final report

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Anaerobic cover material vulnerability

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Executive Summary

Meat and Livestock Australia (MLA) appointed Golder Associates Pty Ltd (Golder) on 18 March 2009 to carry out a review of the availability and reliability of geomembrane covers to anaerobic ponds treating meat processing plant effluent in Australia.

Anaerobic ponds utilize microorganism to break down biodegradable material in the absence of oxygen (anaerobic process). The anaerobic process results in solids, liquor or effluent and biogas. The composition of the effluent and biogas will vary depending on the input materials. Generally, the effluent has high concentrations of FOG and the biogas has high concentrations of methane.

Geomembrane covers on anaerobic ponds are used in the meat industry to manage odour and control biogas release to the atmosphere or capture for energy production. However, floating or fixed polymer covers used on meat effluent anaerobic ponds have been known to experience issues associated with durability and in-service performance.

This report considers potential materials for anaerobic ponds and summarises performances of cover materials for various selection criteria. A literature study was carried out to assess the publically available information on cover materials used on anaerobic ponds. However, the research indicated that information on anaerobic pond covers was limited. Information on operating anaerobic ponds was also obtained through site visits at the following facilities:

- Werribee Waste Water Treatment Plant (WWTP) owned and operated by Melbourne Water Corporation (MWC);
- E.C. Throsby Pty Ltd (Throsby);
- AJ Bush and Sons Pty Ltd (Bush); and
- Ingham Murarrie Pty Ltd (Ingham).

The site visit to a WWTP was carried out since sewage also has high concentrations of fats, oils and greases. It was found that many of the facilities had experienced issues with durability and performance of the operating anaerobic pond covers.

Operating conditions for anaerobic ponds will affect the performance of the cover materials. The following operating conditions should be considered in the design of the cover:

- Composition of the effluent or liquor (fats, oils and greases can plasticise and soften the polymers in the geomembrane cover material);
- Acidic species in the effluent (e.g. sulphurous acid/sulphurous compounds) can promote acid hydrolysis of the polyester reinforcing scrims commonly used in reinforced geomembranes
- Temperature within the pond (based on the primary type of bacteria, mesophillic bacteria, commonly used in Australia, are able to survive optimally in temperatures between 35-40°C and thermophillic bacteria are able to survive optimally in temperatures between 55-60°);
- Expected effluent levels (static elevation covers can be constructed of stiffer material however variable elevation covers may require more flexible materials);
- Potential for floating crust or scum layers (scum layers can restrict gas paths, apply shear loads on the cover, disrupt drainage of the cover by distorting the shape, or subject the cover material to concentrated substances);
- High cover temperatures due to solar heating can cause the floating scum to desiccate leading to ‘scumbergs’ that are buoyant and which may place upthrust stresses on the cover, and
- External environment exposure (UV exposure, wind uplift, and animal attacks)

The materials selection for anaerobic pond covers is a critical part of the pond design and should also consider the following:

- Flexibility requirements;
- Tear resistance;
- Need for human traffic on the cover for removal of weeds, routine cleaning and maintenance
- Rain water management
- Rise and fall of the pond level
- Thermal expansion and contraction effects
- Avoiding blocking of gas collection paths
- Wind resistance;
- UV resistance;
- Fats, oils and grease resistance and durability;
- Scum adhesion;
- Top cover material colour;
- Installation restrictions;
- Susceptibility to animal attack;
- Ease of in-service repair; and
- Cost.

The following are recommendations are based on the relative comparison of cover materials for the anaerobic ponds. Cover materials for anaerobic ponds of meat and livestock effluent are constantly subjected to chemical attacks from the fats, oils and greases in the effluent. Materials with good resistance to FOGs should be given more consideration. This is especially critical given that FOG compounds are lighter than water and therefore preferentially concentrate at the water surface.

As the covers are exposed to long term UV radiation they need to have good resistance to degradation from UV radiation and associated heat effects hence they must also be resistant to long-term thermal oxidation. Cover materials comprised of HDPE would be best suited for fixed (constant) elevation ponds since HDPE is not as flexible, but it should be noted that careful consideration should be given to designing around difficult geometry. CSPE, R-EIA would be best suited for variable elevation ponds since these materials are more flexible. However, CSPE cures with time, which may impede repairs during the design life of the cover and R-EIA can undergo cracking and scrim degradation if the scrim reinforcement is left exposed hence the need to specify that the material has encapsulated edges. Therefore, the design of the cover material should consider any modification requirements after the initial installation and methods for protecting the scrim reinforcement. LLDPE and fPP are also quite flexible and may be chosen as cheaper alternatives to R-EIA and CSPE for variable elevation ponds. However, LLDPE and fPP are not as resistant to FOG and UV as HDPE and CSPE and may result in a shorter operational life.

In general if the stiffness of HDPE can be addressed in the design of the cover, this product is the material of choice due to its ready availability, low cost, and chemical robustness. Sometimes a large part of a cover is designed using HDPE and then the area that requires more flexibility are designed with a different product. This requires careful design of the interface and join of the different materials.

It should also be noted that specialist manufacturers of geomembrane products continue to develop alternative products and the application to floating covers to improve the long term durability, particularly with respect to flexibility and UV resistance is an aspect that has been identified for material improvement.

Glossary and Abbreviations

Absorption	The process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body, also, the increase in mass of a porous solid body resulting from penetration of a liquid into its permeable pores.
Aging	The process of exposing materials to an environment for an interval of time.
Anchor Trench	An excavated ditch in which the edges of a geomembrane are buried in order to hold it into place.
Antioxidants	Protects rubber compounds from damage from oxygen, light and heat.
Chemical resistance	The ability of the geomembrane to resist chemical attack.
CSPE	Chlorosulfonated polyethylene
Density	Mass per unit volume.
EIA	Ethylene interpolymer alloy.
Elasticity	The property of matter by virtue of which it tends to return to its original size and shape after removal of the stress which caused the deformation.
Embrittlement	The loss of toughness of a material such that if a crack is formed it rapidly propagates under an applied load. In the absence of an applied stress the polymer will often fail due to internal stresses developed. The loss of toughness is often seen in a reduction to a very low level of the elongation at fail (see mechanical properties).
EPDM	Ethylene propylene diene M-class rubber is an elastomer (ie. rubber) which is characterized by wide range of applications. The E refers to Ethylene, P to Propylene, D to diene and M refers to its classification in ASTM standard D-1418. The “M” class includes rubbers having a saturated chain of the polyethylene type.
Environmental stress cracking resistance (ESCR)	Resistance to brittle cracks that occur in ductile material under a constant stress lower than the short term yield or break strengths of the material. Such cracking generally occurs in the presence of chemicals such as of detergents, oxidizing acids and silicone fluids.
Failure	A condition or state that prevents the geomembrane from fulfilling its "intended purpose". Failure of the geomembrane therefore refers to a leak that permits process liquids to escape in significant quantities. An arbitrary point beyond which a material ceases to be functionally capable of its intended use.
FOG	Fats, oils and greases
fPP	Flexible polypropylene
Floating cover	A geomembrane floating on a liquid containment facility (e.g. pond) that is sealed around the edges of the pond by cables, batten strips or a ring beam and that falls and rises as the liquid level changes. A floating cover is mainly used for preventing evaporative losses and contamination of potable water, preventing contamination of valuable products such as molasses, for harvesting biogas and preventing odorous emissions.

Geomembrane	An essentially impermeable geomembrane composed of one or more synthetic sheets. According to ASTM D 4439 Standard Test Method, a geomembrane is a geosynthetic membrane or barrier with low permeability used with any geotechnical engineering related material so as to control fluid migration from a man-made project, structure, or system.
Hindered amine light stabilizers (HALS)	Additives that are incorporated in polyolefins and other polymers principally to confer UV stability but which also offer long-term thermo-oxidative stability at service temperatures by being retarders of oxidation. The polymer stabilization reactions generate reactive intermediates that are also stabilizers and are consumed only slowly in the polymer. Examples are Chimassorb 944 and Tinuvin 622.
HDPE	High Density Polyethylene
HP-OIT	High Pressure Oxidative Induction Time. Measurement of the Oxidation Induction Time of a polymer under the conditions of 150 deg C and 3.5MPa pressure of oxygen as described in ASTM D5885 for HDPE.
HRAL	High Rate Anaerobic Lagoon
Langley (Ly)	A unit of measurement of solar radiation
Leak	Holes, punctures, tears, knife cuts, seam defects, cracks and similar breaches in an installed geomembrane.
LLDPE	Low Linear Density Polyethylene
Millimetre (mm)	Unit of measure in which the thickness of a geomembrane is expressed. European and Australian units mm (1mm = 39.37 mil)
Mils	Unit of measure in which the thickness of a geomembrane is expressed. American units mil (1 mil = 0.0254 mm)

American unit of measure (mils)	Australian/ European unit of measure (mm)
40	1.0
60	1.5
80	2.0

Mechanical properties	Those properties, such as strength, stiffness and toughness that have been shown to be important for the mechanical performance of a material. The testing procedure involves the subjecting of a small test sample of defined shape and size to a deformation while measuring the stress that is produced as the sample is elongated (or strained) until it fails. This measurement if carried out in tension produces the following parameters – yield stress, yield strain, tensile modulus, yield elongation, break stress, break elongation. The area under a plot of stress against strain is a measure of the toughness of a polymer.
Membrane	A continuous sheet of material. Usually if carries the connotation of being impermeable although this is not strictly true.
OIT	Oxidation Induction Time. The measurement of the time taken for a sample to show heat evolution in a Differential Scanning Calorimeter (DSC) due to the onset of oxidation of the sample under the applied conditions.

Plasticiser	A material added to a plastic or rubber to increase its ease of working or flexibility.
Polymer	A macromolecule formed by the chemical combination of monomers with either the same or different chemical compositions. Plastics, rubbers and textile fibres are all high-molecular-weight polymers
Polyolefins	A group of hydrocarbon-derived polymers that are based on a repeat unit of which ethylene is the parent hydrocarbon (hence polyethylene). Examples include polypropylene (PP) and many copolymers such as linear low density polyethylene (LLDPE). The properties of polyolefins depend on the degree of crystallinity which is controlled by the structure of the polymer backbone defined by the monomers and the type of polymerization reaction.
Polyvinyl Chloride (PVC)	A synthetic thermoplastic polymer prepared by polymerization of vinyl chloride. PVC can be compounded into flexible and rigid forms through the use of plasticisers, stabilizers, fillers and other modifiers.
Puncture Resistance	The inherent resisting mechanism of the test specimen to the failure by a penetrating or puncturing object. The extent to which a geomembrane is able to withstand the penetration of an object without perforation.
Reinforcement	The layer of woven or knitted textile (usually an open-weaved mesh) used as a structural support and rip-stop in reinforced geomembranes (also known as scrim or fabric reinforcement). The reinforcement is usually enclosed between two geomembrane sheets, which are bonded together.
R-EIA	Reinforced Ethylene Interpolymer Alloy
R-fPP	Reinforced Flexible Polypropylene
Resin Manufacturer	Manufactures the resin from which the geomembrane rolls are made.
Selvage	The woven edge portion of a fabric parallel to the warp where the reinforcing scrim is encapsulated by the polymer plies such that the scrim fibres are not exposed.
S-OIT	Standard Oxidation Induction Time. Performance of an Oxidation Induction Time measurement in accordance with standard conditions described in ASTM D3895 of 200 deg.C and 1 atmosphere of oxygen for testing of HDPE.
Specification	A precise statement of a set of requirements to be satisfied by a geomembrane material or system that indicates the procedures for determining whether each of the requirements is satisfied.
Stiffness	Resistance to bending.
Strain	The increase in length per unit original length when a tensile stress (or flexural stress) is applied. The elongation of the polymer when expressed as a % increase of the original length is a measure of the strain. The change in length per unit of length in a given direction (synonymous with elongation).
Stress crack	An external or internal crack in a geomembrane caused by tensile stresses less than its short-time tensile strength.
Tear strength	The force required either to start or to propagate a tear in a geomembrane under specified conditions. Test results are dependent on direction of tear, specimen geometry and rate of tear.

Tensile Strength	The maximum resistance to deformation developed for a specific material when subjected to tension by an external force.
Thermoplastic	A plastic capable of being repeatedly softened by increase of temperature and hardened by decrease in temperature. Most polymeric membranes are supplied in thermoplastic form because the thermoplastic form allows for easier seaming.
Typical value	For geomembranes, the mean value calculated from documented manufacturing quality control test results for a defined population obtained from one test method associated with on specific property.
UV Degradation	The breakdown of a geomembranes polymer when exposed to sunlight.
Wicking	Transport of water along scrim reinforcement fibres due to capillary action. Via this mechanism water ingress into reinforced geomembranes can occur leading to deleterious effects such as hydrolysis of the polyester scrim, blistering and delamination.

1 Introduction

Meat and Livestock Australia (MLA) appointed Golder Associates Pty Ltd (Golder) on 18 March 2009 to carry out a review of the availability and reliability of geomembrane covers to anaerobic ponds treating meat processing plant effluent in Australia.

1.1 Background

Anaerobic ponds play an important part in the effluent treatment system for meat processing facilities. An anaerobic pond is an economical method for treating high strength effluent such as the effluent generated by the meat processing industry (Johns 1995; MLA 1998). The benefits are the production of stable, odour-free sludge that can be used as a fertiliser and the production of biogas for energy production. The major adverse issues with anaerobic ponds are odour generation and uncontrolled release of methane and carbon dioxide to the atmosphere. Installing a geomembrane cover, fixed or floating, over anaerobic ponds reduces odour release and permits the capture of methane rich gas.

Capturing of methane gas for power generation, if economically viable, is becoming attractive in light of the Carbon Pollution Reduction Scheme. If power generation is not viable, flaring of the gas can still lower the carbon footprint of the meat processing plant. A life cycle analysis by Turnbull and Kamthunzi (2005) on using covered anaerobic ponds to treat dairy manure on a 400 cow dairy in California showed that the greenhouse emissions and global warming potential could be reduced by 79% compared to the same dairy with no anaerobic pond. If biogas was collected from the anaerobic ponds at a typical meat processing facility and used in a gas boiler to displace 15% of fuel, it would save 56 GJ/day of fuel energy and the pay back period would be approximately 4 years (MLA 2002).

Geomembrane covers on anaerobic ponds are used in industries where odour and gas control is of importance. Some of these industries include food waste, meat processing and sewage treatment facilities. Floating covers have been used in the Unites States of America (USA) over anaerobic ponds in piggeries to collect the methane gas and control odours (Peggs 2005).

Floating or fixed geomembrane covers used on meat effluent anaerobic ponds have been known to experience issues associated with durability and performance. The contents of anaerobic ponds treating meat processing plant effluent are different to typical sewage treatment ponds. The high levels of fats, oils and greases in the meat plant effluent may have adverse effects on the durability of the polymer cover. In addition, the highly reducing environment with reduction potential in the lower ranges of -450 mV may affect the chemistry of the geomembrane cover. The high rate of biogas generation, the elevated temperature and rumen fluid contents makes the structural design of the cover system different to that of other industries where such covers are applied. The impurities of hydrogen sulphide, amines and siloxanes are known to cause corrosion and other operational problems to gas engines and boilers. These impurities could have adverse effects on the durability and performance of the cover materials.

The crust that forms on the surface of meat effluent can also have adverse effects on the durability and performance of the cover materials. The crusts on anaerobic ponds can provide a method for odour control where there is no synthetic cover. However, the crust can cause maintenance and operational problems should it form underneath the geomembrane cover. Crusts are lighter in specific gravity than the effluent and therefore can exert buoyancy to the geomembrane cover, affecting the operation of the anaerobic pond and gas extraction efficiency.

1.2 Scope of Work

The scope of work for the project was divided into three phases:

- **Phase 1 – Site Visits**
  Site visits were carried out at three different locations identified and facilitated by the MLA. The purpose of the site visits was to assess operational characteristics and issues related to floating covers.
- **Phase 2 – Desktop Study**
  A desktop study was carried out to identify the current practices in Australia and internationally. Other industries where anaerobic ponds are utilised were included in the study.
- **Phase 3 – Reporting**
  The findings of the investigation and assessment of the available materials were compiled into a report.

1.3 Objectives

The aim of this project is to improve the understanding and performance of geomembrane covers available to the meat processing industry in Australia, based on available information, current trends and international and local experience.

The detailed objectives are:

- A review and summary of the types, properties and typical costs of materials normally used in Australia for covering anaerobic waste water treatment plant ponds;
- Review of the operational performance of anaerobic pond covers in Australia including relevant details concerning their application, specification and robustness. The study is expected to identify failures and report the causes of failures, if known;
- Review of the vulnerability of the geomembrane chemistry of commonly used cover materials to attack by effluent components, especially fats, oils and greases or their breakdown products, elevated temperature of the meat processing plant effluent (in some cases over 45°C), gases such as hydrogen sulphide, amines, siloxanes and ammonia in biogas, physical factors such as rainfall, wind and sun, crust formation and the buoyancy effects of the crust and moisture level in the biogas; and
- Identify the major types of materials used for anaerobic pond covers and provide recommendations.

2 Anaerobic Ponds

2.1 General Description

2.1.1 Anaerobic Process

The anaerobic process utilises microorganisms to break down biodegradable material in the absence of oxygen. The process is regularly used to treat waste water sludges and organic waste because it provides both volume and mass reduction of the input materials. The anaerobic process results in solids, liquor or effluent and methane rich biogas suitable for energy production. The composition of the effluent and biogas will vary depending on the input materials.

The anaerobic process can be summarised into four steps as shown on Figure 1: hydrolysis, acidogenesis, acetogenesis, and methanogensis.

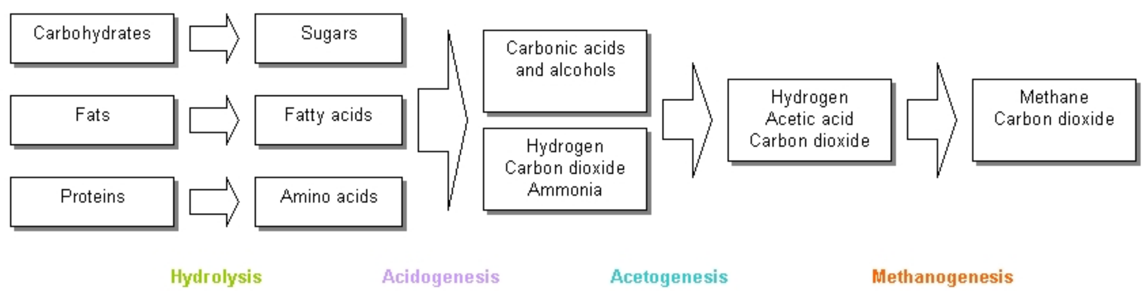

Figure 1. The key processing stages of anaerobic process (Koerner 2008)

The process, as described by Koerner (2008), begins with bacterial hydrolysis of the input materials in order to break down insoluble organic geomembranes such as carbohydrates and make them available for other bacteria such as fatty acids and amino acids. Acidogenic bacteria then convert the sugars, amino acids and volatile fatty acids into carbon dioxide, hydrogen, ammonia and organic acids. Acetogenic bacteria then convert these organic acids into acetic acid along with additional ammonia, hydrogen and carbon dioxide. Methanogenic bacteria finally are able to convert these products to methane and carbon dioxide. Careful control of the pond temperature, pH and loading rates are needed to obtain efficient breakdown of the influent matter.

Therefore, the anaerobic pond covers may be subjected to chemical attack from the resulting compounds of the anaerobic process.

2.1.2 Pond Operation

The anaerobic pond process consists of feeding a pond preferably continuously or with shorter regular feeds. The anaerobic bacteria break the organic constituents down to the basic compounds of water, methane and carbon dioxide. The content of the pond is generally well mixed, as the gas being generated in the anaerobic process mixes the influent. The effluent can be continuously decanted from the anaerobic pond to maintain the top level by either allowing the suspended solids to settle before discharge of the liquor, or directly dewatered. The resulting filtrate or liquor will contain high concentrations of nutrients and can not be discharged without further treatment. The solids can be used as fertiliser.

Mixing of the anaerobic pond contents may be with the use of mechanical mixers or by recirculating from various ponds. The mixing action can also be used to break any crust or disperse any foam that may form.

Separation of the solids can also be achieved in the anaerobic pond by stopping any inflow and mixing, letting the solids settle to the bottom and decanting clear liquor. The solids can remain in the anaerobic pond and will further degrade. At some stage, the anaerobic pond will have to be decommissioned and cleaned of the accumulated solids.

2.1.3 Biogas Collection

Biogas is a product of the anaerobic process and will vary in composition depending on the type of input material. The biogas from biodegradable feedstock used as input, mostly results in methane and carbon dioxide with a small amount of hydrogen and trace hydrogen sulphide. The gas is normally stored on top of the anaerobic pond in an inflatable gas bubble or extracted and stored next to the facility in a gas holder. The anaerobic pond cover may therefore be subjected to negative pressures (suction) as gas is vacuumed from the anaerobic pond surface to storage facilities. Conversely, the cover may also be subjected to positive pressure and allowed to inflate as gas builds up on the surface of the anaerobic pond prior to gas extraction, depending on the design.

The biogas may become explosive due to high methane gas content and if it is exposed to air/oxygen. It is therefore necessary to limit ingress of oxygen and to prevent any open flames near the installation.

The methane in biogas can be burned to produce both heat and electricity, where the electricity and waste heat generated may be used to heat the anaerobic pond, or any other heating and drying applications. Anaerobic ponds operated in the mesophilic to thermophilic temperature range operate effectively, produce large amounts of biogas and are smaller due to the shorter retention periods required for effective degradation. Electricity can also be generated to power other activities related to the waste treatment or meat processing industry.

Biogas may require treatment or 'scrubbing' to refine or clean it for use as a fuel in boilers or gas engines. Hydrogen sulphide is a toxic product formed from sulphates in the feedstock and is released as a trace component into the biogas. Environmental enforcement agencies put strict limits on the hydrogen sulphide content of gasses both due to its toxic properties and odorous nuisance value. If the levels of hydrogen sulphide in the biogas are high, gas scrubbing and cleaning equipment (such as amine gas treating or calcium hydroxide scrubbing) will be needed to process the biogas to within regionally accepted limits. Current practice in Australia is to flare the biogas extracted from the anaerobic ponds, to control odours. This treatment method generally complies with environmental enforcement agency requirements. An alternative method to this is by the addition of ferric chloride ($FeCl_3$) to the ponds in order to inhibit hydrogen sulphide production. The drawback is that the resulting sludge may not be suitable as a fertiliser should the heavy metal concentration be too high for land application.

2.2 Operating Conditions

Operating conditions for anaerobic ponds will affect the performance of the cover materials. The following operating conditions should be considered in the design of the cover and are discussed below:

- Composition of the effluent or liquor;
- Temperature within the pond;
- Expected effluent levels;
- Potential for crust and scum layers; and
- External environment exposure.

2.2.1 Effluent Composition

The composition of the effluent or liquor from the anaerobic process will vary depending on the input materials and operating conditions (temperature, pH and residence time). The input materials can be composed of biodegradable feedstocks (blood, organic matter, skin, gristle), water, oils, grease, nutrients (nitrogen and phosphorus) and bacteria. Typical values from abattoir wastes are provided in the Table 1.

Table 1. Typical Values of Effluent from Abattoir Raw Waste

Parameter	**Typical Abattoir Raw Waste Water (all meats) (mg/L)***
Biochemical Oxygen Demand	1,600 to 3,000
Chemical Oxygen Demand	4,200 to 8,500
Oils and Grease	100 to 2000
Total Suspended Solids	1,300 to 3,400
Total Nitrogen	100 to 400
NH_4-N (Ammonia compounds)	65 to 100
Total Phosphorous	20 to 60
Volatile Fatty Acids	175 to 400
Alkalinity	350 to 800

* Based on published data from Meat and Livestock Australia 1998 and communication with Mike Johns

The bacteria present will depend on the pond operating pH and temperature. Mesophillic bacterial will require lower operating temperatures than thermophillic bacteria. The wastewater temperature may also contribute to the selected operating temperature range and associated bacteria.

Typically, the pH is maintained around 7 to 7.4 to efficiently promote all four stages of the anaerobic process. However, a high percentage of acidogenic bacteria will result in higher production of acidic compounds and a decrease in pH, and a high percentage of methanogenic bacteria will result in consumption of acidic compounds and an increase in pH. Therefore, lime may be added to the effluent to control the pH levels as the acidogenic bacteria may proliferate faster and cause the pond to go ‘sour’ and not produce methane gas. Under Australian conditions, it has been found that the ammonia buffers the pH and the anaerobic ponds do not go ‘sour’.

2.2.2 Effluent Temperature

Different species of bacteria are able to survive at different temperature ranges. Mesophiles or mesophillic bacteria are able to survive optimally in temperatures between 35-40°C. Thermophiles or thermophillic bacteria are able to survive optimally in temperatures between 55-60°C. Thermophilic systems are however not likely to be used in the Australian meat processing industry.

The operating temperature for an anaerobic pond is based on the primary type of bacteria required, as the operating conditions will favour the selection and growth of the organisms that proliferate under those conditions. The anaerobic process slows down or stops completely when the temperature is below 15°C.

There are a greater number of species of mesophiles than thermophiles. These bacteria are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore considered to be more stable than thermophilic systems. (Koerner 2008).

Thermophilic systems are considered to be less stable, however the increased temperatures facilitate faster reaction rates, improved degradation efficiencies and hence greater gas yields.

(Koerner 2008). High operating temperatures may not be ideal when using floating gas covers as the temperature range is not compatible to many types of cover materials and cause degradation of the materials. The construction materials of the pond may also be compromised at higher temperatures or may require the use of special heat resistant materials that are costly i.e. pond liners at the bottom of the ponds or certain concretes.

2.2.3 Effluent Levels

The effluent level can be maintained depending on the mode of operation and the type of pond cover. If a constant level is preferred, the pond can be operated to overflow when feed is introduced. Alternatively it can be operated in a fill and draw mode by withdrawing effluent prior to introducing fresh feed or by letting the solids settle and withdrawing clear liquor at intervals.

The type of cover design for ponds with varying effluent levels will be different from the ponds with relatively constant effluent levels, which is further discussed in Section 4.

2.2.4 Crusts and Scum Layers

A floating crust, scum or foam layer can form on the surface of the pond. These are also known as scumbergs or sludgebergs. It is believed in the industry that scum is largely a combination of floating solids, fats, oils, greases, matted hair or other fibrous material and buoyed sludge. The scum can accumulate in varying thicknesses and have the following effects on the anaerobic pond (SKM, 2007):

- Restricts gas flow paths and may give rise to ‘whalebacks’ or ‘whales’. (Although in practice it is thought that the dry upper crust of scum is porous, which allows gas migration to continue under apparently adverse conditions.);
- Applies shear load and localised stresses on the cover;
- Affects surface grades;
- Restricts free movement of the cover during thermal cycles;
- Limits the ability of the cover to return from a distorted shape;
- Lifts gas sealing curtains causing gas to escape and odorous conditions to develop; and
- Subjects the cover to concentrated substances, such as fatty acids, greases, oils and their degradation products.

The floating scum can be periodically removed from anaerobic ponds by either flushing out the pond with the stored liquid with the cover intact or by removing the cover and mechanically excavating out the floating scum. Removal of the cover has a higher potential for compromising the integrity of the cover system from punctures incurred during the removal process. Removal of the cover also poses odour concerns. Therefore, hydraulic removal of scum and sludge is often preferred and should be considered in the design of the anaerobic ponds, as well as the inlet and outlet details. The potential effects of the floating scum should also be considered in the anaerobic pond cover design and is discussed further with respect to material selection in Section 5.

2.2.5 Environmental Exposure

Anaerobic pond covers can be exposed to various external environmental factors including the following:

- Temperature fluctuations (heat from the sun in addition to the heat from the anaerobic processes);
- UV radiation (sun exposure);
- Uplift forces (wind exposure);
- Drag forces and out-of-plane stresses (ponding water on the surface of the cover); and

- Animal attacks (animals walking on the cover or chewing on it).

The potential effects from environmental exposure should be considered in the anaerobic pond cover design and is discussed further with respect to material selection in Section 5. Anaerobic ponds are generally fenced to prevent animal migration on to the pond cover, as it is not practical to design the covers against puncture from hoofed animals.

3 Site Visits

3.1 Participating Facilities

The MLA contacted four facilities to take part in this project. Three of the facilities were meat processing facilities while the fourth was a sewage treatment plant:

- Werribee Waste Water Treatment Plant (WWTP) owned and operated by Melbourne Water Corporation (MWC);
- E.C. Throsby Pty Ltd (Throsby);
- AJ Bush and Sons Pty Ltd (Bush); and
- Inghams Enterprises Pty Ltd (Inghams) – Murrarie Processing Plant.

As part of the investigation all but one (Inghams) of the facilities were visited to observe the anaerobic pond covers in operation.

3.1.1 Werribee Waste Water Treatment Plant

The Werribee Waste Water Treatment Plant (WWTP), owned and operated by Melbourne Water Corporation (MWC) was visited on 6 May 2009 by Mrs Liza du Preez (Golder) and Dr John Scheirs (ExcelPlas). They met with Messrs George Judkins and Trevor Gladstone of MWC who accompanied them on the site visit.

The WWTP has three anaerobic ponds with floating covers. One pond has a cover constructed from a single 2.5 mm thick High Density Polyethylene (HDPE) layer, which covers an area of approximately 3 ha. The other two ponds have a three layer cover system and cover an area of 4 ha and 9 ha, respectively. The three layer cover system consists of ethylene interpolymer alloy (EIA) with polyester scrim reinforcing bottom layer, followed by a foam layer with a top layer consisting of either HDPE or Reinforced flexible Polypropylene (R-fPP). All three ponds are operated under a nominal (-3 mm water head) suction, which is applied at the outlet to collect gas from the surface of the ponds.

The HDPE cover does not appear to be exhibiting any problems. The covers of the two ponds with the three layer system will be replaced in the near future. The R-fPP has reportedly lost strength (as experienced by the MWC representatives) due to acid hydrolysis of the polyester reinforcement layer. The ponds have also experienced problems with the build up of buoyant scum 'scumbergs' below the floating covers.

The MWC had commissioned Sinclair Knight Merz (SKM) to carry out a design review of the replacement cover design, the following is an excerpt from the report on R-fPP covers, *"…Its base material is probably more permeable to fat. Its base material is probably more susceptible to chemical attack. There have been several cases of deterioration of R-fPP. These cases seem to be related to exposure to either chlorine or high concentrations of fats...*" (SKM, 2007) R-fPP covers are discussed further in the following sections.

3.1.2 Throsby Meats

E.C. Throsby Pty Ltd (Throsby) in Singleton, NSW was visited on 3 June 2009 by Ms Liza du Preez (Golder), who met with Mrs Winifred Perkins (ProAnd Associates Australia – Environmental Consultant to Throsby) and Mr Bryan Hornery (Environmental Manager for Throsby).

The anaerobic and aerobic ponds at Throsby were constructed approximately 10 years ago. The anaerobic pond measures 64 m by 64 m and is 6.7 m deep. The gas from the anaerobic pond is extracted from one corner and flared.

The anaerobic pond cover was installed during initial construction and is a 2 mm thick single HDPE cover anchored in a soil filled anchor trench (approximately 1 m deep by 0.6 m wide) along its perimeter. Mr Hornery expressed his view that he expects the life of the cover to be another 5 to 6 years, based on his experience at Throsby.

The effluent is treated prior to disposal to the anaerobic pond to reduce fats and greases. Mr Hornery expressed his view that the anaerobic pond has never had a crust forming on the surface of the liquid below the cover, since the effluent is pretreated. Mr Hornery has periodically taken temperature measurements last year of the liquid in the anaerobic pond and it was between 32°C and 34°C.

3.1.3 AJ Bush and Sons

AJ Bush & Sons (AJ Bush) in Beaudesert, QLD, was visited on 4 June 2009 by Ms Liza du Preez (Golder), who met with Mr David Kassulke (AJ Bush & Sons) and Mr Lionel Freedman (Quantum BioEnergy, operators and designers of AJ Bush's energy recovery facility).

Quantum BioEnergy managed the installation of two anaerobic ponds for AJ Bush. A 2 Ml trial pond was installed in September 2005. The final 21 Ml pond was installed less than a year ago. Both of the ponds have single HDPE covers, either 2 mm or 2.5 mm material thickness, and were installed by Fabtech, an installation company based in South Australia.

The effluent is pre-treated through an ultrasound process. Mr Freedman reported that the pre-treatment process is the reason that no crust forms below the cover on this site. The mesophilic anaerobic process operates at a temperature of approximately 37°C to 39°C.

AJ Bush has reported no serious performance problems with covers for either the trial pond or final pond, to date.

3.1.4 Inghams Enterprises Pty Ltd – Murrarie Processing Plant

A teleconference was held with Ms Julia Seddon from Inghams Murarrie, located in Queensland. Ms Seddon indicated that she would prefer that Golder not visit the site as they were currently in the process of commissioning a new WWTP.

Inghams had a floating cover consisting of R-fPP and was first installed in June 2001. The R-fPP cover was made of tan coloured, 1.14 mm thick reinforced polypropylene, fabricated by Stevens and installed by Fabtech (South Australian based installer). Deterioration was noted in March 2005 and a new cover was installed in October 2007. The R-fPP pond cover was designed to accommodate up to 3 m vertical movement as the pond level fluctuated.

Investigations were carried out to determine the cause of failure. Aspects investigated in relation to the cover failure included polymer construction, stabiliser failure, UV degradation, polymer stability and impact of effluent on the material and effects of other external factors. Professor Graeme George from QLD University of Technology, undertook a detailed assessment of the material. Fabtech also undertook detailed testing to assess the failure. The results of the Professor Graeme George's investigation were provided as reference material by Inghams.

Professor Graeme George states the following based on his investigation, "*…the most likely reason for failure is weathering degradation due to localised loss of stabiliser from the polypropylene outer layer. There does not appear to be an external cause for this and it may be linked to the degradation products of the effluent in the pond that have depleted the stabiliser. In severe cases, these appear to have migrated through the layers of the cover from beneath the liner. The severe localised cracking has compromised the strength of the liner in those areas…*" (George, 2005)

The pond cover installed in October 2007 was tendered by four companies. The four companies recommended cover materials ranging from 2 mm HDPE/LLDPE, 1.5 mm HDPE, 1.35 mm Polypropylene to 2.5 mm HDPE. The replacement cover implemented was a 2 mm HDPE/LLDPE co-extruded geomembrane with bright exposure colour (white) to limit temperature impacts. The cover design also incorporated a sacrificial layer (0.5 mm modified LLDPE) between the effluent and the top cover material.

3.2 Literature Study

A literature study was carried out to assess the publically available information on cover materials used on anaerobic ponds. However, the research indicated that information on anaerobic pond covers was limited. The following case studies were available on the internet:

- Werribee WWTP (discussed above);
- Mooroopna and Tatura High Rate Anaerobic Lagoon Reactor (HRAL) Systems – Goulburn Valley Australia; and
- AgSTAR Charter Farm Program (US EPA, 1999).

In general, the relevant experience of Golder and Dr. Scheirs were the main reference sources for this report. The reference list at the end of the report summarises the published information sources. The information on the internet for the Werribee WWTP was similar to the information provided during the site visit and is summarised in the previous section.

The case study on the Mooroopna and Tatura ponds, discussed in general the HRAL system upgrades to the facilities (Wall, 2000 and Messenger, 1998). The facilities received food processing and domestic effluent equivalent to half a million people. The existing anaerobic ponds at these plants needed upgrading to increase capacity, to reduce odours and to improve the final effluent quality. The HRAL reactors were selected for this upgrade in preference to the more traditional upgrade methods of aeration or construction of additional primary ponds to reduce organic loading rates. The cover material selected for use at both the Tatura and Mooroopna plants was reinforced polypropylene (R-fPP). A concrete anchor beam was constructed around the perimeter of the ponds and the covers attached to this beam using stainless steel fixtures. This system allowed the covers to be removed or partially pulled back for maintenance or sludge removal. A ballast tube, filled with cement grout, has been placed on top of the covers to assist with collection and drainage of storm water and to encourage gas migration under the cover.

The case study on the AgSTAR Charter Farm Program discussed five farms in USA that installed floating covers on anaerobic ponds in 1998: Apex Pork, Barham Farm, Boland Farm, Cal Poly Dairy and Piney Woods School Farm. The AgSTAR Program was a voluntary program jointly administered by U.S. government and encouraged the use of methane recovery technologies at confined animal feeding operations that managed manure as liquids or slurries to reduce greenhouse gas concentrations while achieving other environmental benefits. The case study discussed in general the benefits of floating covers including methane recovery, energy production, odour control and exclusion of uncontaminated stormwater.

For Apex Pork, Boland Farm and Cal Poly Dairy odour control was the primary motivation for the installation of a pond cover. Barham Farm wanted to utilise and realise environmental and energy benefits through methane recovery, and Piney Woods looked primarily to demonstrate the applicability of methane recovery technologies to area farms. Two designs of floating cover were available, bank to bank and modular. Although bank to bank covers were the predominant choice, both bank to bank and modular designs were feasible to provide effective methane recovery and odour reduction. In both cases however, gas transfer and rainfall management were the design elements that were key to the success of a biogas cover.

Other critical issues in cover selection in the AgSTAR programme were: design, material and fabrication warranty, and cost. Materials suitable for biogas covers included HDPE, fPP and EIA. The majority of suppliers included manufacturers warranty on the cover material for 10-20 years. Warranties on workmanship were typically one to two years.

4 Floating and Fixed Covers

4.1 Types of Covers

The cover on anaerobic ponds generally comprises a geomembrane liner system that either floats or is suspended by floating mechanism on top of the effluent in the pond. The geomembrane system is anchored and sealed around the edges to hold the cover in place, and limit inwards and outward migration of gases or liquids.

A fixed or static elevation cover is installed for many anaerobic pond covers if the effluent level is generally fixed by a control system and the pond size is relatively small. Therefore, the cover can be designed with limited deformation requirements since the geometry does not change.

A floating or variable elevation cover is installed if the effluent level varies to allow the cover system to move with the effluent levels. The change in effluent level can result in significant changes in the surface shape and area of the cover. Therefore, the cover design should consider the effects of deformation from the change in geometry.

In addition to considering the effects of deformation from the change in effluent level, the design of fixed or floating covers should also consider the following:

- Durability of the cover materials given the expected operating conditions and environmental exposure;
- Separation of the effluent from the external environment;
- Collection and extraction of stormwater runoff;
- Collection and extraction of biogases; and
- Removal of scum and sludge.

The durability of the cover materials is discussed further in Section 5 with respect to material selection. The collection and extraction of stormwater runoff and biogases depends on the type of cover design, fixed or floating. This is discussed further in the following sections.

4.2 Fixed Cover (Static Elevation Cover)

Fixed geomembrane covers are typically installed on the surface of a relatively constant effluent level. The design of fixed elevation covers typically adopts relatively thick geomembrane sheets welded together and floated on the effluent.

The fixed cover system is often constructed sequentially and launched over a filled pond. The design may restrict movement of the cover material by placing stiffener strips in the cover to prevent movement from drag effects due to currents in effluent below the cover and from wind above the cover.

To improve scum or gas collection from the pond a series of floats or void formers may be included below the cover system to form a space above the effluent surface. The biogases accumulate in this space and are removed by the application of low suction pressure.

The stormwater collection systems for fixed covers are designed to shed runoff to designated low points on the cover (sump areas) and removed by pumping. It is generally not practical to remove all runoff from the cover and some runoff is removed by evaporation from the cover surface.

4.3 Floating Cover (Variable Elevation Cover)

Floating covers are installed over the surface of a pond or reservoir that rises and falls with the changing effluent level. These covers are generally more flexible than the fixed elevation covers, and require additional flexible restraint measures to maintain the cover in the desired shape. Floating devices and weighting devices are generally used to control the shape of the deforming cover and to manage stormwater runoff.

There are two main types of floating covers based on the method used for stormwater runoff management: defined sump and mechanically tensioned floating cover systems. Defined sump covers use floats and weights to create stormwater collection sumps in the cover and to accommodate changes in effluent level. The weights and floats create channels in the cover that provide liner slack and as sumps to collect stormwater. Defined sump floating covers are usually constructed by a series of floats arranged in parallel pairs with weights (i.e. ballast, such as sand filled PE pipes) centred between floats to form the sumps or troughs. The alignment of the geomembrane slack is usually designed to direct stormwater to the troughs and then to dewatering sumps for removal. The floats are made from either rotomoulded polyethylene or encapsulated expanded polystyrene.

Mechanically tensioned floating cover systems consist of tension elements attached to the cover's interior at specific intervals all around the tank's or dams perimeter. The mechanically tensioned portion of the cover is held into place and is protected from wind uplift and drifting. The outer cover perimeter is relaxed and forms a sump when storm water can be diverted off the cover through a drainage system.

Floating covers generally require more flexibility in the cover materials to accommodate the effect of geometric changes in the shape and surface area of the cover resulting from varying the effluent level. Therefore, some of the stiff geomembrane materials that may be considered for a fixed cover may not be suitable for deforming parts of the floating covers. Variable Elevation Covers may include both very flexible and stiffer geomembrane materials to achieve a design outcome, particularly where the pond surface is large.

Floating covers typically use a series of floats or void formers below the cover system to form a space above the effluent surface. The biogases accumulate in this space and are removed by the application of low suction pressure.

Floating scum can be removed from the pond, hydraulically since the pond cover can accommodate the changes in the effluent level.

5 Material Review

5.1 General

The materials selection for anaerobic pond covers is a critical part of the pond design. The selection process should consider the following:

- Flexibility requirements;
- Tear resistance;
- Wind resistance;
- UV resistance and solar heating potential;
- Fats, oils and grease resistance and durability;
- Scum adhesion;
- Top cover material colour;
- Installation restrictions;
- Susceptibility to animal attack;
- Ease of in-service repair; and
- Cost.

The following sections provide a general overview of these considerations with respect to different material types. The anaerobic pond cover materials that were reviewed include the following:

- Reinforced and unreinforced materials;
- High Density Polyethylene (HDPE);
- Low Linear Density Polyethylene (LLDPE);
- Flexible polypropylene (R-fPP);
- Ethylene Interpolymer Alloy (EIA); and
- Chlorosulphonated Polyethylene (CSPE).

5.2 Selection Considerations

5.2.1 Flexibility Requirements

Cover material may be subjected to varying stresses due to geometry changes from fluctuations in effluent level or stored gas volume fluctuations. Operating effluent levels of anaerobic ponds can vary, for example, the effluent level can fluctuate by up to 3 m at the anaerobic pond for Inghams, Murarrie (email communication from J. Seddon).

The gas collection systems for anaerobic ponds can operate under negative or positive pressure. In the instance where the facility is operated under negative pressure, a slight suction is applied to the gas extraction pipes. In the instance where the facility is operated under positive pressure, the cover is allowed to inflate thereby building up positive pressure and utilising the storage capacity below the cover. Systems that would normally operate under negative pressure are sometimes allowed to build up pressure, i.e. storage of gas below the cover, during maintenance periods.

Therefore, the cover material must be flexible enough over the design life of the cover to continue operating without failure, but strong enough to accommodate the stresses that are imposed on the cover system.

The flexibility of the geomembrane also has a direct bearing on the operational performance of the cover. A cover that is too flexible allows stormwater to pond easily, which inhibits gas flow paths and promotes the formation of gas mounds or 'whale-backs'. These inflated areas are prone to wind action causing 'fluttering' and this in turn may result in mechanical cyclic fatigue being imposed on the cover system.

5.2.2 Tear Resistance

Cover materials for anaerobic pond will be exposed to a number of events during installation and operation that may lead to minor puncture or tear damage or encourage propagation of existing tears and punctures. The design of the cover should consider materials that generally display a high tear resistance.

The materials considered in this report include reinforced and unreinforced cover materials. Generally, unreinforced materials provide lower tear resistance than reinforced materials. Typically as the cover materials become thicker, tear during installation becomes less of an issue, and the design-related in-service tear stresses become the critical values. The tear resistance of many thin non-reinforced cover may be quite low, from 19 to 130 N. (Koerner, 2005).

5.2.3 Wind Resistance

Wind resistance refers to the resistance of the cover to uplift and lateral movements and the potential to retain the required shape (geometry) due to wind forces. Strong winds can uplift a cover, pulling it out of the anchor trenches or from the batten strips and cause tearing.

It has been shown that the ability of cover materials to tolerate uplifting by strong winds is a function of its mass per unit area. Table 2 shows the mass per unit area of various geomembrane types and the minimum wind speed required to uplift a geomembrane under its own weight [Giroud, 1995]. The thinner cover materials require less wind speed to be uplifted. The heavier gauge cover materials and particularly high specific gravity cover materials require higher wind speed for uplifting to occur. For example, a 3 mm thick bituminous geomembrane can require wind speeds as high as 34 km/h for uplifting to occur. Since fPP cover materials have the lowest specific gravity of all common geomembrane materials (0.91 g/cc) they are highly susceptible to wind uplift.

Table 2. Summary of Wind Velocity to Uplift Various Geomembrane Types

Geomembrane Type	Thickness (mm)	Mass per Unit Area (kg/m^2)	Minimum Wind Velocity for Uplift (km/hr)
HDPE	1.0 1.5 2.0 2.5	0.94 1.41 1.88 2.35	13.6 16.7 19.2 21.5
EIA-R	0.75 1.0	1.0 1.30	14.0 16.0
CSPE-R	0.75 0.90 1.15	0.9 1.15 1.50	13.3 15.0 17.2

*Giroud, 1995

EIA cover materials have better resistance to wind uplift than HDPE geomembrane (on a direct thickness comparison). The wind resistance of LLDPE cover materials are similar to those of HDPE. If wind gets under a leading edge of the geomembrane then tremendous forces can be applied to the geomembrane. Permanent crease marks or severely folded and crimped geomembrane areas are generally undesirable due to the localised stresses they create. Such areas are deemed as damaged and should be cut out and patched. Wind crimping (or 'wind damage crimps') of cover materials can caused thinning of the geomembrane cross-section.

Typically, the self weight of the cover is insufficient to resist wind uplift given moderate or high wind velocity conditions. The cover design should incorporate restraints around the pond to manage the lateral drag effects from the wind. The effects of wind uplift may also be reduced by suction below the cover or by the inclusion of a ballast system on the cover system. The introduction of a ballast system may adversely impact on the gas collection system as it may reduce the void space for gas collection below the cover system.

5.2.4 Ultraviolet Radiation Resistance

The top of anaerobic pond covers are exposed to the environment and to ultraviolet radiation exposure over the expected design life. The UV radiation from the sun can penetrate the material causing degradation of the polymers, which impacts the durability of the cover material. The cover materials should be selected for the expected UV exposure during the design life.

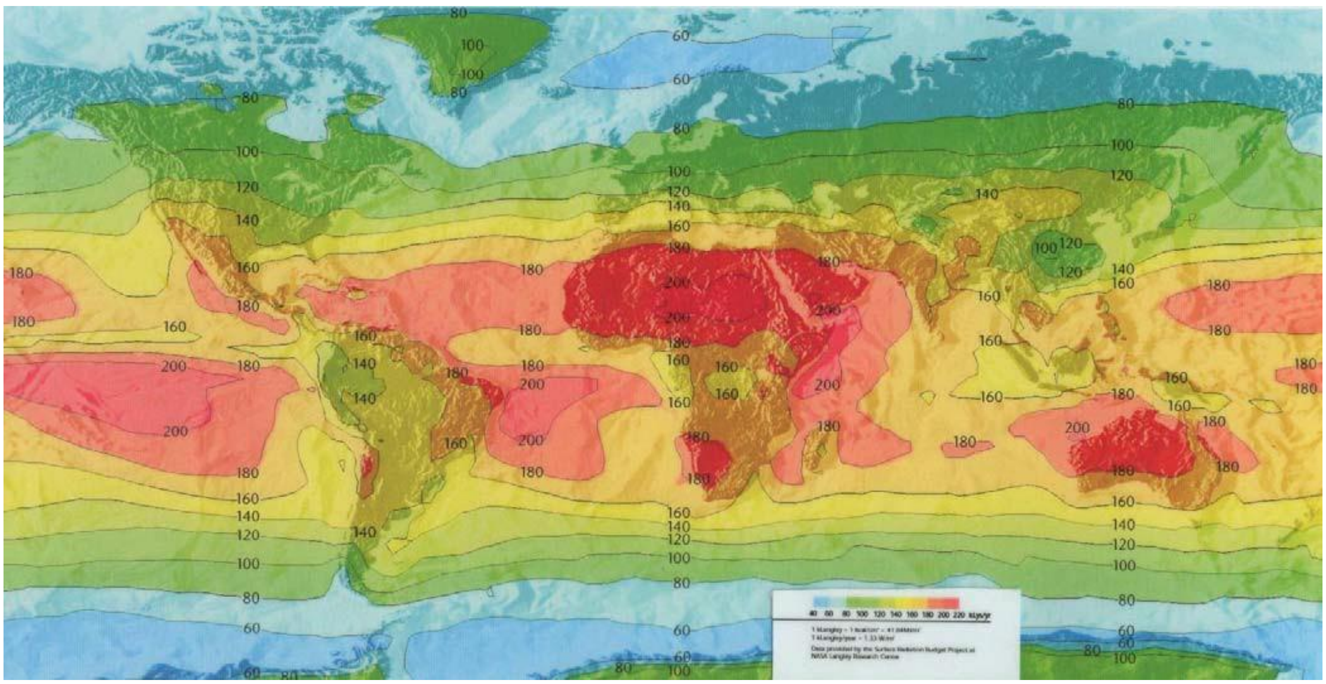

Figure 2. Global UV irradiance (kilolangleys per year, kLy/yr)

Accelerated UV exposure test results can be correlated with real-time weathering for specific geographical regions. UV exposure in New South Wales would be approximately 170 kLy/year[1]. If accelerated UV exposure testing shows a material to be able to withstand 2 mil kLy/year the effective UV stable period would be 11.8 years.

There are currently two accelerated weathering test methods. These are ASTM G155, using Xenon C1-65 and Ci-5000 Weather-O-meters and ASTM D7328 and GRI GM 11 using QUV testing equipment. The first method is very expensive to run and have high replacement costs. The second method is therefore the preferred method. If no specific UV resistance data is available for a specific material, we suggest that it be tested using one of the methods above to assess the material's UV stability.

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[1] A Langley (Ly) is a unit of measure for radiation power distribution over area and is used to measure solar radiation. 1 Langley (Ly) is 41840.00 J/m^2 = 0.04184 MJ/m^2 while 1 kLy = 1 $kcal/cm^2$ = 41.84 MJ/m^2 and 1 kLy/yr = 1.33 W/m^2.

5.2.5 Fats, Oils and Grease Resistance and Durability

The underside of anaerobic pond covers may be subjected to chemical attack from the effluent, specifically from the fats, oils and greases (FOG). In-house testing and published data (Scheirs, 2009) indicates that various FOG may be absorbed by the cover materials and alter the material properties and the performance of the cover material. Effluent that is rich in FOG can plasticise certain polymers such as polyvinyl chloride (PVC), ethylene propylene diene terpolymer (EPDM), and flexible polypropylene (fPP). FOG can also extract additives from polyolefin liners such as linear low linear density polyethylene (LLDPE). HDPE is the most resistant to the extractive effects of effluent containing FOG. Effects noted include increase or decrease in stiffness of the materials, delamination of the material components, blistering and macro cracking of the cover system.

The effluent from meat processing facilities can be highly acidic, which may pose problems for certain functional additives especially hindered amine stabilisers (HALS). For instance, acids such as sulphurous acids, sulphuric acid and dihydrogen sulphide can deactivate conventional HALS which is basic in nature. HALS is an additive that is added to the resin principally to provide UV stability but also to protect the geomembrane against thermo-oxidative degradation. It functions by retarding oxidation of the geomembrane. As an alternative to standard HALS packages, a special HALS additive package can be considered based on non-reactive (NOR) HALS. The types of additive packages added to the resin are proprietary and it can therefore not be confirmed which manufacturers are adding NOR HALS to their formulation. In addition further testing will be required to assess whether NOR HALS will provide sufficient protection for this type of application.

5.2.6 Scum Adhesion

The coefficient of friction of cover materials is expected to have a significant bearing on the amount of scum adhesion to the cover. Table 3 summarises approximate surface energies for various cover materials. Polytetrafluoroethylene (PTFE) is provided for comparison purposes. It should be noted that polyvinylidene fluoride (PVDF) may be potentially used to limit scum adhesion problems by laminating or by extrusion coating the cover materials with PVDF, however, further studies are required.

Table 3. Surface Energies for Cover Materials (dynes/cm)

Polymer Type	**Approximate Surface Energy (dynes/cm)***
Polytetrafluoroethylene (PTFE) (aka Teflon)	18-20
Polyvinylidene fluoride (PVDF)	25
Polypropylene (PP)	29-31
Polyethylene (PE)	30-31
Polyvinyl chloride (PVC), plasticised	35-38

* Low surface energy equates to reduction in adhesion

5.2.7 Top Cover Material Colour

The colour of the cover material can affect the longevity of the cover. Covers of black coloured geomembrane materials can reach surface temperatures of 75-80°C even when the ambient temperature is only 35°C. White or lightly coloured geomembrane covers may be considered for floating covers to keep the surface temperature of the cover materials below 50°C even on very hot summer days.

The temperature of the cover material is important since degradation reactions double for every 10°C increase in temperature. Therefore, white coloured geomembrane covers degrades at a rate 8 times slower than black coloured geomembrane covers. Lower surface temperatures offered by a light coloured cover are also advantageous in that the floating scum does not dry out or desiccate to the same degree. Thus the floating scum does not become so buoyant or encrusted to the cover.

5.2.8 Installation Restrictions

Covers constructed from flexible geomembrane materials such as fPP and PVC can deliver significant installation time savings compared with more rigid HDPE geomembrane materials. For example, where a particular pond is to be lined with 8 panels, fPP panels may require approximately 4.2 hours to field weld while HDPE panels may require approximately 15 hours to field weld (i.e. 3.5 times longer).

Flexible geomembrane materials also allow for fewer field seams. This is most advantageous to the cover design since most leaks occur mainly at field seams. Flexible geomembrane liners such as PVC, ethylene interpolymer alloy (EIA), and fPP can be prefabricated into large panels in a factory environment, then folded and transported to the field site on pallets. In contrast, geomembrane covers made from HDPE are not permitted to be folded and must be field seamed in smaller sections instead.

Material selection should also consider formation of wrinkles during installation. The thermal expansion of different geomembrane cover materials in combination with the difference in stiffness may result in a variable response to temperature effects. The stiff polyethylene based geomembrane materials tend to form larger wrinkles than the materials with lower stiffness. These wrinkles may impact on gas collection and response to wind loading.

5.2.9 Susceptibility to Animal Attack

Potential 'bio-intrusion' from burrowing animals or kangaroos (sharp claws) can compromise the performance of an anaerobic pond cover. The physical impacts from animals can often be minimised by building a fence around the anaerobic pond to limit access. However, smaller rodents or birds can still cause damage. There are a number of documented cases of animals breaching geomembrane cover materials by gnawing or cutting. These include:

- crab damage on Nauru island (one of the Micronesian Islands) in a area where the cover materials were installed in the path of migratory crabs during breeding season;
- rodents (such as prairie dogs in Canada) gnawing or burrowing through liners;
- pecking damage by bird beaks;
- kangaroo paws scratching the geomembrane while hopping on covers; and
- ant penetration particularly for abattoir liners.

HDPE and LLDPE are more resistant to burrowing animals than PVC due to their greater hardness. Flexible cover materials, such as PVC and fPP are more susceptible to gnawing because they are easier to bend than a HDPE geomembrane. However it appears that animals have only managed to attack the cover material at an edge, fold, or seam on which the animal could grip. Large panel geomembrane cover materials may have 80% less seams than small panel geomembrane cover materials, and accordingly less likelihood of having an edge, fold, or weld.

Bird attacks on geomembrane cover materials have occurred with seagulls in particular pecking at exposed covers. The two main areas that the birds pecked at are the flaps on geomembrane seams and the sandbags.

5.2.10 In-Service Repair

In service repair refers to the ease with which the materials can be patched or details changed over the design life of the cover. Repairs might be required to fix tears or punctures from animals or maintenance activities. Modifications to the cover may be required at later stages that involve patching or welding panels to the existing cover. These repairs may require elaborate measures if the cover material has become stiff and brittle over time. The cover material should be selected appropriately if repairs are expected during the design life of the cover.

5.2.11 Cost

The cost of a cover system is dependant on the materials used, thickness of material and the installation requirements, such as access hatches, anchor trenches or concrete beams, stormwater management system, transport cost related to weight of material, and installation costs. It is therefore difficult to provide a cost rate per square meter for a material type, but a relative cost comparison has been prepared based on our experience. Some of the materials would be supplied from manufacturing facilities in Asia, due to Australia's proximity to Asia, but others may however be supplied from the USA or Europe. The relative material costs of various geomembrane cover materials are shown in Table 4. These costs do not include installation, panel manufacture, anchoring and ballasting systems or any other related costs. These relative costs are based on:

- October 2009 global resin prices and a base exchange rate of 1USD = 0.9AUD.
- Materials delivered to Australian ports.
- Supply of geomembrane to cover 10,000 m^2.

Table 4: Relative Geomembrane Cover Material Cost

Geomembrane Type	**Thickness**	**Cost relative to 1.5 mm HDPE**
HDPE	1.00 mm	0.7
HDPE	1.50 mm	1.0
HDPE	2.00 mm	1.3
LLDPE	1.00 mm	0.7
LLDPE	1.50 mm	1.0
fPP (unreinforced)	0.75 mm	1.4
fPP (unreinforced)	1.00 mm	2.2
R-fPP (reinforced)	0.90 mm	1.7
R-fPP (reinforced)	1.10 mm	1.9
R-EIA (reinforced)	0.90 mm	3.8
CSPE	1.00 mm	4.9

HDPE cover materials are the lowest cost on a per kilogram basis. The low material cost of HDPE resins allows for thicker lining cross-section to be used compared to other more expensive cover materials. The increased thickness in some cases results in increased resistance to puncture and abrasion relative to other cover materials. R-EIA cover materials are relatively expensive but can prove to be the least expensive alternative in many containment applications. Currently the cost of LLDPE and HDPE is equivalent. CSPE is costly compared to fPP and typically exhibits somewhat lower physical property characteristics. Furthermore, the density of CSPE is high at 1.47 g/cm^3 compared to say fPP (density 0.90 g/cm^3). The density of CSPE is thus 63% higher than that of polypropylene and this can add to freight costs.

5.3 Reinforced and Unreinforced Materials

Some geomembrane materials considered for covers have low stiffness or are not suitable to resist long term tensile stresses. These materials may however have some chemical and UV stability properties that are desirable for a cover. Manufacturers have therefore introduced a product that includes reinforcement with the desirable material to improve the tensile strength and stability of the geomembrane. These materials are called reinforced or scrim reinforced geomembrane liner materials.

Scrim reinforced geomembrane is a geomembrane with a reinforcement layer near the middle of the thickness of the geomembrane. These geomembrane types exhibit high dimensional stability, more uniform directional properties and increased tear resistance. Most scrim reinforcing is manufactured from polyester although other polymers, such as nylon have also been used. The scrim consists of an open-faced woven material that can be thermally, chemically or mechanically bonded at the joints. The scrim is encapsulated between two layers of polymer, typically through a calendaring process or spread coating method.

The majority of scrim reinforcement materials are polyesters that are susceptible to both acid and alkaline-catalysed hydrolysis. If hydrolysis occurs it may lead to delamination of the reinforced material from the surrounding polymer. There are specialty hydrolysis-resistant polyester scrims that have high molecular weight and low carbonyl end group levels.

5.4 High Density Polyethylene (HDPE)

5.4.1 General

The HDPE formulation consists of a base resin (95–98%), together with stabilisers and antioxidant additives (0.5–2%) and carbon black (2–3%). HDPE has a high crystallinity (up to 65%). The crystallinity of a polymeric material refers to the amount of aligned regions in the polymer chain, which are called "crystallites". The non-aligned regions are called amorphous. The amount of crystallinity results in three major classifications for polymers, which are; semi-crystalline thermoplastic and amorphous thermoplastic. Generally, most polymers used for the manufacture of geosynthetics are semi-crystalline or amorphous thermoplastics as distinct from thermoset polymers, which are cross-linked such as synthetic rubber.

The high crystallinity leads to increased stiffness, heat resistance, tensile strength and chemical resistance and decreased flexibility, impact strength and stress crack resistance. Stress cracking is an issue with HDPE and is related to its sensitivity to stress concentrations over extended periods of time. The stress concentrations are also related to sensitivity to scratches and cuts that may propagate over time as the geomembrane ages. The stress cracking may occur early in the life of a HDPE geomembrane under the appropriate conditions. HDPE should not be stressed in its intended application to limit the risk of stress cracking.

To delay the degradation of the polyethylene resin the geomembrane material includes stabilisers and antioxidants. These additives stabilise the polymer against heat effects during manufacture and limit the effect of oxygen degradation of the polymer during the service life of the geomembrane. Due to the relatively slow rate at which the stabilisers and antioxidants are depleted the HDPE will retain its durability for a long period of time.

5.4.2 Flexibility

HDPE cover materials are quite rigid and have relatively poor flexibility compared to most other geomembrane materials.

The poor flexibility of HDPE cover materials can also be a limitation when connecting the geomembrane to various rigid structures since this can induce localised stresses which are beyond the design limits of the material and can lead to deterioration in the long term. For example bending a HDPE geomembrane through 90° then securing it to the side of concrete support structure is not recommended. This is especially true if there is subsequent deformation which can induce strains in the geomembrane over a corner of a concrete pedestal or support.

The flexibility of cover materials also affects the amount of slack included in the design to compensate for deformation. Flexible materials such as EIA and fPP require less slack than stiff materials such as HDPE. This is because flexible materials can stretch locally (up to 100%) to accommodate thermal contraction without damage, while very low extensions (as low as 2% at low temperatures) will damage HDPE.

For the design of static elevation covers the low flexibility of HDPE is a desirable property, as it assists in maintaining the shape of the cover subject to the effects of wind drag, and to create the desirable void space below the cover system to collect gas.

5.4.3 UV Resistance

Some HDPE cover materials have outstanding UV resistance and some have been in service for over 20 years and are still not showing signs of obvious degradation. The resistance of HDPE geomembrane to UV is related to the additives in the product and there is a significant range of different UV resistance possible in HDPE cover materials. HDPE is a popular product due to its UV resistance, low cost, versatile mechanical properties and very good overall chemical resistance.

5.4.4 FOG Resistance

HDPE cover materials owing to their semi-crystalline structure and absence of reactive groups in their structure show good resistance to the plasticising and extractive effects of FOG.

5.4.5 In-Service Repair

HDPE cover materials are relatively easy to repair while in service using extrusion welding techniques. Extrusion welding was the first welding technique developed for HDPE cover materials. It is a thickness dependant technique that requires a minimum material thickness to create an effective weld without distortion. Extrusion welds in 1.0 mm HDPE cover materials can exhibit some distortion and can sometimes be difficult to prepare around pipe penetrations and mechanical attachments. However, 1.5 mm HDPE can be reliably extrusion welded in most situations. Welds in 2.0 and 2.5 mm cover materials can yield excellent results but do require higher energy inputs due to the thicker material.

Extrusion welding is relatively slow and of lower strength, and therefore typically used only for repairs and details. Extrusion welds require specific preparation and require a minimum clearance of 1 m for welding. This is especially important in sump details where a minimum clearance must be maintained underneath the lowest pipe penetration.

Before welding of aged HDPE cover material, low molecular weight waxes and oxidation by-products need to be removed from the surface of the geomembrane by grinding/buffing and the leading edge of the upper geomembrane needs to be bevelled or tapered to a 45 degree angle. The grinding can be done with a surface grinder but care needs to be exercised that no deep grooves or notches are introduced into the sheet as a result of the grinding process since these can act as stress concentrations which are the precursors to stress cracking.

5.5 Low Linear Density Polyethylene (LLDPE)

5.5.1 General

Low linear density polyethylene (LLDPE) cover materials were introduced to address the principle shortcoming of HDPE which is its relative lack of flexibility. Common LLDPE applications include landfill caps, pond and channel liners, tank liners and sewage processing ponds.

The LLDPE formulation consists of a base resin (95–98%), together with stabilisers and antioxidant additives (0.5–2%) and carbon black (2–3%). LLDPE has a lower crystallinity than HDPE, which leads to decreased stiffness, heat resistance and chemical resistance and increased flexibility and impact strength when compared with HDPE. LLDPE does not suffer from stress cracking due to its low crystallinity, and has a higher capacity to function in a strained condition. LLDPE can strain significantly in two dimensions compared to HDPE. Its lower stiffness generally results in easier construction and generally is less sensitive to variations in the joining procedures compared to HDPE.

5.5.2 Flexibility

LLDPE cover materials are inherently flexible and hence generally easier to install compared to HDPE. LLDPE is more flexible than HDPE. LLDPE can be prefabricated into large panels in a factory environment, then folded and transported to the field site on pallets. In contrast, cover materials made from HDPE are not permitted to be folded and must be field seamed in smaller sections instead. If there is a high potential for significant differential settlement, LLDPE cover materials are recommended on the basis of their elongation and flexibility characteristics.

The high flexibility of LLDPE offers engineering options for the design of variable elevation covers where the cover is required to fold or deform occasionally.

5.5.3 UV Resistance

The resistance of LLDPE to UV is directly related to the stabilisers used in the manufacture of the geomembrane. Some LLDPE geomembrane has only moderate UV resistance compared to similar HDPE geomembrane, but there are formulations that provide very high UV resistance and are specifically designed for exposed applications. Due to the lower crystalininty of LLDPE the rate at which the stabilisers and antioxidants are depleted is generally higher than HDPE.

5.5.4 FOG Resistance

LLDPE cover materials have moderate chemical resistance to FOG when compared to HDPE. LLDPE polymers are less crystalline forms of polyethylene and as such are more flexible and less prone to brittle stress cracking. The trade-off however is that the degree of chemical resistance of LLDPE is lower than HDPE.

However, LLDPE is susceptible to stress cracking only when its antioxidants and stabilisers are depleted and after they have oxidised. This occurs near the end of the functional life of LLDPE. This is a special case and is termed 'Oxidative Stress Cracking'.

5.5.5 In-Service Repair

The in-service repair of LLDPE is similar to HDPE. LLDPE is slightly less sensitive to welding temperature and pressure than HDPE, due to the less crystalline structure of the LLDPE.

5.6 Reinforced Flexible Polypropylene (R-fPP)

5.6.1 General

The fPP formulation consists of a base resin (96–97%), anti-oxidant additives (1–2%) and carbon black (2–3%). The reinforcing is achieved by encapsulating a polyester scrim between two layers of fPP. Reinforced flexible polypropylene has a low crystallinity, which results in a very flexible material with high tensile strength that is resistant to stress cracking.

Flexible polypropylene (fPP) resins are produced by the incorporation of high levels of ethylene propylene rubber (EPR) into the semi-crystalline polypropylene (PP) matrix directly in a polymerisation reactor. The inclusion of ethylene segments in the polymer backbone breaks up the crystallinity of regular PP and confers elastomeric properties.

fPP resins such as Astryn CA743GA are made by Basell using the Catalloy™ process which produces a reactor blended elastomeric alloy of PP and EP rubber. Unlike PVCs and PVC blends, fPP polymers contain no plasticisers that can migrate out of the geomembrane and thus are intrinsically flexible. The Catalloy process enables a high percentage of ethylene-propylene rubber to be copolymerised with polypropylene in the polymerisation reactor.

5.6.2 Flexibility

fPP is a very flexible material which bears little resemblance to regular polypropylene sheet which is far more rigid. fPP is more flexible than LLDPE and HDPE. fPP cover materials are inherently flexible and easy to work with. Due to the high flexibility fPP cover materials can be prefabricated into large panels in a factory environment, then folded and transported to the field site on pallets. In contrast, cover materials made from HDPE are not permitted to be folded and must be field seamed in smaller sections instead. In addition, if there is a high potential for significant differential movement at joints or connections, fPP or LLDPE cover materials are recommended on the basis of their good elongation and flexibility characteristics.

The high flexibility of fPP offers engineering options for the design of variable elevation covers where the cover is required to fold or significantly deform on a frequent basis.

5.6.3 UV Resistance

Research by companies such as Basell/Montell (resin manufacturer) has shown that black fPP cover materials exhibit outstanding weatherability. Testing carried out by Basell/Montell have shown that 1 mm fPP cover materials made with Astryn™ fPP resin resist greater than 3 million Langleys with only negligible effects on the mechanical properties (Montell 1998).

Three million Langleys of sun exposure equates to 125,520 MJ/m^2 and from annual solar radiant exposure tables it has been recorded that NSW, receives about 7100 MJ/m^2 per year (similar to Phoenix, Arizona which receives about 8000 MJ/m^2) , so 3 million Langleys is equivalent to 17.8 years of real time exposure. Applications in Australia would need to be assessed against similar radiation data to estimate field UV resistance.

The tensile strength and elongation of black fPP remain virtually constant even after an accelerated dose of UV equivalent to 15 years in Arizona. (Montell 1998)

The UV stability of fPP cover materials is highly dependant on the nature and effectiveness of the UV stabilisation package, and is not constant in different fPP cover materials. Some fPP cover materials have been noted to show severe cracking after 26 months exposure to UV radiation. (Comer 1998).

5.6.4 FOG Resistance

Care must be exercised when fPP cover materials are in long term contact with the following chemicals groups:

- organic acids and fatty acids (e.g. acetic acid, stearic acid);
- volatile carbonyl-containing organics (e.g. ketones, aldehydes, esters, amides); and
- oils and waxes.

Effluent that is rich in fats, oils and greases ('FOG') can plasticise fPP (and certain other polymers) and can also extract additives from such liners. FOGs can permeate fPP and cause a reduction in mechanical properties. fPP is amorphous (i.e. low crystallinity) and therefore small opportunistic molecules can permeate its structure. A project where 1.14 mm reinforced polypropylene was used to construct a floating cover over animal fats from a chicken processing plant failed after just over five years.

Animal protein is high in sulphur-containing amino acids and these sulphur-based molecules convert to hydrogen sulphide and other sulphurous products during the anaerobic process. The presence of these sulphur compounds leads to an acidic environment in animal fat processing lagoons. This acidic environment can attack and destroy (i.e. deactivate) conventional hindered amine stabilisers. Exposure of the geomembrane to acidic gases can cause the HALS stabilisation system to become inactive. fPP due to its amorphous nature can have some of its additives modified and deactivated by acidic effluent. In particular, the hindered amine stabilisers are basic in nature and these can react with acidic containment effluent, leading to a loss of stabiliser activity. Once the HALS are neutralised by sulphur-derived acids they form a salt and it is not possible to regain any of the initial stabilising ability.

The ease to which acidic gases and sulphur-based acids can permeate the geomembrane increases with decreasing crystallinity in this order HDPE<LLDPE <fPP. In addition, animal fats can solvate and plasticise these polyolefins thus decreasing the resistance to permeation.

The polyester reinforcement in fPP is susceptible to acid-catalysed hydrolysis. Water vapour can permeate fPP and initiate hydrolysis and breakdown of the polyester scrim reinforcement. The edges of R-fPP cover materials should therefore have no exposed scrim and should have edge encapsulation of the scrim on each side.

However, fPP is also susceptible to stress cracking but only when its antioxidants and stabilisers are depleted and after it has oxidised, termed 'Oxidative Stress Cracking'.

Based on these considerations the use fPP for anaerobic pond covers needs to be considered carefully and be assessed specifically with respect to anticipated reactions and processes that are likely to occur in the liquid contained in the pond.

5.6.5 In-Service Repair

Flexible polypropylene cover materials contain low molecular weight waxes and additives that can migrate and diffuse to the surface of the geomembrane and make welding difficult. These waxes and oils produce a weak boundary layer. In addition to this thin layer of wax, the outermost surface of polyolefin cover materials becomes oxidised and the oxidation products which are polar compounds such as ketones and acids can also make welding difficult.

5.7 Reinforced Ethylene Interpolymer Alloy (R-EIA)

5.7.1 General

EIA is an alloy of PVC (Polyvinyl Chloride) and KEE (Ketone Ethylene Ester), which is a non-liquid polymeric plasticiser. Due to the tightly bound structure, the KEE plasticiser will not volatilise out of the PVC and is more resistant to hydrocarbons and weather exposure than cover materials made form any of the components of EIA. EIA cover materials are typically reinforced with a polyester scrim-reinforcing layer to improve their tear and puncture resistance.

EIA is also marketed under the name of XR-5.

5.7.2 Flexibility

EIA cover materials are inherently flexible and easy to work with. EIA cover materials can be prefabricated into large panels in a factory environment, then folded and transported to the site on pallets. The high flexibility makes the geomembrane suitable for applications where large deformations may occur, such a variable elevation cover systems.

5.7.3 UV Resistance

Accelerated UV aging tests have demonstrated that EIA-R cover materials resist fine, shallow regular cracks appearing on the surface and cracking after UV exposures equal to 20 years of normal weathering (Seaman, 2008). Some scrim reinforced cover materials have historically been reported to display fine shallow regular cracking phenomenon, which appears to have been addressed with a revised design of more modern formulations of the geomembrane material.

The UV resistance of EIA cover materials is related to actual formulation of the product and needs to be assessed based on the proposed design life and application of the geomembrane.
(Seamon 2008).

5.7.4 FOG Resistance

Appropriately formulated EIA cover materials are not prone to having their flexibility destroyed by FOG chemicals. R-EIA cover materials have a wide spectrum of chemical resistance's including hydrocarbons. EIA cover materials can also be used for the primary and secondary containment of hydrocarbon liquids that may be chemically aggressive such as crude oil, fuel oils, aviation fuels, diesel, kerosene, refinery wastes, alcohols, glycols, and many other organic substances, and is therefore less sensitive to variations in organics in the contained liquid of the facility.

Floating covers made from R-EIA however can degrade due to cracking problems and scrim degradation related to exposed scrim reinforcement. Hence, care needs to be taken with designing such covers to address this potential issue.

5.7.5 In-Service Repair

EIA-R cover materials can be easily thermally seamed or adhesively bonded in service. The cover material does not significantly change over time, so joining to older parts of the geomembrane can be carried out using conventional methods.

5.8 Chlorosulphonated Polyethylene (CSPE)

5.8.1 General

The CSPE geomembrane formulation consists of a base resin (40–60%), together with filler (40-50%), anti-oxidant additives (5–15%) and carbon black (5–10%). CSPE is based on the use of chlorine and sulphur to modify the polyethylene structure (by disrupting the crystalline structure) to make the material more pliable and flexible and to improve seaming. For a limited period after manufacture, the CSPE can be joined by thermal or solvent bonding, however due to curing when exposed to air and weather, thermal welding is no longer possible after a certain period of time. Once it has cured modifications and repairs must be carried out using a solvent based adhesive and by scrubbing of the seam area. CSPE cover materials are scrim reinforced for dimensional stability.

5.8.2 Flexibility

The basic polymer backbone of CSPE is essentially the same as polyethylene however the introduction of chlorine atoms into its structure along with a controlled number of sulphonyl chloride groups reduces the ability of the polymer to crystallise and the material exhibits flexible and rubbery properties.

The flexibility of CSPE cover materials allows them to easily accommodate significant deformation of the cover. CSPE is therefore considered for variable elevation covers where the geomembrane may be subject to folding and deformation as the pond elevation varies.

5.8.3 UV Resistance

The basic polymer of CSPE is essentially the same as polyethylene and because there are no double bonds, the long polymer chains are relatively impervious to attack from degrading agents such as oxygen, ozone or energy in the form of UV light.

CSPE cover materials cure over time thereby increasing the geomembrane’s tensile strength, chemical resistance and UV resistance. Thus they have excellent UV resistance and weatherability in exposed applications (Schoenbeck, 1984) and a proven long-term track record in exposed applications.

The resistance of CSPE to oxidation, ozone and UV make CSPE the lining of choice in industrial waste applications, floating covers and exposed lagoons.

5.8.4 FOG Resistance

CSPE cover materials are resistant to FOG, are not subject to stress cracking and display resistance to wide range of organic and inorganic chemicals. CSPE is affected by some organic compounds that may affect the geometry and properties of the geomembrane. The consideration of CSPE for anaerobic pond covers should be considered based on the expected compounds that may form in the liquid in the ponds, to decide whether CSPE is appropriate for that specific application.

No plasticisers are used in the formulation of CSPE cover materials, hence there are no issues relating to plasticisers that can leach out and cause embrittlement or cracking of plasticised liners.

Due to the excellent chemical resistance of CSPE cover materials they are often selected for water and waste water applications and also are used to manufacture floating covers. These cover materials have been used as lining materials for more than 30 years now and have shown excellent durability as a cover material.

5.8.5 In-Service Repair

CSPE cover materials continue to cure over time and crosslink into a cured or semi-cured rubber that looses its ability to be easily welded. Whilst this may be beneficial with regard to mechanical properties (for example, the tensile strength continues to increase), its ability to accept repairs decreases with age. For this reason special preparation and bonding agents are often required on older CSPE installations.

CSPE has a narrow installation window. If it is installed too soon after manufacturing, it has low early strength and if left to cure for too long before seaming it is difficult to fusion weld. There have also been problems reported due to auto-adhesion of the laps of the geomembrane in the rolled form. However once the installation phase of the life cycle has been completed, CSPE is a very durable and resistant material with a defensible track record.

6 Recommendations

6.1 Material Selection

Each potential material for the anaerobic pond cover should be evaluated for the specific project and location based on the selection considerations discussed in this report. Table 5 summarises the materials reviewed for anaerobic pond covers relative to the key selection considerations.

Table 5 Relative comparison of materials for anaerobic pond cover

Cover Material	HDPE	LLDPE	fPP	R-EIA	CSPE
Material Supply Cost	Least Expensive	Similar to HDPE	More Expensive than LLDPE	More Expensive than fPP	Most Expensive
Flexibility	Poor Flexibility	Good Flexibility	Best Flexibility	Very Good Flexibility	Very Good Flexibility
Resistance to Wind Uplift	Good Wind Resistance	Good Wind Resistance	Poor Wind Resistance	Moderate Wind Resistance	Highest Wind Resistance
UV Resistance	Good UV Resistance	Moderate UV Resistance	Good UV Resistance *	Good UV Resistance *	Good UV Resistance
FOG Resistance and Durability	Good FOG Resistance	Moderate FOG Resistance	Poor FOG Resistance	Good FOG Resistance	Good FOG Resistance
In-service Repair	Easy to repair	Easy to repair	Difficult to repair	Moderately easy to repair	Most difficult to repair

*Dependent on formulation

The following recommendations are based on the relative comparison of cover materials for the anaerobic ponds. Cover materials for anaerobic ponds of meat and livestock effluent are constantly subjected to chemical attacks from the fats, oils and greases in the effluent. Materials with good resistance to FOGs should be given more consideration. As the covers are exposed to long term UV radiation they need to have good resistance to degradation from UV radiation. Cover materials comprised of HDPE would be best suited for fixed (constant) elevation ponds since HDPE is not as flexible, but it should be noted that careful consideration should be given to designing around difficult geometry. CSPE, R-EIA would be best suited for variable elevation ponds since these materials are more flexible. However, CSPE cures with time, which may impede repairs during the design life of the cover and R-EIA can undergo cracking and scrim degradation if the scrim reinforcement is left exposed. Therefore, the design of the cover material should consider any modification requirements after the initial installation and methods for protecting the scrim reinforcement. LLDPE and fPP are also quite flexible and may be chosen as cheaper alternatives to R-EIA and CSPE for variable elevation ponds. However, LLDPE and fPP are not as resistant to FOG and UV and may result in a shorter operational life.

In general if the stiffness of HDPE can be addressed in the design of the cover, the product is the material of choice due to its ready availability, low cost, and chemical robustness. Sometimes a large part of a cover is designed using HDPE and areas that requires more flexibility are designed with a different product. This requires careful design of the interface and join of the different materials.

It should also be noted that specialist manufacturers of geomembrane products continue to develop alternative products, and the application to floating covers to improve the long term durability, particularly with respect to flexibility and UV resistance in an aspect that has been identified for material improvement.

6.2 Material Testing

The operating conditions to which the cover material will be exposed to are quite severe. It is therefore recommended that the materials should be tested by immersing the geomembrane into the liquid in which it will be in contact with. It is suggested that the testing programme be developed and the test results evaluated by a specialist independent third party.

Whatever geomembrane material is proposed for a particular application, it must be thoroughly tested in the actual process liquids at the operating temperatures, with some samples additionally being tested under applied stress. It is also very important to consider the possible influence on material performance under those ambient conditions during the transition between installation and full service, such as when the geomembrane might experience extreme high and low temperatures. Testing under these conditions allows synergistic effects to be captured in the chemical resistance testing. If these process solutions or liquors are not yet available because the project is still at the design stage, then a conservative approach is recommended and a geomembrane with excellent broad chemical resistance should be selected.

ASTM Method D-543 covers chemical degradation under the title "Resistance of Plastics to Chemical Reagents". The test method is based on measuring changes in weight, dimensions, surface appearance, and strength after various exposure times to reagents at elevated temperatures. This standard while not specific to geomembranes can nevertheless be used as a basic chemical resistance screening test.

In addition the Oxidative Induction Time (OIT) can be tested pre and post immersion to assess the rate at which oxidation occurs. This will give another measure at the expected life of the geomembrane.

Chemical resistance testing of geomembranes using site specific chemicals can also be performed using the following testing methods:

- ASTM D-5747 "*Standard Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids*".
- ASTM D-5322 "*Standard Practice for Laboratory Immersion Procedures for Evaluating the Chemical Resistance of Geosynthetics to Liquids*". This test method covers laboratory immersion procedures for the testing of geosynthetics for chemical resistance to liquid wastes, prepared chemical solutions and leachates derived from solid wastes.

In addition, if no UV exposure data is available from the manufacturer, testing according to ASTM G155, cycle 1 or ASTM D7238 or GRI-GM11 (1600 hrs) should be carried out to assess the UV stability of the geomembrane liner material.

7 References

Comer 1998 Comer, A. I.; Hsuan, Y. G.; Konrath, L., "Performance of flexible polypropylene cover materials in covered and exposed environments". U. S. Bureau of Reclamation, Denver, CO, USA. Editor(s): Rowe, R. Kerry, International Conference on Geosynthetics, Conference Proceedings, 6th, Atlanta, Mar. 25-29, 1, 359,1998

George 2005 Professor Graeme George of Queensland University of Technology, "Report on Testing of Pond Cover, Ingham's Murarrie", 14 September 2005

US EPA 1999 AgSTAR Charter Farm Program: Experience with Five Floating Lagoon Covers, http://www.epa.gov/agstar/resources/cov_costs.html

Johns 1995 John, MR. "Developments in wastewater treatment in the meat processing industry: A review, Bioresource Technology", 54 (3), pp 203-216, 1995

Kamthunzi 2005 Turnbull, J.H and Kamthunzi, W., "Greenhouse gas benefits of an anaerobic digester in the USA", Task 38, IEA Bioenergy, Graz, Austria, 2005

Koerner 2005 Koerner, Robert M. "Designing with Geosynthetics 5th Edition", Prentice Hall, New Jersey, 2005

Koerner 2008 Koerner, G. R. and Koerner, R. M. (2008), "Geomembrane Contained Farm Animal Waste Used as Gas-Generating Biodigesters," Proc. GRI-21 Conference on Geosynthetics in Agriculture and Aquaculture, Cancun, Mexico, IFAI Publ., Roseville, MN, pp. 42-47

MLA 1998 Best Practice Wastewater Treatment, RPDA.308B- Wastewater Manual, Meat and Livestock Australia, Sydney NSW, 174036032X, p 74, 1998

MLA 2002 Eco-Efficiency Manual for Meat Processing, Meat and Livestock Australia, Sydney, NSW, 174036631X (manual), p 138, 2002

Montel 1998 Montell literature entitled 'Astryn Flexible fPP, High Performance Materials for Cover materials', 1998.

Peggs 2005 Peggs, Elizabeth J, "Geosynthetics Solutions to Agricultural Challenges" www.geosynthetica.net

Scheirs 2009 A guide to polymeric geomembranes: A practical approach, pp367

Seaman 2008 Seaman Corp. [www.xr-5.com/downloads/library/cover materials-tech-manual.pdf], 2008.

Schoenbeck 1984 Schoenbeck, M., "Performance of Chlorosulfonated Polyethylene Cover materials after Long Term Weathering Exposure", pp. 136-151

Staff, Charles E. "The Foundation and Growth of the Geomembrane Industry in the United States", International Conference on Cover materials, Denver, U.S.A., pp 5-8, 1984

SKM 2007 Sinclair Knight Merz (SKM), "Western Treatment Plant 55E Cover Replacement Detailed Design", 09 November 2007,