Victorian Landfill BPEM Comparison Table - Appendices

Item	BPEM Requirement	Comment
D	**Appendix D – Guidance on Geomembrane use in Landfills**	
D1	**Introduction**	
	No technical content	
D2	**Background**	
	No technical content	
D2.1	**Types of Geomembranes**	
	Selection of a geomembrane liner should consider: • The hazard posed by the contained material and leachate. • Susceptibility of the liner material to chemical or environmental attack or deterioration while in service. • Tensile strength and elasticity. • Thermal stability. • Puncture, tear and shear resistance. • Anticipated operational life required for effective containment. • Local environmental conditions, including subsoil stability. Geomembrane materials should be selected based on their overall performance with respect to issues such as chemical resistance, mechanical properties, temperature resistance, thermally induced stresses (expansion/contraction), weathering resistance, product life expectancy, installation factors, cost effectiveness, and the type of application.	A 2 mm HDPE liner will be utilised in the base and side walls of the landfill and a 2 mm LLDPE liner used on the landfill cap. Both of these materials are deemed by the international landfill industry to be the most acceptable materials for modern landfill construction and as such, are the most common materials used and represent current best practise.
D2.2	**Selecting Geomembranes**	
	High-density polyethylene (HDPE) fulfils these conditions (refer to this section in the BPEM for detail) and it is not surprising that it is the material almost exclusively used for the geomembrane lining of the base and side slopes of landfill across the developed world in single composite or double composite liners (Giroud and Touze-Foltz 2003).	HDPE is to be used in the base and side slopes and LLDPE in the capping layer.
	In general, the choice of a given geomembrane should be guided by the containment application (basal liners, secondary liners, sideslope liners and capping) and the assessment of the required design life; followed by the assessment of potential physical/mechanical and chemical stresses relevant to the application and their implications on the required design life; and finally, risk assessment, including the consequence of failure.	The selection of geomembranes is consistent with best practise putrescible landfill development.
D2.3	**Material Key Properties**	

D2.3.1	**Geomembrane Thickness**	
	In general, thicknesses of 1.5–2.0 mm are preferred from a welding perspective. The thickness of a geomembrane also dictates performance criteria such as its tear resistance, puncture resistance and its resistance to installation damage.	A 2 mm liner will be used for both the HDPE and LLDPE liners.
	For landfill closure or cell closure, minimal thicknesses vary from 1.0 mm to 2.5 mm, depending on the regulatory agency (Zanzinger and Gartung 2002, Scheirs 2009, EPA SA 2007).	A 2 mm LLDPE liner will be used within the capping system.
D2.3.2	**Strength**	
D2.3.2.1	**Ability to Resist/Accept Stress and Deformation**	
	The design of a geomembrane application needs to consider the various potential stresses imposed on the geomembrane by the in-service configuration and conditions. For instance, such stresses include the following (Scheirs 2009): • Strain imposed at the anchor trench. • Strain imposed over long, steep side slopes • Differential settlement in the subgrade, foundation soils or waste point loading by angular or rough stones.	This assessment has been undertaken by Golder Associates and includes the required considerations.
D2.3.2.2	**Tensile Properties**	
	The tensile properties are arguably the most critical mechanical properties of geomembranes since, during installation and service, there are a range of tensile forces that can act on the geomembrane.	Considered in assessing the suitability of the design.
D2.3.2.3	**Allowable Strain**	
	Table D2 – Maximum Allowable Strain for Various Geomembrane Materials • HDPE smooth = 6% • HDPE randomly textured = 4% • HDPE structured profile = 6% • LLDPE density <0.935 g/cm^3 = 12% • LLDPE density >0.935 g/cm^3 = 10% • LLDPE randomly textured = 8% • LLDPE structured profile = 10%.	These maximum allowable strains has been utilised by Golder Associates when assessing the suitability of the liner design.
D2.3.2.4	**Puncture Resistance**	
	Static puncture may be reduced by using protective layers and rounded soil particles, as well as stiff and thick geomembranes. Dynamic puncture can be eliminated by considerable care in construction (good workmanship is required).	Thick cushion geotextile is used to protect the geomembrane. In addition, the construction specification contains controls on how the subsequent layers are placed on top of the geomembrane to reduce the possibility of damage and this aspect of the construction activity is included in the CQA Plan.
D2.3.2.5	**Slope Stability-Interface Friction**	

	Published values of interface friction should not be used in detailed design. Performance tests using site-specific material and mimicking field conditions should always be conducted. In this respect, the interface shear test (ASTM 5321) is useful in evaluating the interface friction of geomembranes with soils and/or geosynthetic components.	In undertaken the slope stability assessment, Golder Associates has not utilised site-specific materials (as the project has not commenced and hence, there are no materials available to be tested). Golder Associates has however used interface friction values from its internal database established from previous, similar applications, which have previously been based on site specific testing. This provides robust comparison between the theoretical design and anticipated actual performance of the slope stability. Once the liner materials have been delivered to site, the CQA consultant will take representative pieces of material and arrange for shear box testing to be carried out to confirm the suitability of the actual materials in comparison to the design assumptions.
D2.3.2.6	**Long-term Mechanical Performance**	
	Most of the geomembranes resins now have excellent stress crack resistance as a result of intensive research carried out in the 1990s. However, despite all the advances made, stress cracking can still occur due to other factors such as recrystallisation, oxidative embrittlement, sheet scoring/notching and stress rupture.	For information only.
D2.3.2.7	**Durability/Degradation of Polyolefin Geomembranes**	
	The most widely used test for assessing the resistance of polyolefin geomembranes to oxidative degradation in service is the oxidative induction time (OIT) test, which evaluates the quality of the antioxidant additive package and monitors the depletion of antioxidants from the geomembrane.	As set out in the construction specification, this test is required to be carried out by the materials manufacturer.
D3	**Minimum Requirements for HDPE Geomembranes for Basal and Sideslope Liners**	
	The following parameters are considered minimum requirements for geomembranes in basal and sideslope liners to ensure their long service life:	
	1. The geomembrane shall be a high-density polyethylene (HDPE) geomembrane and shall have a minimum thickness of 1.5 mm.	2 mm HDPE liner is utilised.
	2. It is important to select or specify high-grade polyethylene resin that has been specially formulated to meet the specific, unique demands encountered by geomembranes. Resin for the geomembrane should be virgin, first- quality HDPE resin and should not be intermixed with other resin types. Furthermore, it should not contain more than two per cent clean recycled polymer by weight of the HDPE resin. As a minimum, the HDPE resin shall meet the specifications indicated below: • Density* (g/cm^3) > 0.932. • Melt Flow Index (g/10 min) < 1.0. * Base resin density without carbon black and additives added.	The construction specification stipulates these requirements.
	3. The oxidative induction time of the geomembrane shall exceed both (a) 100 min, as determined by ASTM D3895 and (b) 400 min, as determined by	The construction specification stipulates these requirements.

	ASTM D5885.	
	4. The oxidative induction time of the geomembrane after oven ageing at 85 °C for 90 days, as described in ASTM D5721, shall exceed both (a) 55 per cent of the value for the original geomembrane, as determined by ASTM D3895, and (b) 80 per cent of the value for the original geomembrane, as determined by ASTM D5885.	The construction specification stipulates these requirements.
	5. Other design requirements and technical specifications for the geomembrane (such as carbon black dispersion, tensile properties, tear resistance, puncture resistance, stress crack resistance and UV resistance).	The construction specification stipulates these requirements.
	6. The standard specification given below is intended to ensure good quality and performance of HDPE geomembranes in general applications: • 97.5% polyolefin polymer - Must have the right stress crack resistance - NCTL > 300 hrs. • > 2% carbon black - Must be of the right particle size - Particle size ~20 nm. • At least 0.5% antioxidants and HALS stabilisers - Must have high effectiveness and permanence - HP-OIT > 400 mins.	The construction specification stipulates these requirements.
	7. The design of the liner needs to consider the various potential stresses imposed on the geomembrane by the in-service configuration and conditions. It is necessary to include the calculations of the physical stresses due to: • Strains imposed at the anchor trench. • Strains imposed over long, steep side slopes. • Differential settlement of the subgrade and foundation soils, if any. • Point loading by angular or rough stones (using ASTM D5514).	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	8. Provide a statement (with justification) on the chemical compatibility of the geomembrane liner and the leachate, in particular, the ability of the liner to retain adequate strength and performance after exposure to leachate.	HDPE is the worldwide acceptable preferred lining material for low hazard, putrescible landfills.
	9. A statement on the effect of thermal stresses on the liner during installation and construction, and effect of temperature during operation (effect of waste temperatures). Describe how the waste temperature and the thermal stresses will be taken into account.	The construction specifications stipulate maximum ambient temperatures under which lining may occur. Minimum temperatures are not a concern for this location; however, are also covered in the construction specifications. Putrescible landfills generate some heat as a result of waste decomposition. There are numerous factors that influence heat generation, including the following: seasonal variations in temperature, placement of waste, age of waste, depth and location of waste and available moisture content. Typically, temperatures at the liner are below 30 degrees, but in actively decomposing relatively fresh waste, these temperatures can be in the range of 30 to 40 degrees, 40 degrees being an extreme value. The liner materials that have been incorporated into the design are standard materials used in putrescible landfills and have been selected due to their ability to withstand elevated temperatures and retain long-term integrity.

		The landfill is not anticipated to have elevated temperatures above those normally found in other putrescible landfills. With the relatively low annual tonnage and low anticipated percentage of MSW (30%), the landfill temperature should be lower than the industry standard.
	10. A statement on the effect of equipment traffic during installation stresses. In particular the stresses resulting from application of the protection layer placed between the liner and the leachate collection system. Describe how these stresses will be taken into account.	It is not reasonably possible to construct the landfill lining and capping systems without having vehicles trafficking over previously laid liner layers. The construction specification provides guidance and direction to the contractor on how to traffic over previously placed liners. The CQA Plan also includes this aspect of the construction activity for the liner CQA consultant to monitor. The landfill has been designed to ensure that all slopes are readily accessible to construction plant (max. 1 V in 3 H) so that there is no addition strain imposed on the liner by vehicles trying to track up steep slopes.
	11. In the case of installations with sloping sides, it needs to be demonstrated that there is adequate friction between the various components of the liner system to prevent slippage or sloughing on the slopes of the installation. In particular, the following must be assessed: • The ability of the geomembrane to support its own weight on the side slopes. • The ability of the geomembrane to withstand down drag during and after waste placement. • The suitability of the anchorage configuration for the geomembrane. • The ability to maintain a stable state when a granular drainage layer is placed on top of the geomembrane. • The ability to maintain a stable configuration when other geosynthetic components such as geotextiles or geocomposites are placed on top of the geomembrane. • The ability to maintain a stable configuration when installed on top of a compacted clay liner or a geosynthetic clay liner.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	12. A specification for liner strength and the calculations defining the minimum strength requirements: • Stresses resulting from settlement, compression or uplift. • Installation stresses. • Operating stresses. • Thermal stresses. • Climatic conditions.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	13. Specification for the geomembrane protection layer that will be placed between the geomembrane and the leachate collection system, including the method of placement.	Included in the construction specification.
	14. Installation specifications should include details regarding: • Subgrade condition (including cracking and other irregularities) and	Included in the construction specification.

	suitability. • Geomembrane labelling. • Methods of protecting the geomembrane during shipping, storage and handling. • Methods of dealing with thermal effect on geomembrane surfaces on rolls. • Methods of dealing with spotting of deployed geomembranes. • Methods of dealing with thermal expansion and contraction. • Methods of dealing with wind effects. • Panel deployment layout plan, panel identification, method of placement, seam orientation, seam preparation, seaming methods, seaming temperature constraints. • Procedures to deal with damages and defects. • Procedures to be adopted to prevent desiccation of any underlying compacted clayey liner or shrinkage of any underlying GCL (both before and subsequent to the placement of the geomembrane). • Procedures to be adopted to protect the geomembrane from the soil backfill. • Methods of placement of the protective layer and/or leachate collection layer. • Methods of dealing with or managing wrinkles (waves), especially at the time the geomembrane is covered with soil (for example, drainage gravel).	
	15. Inspection activities, describe how the following will be taken into account: • Skill of the welding crew. • Supervision of welding, welding procedure and weld preparation. • Non-destructive and destructive field testing of sheets and seams during installation of the geomembrane. • Action on test failure. • Weather and temperature conditions during geomembrane deployment and seaming. • Control of panel uplift by wind. • Wrinkles and bridging. • Inspection of the surface of the geomembrane. • Presence of damages and defects. • Repair methods.	Included in the construction specification.
	16. CQC/CQA plan.	The CQA Plan covers all required aspects within the BPEM.
	17. Optional requirement (specific to landfills in rural Victoria): Methods of dealing with potential damage to the geomembrane by wildlife during installation.	This is seen as an unlikely occurrence. During construction, prior to the installation of the perimeter fence, any damage caused by wildlife will be repaired by the construction contractor. During operation, there will be a

		perimeter fence around the landfill, which will control wildlife.
D4	**Minimum Requirements for LLDPE Geomembranes for Landfill Cover Systems**	
	1. The geomembrane shall be a linear low-density polyethylene (LLDPE) and shall have preferably a minimum thickness of 1.5 mm. However, a thickness of 1 mm could be selected, provided that additional measures are taken to protect the integrity of the liner, particularly during installation. For example: extreme care is taken during installation (i.e. wedge welding of the geomembrane panels) to avoid possible burnthrough, overheating, buckling and misalignment.	A 2 mm LLDPE liner is utilised.
	2. Resin for the geomembrane should be virgin, first quality LLDPE resin and should not be intermixed with other resin types. Furthermore, it should not contain more than two per cent clean recycled polymer by weight of the LLDPE resin As a minimum, the LLDPE resin shall meet the specifications indicated below: • Density* (g/cm3) ≥0.915 and ≤ 0.926. • Melt Flow Index (g/10 min) < 1. * Base resin density without carbon black and additives added.	The construction specification stipulates these requirements.
	3. The oxidative induction time of the geomembrane shall exceed both (a) 100 min, as determined by ASTM D3895 and (b) 400 min, as determined by ASTM D5885.	The construction specification stipulates these requirements.
	4. The oxidative induction time of the geomembrane after oven ageing at 85 °C for 90 days, as described in ASTM D5721, shall exceed both (a) 35 per cent of the value for the original geomembrane, as determined by ASTM D3895, and (b) 60 per cent of the value for the original geomembrane, as determined by ASTM D5885.	The construction specification stipulates these requirements.
	5. Other design requirements and technical specifications for the geomembrane (for example, carbon black dispersion, tensile properties, two per cent modulus, tear resistance, puncture resistance, axi-symmetric break resistance strain and UV resistance).	The construction specification stipulates these requirements.
	6. The standard specification below is intended to ensure good quality and performance of LLDPE geomembranes in general applications: • 97.5% polyolefin polymer: Axi-symmetric break resistance strain > 30%. • > 2% carbon black: Must be of the right particle size - Particle size ~20 nm. • At least 0.5% anti-oxidants and HALS stabilisers: Must be have high effectiveness and permanence - HP-OIT > 400 mins.	The construction specification stipulates these requirements.
	7. The design of the liner needs to consider the various potential stresses imposed on the geomembrane by the in-service configuration and conditions. It is necessary to include the calculations of the physical stresses due to:	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.

	• Strains imposed over steep side slopes, if cover is sloped and consequently strains imposed at the anchor trench. • Differential settlement of the waste.	
	8. A statement on the effect of thermal stresses on the liner during installation and construction. Describe how these stresses will be taken into account.	The construction Specifications stipulate maximum and minimum ambient temperatures under which lining may occur. Minimum temperatures are not a concern for this location. The maximum temperature is set primarily to prevent the (soft) liner material being damaged during deployments as well as limiting the impact of contraction of the welded liner material when the temperature drops, which could put the liner under tension.
	9. A statement on the effect of equipment traffic during installation. In particular the stresses resulting from application of the top soil/cover soil/or drainage layer. Describe how these stresses will be taken into account.	It is not reasonably possible to construct the landfill lining and capping systems without having vehicles trafficking over previously laid liner layers. The construction specification provides guidance and direction to the contractor on how to traffic over previously placed liners. The CQA Plan also includes this aspect of the construction activity for the liner consultant to monitor. The landfill has been designed to ensure that all slopes are readily accessible to construction plant (max. 1 V in 3 H) so that there is no addition strain imposed on the liner by vehicles trying to track up steep slopes.
	10. In the case of installations with sloping sides, it needs to be demonstrated that there is adequate friction between the various components of the liner system to prevent slippage or sloughing on the slopes of the installation. In particular, the following must be assessed: • The ability of the geomembrane to support its own weight on the side slopes. • The suitability of the anchorage configuration for the geomembrane. • The ability to maintain a stable state if a granular drainage layer is placed on top of the geomembrane. • The ability to maintain a stable configuration if other geosynthetic components such as geotextiles or geocomposites are placed on top of the geomembrane. • The ability to maintain a stable configuration if installed on top of a compacted clay liner or a geosynthetic clay liner.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	11. A specification for liner strength and the calculations defining the minimum strength requirements due to: • Stresses resulting from differential settlement. • Installation stresses. • Thermal stresses. • Climatic conditions.	The assessment of the proposed design has been undertaken by Golder Associates and includes the required considerations.
	12. Specification for the geomembrane protrusions and penetrations. Describe how the geomembrane will be attached to penetrations and	There will only be penetrations through the landfill capping layer to

	structures. Describe how the effect of differential settlement and/or lateral movement of the materials around the protrusions/penetrations will be taken into account.	accommodate the landfill gas extraction pipes, landfill gas condensate return pipes and leachate extraction points. These penetrations will be kept to a minimum and will only occur near the perimeter of the landfill footprint where waste depth and hence settlement will effectively be negligible. The landfill gas infrastructure will be installed prior to the geosynthetic capping system being installed. The liner installer will seal around the penetrations in accordance with the drawings and material manufacturer's installation instructions. The leachate extraction points (concrete headworks) will be sealed by the liner material being fixed to the concrete slab.
	13. Installation specifications should include details regarding: • Subgrade condition and suitability. • Geomembrane labelling. • Methods of protecting the geomembrane during shipping, storage and handling. • Methods of dealing with thermal effect on geomembrane surfaces on rolls. • Methods of dealing with spotting of deployed geomembranes. • Methods of dealing with thermal expansion and contraction. • Methods of dealing with wind effects. • Panel deployment layout plan, panel identification, method of placement, seam orientation, seam preparation, seaming methods, seaming temperature constraints. • Procedures to deal with damages and defects. • Procedures to be adopted to prevent desiccation of any underlying compacted clayey liner or shrinkage of any underlying GCL (both before and subsequent to the placement of the geomembrane). • Procedures to be adopted to protect the geomembrane from the soil backfill and equipment traffic. • Methods of placement of the top soil/cover soil. • Methods of dealing with or managing wrinkles (waves). • Methods of dealing with installation around protrusions and penetrations.	Included in the construction specification.
	14. Inspection activities — describe how the following will be taken into account: • Skill of the welding crew. • Supervision of welding, welding procedure and weld preparation. • Non-destructive and destructive field testing of sheets and seams during installation of the geomembrane. • Action on failing tests. • Weather and temperature conditions during geomembrane deployment and seaming. • Control of panel uplift by wind.	Included in the construction specification.

	• Wrinkles and bridging. • Inspection of the surface of the geomembrane. • Presence of damages and defects. • Repair methods.	
	15. CQC/CQA plan.	The CQA Plan covers all required aspects within the BPEM.
	16. Optional requirement (specific to landfills in rural Victoria): methods of dealing with potential damage to the geomembrane by wildlife during installation.	This is seen as an unlikely occurrence. During cap construction, if the original perimeter fence has been removed (impacting on construction activities), any damage caused by wildlife will be repaired by the construction contractor. During the post closure period, the capping lining system will be covered by a minimum of 1 m of soil, which will protect the synthetic liner from damage by wildlife.
D5	**Requirements for the Installation of Liners to be used in Landfills**	
D5.1	**Geomembrane Installation**	
	In most cases the lining task involves large areas; therefore, it is important to proceed stage by stage in the geomembrane installation process. It is suggested that the installation be composed of the following phases: 1. Installation planning and pre-installation conformance testing. 2. Construction and preparation of the subgrade. 3. Placement of the geomembrane including transport, unrolling and placing, anchorage. 4. Welding of the geomembrane panels, connection to structure penetration systems, testing of welds. 5. Placement of the protective layer.	Included in the construction specification.
D5.1.1	**Planning and Pre-Installation Conformance Testing**	
	The installation process must be preceded by a planning phase which should result in a detailed panel layout irrespective of the type of application. The layout should specify to scale the arrangement of the geomembrane panels in the area to be lined and the penetrations and connections.	The specification includes the requirement for a pre-construction meeting before any liner works are carried out.
	Each roll of geomembrane shall be labelled to provide the following identifying data: • Name of manufacturer and type. • Material thickness. • Roll number. • Roll length. • Roll weight. • Roll width. • Reference numbers to raw material batch and laboratory certified reports. • The manufacturer's approved QA stamp and the technician's	Included in the construction specification. The specification also allows that the requirement for the manufacturer's QA technician's signature on each roll can be substituted by the technician's signature on the manufacturer's roll testing documentation. This is seen as achieving the same outcome; however, less onerous to achieve.

	signature.	
	The geomembrane should be tested for all critical properties including stress crack resistance and oxidative resistance by a third-party accredited independent laboratory before installation.	Included in the construction specification.
D5.1.2	**Subgrade**	
	For a composite liner system to function optimally and efficiently the geomembrane is required to be in intimate contact with the underlying GCL or compacted clay liner (CCL). The geomembrane liner shall be placed above a smooth surface (GCL or compacted clay liner). If the material onto which the geomembrane is to be laid is a GCL then the latter needs to be placed flat on a well compact, smooth and firm foundation material. If the material onto which the geomembrane is to be laid is a CCL then the surface of the latter shall be free of any sharp objects, stones, debris, water, sudden changes in grade, and desiccation cracks. In either case, the geomembrane shall not be installed until inspection of the finished surface has been undertaken and deemed suitable by the CQA engineer.	Included in the construction specification.
D5.1.3	**Panel Placement**	
	The geomembrane sheets shall be installed such that the panels are continuous down side walls/slopes and across the base. The arrangement of the geomembrane sheets should be according to a predetermined plan to minimise the amount of welding needed.	Included in the construction specification.
	All panels shall be overlapped onto adjacent sheets by a minimum of 125 mm and orientated so that the lap is in the down sloping direction and across the flat base. All welds should run down a slope or be on the flat base. All primary welds used to connect panel ends to sheets shall form T-joins (tees). These T-connections must have a distance of at least 0.5 m. The welding seams of the GM cannot cross (no cruciform connections).	Included in the construction specification.
	On slopes, the seams shall to a large extent run parallel to the line of maximum slope. Patching GM panels using transverse joints on slopes is not permitted. The connecting seam between geomembranes on the slope and the base should be located in the base at a distance of at least 1.5 m from the slope toe.	Included in the construction specification.
	The entire surface area of each and every roll shall be inspected by the CQA engineer, prior to works commencing. The geomembrane surface inspection may occur during unrolling/installation to ensure that there are no tears, punctures, abrasions, indentations, cracks, thin spots or other faults in the material. If damages are identified, they will need to be repaired according to the specifications put in place for the site.	Included in the construction specification.
	During installation sand bags should be placed over the panel's free edges and other areas at the end of each working day to prevent wind uplift. In expected windy conditions sandbags or similar shall be used to temporarily hold the geomembrane in position and prevent the sheet moving during	Included in the construction specification.

	welding.	
	Installation of a geomembrane can result in scratching or scoring which can affect the geomembrane's ability to stretch or conform. The method used to unroll and deploy the panels shall not score, scratch or crimp the geomembrane.	Included in the construction specification.
	Wrinkles generally occur in geomembranes during installation due to temperature variations. They tend to expand when they are heated and contract when they are cooled. This expansion and contraction must be considered when placing, seaming, and backfilling geomembranes in the field. Wrinkles are undesirable as they increase the incidence of construction damage, adversely affect the durability of the geomembrane (local regions of stress concentration), and increase the infiltration beneath the geomembrane due to a lack of intimate contact between the geomembrane and the subgrade.	Included in the construction specification.
	The geomembrane should be installed without undergoing substantial buckling, wrinkling or tensioning. In particular, care shall be taken during installation of the geomembrane to ensure that the surface of the geomembrane after installation is substantially free from buckles, wrinkles, ripples, creases and folds before the cover material is placed above it.	Included in the construction specification.
	Geomembranes installed on slopes are required to be fixed in anchor trenches. This is done to secure the geomembrane and prevent it from sloughing or slipping down the inside side slopes during construction or service.	Included in the construction specification.
	A normal minimum requirement is that the anchor trench must be at least one meter back from the top edge of the slope. Anchorage of the geomembrane should be carried out when the geomembrane is cool, to prevent bridging of the geomembrane at change of grade. The geomembrane should be laid on the inside wall and base of the trench only. The trench should be backfilled with low hydraulic conductivity soils and compacted as soon as after the geomembrane is laid.	Included in the construction specification.
	Geomembranes should not be installed if it rains, hails, during periods of high wind or excessive dust, or if the subgrade is very wet.	Included in the construction specification.
D5.1.4	**Geomembrane Welding**	
	The function of a geomembrane liner is to prevent liquid flow or gas migration into the environment, a key aspect for a successful functioning of the liner is the seaming (welding) in the field of the deployed geomembranes panels. Geomembranes can be welded by either thermal methods or chemical welding (solvent methods). The latter is not commonly used in landfills and will not be discussed further in this document. Thermal methods rely on fusion of the surfaces to be joined using applied heat (this includes wedge welding, hot air welding and extrusion welding). Only hot wedge welding and extrusion fillet welding shall be used.	Included in the construction specification.

	The weld surfaces should be clean prior to welding. The weld area should be free of moisture, dust, dirt, debris, markings and foreign material. To minimise this problem some manufacturers apply a removable tape to the edges of the geomembranes which can be removed just prior to welding.	Included in the construction specification.
	In the case of extrusion fillet welding, oxidation by products need to be removed from the surface to be welded by grinding/buffing. Grind marks should not be deeper than 10 per cent of the geomembrane thickness. Welding should be performed shortly after grinding so that surface oxide formation does not reform.	Included in the construction specification.
	The contractor shall be responsible for regularly checking, calibrating and recording the following items: • Preheat air flow and temperature at the nozzle. • Extrudate flow and temperature at the barrel outlet. • Split copper wedge temperature on both contact points.	Included in the construction specification.
	The contractor shall have an independently calibrated hand held temperature measuring device to confirm temperatures of each and every welding machine prior to the commencement of any test or field welds. All information regarding the results gained from the temperature device shall be recorded for each welding machine.	Included in the construction specification.
D5.1.5	**Welding Method**	
	Welding of all main joints between adjacent geomembrane panels (primary welds) shall be conducted using hot-wedge welding, producing two parallel seams with an air channel in between (dualtrack fusion welding). The hot-wedge welding shall be conducted out using the split head wedge fusion weld method which will fuse the upper and lower overlapped geomembrane sheets.	Included in the construction specification.
	The welding equipment shall be a fully automated device comprising of a heated copper wedge, pressure rollers and electronic controls. The copper wedge shall be controlled and constantly monitored by a programmable controller with an audible off temperature alarm and a variable speed drive unit. The copper wedge shall create two contact fusion areas of a minimum width of 15 mm and a 5 mm minimum wide void between each of the separate parallel weld zones. This void shall be created over the entire seam length to allow for field weld pressure testing.	Included in the construction specification.
	The extrusion process is used primarily for detailed work and repair work (secondary weld) or where approved in areas that would be inaccessible to the dual track fusion weld (such as around structures, pipes and other penetrations). The extrusion welding shall be conducted using the manufacturers' surface extrusion hand welders.	Included in the construction specification.
	The minimum width of the surface extruded bead shall be 30 mm. The surface extrusion welder shall be semi-automated and equipped with electronic controls which constantly monitor outputs for both preheat and extradite. The unit shall be capable of pre-heating the sheet just prior to the	Included in the construction specification.

	casting of the extradite over the upper and lower section of the weld zone.	
	The extruded granulate for surface extrusion welding shall be manufactured from the same resin type used in the manufacture of the geomembrane. All physical properties shall be identical to those possessed by the geomembrane raw material. The manufacturer shall provide certified test data with each batch of welding granulate. All granulate supplied shall be packed to prevent the ingress of moisture and other contaminants. If necessary, the contractor shall also employ an apparatus specifically built for drying granulate to ensure weld quality.	Included in the construction specification. Welding rods are more commonly used, if so, the same specification is applicable, except for the concern about moisture, which is of lesser concern with rods.
	Careful control the temperature and speed of welding according to the nature and thickness of the material and the ambient temperature. Overheating during welding can lead to structural changes or melting and weakens the geomembrane. A too low temperature will result in a poor quality weld and low seam strength. Welding of any one joint should be carried out in one direction only.	Included in the construction specification.
	All geomembrane panels subject to hot wedge welding shall be overlapped by a minimum of 125 mm and a minimum of 75 mm for extrusion welding to allow for proper construction quality assurance testing.	Included in the construction specification.
	The contractor shall ensure prior to any primary or secondary welding that weld zones be clean, free from moisture, dust and any other foreign matter. All weld zone surfaces shall be either cleaned or abraded no more than 30 minutes prior to the commencement of welding any seam. In extremely bad conditions it may be necessary for the contractor to clean and/or abrade the weld zone areas only minutes prior to the required weld.	Included in the construction specification.
D5.1.5.1	**Weld Testing**	
	Weld testing involves both destructive testing (field and laboratory) and non-destructive testing.	Included in the construction specification.
	Destructive testing involves cutting out sections of the finished welds and testing them in shear and peel modes according to specific standards. Destructive testing is by its nature confined to spot checks on limited lengths of geomembrane seams and does not give adequate information on the continuity and completeness of the entire seam between sampling locations.	Included in the construction specification.
	On the other hand, non-destructive tests aim to assess the integrity of the seam in a continuous approach with a view of validating 100 per cent of the seams.	Included in the construction specification.
D5.1.5.2	**Destructive Testing**	
	Destructive testing is necessary to validate the strength and integrity of a weld and is part of the overall construction quality assurance programme where a sample of an installed geomembrane weld is cut out of the geomembrane and tested for shear and peel strength.	Included in the construction specification.

	Destructive testing is required for the trial seams needed to prequalify welding personnel on a daily basis, equipment and procedures for making seams on identical geomembrane material used on site and under the site conditions.	Included in the construction specification.
	Testing will need to be repeated if any welding stoppage exceeds one hour and if weather conditions change. The trial weld sample shall be at a minimum 1.0 m long by 0.3 m wide with the weld centred lengthways. Four 25 mm wide samples shall be cut from the trial weld sample using a calibrated die cutter and tested in shear and peel using a calibrated tensiometer to determine whether the test welds have passed or failed.	Included in the construction specification.
	Destructive seam tests shall also be performed at random locations (selected by the CQA Authority) during the installation at a minimum of one sample every 150 m of seam (for basal and sideslope liners) as per Table D3, and for capping liners in accordance with Table D4. Shorter intervals can be specified for extrusion welds. The purpose of these tests shall be to confirm and evaluate seam strength and continuity during the field seaming.	Included in the construction specification.
	Each sample shall be cut using a calibrated die cutter into five x two (5 x 2) 25 mm wide pieces and shall be sent to a third-party independent accredited geosynthetics laboratory for shear and peel testing. On-site testing shall also be conducted by the installer using a calibrated tensiometer. Any remaining samples shall be stored by the facility owner. In the event of a failure, all prior welds shall be tested back to the last test that passed. It will be the responsibility of the installer to repair and make good the seam/seams to the satisfaction of the CQA authority.	Included in the construction specification.
D5.1.5.3	**Non-Destructive Tests**	
	Non-destructive tests for geomembrane include air pressure testing for dual track fusion welds and vacuum testing for extrusion welds. Non-destructive testing should be performed over the entire length of the seam.	Included in the construction specification.
	The pressurised air test is described in the standard ASTM D5820 *Standard practice for pressurised air channel evaluation of dual seamed geomembranes*. The test can begin no earlier than one (1) hour after welding.	Included in the construction specification.
	Testing tightness of the extrusion fillet seams is more laborious. They must be tested piece by piece by applying a vacuum box. The vacuum box test is described in the standard ASTM D5641 *Standard practice for geomembrane seam evaluation by vacuum chamber*. This test should also start no earlier than one (1) hour after welding.	Included in the construction specification.
	In addition to the above tests, the welds can also be visually inspected to assess the quality of the workmanship and the appearance of the welded seam. For wedge welds the observed needs to observe a consistent 'squeeze out' on the weld edge which is an indicator that the correct temperature and pressure were used during installation. In the case of extrusion fillet welds, the weld appearance should be smooth, uniform and	Included in the construction specification.

	free of streaks and lumps. In addition, there should be no obvious scoring, notches or deep scratches introduced by the surface grinding.	
D6	**Quality**	
D6.1	**Manufacturing Specifications and Quality Control**	
	The quality of the geomembranes shall be in accordance with the requirements of the Geosynthetic Research Institute (GRI) – GM13 and GM17. The minimum specifications for a quality HDPE and LLDPE geomembrane products are contained in GRI Test Method GM-13 Standard Specification for 'Test Properties, Testing Frequency and Recommended Warranty for High Density Polyethylene (HDPE) Smooth and Textured Geomembranes' and GRI Test Method GM-17 Standard Specification 'Test Properties, Testing Frequency and Recommended Warranty for Linear Low Density Polyethylene (LLDPE) Smooth and Textured Geomembranes'.	Included in the construction specification.
	In addition to the above, a statement on the origin of the resin, its identification (type and lot number), its production date and the maximum amount of recycled polymer material added to the raw resin must be included as well as certified copies of the quality control certificates issued by the resin supplier and reports on the tests conducted by the manufacturer to verify the quality of the resin used to manufacture the geomembrane rolls assigned to the project.	Included in the construction specification.
D6.2	**Construction Quality Control (CQC)**	
	Installation and seaming of the geomembranes must be undertaken by geomembrane installers with extensive experience in seaming the same type of geomembrane being installed and using the same seaming procedure to be used on site. They must hold a current independent certification for seaming and installation to a recognised industry standard (national or international) and must provide experience records prior to any installation.	Included in the construction specification. Although the requirement for all liner installers to hold a current independent certificate for seaming is desirable, this is not commonly available in Australia and would seriously limit the availability of installers; consequently, the specification also includes a minimum requirement that the installers have the following minimum experience: • Field Installation Supervisor – 500,000 m^3; • Master Seamer – 300,000 m^3 and • Installer – 100,000 m^3 and be under fulltime supervision by one of the above.
D6.2	**Third-Party CQA Consultant**	
	An independent third-party CQA consultant with experience with geomembranes and knowledgeable of geomembrane and seam performance characteristics must be appointed to verify that the works have been carried out to the agreed standards.	An appropriately experienced third-party CQA consultant will be appointed to verify that the Works have been carried out to the agreed standards. The Synthetic Liner CQA Plan sets out the aspect of the Works that are to be verified.
	The duties of the third-party CQA consultant include inspections, verifications, audits and evaluation of materials and workmanship, provision of advice on installation, testing, repair, and covering of the geomembrane	Included in the Liner CQA Plan.

	lining system and issuing a final CQA report documenting the quality of the constructed facility.	
D6.4	**CQA Plan**	
	A CQA plan shall be submitted to EPA prior to the geomembrane installation. The CQA plan needs to provide procedures for identifying non-conformance and for corrective action.	The CQA Plan is included in the Works Approval application documentation.
D6.5	**CQA Testing**	
	Tables D3 and D4 (refer below) provide guidance on the test properties and recommended minimum testing frequencies. Higher testing frequencies might be required in certain applications (i.e. need to identify the importance of the geomembrane for the safety of the works, construction and stability included). The onus is on the engineer of record to establish if higher requirements are more appropriate.	Included in the CQA Plan. One amendment to Table D4 conformance testing requirements is that the 90 day Oven Aging and Oxidative Induction Time (OIT) test will not be undertaken on materials delivered to site due to the time delay between awarding the construction contract, ordering the material (7 – 9 weeks) and then a further +90 days of testing. Only the 100 minute and 400 minute OIT tests will be carried out to confirm the material's suitability.
D6.6	**CQA Report**	
	A CQA report must be prepared by the CQA consultant to demonstrate that all requirements of the project specifications and CQA plan have been complied with.	The CQA consultant will provide a CQA Verification Report, which will be included in the Works Approval Compliance Certification documentation sent to the DER on completion of the works.

Table D3: Guidance on CQA testing for HDPE geomembranes

Item	Property	Standards	Frequency
Conformance testing (upon shipment of geomembrane to the site)	Thickness --- Density Tensile properties (yield and break stress, yield and break elongation) Puncture resistance Tear resistance Carbon black content Carbon black dispersion --- Stress crack resistance Oxidative induction time	ASTM D5994 --- ASTM D1505, ASTM D792 ASTM D6693 type IV ASTM D4833 ASTM D1004 ASTM D1603 ASTM D5596 --- ASTM D5397 ASTM D3895,ASTM D5885	Each roll --- One sample per 5000 m^2, or every five rolls delivered to site whichever is the greatest number of tests --- One sample every 10,000 m^2, or resin type or manufacturing run.
Start-up test weld	Welding equipment --- Weld conditions	--- 	Checked daily at start of works, and whenever the welding equipment is shut-off for more than one hour. Also after significant changes in weather conditions --- Test weld strips will be required whenever personnel or equipment are changed and/or wide temperature fluctuations are experienced. Minimum 1.5 m continuous seam
Destructive weld testing	Onsite, hand tensiometer in peel and shear --- Offsite – weld seam strength in peel and shear	ASTM D6392 --- ASTM D6392	Every weld --- Every 150 m (if fusion weld), every 120 m (if extrusion weld)
Non-destructive weld testing		Air pressure test, ASTM D5820 Vacuum box test, ASTM D5641	All seams over full length
Visual inspection of geomembrane	Tears, punctures, abrasions, cracks, indentations, thin spots, or other faults in the material.		Every roll
Thickness of geomembrane	Onsite		Five per 100 m, 20 m apart, taken at the edge of the sheet

Note:

1 All conformance tests must be reviewed, accepted and reported by a CQA consultant before deployment of the geomembrane.
2 All testing must be performed on samples taken from the geomembrane delivered to site under the CQA consultant supervision.
3 All laboratory tests must be performed in a third-party independent accredited geosynthetics laboratory.
4 The required testing frequencies may be revised by the CQA consultant to conform with improvements in testing methods and/or in the state of the art practice and/or to account for the criticality of the application (i.e. to account for the importance of the geomembrane for the safety of works). Revisions must be approved by the relevant authorities before application.

Table D4: Guidance on CQA testing for LLDPE geomembranes

Item	Property	Standards	Frequency
Conformance testing (upon shipment of geomembrane to the site)	Thickness	ASTM D5994	Each roll
	Density	ASTM D1505, ASTM D792	One sample per 5000 m^2, or every five rolls delivered to site whichever is the greatest number of tests
	Tensile properties (yield and break elongation)	ASTM D6693 type IV	
	Puncture resistance	ASTM D4833	
	Tear resistance	ASTM D1004	
	Carbon black content	ASTM D1603	
	Carbon black dispersion	ASTM D5596	
	Axi-symmetric break resistance strain	ASTM D5617	Per formulation
	Oxidative induction time	ASTM D3895,ASTM D5885	One sample every 10,000 m^2, or resin type or manufacturing run.
	Oven ageing and oxidative induction time	ASTM D5721, ASTM D3895, ASTM D5885	
Start-up test weld	Welding equipment		Checked daily at start of works, and whenever the welding equipment is shut-off for more than one hour. Also after significant changes in weather conditions
	Weld conditions		Test weld strips will be required whenever personnel or equipment are changed and/or wide temperature fluctuations are experienced. Minimum 1.5 m continuous seam
Destructive weld testing	Onsite, hand tensiometer in peel and shear	ASTM D6392	Every weld
	Offsite – weld seam strength in peel and shear	ASTM D6392	Every 300 m (if fusion weld), every 150 m (if extrusion weld)
Non-destructive weld testing		Air pressure test, ASTM D5820 Vacuum box test, ASTM D5641	All seams over full length
Visual inspection of geomembrane	Tears, punctures, abrasions, cracks, indentations, thin spots, or other faults in the material.		Every roll
Thickness of geomembrane	Onsite		Five per 100 m, 20 m apart, taken at the edge of the sheet

Note:
1 All conformance tests must be reviewed, accepted and reported by a CQA consultant before deployment of the geomembrane
2 All testing must be performed on samples taken from the geomembrane delivered to site under the CQA consultant supervision
3 All laboratory tests must be performed in a third-party independent accredited geosynthetics laboratory
4 The required testing frequencies may be revised by the CQA consultant to conform with improvements in testing methods and/or in the state of the art practice and/or to account for the criticality of the application (i.e. to account for the importance of the geomembrane for the safety of works). Revisions must be approved by the relevant authorities before application