New developments in prevention and protection of water resources.

Why PVC-EIA alloys are the best choice for long-term, improved performance.

GEOANZ #1 ADVANCES IN GEOSYNTHETICS
7–9 JUNE 2022 | BRISBANE CONVENTION & EXHIBITION CENTRE

- Company introduction
- Geomembranes for liner and covers in potable water applications
- Development of PVC-EIA coated fabrics
  - Physical design parameters
  - Long term weathering
  - Chemical resistance
- Future considerations: PFAS containment
- Conclusions

Cooley Group, Long History of Firsts

Cooley Established – Begins manufacturing **first** cotton awning fabrics

First company to introduce PVC-finished awnings and truck tarpaulins

First company to produce DuPont Hypalon and **first** company to purchase an extruder for industrial coated fabrics

First company to produce thermoplastic roofing in North America

First company to introduce DuPont Kevlar-reinforced TPU for oil booms

First company to introduce Aramid edge reinforcement for world-leading C3 Elvaloy (EIA) roofing products

First Cooley Acquisition - Vintex (Mount Forest)

1926 **1950** **1960** **1970** **1980** **1990** **2020's**

Cooley's Six Global Business Units

Containment Solutions

Waterproofing Solutions

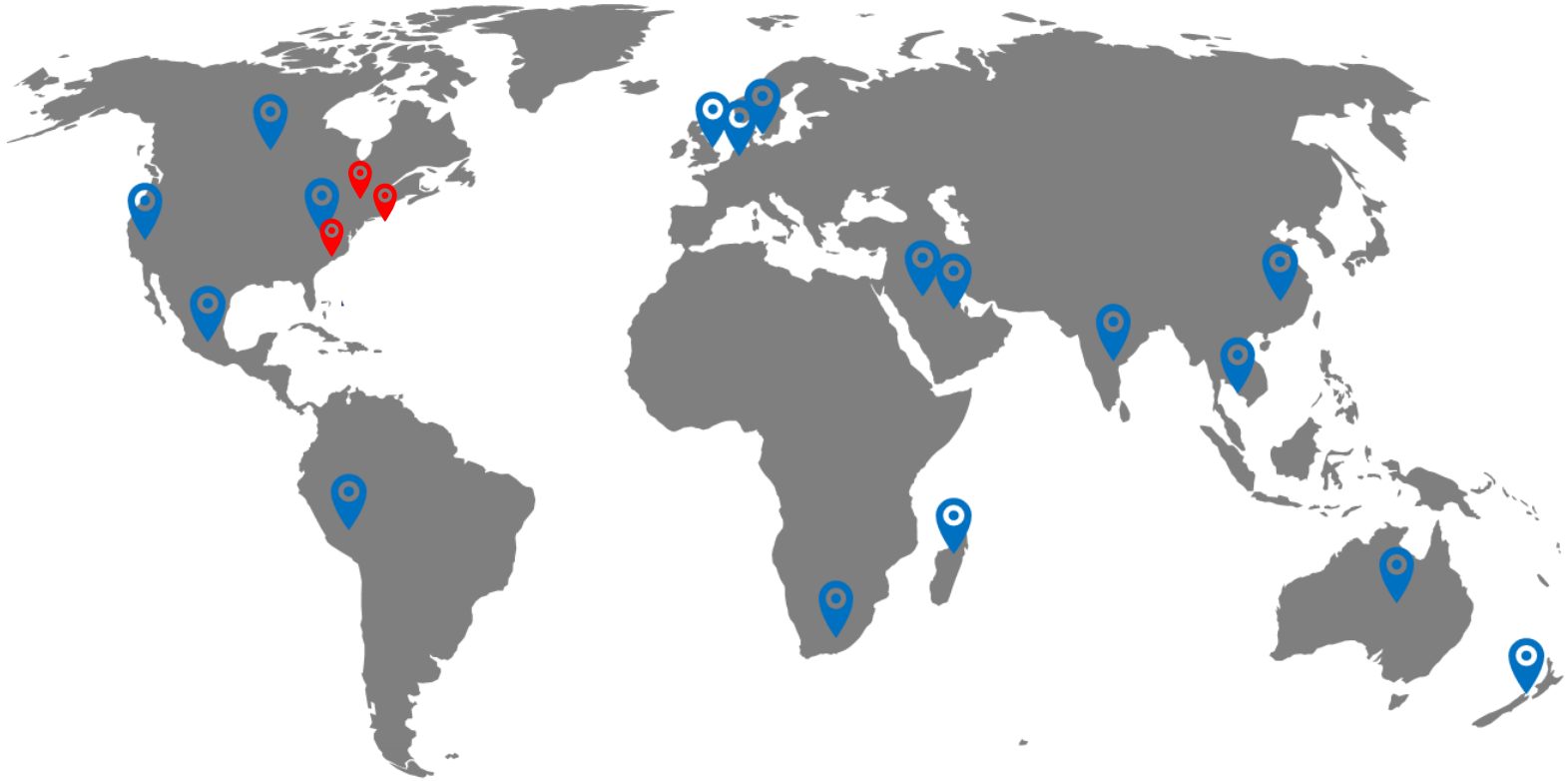
Healthcare Solutions

Print Media Solutions

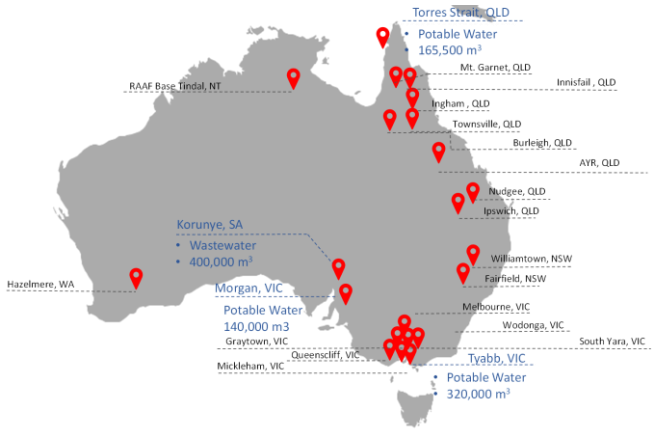
Custom Solutions

Sign & Shade Solutions

Cooley's Liquid Containment Projects



- Over 30 years experience developing and manufacturing water and wastewater management solutions
- Over 1,600 water & wastewater projects worldwide for commercial, industrial & government customers;
- Over 100 million cubic meters of water & wastewater containment
- Australia: 4.3 million m^3 (30 projects)

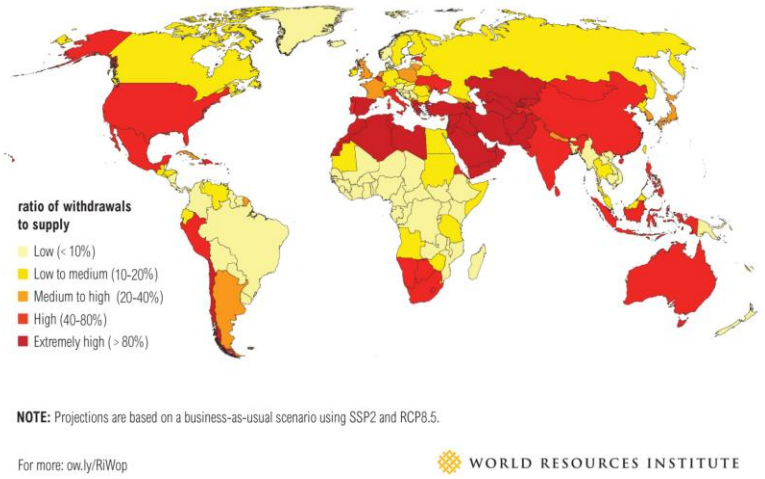


Cooley Group locations

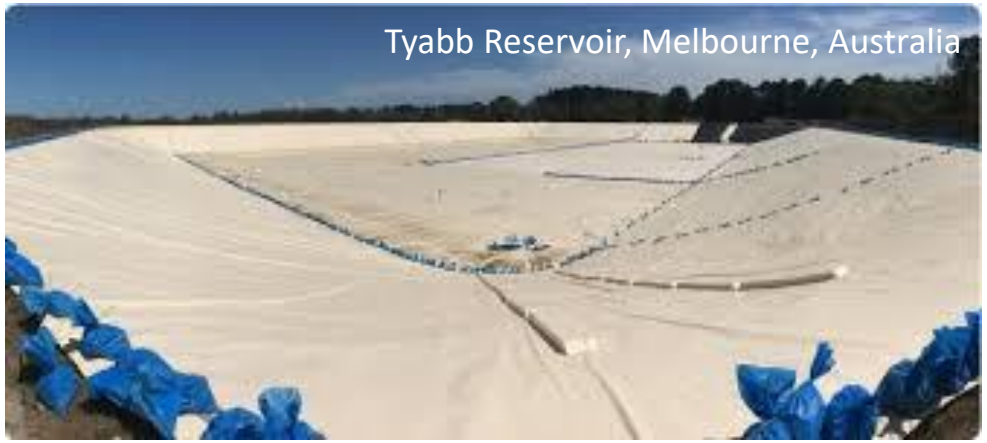
Containment projects

Water Protection and Preservation

- Once considered a ‘revolutionary’ solution in the potable water industry, floating covers/liners are now validated by decades of successful, global applications
- Australia’s largest water authorities moved from concrete construction to geomembrane lined and covered earthen construction – i.e.: Sydney Water, Gippsland Water, Baron Water, & South Australia Water
- Benefits include:
  - Excludes sunlight (preventing algae & reactive byproducts that affect water taste / odor)
  - Prevents evaporation of water
  - Prevents evaporation of disinfectant
  - Prevents dilution from precipitation
  - Lowers life cycle costs compared to concrete reservoirs and steel tanks



Water Stress by Country: 2040



Economic Comparison

Geomembrane Solution

- Location: Oregon, USA
- Storage Volume: 378,500 m^3
- Project Cost: US$16 million
- Cost / liter: US$0.0422

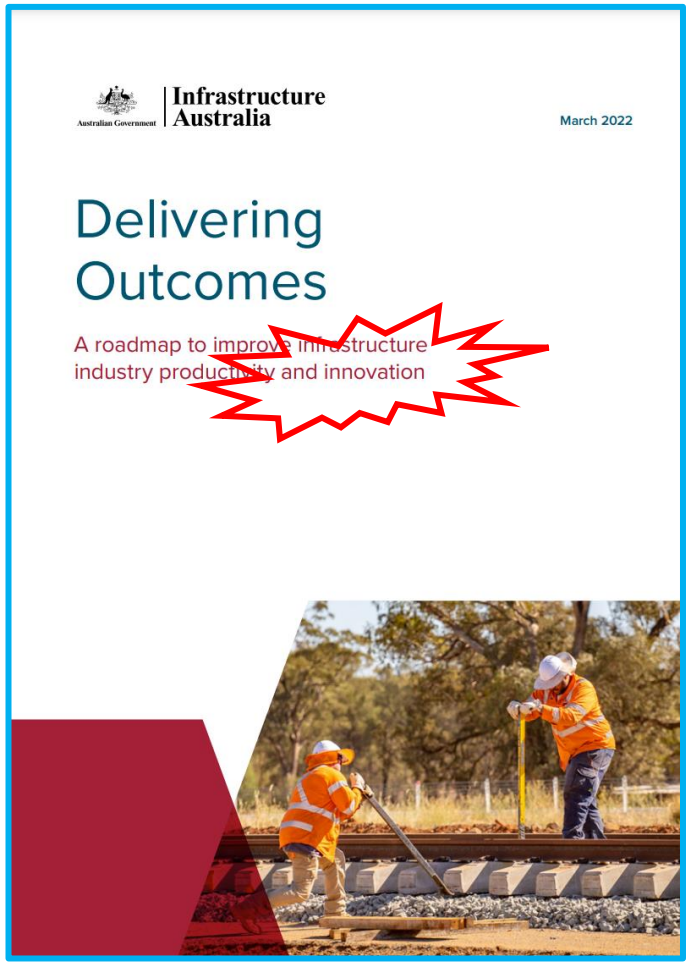
Concrete Solution

- Location: Jeddah, KSA
- Storage Volume: 2,062,500 m^3
- Project Cost: US$201 million
- Cost / liter: US$0.0975*

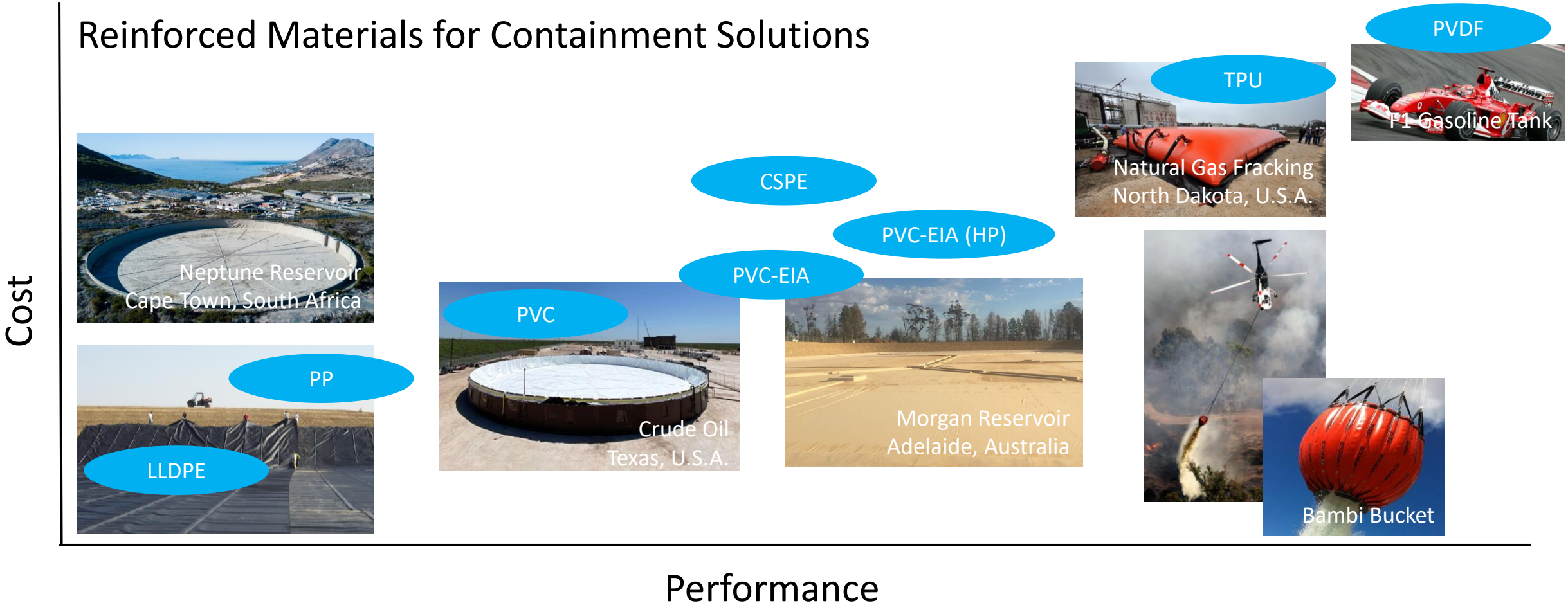
Note: Comparable cost for concrete solutions in US higher cost factors = $0.167 (58% cost premium versus KSA)

Changing Requirements

- Infrastructure Australia report (ISBN: 978-1-925352-67-2):
- Public infrastructure projects and programs, including transport, energy, waste, **water**, telecommunications, and social infrastructure
- Reforms put forward respond to the current state of the sector, key challenges and root causes **impeding productivity and innovation** and sets out the desired future state for the sector.
- Australian infrastructure sector to **move away from traditional scope-based delivery models** and progressively adopt outcome-focused solutions which result in cost and time savings.



Innovation through Material Development



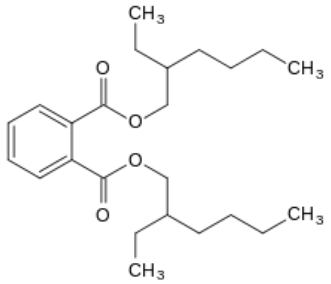
Requirements Liners and Covers for Water Storage

- Physical Properties
  - Withstand rigors of installation
  - Protect against rocks, vegetation, etc
  - Covers are dynamic → withstand tear (propagation), strain on seams
- Weathering
  - Exposure against sun light
  - High temperatures require proper stabilization of polymer matrix
  - Use in cold conditions requires proper low temperature properties
- Chemical Resistance
  - Use of disinfectants (chlorine, chloramine)
- Potable Water Certification
  - Safety, smell, taste → determines selection of additives

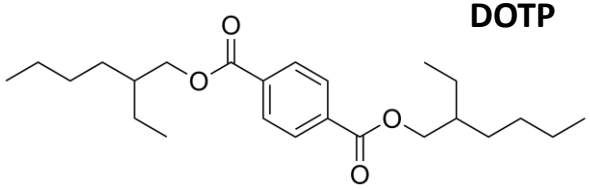
PVC-EIA Materials, Designed for Performance

To make PVC flexible and suitable to use in coated fabrics, plasticizers are added to the resin to reduce the glass transition temperature from 80-100°C to 10-20°C.

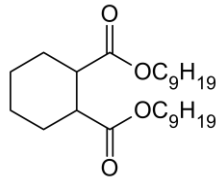
- Originally phthalates → health concerns (depending on fatty acid chain) has led to development of alternatives
- Relatively low molecular weight ("liquid plasticizers") with tendency to migrate out of the plastic



DEHP

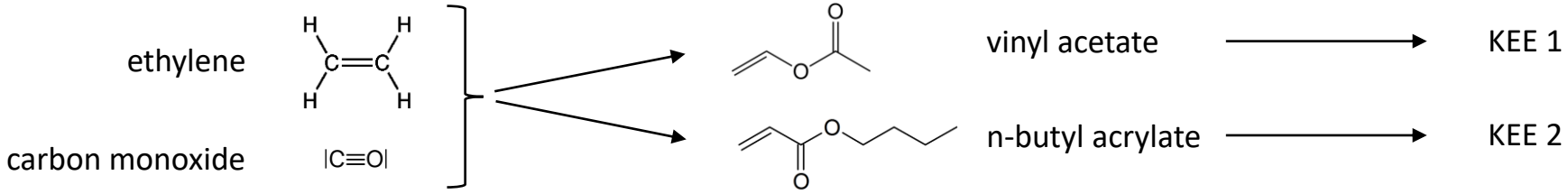


DOTP



DINCH

- DuPont developed high molecular weight Ketone Ethylene Esters (KEE, ELVALOY™) with different monomers that are miscible with PVC and form an Ethylene Interpolymer Alloy (EIA) and do not migrate out of the polymer matrix.



PVC-EIA Materials, Multiple Generations

- **Cooley collaborated with DuPont to develop a high performance (HP) KEE for potable water geomembrane**
- Improved physical properties
- Less stiffness
  - 750,000 flex cycles at 23˚C (ASTM D2097)
  - Geomembrane better able to conform to uneven subgrades
  - Easier handling for detail work (note: 5m wide rolls available)
- Better low temperature flexibility
  - 200,000 flex cycles at -5˚C (ASTM D2097)
- Better thermal stability
  - Longer life cycle in hot environments
  - Higher end use temperature

Product	Tg / -40C Bend
PVC-EIA (HP)	-29°C / Pass
PVC-EIA	-17°C / Fail

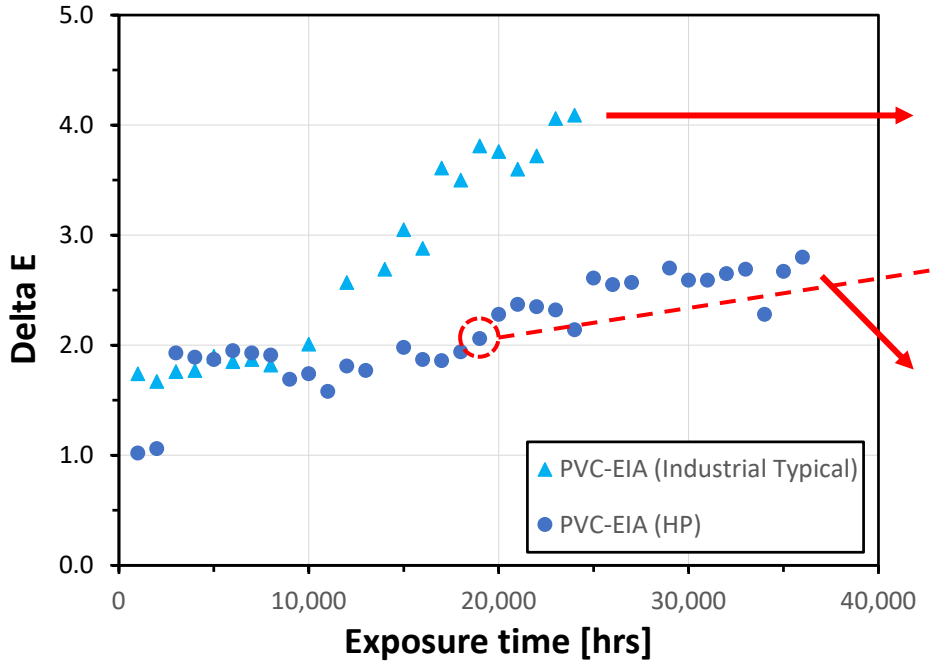
PVC-EIA (HP), Physical Properties

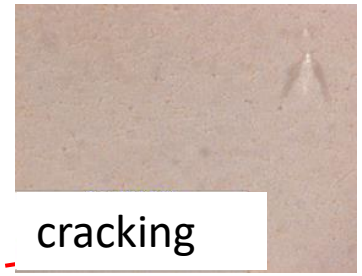
Properties	Test Method	Typical specifications	PVC-EIA (Industry Typical)	PVC-EIA (HP)
Thickness	D751	1.5 mm	1.5 mm	1.5 mm
Thickness – Lowest individual	D5199	-5%	-10%	-10%
Tensile strength – Grab test	D751A	> 1,100 N	1,500 x 1,500 N	2,000 x 2,000 N
Tensile elongation – Grab test	D751A	> 25%	25-30 x 25-30%	30 x 30%
Wide width – Tensile strength	D4885	20 kN/m	*No data*	50 kN/m
Tongue tear resistance	D751B	>165 N	110 – 130 N	580 N
Puncture resistance screwdriver	D751	>250 N	290 – 310 N	330 N
Abrasion resistance	D3389	>2,000 cycles	2,500 cycles	10,000 cycles
Seam peal adhesion	D7747 Meth A	> 100 N/25mm	70 – 100 N/25mm	110 N/25mm
Seam shear strength (grab)	D7749	> 900 N	900 N	1,200 N
Seam shear strength (strip)	D7747 Meth A	> 300 N/25mm	400 N/25mm	1,000 N/25mm

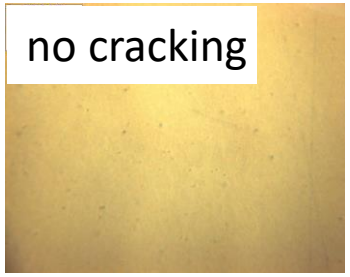
- Specifications vary per project and may be higher than shown
- Data for industry typical PVC-EIA material are average data for different materials used in water reservoir applications obtained from the field
- Data for PVC-EIA (HP) are typical values.

PVC-EIA (HP), Longevity – UV Exposure

- Long term performance is further improved through enhanced stabilization package.
- Based on proven durability of roofing membranes that performed for over 30 years without a single failure.







PVC-EIA (HP)	CRIT Retention, 19k hrs
Congo Red	10%
HPOIT	40%

Data show additives still in place after equivalent 19-year exposure.

ASTM G154: UVA 340nm (0.68 irradiance W/m2) 60°C 8:00 hrs - Cond. 50°C 4:00 hrs cycle; 1,000hrs ~ 1 year outdoor exposure

- PVC-EIA (HP) was exposed to accelerated UV testing in Arizona for 57 months, accumulating approximately 73,014 kW-hr/m2 – equivalent to 47 years in Melbourne[1] without cracking when viewed under 7X magnification.

[1] Total irradiance in Melbourne (2019) = 1,538 kW-hr/m^2 (Bureau of Meteorology).

PVC-EIA (HP), Longevity - Temperature

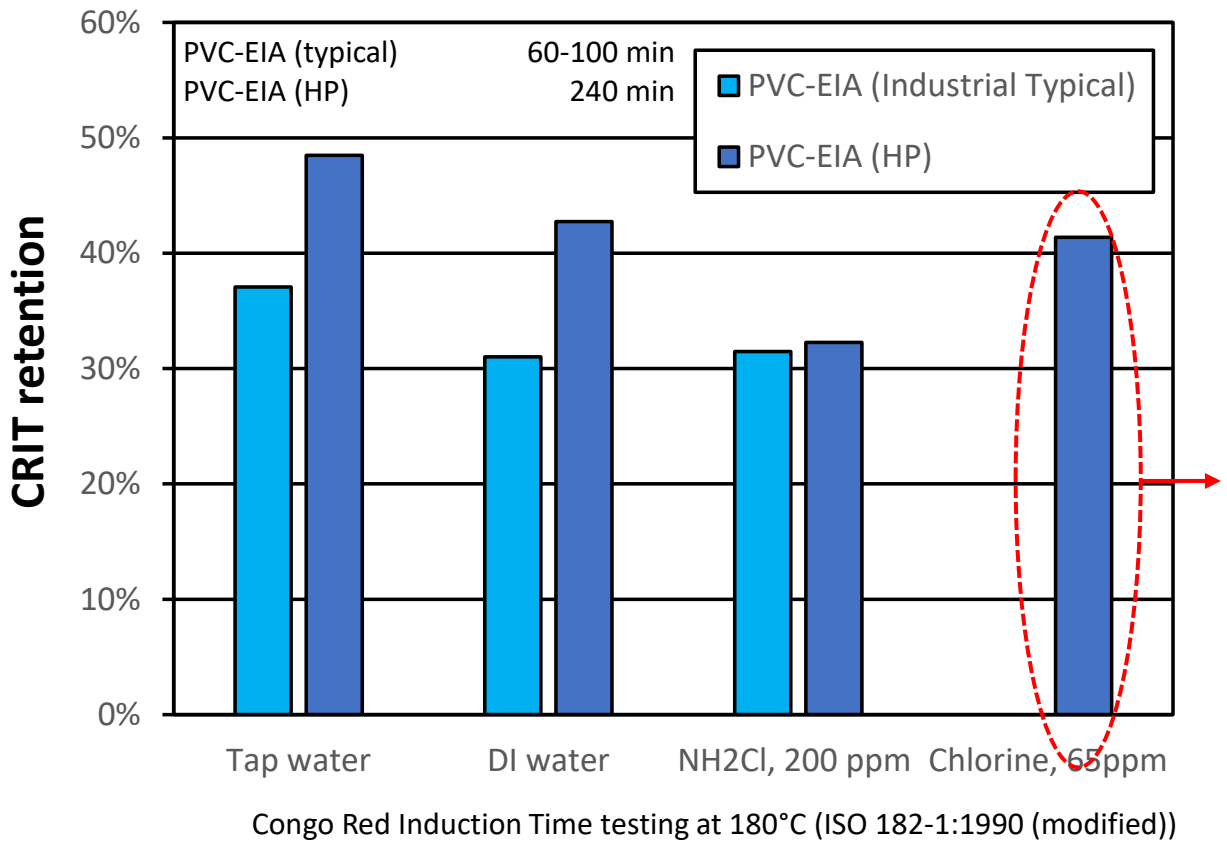
Resistance to the effects of a hot, dry environment was evaluated in accordance with ASTM D5721. Materials were aged for 90 days at 85°C (185°F) in an air circulating oven.

PVC-EIA (HP) (1.14 mm)	**BEFORE**	**AFTER**	**RETAINED**
Weight	1,450 g/m^2	1,435 g/m^2	99%
Tensile Strength, Strip	334 N/cm	334 N/cm	100%
Elongation at Break, Strip	36.3%	37.8%	100%
Tensile Strength, Grab	1,486 N	1,503 N	100%
PVC-EIA (HP) (1.52 mm)	**BEFORE**	**AFTER**	**RETAINED**
Weight	1,837 g/m^2	1,831 g/m^2	99%
Tensile Strength, Strip	572 N/cm	567 N/cm	99%
Elongation @ Break, Strip	37.8%	39.0%	100%
Tensile Strength, Grab	2,224 N	2,233 N	100%

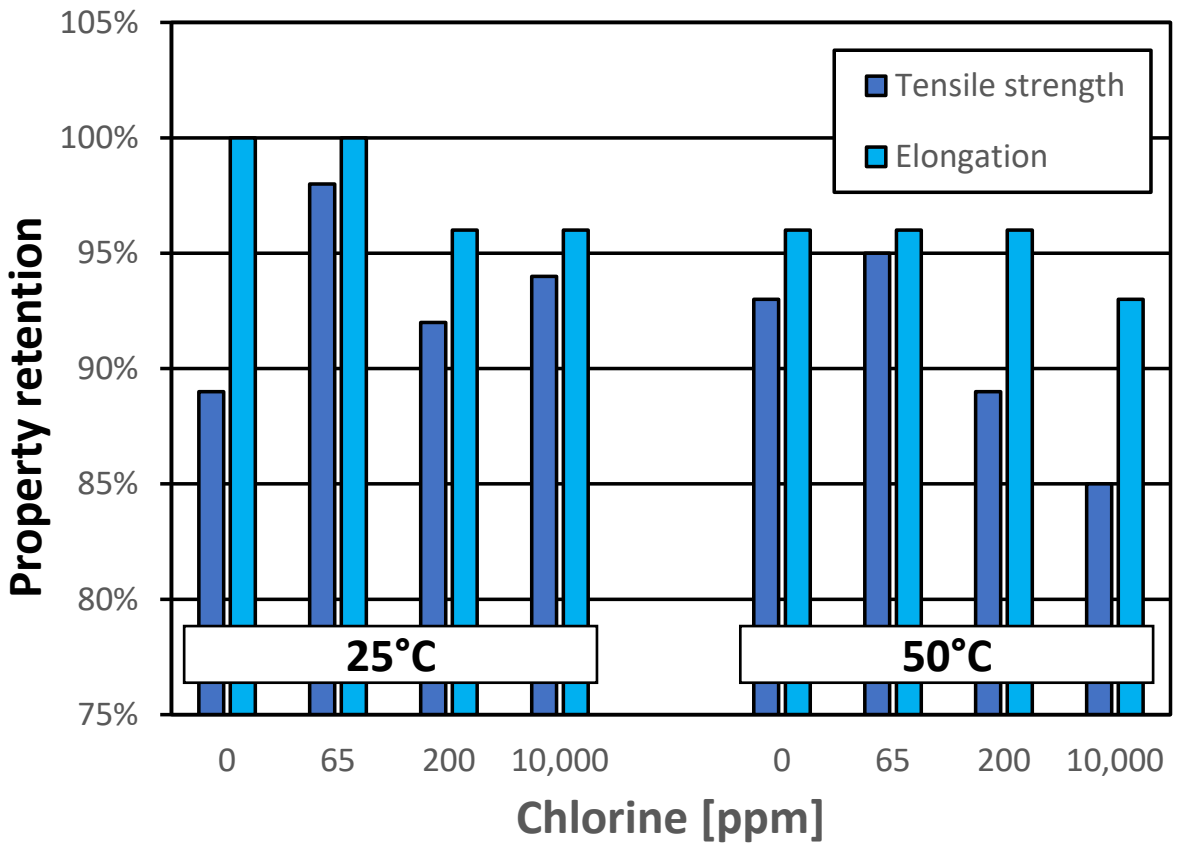
Extrapolated using a simple rate reaction model (reaction doubles with every 10°C change) → equivalent to 16 years at 25°C.

PVC-EIA (HP), Chemical Resistance Immersion

Immersion (50°C for 120 days)

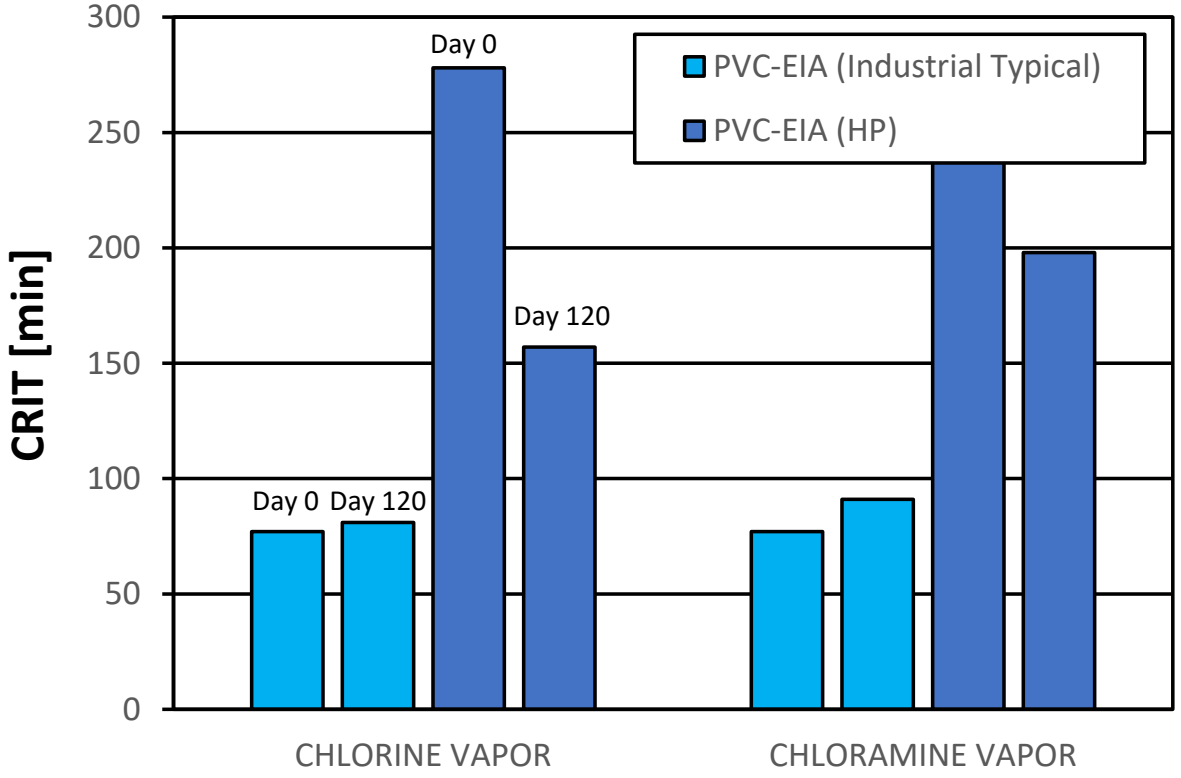


Congo Red Induction Time testing at 180°C (ISO 182-1:1990 (modified))

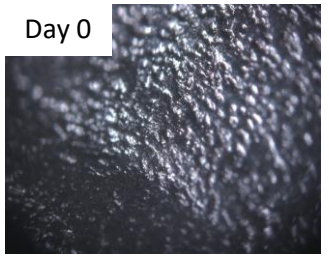


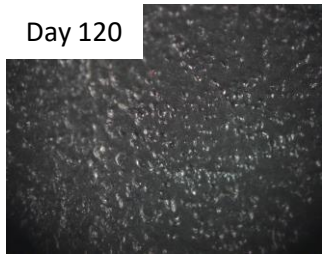
PVC-EIA (HP), Chemical Resistance Vapors

Exposure to Vapor for 120 days



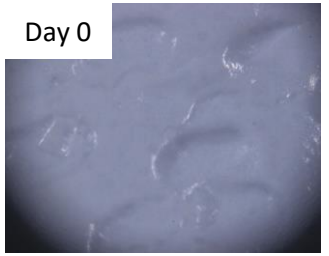
PVC-EIA (Industrial Typical), no major changes on surface

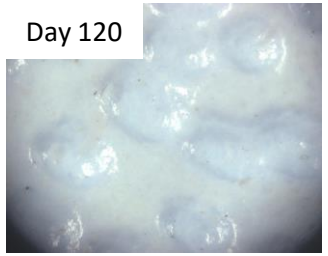


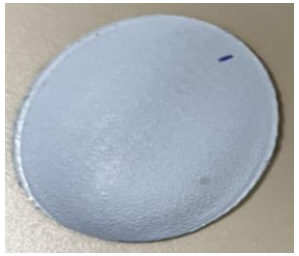


Chloramine exposure

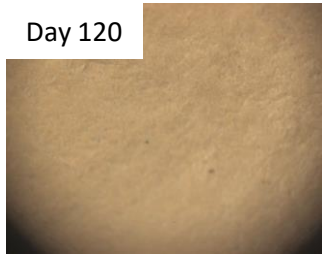
PVC-EIA (HP), no major changes on surface

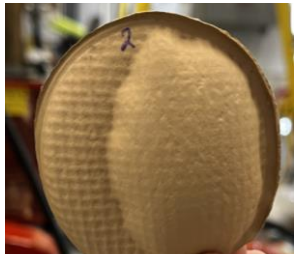






Chlorosulfonated polyethylene (CSPE), no major changes on surface



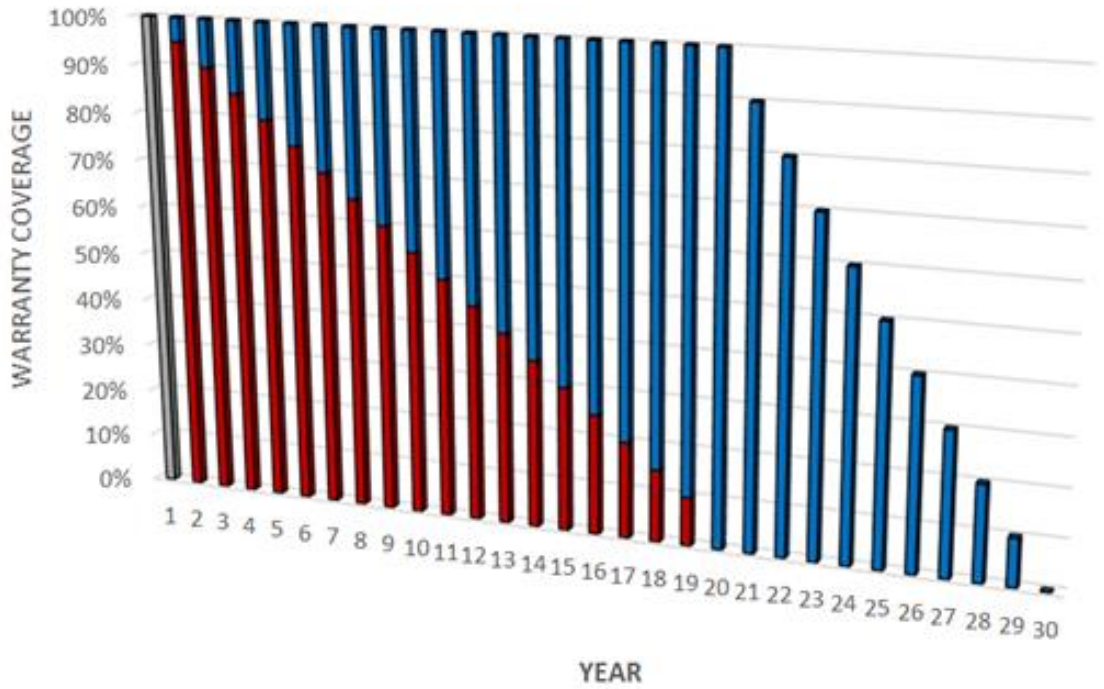


Bubbling and delamination after 60 days

Innovation Leads to Extended Warranty

New developments in PVC-EIA (HP) has led to improved:

- Physical Properties
  - Extra High strength / Anti Wick reinforced scrim
  - RF, wedge, and hot air weldable
  - Low T flexibility
- Weathering
  - Ultra UV, ozone, and weathering resistant
  - No curing out
- Chemical Resistance
  - Aqueous solutions
  - Vapors
- Potable Water Certification
  - NSF Standard 61
  - AS/NZS 4020
  - SI 5452



PVC-EIA Industry Typical: 20 years total, years 1-20 prorated

PVC-EIA (HP): 30 years total, years 1-20 Straight warranty at 100%, years 20-30 prorated

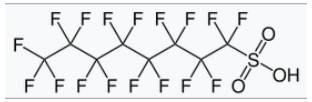
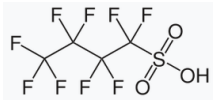
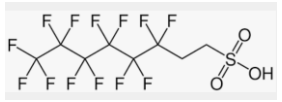
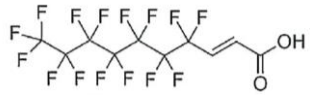
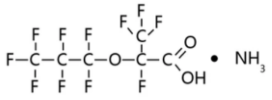
Reinforced PVC-EIA for PFAS Containment

- Per and polyfluoroalkyl substances (PFAS, “forever chemicals”)
  - Surfactants, extremely stable, oil and water resistant.
  - Thousand of different substances known, have been used in industrial and consumer goods
  - Present on fire training / fire response sites, airports, industrial sites, landfills, and in wastewater.
  - Severe health concerns have led to extreme low acceptance levels in drinking water (<20ppt).

- To contain these materials in (temporary) landfill sites, liner materials are required that:
  - Have a low **permeability** against these chemicals
  - Show good **chemical resistance** against these chemicals (minimal impact on longevity)

Reinforced PVC-EIA for PFAS Containment

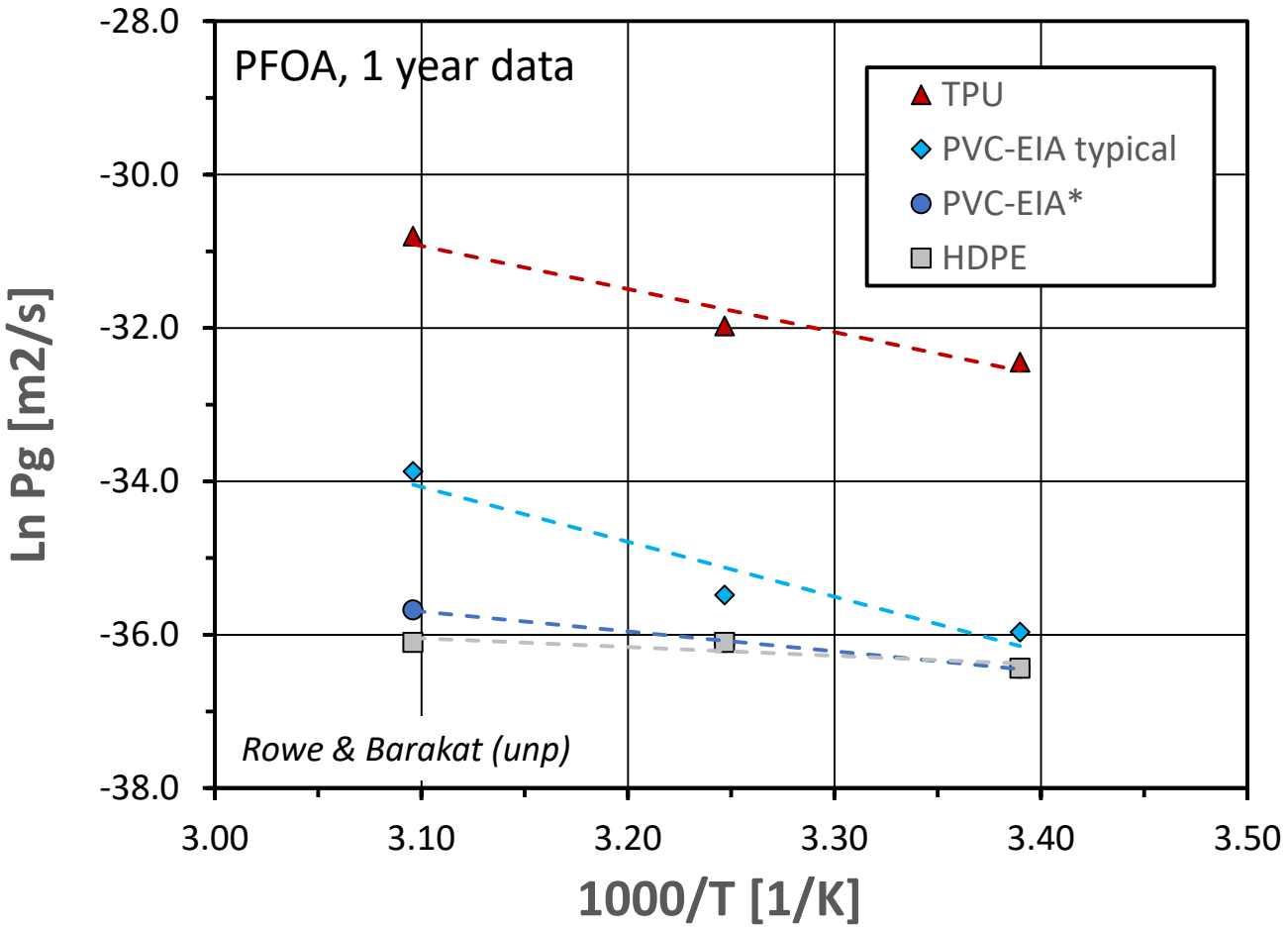
- Study to establish permeability coefficients of different PFAS molecules through materials
  - Plastic films of HDPE (control), TPU, and 3 different PVC-EIA materials (0.3mm) mounted in diffusion cells
  - Feed solutions with PFOS, PFOA (20ppm), PFBS, 6:2 FTS, 7:3 FTCA, and GenX (2ppm)

  - Different temperatures
  - Measure concentrations on source and receptor side of diffusion cells over time (>1 yr)

- Study to evaluate chemical resistance of geomembranes against PFAS molecules:
  - Incubation of coated fabrics of above materials in MSW, aqueous PFAS solutions, and MSW containing PFAS
  - Different temperatures
  - Compare mechanical properties before and after exposure

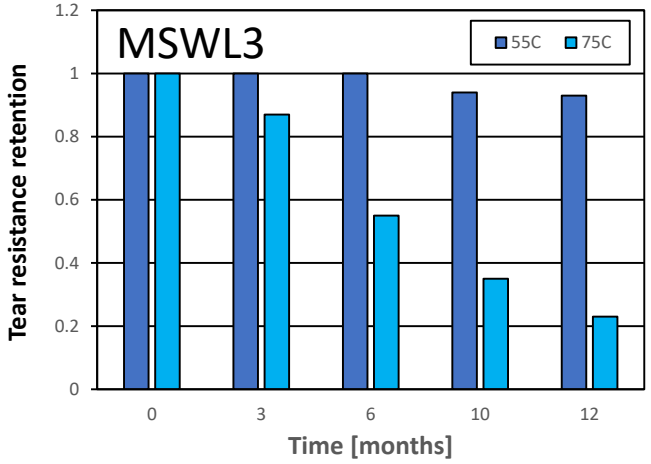
Reinforced PVC-EIA for PFAS Containment

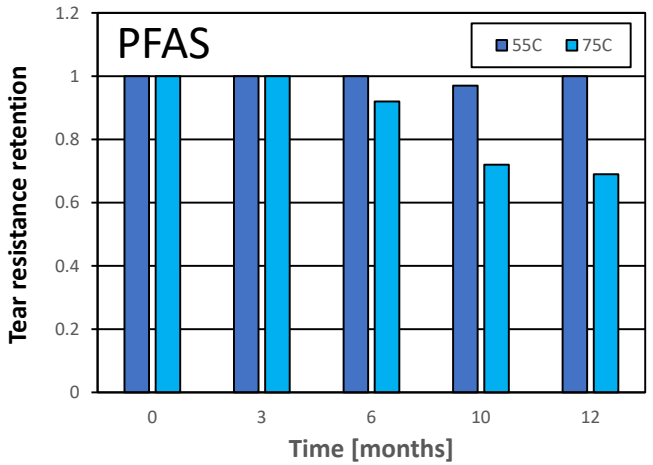


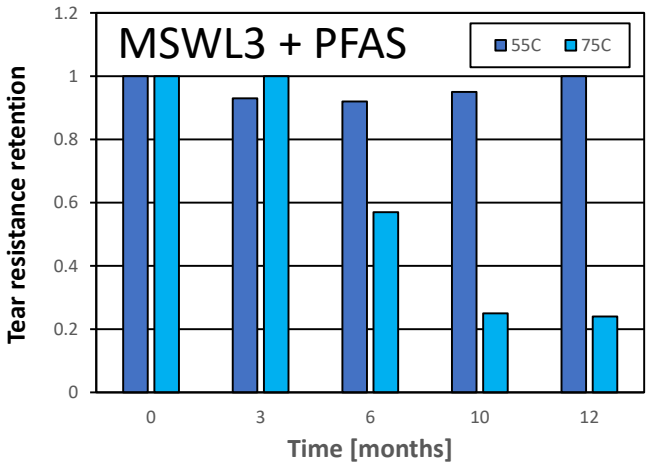
- Trend for PFOS follows PFOA trend.
- Concentrations of smaller PFAS molecules at receptor end in many cases still below detection limit, so no Pg can be determined.
- Special PVC-EIA is an equally good diffusive barrier to PFOS and PFOA.
- Any holes in the membrane will cause leakage and increase PFAS transport with orders of magnitude – double lined landfills are recommended by Rowe & Barakat (2021) & Rowe & Jefferis (2022).
- PFAS may further affect the service life of geomembranes (chemical resistance)

PFAS – Longevity of Geomembranes

- Exposure of reinforced PVC-EIA geomembranes to aqueous PFAS solutions (PFBS, PFPeA, PFHxA, PFOA, and PFOS, all 20ppm), synthetic MSWL, and PFAS in MSWL. Evaluation of retention of tear resistance, FTIR, and water absorption.



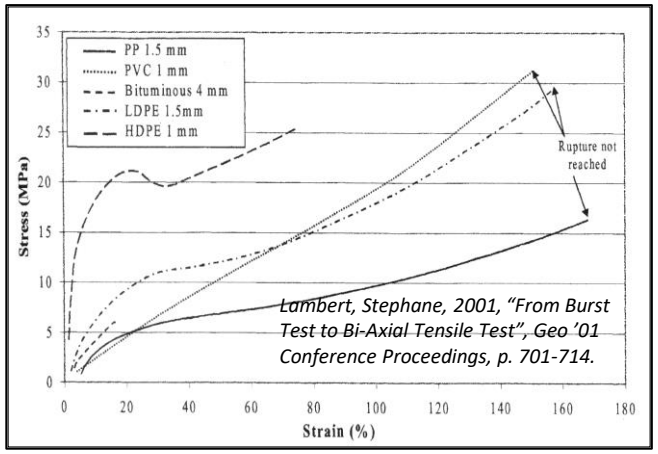




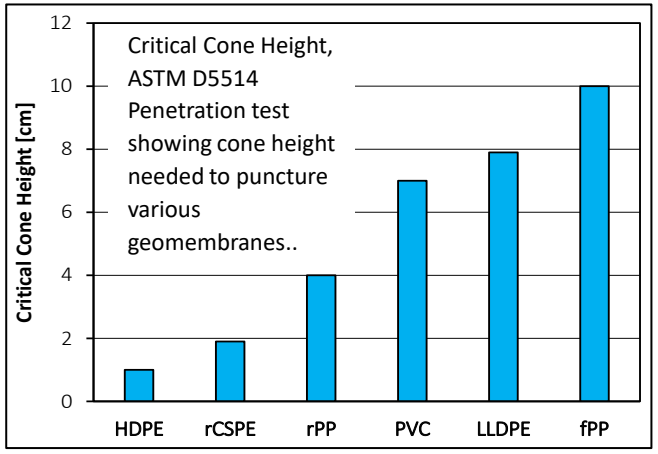
Rowe & Somuah (unp)

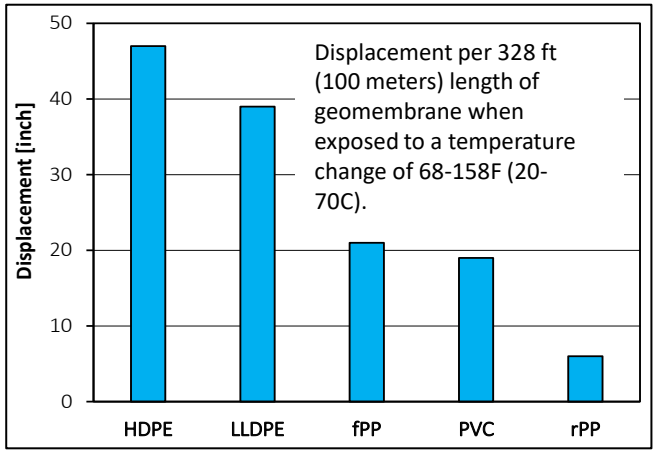
- Arrhenius predictions from data show time to nominal failure of >1,000 years at 20°C and ~200 years at 40°C.
- Preliminary evidence from other study indicates accelerated HDPE degradation when PFAS combined with leachate (Rowe, GTI presentation July 2021).
- Need more data and in-depth comparative study.

Reinforced PVC-EIA *vs.* HDPE for PFAS Containment



Mechanical Attributes	PVC-EIA	HDPE
Tensile Strength	Good	Good
Uni-Axial Elongation	Excellent	Excellent
Bi-Axial Elongation	Excellent	Poor
Puncture Resistance	Excellent	Fair
Durability Attributes		
Chemical Resistance	Excellent	Fair
UV Exposure	Excellent	Excellent
Stress Cracking	Excellent	Fair
Installation Attributes		
Thermal Stability	Excellent	Poor
Seaming Methods	Excellent	Excellent
Field Repairs	Excellent	Fair
Flexibility	Excellent	Fair





Conclusions

- Use of geomembranes for liners and covers for (PW) water containment applications now well established.
- Specific application requirements will determine choice of materials.
- Material development continues and lab data combined with actual use experience has shown that improved solutions are available over the traditionally used materials.
- Future requirements (e.g., PFAS containment) will demand further product development and a need for the industry to adopt new materials.

Include Raw Material Suppliers in Decision Process Containment Projects

Cooley Group - Product Applications

INDUSTRIES	APPLICATIONS	Lower cost ← COOLTECT® Polyethylene	COOLPRO® Polypropylene	COOLGUARD® Elvaloy (EIA)	COOLTHANE® Urethane	→ Higher cost COOLSHIELD® PVDF
MINING	Leach Pad	X	X			
	Pond Liner	X	X			
INDUSTRIAL	Foundation Liner	X	X	X	X	
	Lagoon Liner	X	X	X		
	Tank Farm Liner (fuel)			X	X	X
	Digester Liner/Covers		X	X	X	
POTABLE WATER	Reservoir Liners	X	X	X		
	Floating Covers	X	X	X		
	Tank Liners	X	X	X	X	
	Concrete Liner	X	X	X	X	
	Baffle Systems		X	X		
AQUACULTURE	Fishpond Liners	X	X			
CONSTRUCTION	Waterproofing		X	X	X	
	Secondary Containment	X	X	X	X	
PAPER/PULP	Black Liquor Pond Liner	X	X			
MANUFACTURING	Solvents					X
	High temp/extreme chemicals					X
CONTAINMENT	Fuel and Water Bladders				X	
	Fuel Farm Containment Liner			X	X	X
	Oil Booms			X	X	
PETROLEUM INDUSTRY	Tank Farm Secondary Containment			X	X	X
	Hydraulic Fracturing Pad	X	X	X	X	
	Tank Seals				X	X
	Collection Pond Liner	X	X	X	X	

Thanks to Cooley Develop Team and Queen's University for data collection.

THANK YOU FOR YOUR ATTENTION

Contact Information

- JP Lens; EVP, Research and New Business Development, lensj@cooleygroup.com
- Ray Peebles; Global Product & Market Manager Containment Solutions, peeblesr@cooleygroup.com
- Lance Reed; VP, Technical Services, reedl@cooleygroup.com