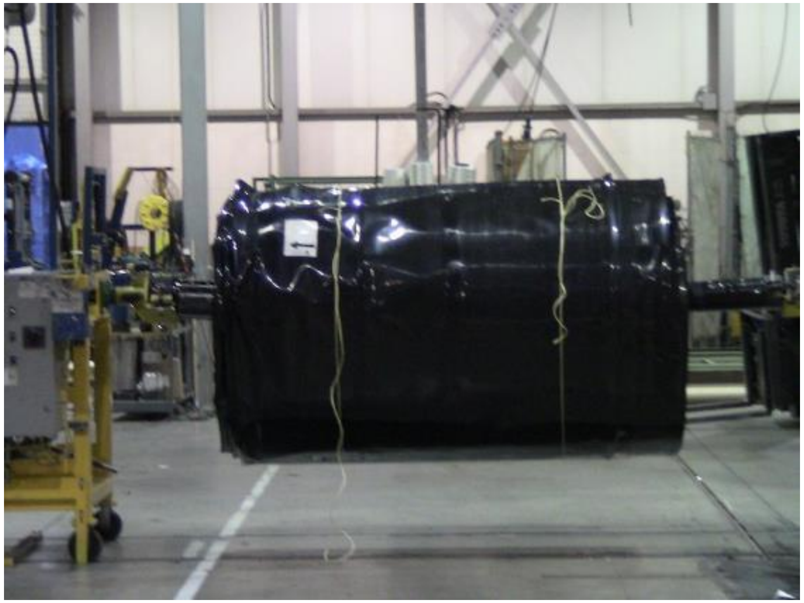
- UV Radiation
- Temperature
- Condensation
- Methane Exposure
- Material Burst Strength

Fabrication (in-Factory) Welding

- Factory panels welded in a controlled environment
- 75% reduction in field welds, reduced construction time & cost
- 2” (50 mm) thermally welded seams
- Factory Seams – Peel and Shear Testing
  - ASTM D7982 & D7747 (reinforced geomembranes)
  - ASTM D6392, 6214, D882 (unreinforced geomembranes)
  - ASTM D4437 – Air-lance testing of all seams & repairs
- Prefabricate components - aeration mixer access hatches required for buoyancy



Fabrication (in-Factory) Welding



Sequencing of Cover Installation

1. Appropriate work area at one end of lagoon for staging, unrolling, welding and deployment
2. Good weather conditions – low wind conditions
3. Reinforced leading edge for pulling cover
4. Proper sized pulling equipment & heavy gauge ropes evenly spaced in place
5. Larger projects require multiple fabricated panels to be welded together on site sequentially and floated into place
6. Material needs to be adjusted & distributed properly into the anchor trench and then backfilled

Cover Installation

7. Install ballasting weights, support straps, webbing
8. Install all cover appurtenances
   - Mixer hatches, gas vents, gas collection pipes, emergency release vents, sludge sampling ports, gas testing valves

- Note: Gases can start building up as soon as the cover is pulled into place

Cover Installation

Unrolled accordion folded prefabricated panels prior to installation

Cover Installation

Wood wrapped reinforced leading edge of geomembrane (left) and biogas cover being pulled into place (right) by yellow ropes and equipment

Cover Installation

Cover Installation

6” diameter ballasting pipe filled with structural grout concrete and ballast straps (left) and ground anchoring of the ballast pipe outside of the containment area (right)

Cover Installation

Installation of floating mixer hatch opening using an elevated foam base required for positive buoyance of the steel hatch.

Cover Installation

Installation of gas vent in cover (left) and main gas recovery piping system (right)

Operations & Maintenance

- Biogas covers are constantly moving
- Exposure to UV, wind, rain, snow, temperature variances & thermal expansion can accelerate wear
- Recommended annual inspection and maintenance performed
  - Inspected by qualified geomembrane inspection company
  - Properly document & record all visual observations
  - Inspection for punctures, tears, cracks, seams and repairs
  - Inspect all surface area including cover appurtenances
  - Inspect anchor trench and ballasting system
  - All repairs to be properly tested and documented

Reference - FGI Operation and Maintenance Guideline for Geosynthetic Lined Water Reservoirs

Positive Pressure Biogas Covers

Completed digester liner & cover system in Central Valley, CA

Positive Pressure Biogas Covers

Positive Pressure Biogas Covers

Questions?

Thank You

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