GEOTECHNICAL MATERIALS ASSESSMENT

EPS and XPS Foam in HSR Foundation Systems: Peterborough–Ottawa Segment

Technical and Environmental Assessment — ALTO HSR Public Consultation

Prepared by	ALTO HSR Citizens Research Initiative
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KEY FINDINGS

A route through the southern corridor is estimated to require 2.0–3.0 times more EPS geofoam than one chosen through the northern corridor for the Peterborough–Ottawa segment, driven by greater exposure to Leda clay, karst terrain drainage complications, and wetland crossings. This differential represents an estimated $124–187 million in additional construction cost and a significant unquantified long-term environmental and decommissioning liability. Alto's public consultation documents contain no geotechnical comparative analysis of this kind.

Section 1 — Background: Why Foam Materials Matter for HSR

1.1 Two distinct foam engineering functions

High-speed rail requires track geometry precision orders of magnitude tighter than conventional rail. At 250–360 km/h, track irregularities of even a few millimetres can cause passenger discomfort, accelerated wear, or safety-critical instability. Two distinct categories of polystyrene foam serve complementary engineering functions in HSR foundation systems:

- XPS (Extruded Polystyrene): Dense, closed-cell rigid foam used as a thermal insulation layer beneath the track formation to prevent frost penetration into frost-susceptible subgrade. Required continuously along the full corridor in Ontario's climate.
- EPS (Expanded Polystyrene) Geofoam: Lightweight structural fill blocks (approximately 1–2% of the density of granular fill) used in embankments over soft, compressible soils where conventional fill would impose unacceptable consolidation loads.

1.2 XPS: frost protection in northern climates

Ontario's climate produces frost penetration depths of 1.2–1.8 metres in the Peterborough–Ottawa corridor. Without thermal insulation, repeated freeze-thaw cycling of frost-susceptible subgrade materials causes progressive heaving and settlement that destroys track geometry. Standard practice on Scandinavian HSR projects specifies XPS at 75–100 mm thickness across an 8–10 metre formation width. XPS is preferred over EPS for this application due to its lower long-term moisture absorption (<0.3% by volume) and higher compressive resistance (150–700 kPa), preventing creep deformation under sustained loading.

1.3 EPS geofoam: lightweight embankment fill

EPS geofoam blocks have a bulk density of approximately 15–30 kg/m³, compared to 1,800–2,000 kg/m³ for granular fill. This dramatic weight reduction eliminates the consolidation settlement that would otherwise occur when heavy fills are placed over Leda clay, peat, or organic deposits, where post-construction settlement tolerance for HSR slab track is less than 5 mm over any 10-metre chord length. EPS geofoam is used in three primary HSR configurations: embankment fill over soft ground; bridge approach wedges to reduce the stiffness differential at abutment transitions; and retaining structure backfill to reduce lateral earth pressure.

Section 2 — Corridor Characterisation: Peterborough to Ottawa

2.1 Divergent geotechnical profiles

The Peterborough–Ottawa segment spans approximately 270 km through highly variable terrain. The two candidate corridors present fundamentally different geotechnical profiles that drive divergent insulation and geofoam requirements.

Parameter	Northern Route (Hwy 7)	Southern Route (Frontenac Arch)
Total length	~270 km	~270 km
Dominant geology	Meta-sedimentary rock, competent till	Precambrian granite, karst limestone, Leda clay
Soft ground exposure	~10–15% of route	~25–30% of route
Leda clay sections	~20–30 km (Ottawa approaches)	~40–60 km (Ottawa approaches + South Nation valley)
Wetland / organic crossings	~15–25 km	~30–45 km
Karst / sinkhole risk	Low	Moderate to High
Average embankment height over soft ground	3.0 m	4.0 m

2.2 Leda clay zones

Leda clay (quick clay / sensitive marine clay) was deposited in the Champlain Sea between approximately 10,000 and 8,000 years before present and is characterised by extremely high water content, low shear strength, and a tendency toward catastrophic liquefaction upon disturbance. The 1971 Saint-Jean-Vianney landslide (31 killed) and the 2010 Saint-Jude slide are examples of Leda clay failure events. For HSR embankment construction, Leda clay cannot support conventional granular fill loads without triggering consolidation settlements of 0.5–1.5 metres over 5–10 years following construction, rendering conventional fill technically unacceptable given HSR post-construction settlement tolerances. The southern corridor's greater exposure to Leda clay deposits in the valleys between Smiths Falls and Ottawa substantially expands the length of corridor requiring EPS geofoam treatment.

2.3 Wetland and organic soil crossings

Both corridors cross wetland complexes associated with the Rideau, Mississippi, and Madawaska river systems. Organic soils (peat and muskeg) present similar challenges to Leda clay: high compressibility, long consolidation timescales, and very low bearing capacity for conventional fill. The southern route crosses a greater total length of wetland terrain, including portions of the Frontenac Arch Biosphere Reserve and its associated Provincially Significant Wetland complexes.

2.4 Karst terrain and drainage complications

The southern corridor traverses zones of Ordovician limestone on the Kingston and Napanee plains and near the Rideau Lakes area. Karst terrain creates additional complications for EPS geofoam installation: differential void collapse can destabilize geofoam fills; groundwater drainage through karst conduits creates channels for contaminant transport that would normally be attenuated in intact soil, a concern directly relevant to the flame retardant and styrene leaching risks assessed in Section 5.

Section 3 — Quantity Estimates and Cost Differential

3.1 XPS frost insulation: both corridors equivalent

XPS frost insulation is applied essentially continuously along the full formation length, regardless of corridor, as both routes experience equivalent climatic frost penetration depths.

Parameter	Value	Basis
Route length	270,000 m	Approximate corridor length
Formation width covered	8.0 m	Standard HSR slab track / ballasted formation
Board thickness	0.075 m (75 mm)	Frost depth requirement, Ontario Zone 5
Total XPS volume	162,000 m³	270,000 × 8.0 × 0.075
XPS mass (at 35 kg/m³)	~5,670 tonnes	Estimated density mid-range
Installed unit cost (2024 CAD)	$180–$220/m³	Ontario infrastructure market
Estimated installed cost	$29–$36 million	Full segment; equal for both corridors

3.2 EPS geofoam: northern corridor

Parameter	Low Estimate	High Estimate
Soft-ground route length	27,000 m	40,000 m
Average embankment base width	12.0 m	12.0 m
Average geofoam fill depth	3.0 m	3.5 m
Total EPS geofoam volume	972,000 m³	1,680,000 m³
EPS mass (at 20 kg/m³)	~19,440 tonnes	~33,600 tonnes
Installed unit cost (2024 CAD)	$60/m³	$80/m³
Estimated installed cost	~$58 million	~$134 million

3.3 EPS geofoam: southern corridor

Parameter	Low Estimate	High Estimate
Soft-ground route length	65,000 m	80,000 m
Average embankment base width	12.0 m	14.0 m
Average geofoam fill depth	3.5 m	4.5 m
Total EPS geofoam volume	2,730,000 m³	5,040,000 m³
EPS mass (at 20 kg/m³)	~54,600 tonnes	~100,800 tonnes
Installed unit cost (2024 CAD)	$60/m³	$80/m³
Estimated installed cost	~$164 million	~$403 million

3.4 Comparative summary

Category	Northern Route	Southern Route	Differential
XPS insulation volume	162,000 m³	162,000 m³	None
XPS insulation cost	$29–$36M	$29–$36M	None
EPS geofoam volume (mid-range)	~1.3M m³	~3.9M m³	+~2.6M m³ southern
EPS geofoam cost (mid-range)	~$96M	~$283M	+~$187M southern
Total foam materials cost	~$125–$170M	~$312–$439M	+$187–$269M southern

Section 4 — Environmental Impact: Manufacturing Phase

4.1 Embodied carbon

Both XPS and EPS are derived from styrene monomer synthesised from petroleum and natural gas feedstocks. Embodied carbon accumulates significantly at the quantities required for a major HSR corridor.

Material	Mass (southern, mid)	Embodied CO_2 factor	Estimated CO_2 (tonnes)
XPS insulation	~5,670 t	~3.0 kg CO_2/kg	~17,010 t CO_2
EPS geofoam (southern)	~77,700 t	~2.5 kg CO_2/kg	~194,250 t CO_2
EPS geofoam (northern)	~26,520 t	~2.5 kg CO_2/kg	~66,300 t CO_2
Total (southern route)	—	—	~211,260 t CO_2
Total (northern route)	—	—	~83,310 t CO_2

Embodied carbon factors from the Inventory of Carbon and Energy (ICE) database v3.0 (University of Bath) and European Plastics in Buildings database. The ~128,000 tonne CO_2 differential between corridors directly contradicts the project's stated climate credentials and has not appeared in any Alto environmental assessment document.

4.2 Blowing agents in XPS manufacture

XPS insulation boards are manufactured using blowing agents that create and stabilise the closed-cell foam structure. Many XPS products still use hydrofluorocarbons (HFCs) with Global Warming Potentials of 700–1,400 times CO_2 over 100 years. European manufacturers have largely transitioned to CO_2-blown or hydrofluoroolefin (HFO) systems with GWPs below 10, but Canadian market penetration of low-GWP XPS is not yet universal. At the procurement stage for an HSR project of this scale, specification of low-GWP blowing agents should be a contractual requirement.

POLICY IMPLICATION

Alto's environmental assessment obligations should include a requirement for manufacturers to disclose blowing agent type and GWP. Failure to specify this in design criteria could result in XPS procurement with effective embodied carbon 5–10 times higher than the estimates in this document.

4.3 Fire retardant additives

Both EPS and XPS products for civil engineering use typically incorporate brominated or phosphorus-based flame retardants. Hexabromocyclododecane (HBCD), the most common EPS additive historically, was listed as a Persistent Organic Pollutant under the Stockholm Convention in 2013 and is now banned for most uses in Canada. Replacement flame retardants include polymeric flame retardants (PolyFR). Flame retardant compounds in buried foam can leach into groundwater over time, a concern of heightened severity on the southern corridor, where karst conduits can transport contaminants over distances of tens of kilometres with minimal attenuation, reaching sensitive wetlands, springs, and municipal water intakes.

Section 5 — Environmental Impact: Operational Service Life

5.1 Chemical leaching from buried EPS geofoam

EPS geofoam placed in groundwater-influenced zones is subject to slow chemical leaching over the operational lifetime of the infrastructure. Key leachate compounds of concern include:

- Styrene monomer: A potential human carcinogen (IARC Group 2B) and neurotoxin at elevated concentrations. CCME freshwater quality guideline: 20 μg/L.
- Flame retardant residues: Depending on additive chemistry, leaching of brominated or organophosphate compounds is possible, with potential endocrine-disrupting effects on aquatic organisms.
- Oligomers and cyclic dimers/trimers of styrene: Emerging contaminants with growing evidence of aquatic toxicity and limited regulatory frameworks.

5.2 Particular risks on the southern corridor

The combination of EPS geofoam at greater volume, proximity to karst conduits, and the presence of provincially and federally significant wetland ecosystems creates a materially higher risk profile for operational-phase chemical leaching than the northern corridor. The Frontenac Arch Biosphere Reserve's Key Biodiversity Areas contain habitat for grey ratsnake (Threatened), Blanding's turtle (Threatened), and multiple fish species at risk. Groundwater quality degradation in these ecosystems could affect breeding and foraging habitat without triggering visible surface disturbance.

5.3 Physical fragmentation and microplastic generation

EPS is mechanically fragile and breaks into small beads (2–5 mm) and sub-millimetre fragments under compressive cycling, freeze-thaw stress, and UV exposure. While buried geofoam is not directly UV-exposed, edge sections, drainage boundaries, and zones of differential settlement can expose fragmented EPS to drainage pathways. Polystyrene microplastics have been detected in freshwater and marine environments globally and have been identified in the tissues of fish, macroinvertebrates, and aquatic birds.

5.4 Settlement monitoring and maintenance costs

For HSR applications, where vertical track geometry must be maintained within 5 mm over a 10-metre chord length throughout a 100-year design life, EPS geofoam creep potential requires periodic geometric surveying, pre-construction creep testing under anticipated load conditions, and contingency allowance for differential settlement at transitions between geofoam-supported embankments and conventional fill or rock-founded sections, a historically problematic zone in geofoam applications.

Section 6 — Decommissioning and End-of-Life Liability

6.1 Removal challenges

Removal of buried EPS geofoam presents significant engineering and environmental challenges: geofoam embankments 3–5 metres deep require significant excavation and dewatering with associated Leda clay instability risks; mechanical excavation generates extensive fragmentation and polystyrene debris; and groundwater dewatering can mobilise leachate and microplastic-laden water requiring treatment before discharge. XPS insulation boards are typically bonded to the concrete slab or formation surface and require mechanical breaking for removal.

6.2 Decommissioning liability summary

Decommissioning Item	Northern Route	Southern Route
EPS geofoam removal (mid-range volume)	~$15–$34M	~$58–$97M
XPS insulation removal (both corridors equal)	~$8–$16M	~$8–$16M
Soil remediation (leachate zones)	Low to medium	Medium to high
Contaminated foam disposal premium	Possible (HBCD)	Possible (HBCD)
Total estimated decommissioning range	$23–$50M	$66–$113M

EPS geofoam manufactured with HBCD flame retardant, the industry standard until approximately 2015–17, may be classified as contaminated special waste under Ontario Regulation 347 and CEPA upon decommissioning, substantially increasing disposal costs. For the volume of EPS estimated for the southern corridor (~3.9 million m³ mid-range), recycling or recovery at scale would require infrastructure that does not currently exist in Ontario at adequate capacity.

Section 7 — Policy Gaps and Recommendations

7.1 Information absent from Alto's public documentation

Alto's public consultation materials contain no comparative geotechnical analysis of the foundation engineering requirements for alternative corridor alignments. The quantities, costs, environmental risks, and decommissioning liabilities associated with foam insulation and geofoam materials are nowhere addressed. This represents a material gap in Alto's disclosure obligations under the Impact Assessment Act and leaves public participants unable to evaluate the relative merits of corridor options on a technically informed basis.

1. **Publish geotechnical baseline studies for both corridors**
   Including CPT (cone penetration test) and borehole data sufficient to characterise Leda clay extent, depth, and sensitivity; wetland and peat depths; and karst void risk zones. Without this, EPS geofoam quantity estimates remain order-of-magnitude only.

2. **Include foam lifecycle assessment in the Environmental Impact Statement**
   A lifecycle environmental assessment of all major polymer and synthetic materials used in foundation construction, including embodied carbon, operational leaching risk, and decommissioning costs, is required under the Impact Assessment Act.

3. **Prohibit HBCD flame retardants and specify low-GWP blowing agents**
   Alto's project specifications should explicitly prohibit the use of HBCD flame retardants and require low-GWP blowing agents (GWP < 10) in all XPS procurement. Failure to do so creates significant decommissioning liability and embodied carbon underestimation.

4. **Include decommissioning provisions in financial disclosure**
   Decommissioning cost provisions for buried polymer materials should be included in the project's financial disclosure and Infrastructure Canada funding application. These represent a long-term public liability not currently captured in any published cost estimate.

5. **Include geofoam lifecycle costs in Parliamentary Budget Officer review**
   A PBO review of the full lifecycle cost of Alto should include a line item for geotechnical material quantities and decommissioning, informed by the quantity estimates in this document and analogous international comparators including HS2 and Scandinavian HSR programmes.

References

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