ALTO HSR CITIZEN RESEARCH INITIATIVE — RESEARCH NOTE

Construction Carbon Analysis

Construction-Phase CO_2 Emissions of High-Speed Rail Projects- Model Input 1

Evidence from International Projects Applied to Alto's Proposed Toronto–Québec City Corridor (1,000 km), including Penalties for the Leda Clay Ground Treatment Penalty for the Ottawa–Montréal Segment, and Cold Weather.

Alto HSR Citizen Research Initiative — March 2026 — altohsrcitizenresearch.ca

EXECUTIVE SUMMARY

Alto has not published a comprehensive lifecycle carbon assessment for the construction phase of its proposed Toronto–Québec City high-speed rail corridor. This document assembles evidence from international HSR projects to estimate the scale of construction-phase CO_2 emissions that Alto's project would likely generate. The categories covered include embodied carbon in materials, heavy machinery operations, tunnel and bridge construction, wetland drainage, stream diversion, and debris disposal.

Based on data from the UK's HS2, California's HSR, Chinese HSR lines, Spanish and French systems, and peer-reviewed lifecycle assessments, we estimate that construction of Alto's approximately 1,000 km corridor would produce between 6 and 17+ million tonnes of CO_2 equivalent from conventional construction categories. This document adds a new quantification of a material but previously uncosted item: the ground treatment carbon penalty for approximately 200 km of Leda clay (quick clay) terrain between Ottawa and Montréal.

Leda clay underlies a substantial portion of the Ottawa Valley and the St. Lawrence Lowlands west of Montréal. High-speed rail at 300 km/h is fundamentally incompatible with untreated Leda clay: dynamic loading at HSR speeds destabilises the metastable clay structure, producing differential settlement and risk of rapid undrained failure. Three credible treatment approaches are evaluated here — deep soil mixing, pile-supported slab track, and full elevated viaduct — producing a Leda clay CO_2 penalty of 0.3 to 4.5 Mt on top of the base construction estimate.

REVISED TOTAL: 6.9–29.7+ Mt CO_2e for the full construction phase, incorporating the Harbin–Dalian cold-climate design premium and Leda clay ground treatment. Neither category appears in any Alto public document.

1. International Construction Emissions: Project-Base Level Data

The following table presents documented construction-phase CO_2 emissions from major HSR projects worldwide. These figures represent the most reliable published data available and provide the basis for estimating Alto's likely emissions profile.

Project	Length	Construction CO_2e	CO_2e per km	Source
HS2 Phase One (UK)	225 km	5.5–6.2 Mt	~24,400–27,600 t/km	HS2 Environmental Statement (2013); Parliamentary evidence
HS2 BBV Contract Baseline (UK)	Partial	4.15 Mt baseline	N/A (partial)	BBV/HS2 Learning Legacy (2024)
California HSR Phase 1 (USA)	~795 km	9.7 Mt	~12,200 t/km	Chester & Horvath, UC Berkeley (2010)
California HSR SF–Anaheim (USA)	~725 km	2.4 Mt	~3,300 t/km	Chang & Kendall, ScienceDirect (2011)
Beijing–Shijiazhuang (China)	~281 km	9.2 Mt	~32,700 t/km	Chang et al., ResearchGate (2019)
Beijing–Tianjin (China)	~120 km	3.67 Mt	~30,600 t/km	Multi-footprint LCA study
Madrid–Toledo (Spain)	~75 km	0.122 Mt	~1,600 t/km	ScienceDirect (2023) — flat terrain, few structures
Vietnam NSER (projected)	~1,545 km	0.70 Mt steel only	~454 t/km (rail steel only)	MDPI Sustainability (2021)

Key observations: Per-km construction emissions vary enormously, from roughly 1,600 t CO_2e/km for flat, at-grade routes with minimal structures (Madrid–Toledo) to over 30,000 t CO_2e/km for lines requiring extensive tunnelling, bridges, and elevated sections (Chinese projects). The Alto corridor through Eastern Ontario and the Ottawa Valley, with its mix of Canadian Shield bedrock, Leda clay deposits, wetlands, and the Frontenac Arch, would face terrain challenges placing it toward the higher end of this range, particularly notable given the 1,000 km corridor length adopted in this analysis.

2. Emissions Breakdown by Construction Category

2.1 Embodied Carbon in Materials (Concrete, Steel, Rails, Fencing)

Embodied carbon in materials consistently represents the single largest share of construction-phase emissions across all studied projects. HS2's lifecycle assessments found that embodied emissions from product manufacturing (stages A1–A3) contribute more than 50% of total construction-phase carbon, with steel and concrete identified as the dominant sources. The BBV contract on HS2 reported that transport to site (A4) accounted for approximately 17% and on-site construction activities (A5) around 25%.

For HSR track alone, each kilometre requires an estimated 30,000–50,000 tonnes of concrete and several thousand tonnes of steel. The World Steel Association estimates that producing one tonne of steel generates approximately 1.9 tonnes of CO_2. Cement production generates roughly 0.88 tonnes of CO_2 per tonne. For Vietnam's proposed 1,545 km line, the rail steel alone was calculated to produce approximately 703,000 tonnes of CO_2, and this excludes concrete, stations, electrification, and all other infrastructure.

For the UIC (International Union of Railways), the construction emissions of HSR lines range from 58 to 176 tonnes CO_2 per km per year (annualised over the infrastructure's lifespan). Lines with few terrain constraints (e.g., French TGV on flat land) sit near 60 t CO_2/km/year, while projects with significant space or relief constraints (China, Taiwan) range from 139–176 t CO_2/km/year.

ALTO ESTIMATE	*Materials manufacturing alone would likely produce 2.5–10 million tonnes CO_2e for the 1,000 km corridor, depending on the proportion of tunnels, bridges, and slab track vs. ballasted track.*

2.2 Heavy Machinery and Construction Equipment Emissions

On-site construction activities (diesel excavators, haulers, cranes, concrete pumps, pile drivers, tunnel boring machines) constitute the A5 stage in lifecycle assessments. HS2 data indicates this stage accounts for approximately 25% of total construction emissions. HS2's enabling works contract documented that operational emissions from machinery were significant enough to warrant a dedicated decarbonisation strategy, including the goal of diesel-free construction sites by 2029.

California's HSR Authority reported that contractor vehicles alone produced 1,400 metric tonnes of CO_2 in 2015, and that was a single year during early-stage construction on a fraction of the total route. The transport of materials to site (A4) adds further emissions, accounting for roughly 17% on HS2.

ALTO ESTIMATE	*Heavy machinery and construction transport would likely generate 1.25–3.3 million tonnes CO_2e over the multi-year construction period (scaled to 1,000 km corridor).*

2.3 Tunnels

Tunnelling is the most carbon-intensive element of HSR construction per kilometre. Research on the Xikema No. 1 HSR tunnel in China found that nearly 97% of tunnel CO_2 emissions were generated during construction, primarily from the intensive use of concrete and steel for tunnel linings. On California's HSR, despite tunnels and aerial structures comprising only 15% of the route's length, they were responsible for 60% of total construction emissions.

The UIC's sensitivity analysis found that the share of tunnels and bridges is the single most critical variable in determining a line's overall construction carbon footprint. Moving from 5% tunnels/bridges to 35% tunnels/bridges roughly triples the construction carbon per kilometre. HS2's own data confirms this: the biggest component of HS2's carbon footprint is steel for track, followed by concrete, and tunnelling significantly increases requirements for both.

Relevance to Alto: The southern corridor through the Frontenac Arch and Canadian Shield would require significant tunnelling through granite bedrock, or, alternatively, environmentally destructive surface cuts. Either approach generates substantial emissions. Alto has not disclosed its tunnel/bridge percentage, which is arguably the single most important variable for estimating construction carbon.

2.4 Bridges and Elevated Structures

Bridges and viaducts require large quantities of structural steel and reinforced concrete — both carbon-intensive materials. The California HSR study found aerial structures to be a primary driver of construction emissions. The Beijing–Tianjin study confirmed that bridge and rail systems together contribute above 74% of the environmental footprint of construction.

The Spanish Basque Y project, with its high proportion of tunnels and viaducts over complicated terrain, was projected to have no energy or carbon emissions offset at all over its entire lifecycle. The environmental cost of building it would never be recovered through operational savings.

Relevance to Alto: Eastern Ontario's and the Ottawa Valley's landscape of rivers, wetlands, and rocky terrain would require numerous bridge crossings. Each major waterway crossing (Rideau River, Cataraqui River, Salmon River, Moira River, Trent River, Ottawa River tributaries, and dozens of smaller watercourses) adds bridge emissions to the total.

2.5 Wetland Drainage and Peatland Disturbance

Wetland drainage releases stored carbon accumulated over thousands of years. This category is almost never included in HSR construction carbon assessments, yet the science demonstrates it can be significant. The IPCC emission factor for drained peatlands is 2.46 ± 0.25 tonnes of carbon per hectare per year (2023 estimate), with emissions continuing for decades after initial drainage. For Eastern Canada specifically, a Tier 3 assessment estimated 1.4 ± 0.25 t C/ha/year for typical extraction sites.

Ontario's wetlands contain an estimated 29 billion tonnes of carbon. Globally, drained peatlands release approximately 2 billion tonnes of CO_2 annually, roughly 5% of all anthropogenic greenhouse gas emissions. A 2025 Canadian study found that mineral-soil wetland drainage produces substantial greenhouse gas emissions not currently included in Canada's National Inventory Report.

Relevance to Alto: The southern corridor passes through wetland-rich areas including portions of the Frontenac Arch Biosphere Reserve. The Ottawa–Montréal section passes through the South Nation and Rideau watersheds, which contain regionally significant wetland complexes. The carbon cost of draining or displacing these wetlands is entirely unaccounted in Alto's public materials.

2.6 Stream and Watercourse Diversion

HSR construction routinely requires diversion of streams, creeks, and drainage channels. While direct CO_2 emissions from this activity are not well-quantified in the HSR literature, the construction of diversion channels involves earthworks, concrete culverts, and heavy machinery, all generating emissions. More importantly, disrupting riparian corridors destroys vegetated buffer zones that serve as carbon sinks, and altering stream hydrology can dry out adjacent wetlands, triggering additional carbon release.

Relevance to Alto: Eastern Ontario's and the Champlain Sea plain's dense network of watercourses draining into Lake Ontario and the St. Lawrence means stream diversions would be frequent along any route alignment.

2.7 Debris, Waste Disposal, and Demolition

Construction waste from HSR projects is substantial. HS2's enabling works involved demolition of buildings, utility diversions, and archaeological works, all generating waste with embodied carbon. The BBV contract on HS2 documented that the majority of HSR construction waste (e.g., 24 million tonnes of concrete products from Chinese HSR by 2020) was landfilled or backfilled rather than recycled.

California's HSR reported avoiding approximately 57,800 tonnes of CO_2 through construction recycling — but this figure represents only what was successfully diverted from landfill, not the total waste generated. HS2 imported over 125,000 tonnes of recycled aggregate for the enabling works alone, saving 574 tonnes of carbon compared to virgin materials.

Relevance to Alto: Rock excavation from Canadian Shield granite, removed topsoil, demolished structures along the right-of-way, and general construction debris all require transport and disposal, generating additional CO_2.

2.8 Land Clearing and Deforestation

Removing existing trees and vegetation releases stored carbon and eliminates ongoing carbon sequestration. HS2 estimated this represents about 2% of total project carbon — seemingly small, but on a project generating millions of tonnes of CO_2, that 2% translates to over 100,000 tonnes.

HS2 planned to plant 7 million trees and shrubs to create 900 hectares of new woodland as mitigation, but acknowledged that newly planted trees absorb far less carbon than the mature woodlands they replace, particularly in the critical near-term decades.

Relevance to Alto: The Frontenac Arch supports mature mixed forest that serves as a critical ecological corridor. Clearing this for a rail right-of-way destroys both stored carbon and ongoing sequestration capacity. The Ottawa–Montréal agricultural plain has lower standing tree carbon but severs established shelterbelts and riparian corridors.

2.9 Cold Climate Construction: Lessons from the Harbin–Dalian HSR

NEW SECTION	*This section was not present in earlier versions of this document. It quantifies the construction carbon premium arising from cold-climate design practices that would be mandatory for any HSR operating in Eastern Ontario's climate. The evidence base is the Harbin–Dalian Passenger Dedicated Line (HDPDL) — the world's only operational precedent for high-speed rail in a deep seasonally frozen region.*

2.9.1 The Harbin–Dalian HSR as the Mandatory Reference

The Harbin–Dalian Passenger Dedicated Line (HDPDL), opened December 2012, is 921 km long, operates at up to 350 km/h in summer and 200–250 km/h in winter, and must function in temperatures as low as −40°C. It is the world's first and only fully operational HSR in a deep seasonally frozen environment. Its construction cost CN¥95 billion — approximately 25% above original budget, and parts of the line had to be rebuilt before opening due to frost heave deformation exceeding design limits.

Eastern Ontario’s climate is directly comparable. Ottawa’s average January temperature is −10.4°C; extreme lows reach −30°C. Standard frost depth along the Alto southern corridor ranges from 1.2 to 1.8 m, matching the 0.93–2.05 m range observed along the HDPDL. The corridor receives 200–300 cm of annual snowfall and experiences 120–150 days below freezing each year. There is no existing HSR anywhere in a comparable North American winter climate. The HDPDL is the design template Alto would be legally and technically obligated to follow.

FROST HEAVE FAILURE

Despite applying all known cold-climate engineering measures, the HDPDL experienced widespread frost heave during its first winter of operation. Maximum heave of 35.2 mm was recorded in some sections — 7 times the design limit of 5 mm for ballastless track. Sections required reconstruction before opening. This is not a design failure peculiar to China: it reflects the fundamental difficulty of controlling frost heave in seasonally frozen ground beneath ballastless slab track, which transmits dynamic stress deeper into the subgrade than ballasted track. (Liu et al., 2016; Niu et al., 2017; Canadian Geotechnical Journal, 2015)

2.9.2 Cold-Climate Design Specifications and Their Carbon Implications

The following six design elements are mandatory, not optional enhancements, for HSR in seasonally frozen ground. Each involves additional materials over the standard HSR subgrade specification, generating additional embodied carbon that is entirely absent from Alto’s public cost or environmental estimates.

A. Enhanced Subgrade Depth (3.1 m vs. Standard 1.5 m)

Standard HSR subgrade bed depth (non-frost climate): approximately 1.0–1.5 m of compacted fill. The HDPDL specification requires a 3.1 m subgrade bed structure: 0.7 m cement-stabilised graded crushed stone surface layer (5% cement, fine particle content <5%) + 0.1 m XPS insulation board + 2.3 m anti-frost-resistant bottom fill. This is more than twice the standard depth. For 1,000 km of double-track HSR at 8 m treatment width:

- Standard fill volume: 1,000,000 m × 8 m × 1.5 m = 12.0 million m^3
- Cold-climate fill volume: 1,000,000 m × 8 m × 3.1 m = 24.8 million m^3
- Additional fill: ~12.8 million m^3 of quarried, crushed, transported A/B group aggregate
- CO_2 for quarrying, crushing, transport of additional aggregate: ~25–50 kg CO_2/tonne × 2,000 kg/m^3 = ~50–100 kg CO_2/m^3
- Additional fill CO_2: 12.8 million m^3 × 75 kg/m^3 = ~0.96 Mt CO_2e

B. Cement-Stabilised Surface Layer

The 0.7 m surface layer of the HDPDL subgrade is graded crushed stone mixed with 5% cement by weight, creating a bound, frost-resistant composite. Standard HSR subgrade surface layers use unbound granular fill or hydraulically bound material at lower cement content. For the full 1,000 km corridor:

- Volume: 1,000,000 m × 8 m × 0.7 m = 5.6 million m^3
- Cement content: 5% by mass × 2,000 kg/m^3 = 100 kg cement/m^3
- CO_2 per kg cement: 0.88 kg CO_2
- Surface layer cement CO_2: 5.6 million m^3 × 100 kg/m^3 × 0.88 = ~0.49 Mt CO_2e

C. XPS/EPS Thermal Insulation Board

A 100 mm thick layer of extruded polystyrene (XPS) insulation board is placed between the surface and bottom layers to reduce heat transfer into the subgrade, limiting frost penetration depth. XPS is manufactured from petroleum feedstocks using a gas-blown extrusion process. Its embodied carbon (including the HFC or CO_2 blowing agents) is approximately 3.0–4.5 kg CO_2e/kg. For 1,000 km:

- Volume (80% coverage, allowing for transitions): 1,000,000 m × 8 m × 0.1 m × 0.8 = 640,000 m^3
- XPS density: ~32 kg/m^3
- XPS mass: 640,000 m^3 × 32 kg/m^3 = ~20,480 tonnes
- Embodied CO_2: 20,480 t × 3.5 kg CO_2/kg = ~71,700 t = 0.07 Mt CO_2e

Note: XPS insulation on HDPDL was applied at the DK140 test section at 0.1 m thickness and proved effective at reducing frost penetration depth. However, multiple subsequent studies found that frost heave still occurred in adjacent sections, indicating that insulation alone is insufficient; all layers of the full 3.1 m specification must be applied simultaneously. (HDPDL engineering test research, ResearchGate, 2016)

D. Asphalt Concrete Drainage and Surface Sealing

Research on the HDPDL confirmed that the optimal anti-frost subgrade bed structure adds an asphalt concrete pavement layer plus cement stabilised macadam above the insulation board. This layer prevents surface water infiltration — a primary source of the moisture that drives frost heave. A 50–75 mm bituminous layer across the full treatment width:

- Volume: 1,000,000 m × 8 m × 0.063 m (average 63mm) = 504,000 m^3
- Asphalt concrete CO_2: ~75 kg CO_2/m^3 (bitumen + aggregate + mixing energy)

- Total: 504,000 × 75 = ~37,800 t = 0.04 Mt CO_2e

E. Enhanced Drainage Infrastructure (Groundwater Table Lowering)

The HDPDL design specifications require active lowering of the groundwater table beneath the subgrade to reduce soil water content, which is the primary driver of frost heave. This requires longitudinal drainage trenches, geotextile-wrapped granular drains, precast concrete drainage channels, and pumping infrastructure. Compared to standard HSR drainage, cold-climate drainage is significantly more extensive and uses substantially more concrete, geotextile, and precast elements:

- Additional drainage concrete (channels, manholes, culverts): estimated 0.15–0.4 Mt CO_2e for 1,000 km
- This range reflects the significant uncertainty in drainage density required: HDPDL drainage design was revised multiple times during construction as frost heave problems emerged

F. Cold-Weather Construction Premium (A5 Stage)

Concrete placement below 0°C requires heated formwork, accelerating admixtures (additional cement), temporary enclosures, and extended curing time. Concrete poured without cold-weather protection in temperatures below −5°C will not achieve design strength and must be demolished and replaced. The HDPDL was constructed between 2007 and 2012 over five winters. Cold-weather concrete practices increase per-pour energy demand by 15–30% and typically require 10–15% additional cement for accelerated strength gain:

- Cold-weather concrete cement premium (+12% average across winter pours): ~0.22 Mt CO_2e on central concrete estimate of 1.8 Mt for 1,000 km at-grade construction
- Heated construction energy (diesel generators, temporary boilers): approximately +20% on A5 equipment diesel emissions over winter construction months
- Extended construction schedule premium (HDPDL was nearly one year behind schedule): +5–10% on total A5 stage — more equipment operating hours, longer temporary facility operations
- Combined cold-weather A5 premium: ~0.25–0.65 Mt CO_2e on central A5 estimate of 2.1 Mt

G. Pre-Opening Remediation and Post-Opening Maintenance

The HDPDL required reconstruction of frost-heaved sections before its December 2012 opening, a unique and unreported construction carbon cost. Post-opening, annual frost heave monitoring data from 2012 to 2018 showed persistent heave in both cut and embankment sections, requiring ongoing remediation. For a 1,000 km corridor in Eastern Ontario with comparable frost conditions, a pre-opening remediation allowance of 0.1–0.4 Mt CO_2e is prudent.

2.9.3 Cold-Climate Construction Carbon: Consolidated Estimate

Cold-Climate Design Element	Low CO_2e	Central CO_2e	High CO_2e	Basis
A. Enhanced subgrade depth (3.1m vs. 1.5m standard)	0.50 Mt	0.96 Mt	1.80 Mt	12.8M m^3 additional A/B aggregate; 50–100 kg CO_2/m^3
B. Cement-stabilised surface layer (5% cement, 0.7m)	0.20 Mt	0.35 Mt	0.65 Mt	5.6M m^3 × 100 kg cement/m^3 × 0.88 kg CO_2/kg
C. XPS/EPS insulation board (100mm, 80% coverage)	0.04 Mt	0.07 Mt	0.12 Mt	20,480 t XPS × 3.5 kg CO_2/kg
D. Asphalt concrete drainage surface layer	0.02 Mt	0.04 Mt	0.08 Mt	504,000 m^3 × 75 kg CO_2/m^3
E. Enhanced drainage infrastructure	0.15 Mt	0.28 Mt	0.50 Mt	Longitudinal drains, channels, groundwater control
F. Cold-weather construction premium (A5 stage)	0.25 Mt	0.45 Mt	0.80 Mt	+12% cement, +20% A5 diesel, schedule extension
G. Pre-opening remediation (frost heave reconstruction)	0.05 Mt	0.15 Mt	0.40 Mt	HDPDL precedent: sections rebuilt before opening
TOTAL COLD CLIMATE CONSTRUCTION PREMIUM	~1.21 Mt	~2.30 Mt	~4.35 Mt	Applies across full 1,000 km corridor

ONTARIO VS HARBIN-DALIAN CLIMATE COMPARISON	*Harbin: annual mean 4.9°C; frost depth 0.93–2.05 m; days below 0°C: ~150. Ottawa: annual mean 6.3°C; standard frost depth 1.2–1.8 m; days below 0°C: ~130–145. The climates are essentially equivalent for engineering purposes. Every cold-climate design provision mandated on the HDPDL is equally mandated on an Alto HSR corridor through Eastern Ontario. Unlike conventional HSR projects in temperate climates, Alto cannot avoid this premium — it is a non-negotiable engineering requirement.*

Note on ballastless vs. ballasted track: The HDPDL uses CRTS I Shinkansen-derived ballastless slab track throughout. Alto, operating at 300 km/h, would also require ballastless track (ballasted track cannot maintain the ±2 mm alignment tolerance required at 300 km/h in freeze-thaw conditions). Ballastless slab track transmits cyclic stress deeper into the subgrade than ballasted track, typically reaching 3 m depth rather than 1.5 m, making the enhanced 3.1 m subgrade bed even more critical, not less.

2.9.4 What Alto Has Not Disclosed About Cold-Climate Design

Alto’s public consultation materials contain no reference to cold-climate subgrade design requirements, frost heave mitigation, anti-freeze layer specifications, or the Harbin–Dalian HSR as a design precedent. This is a significant omission: the cold-climate construction premium of 1.2–4.4 Mt CO_2e is larger than the entire estimated carbon cost of bridges and elevated structures along the corridor (0.25–1.7 Mt), and represents a category of construction carbon that has no counterpart in any of the international HSR project comparisons cited in Alto’s documents, because none of those projects operate in a comparable winter climate.

The HDPDL’s 25% construction cost overrun, and the need for pre-opening reconstruction, demonstrate that cold-climate HSR is materially more expensive and carbon-intensive than temperate-climate HSR. The per-kilometre carbon footprint of the HDPDL was approximately 30,000–35,000 t CO_2e/km, among the highest of any HSR project globally, reflecting both its terrain (elevated viaducts across river floodplains) and its cold-climate subgrade specifications. Alto’s corridor is somewhat more benign in terrain but faces the same cold-climate premium across its full length.

3. Leda Clay Ground Treatment: The Ottawa–Montréal Carbon Penalty

NEW SECTION

This section was not present in earlier versions of this document. It quantifies a construction carbon cost that is entirely absent from Alto’s public materials: the ground treatment required for approximately 200 km of Leda clay (quick clay) terrain between Ottawa and Montréal.

3.1 What Is Leda Clay and Why Does It Matter for HSR?

Leda clay is a marine quick clay deposited at the bottom of the Champlain Sea, which occupied the Ottawa and St. Lawrence valleys between approximately 12,500 and 7,000 years BP following the retreat of the Laurentide Ice Sheet. It underlies much of the Ottawa River plain, the South Nation Valley, and the lowlands west of Montréal. It is also present around Smiths Falls and the western edge of the former Champlain Sea limit, confirmed by whale bone specimens found 3 miles north of Smiths Falls (Dawson, 1883).

Leda clay has a metastable, "salt-flocculated" structure formed in the saline Champlain Sea environment. Over millennia, fresh groundwater has leached salt from the pore water, leaving a clay that is structured but deeply unstable when disturbed. Its key geotechnical properties make it uniquely problematic for high-speed rail:

- Extremely low undrained shear strength: typically 10–30 kPa, sometimes below 10 kPa in fully leached zones, roughly equivalent to soft cheese
- High water content: 40–80% by dry weight, far exceeding liquid limit
- Quick behaviour: when shear stress exceeds undrained strength, Leda clay loses virtually all strength almost instantaneously, flowing like a viscous liquid — the mechanism behind catastrophic landslides at Saint-Jean-Vianney (1971, 31 deaths) and South Nation River (1910)
- Remoulded strength near zero: once disturbed, the clay cannot recover its original structure
- Settlement: even without failure, consolidation settlement under sustained load can continue for decades

SPEED LIMIT IMPLICATION

HSR at 300 km/h imposes continuous cyclic dynamic loading on the track foundation. Studies of existing high-speed lines on soft ground (notably the Harbin–Dalian HSR in China, the world's only comparable cold-climate precedent) found that the critical speed — the speed at which ground response resonance causes rapid track degradation — on untreated soft clay is typically 130–190 km/h. Alto's 300 km/h design speed exceeds this limit by a factor of 1.5–2.3 across the entire Leda clay zone.

3.2 Extent of Leda Clay Along the Ottawa–Montréal Corridor

The Champlain Sea plain is the dominant landform between Ottawa and Montréal. Natural Resources Canada's surficial geology mapping shows continuous Leda clay coverage across the corridor from eastern Ottawa (Orleans/Gloucester) through the South Nation Valley, Casselman, Hawkesbury, and the Quebec lowlands through Vaudreuil-Dorion to Montréal. Depths range from 5–10 m in upland transition zones to over 40 m in valley floors.

Any route alignment between Ottawa and Montréal, whether following the Highway 417/40 corridor, the VIA Rail alignment, or a new alignment further south, must cross this plain. There is no practicable routing between Ottawa and Montréal that avoids Leda clay. The 200 km figure used in this analysis is a conservative estimate of the length requiring special treatment, based on:

- Continuous Leda clay coverage along the Ottawa Valley and St. Lawrence Lowlands identified in Natural Resources Canada surficial geology mapping
- NRC's Sensitive Marine Clay database identifying 'moderate' to 'high' sensitivity zones throughout the corridor
- Exclusion of bedrock outcrops and elevated terrain (Rockcliffe escarpment, Oka Hills) that may allow at-grade construction

- Conservative assumption that approximately 15–20% of the 200 km segment can be built on undisturbed, non-sensitive glacial till or bedrock outcrops

3.3 Treatment Options and Their Carbon Costs

Three treatment approaches are technically credible for HSR on Leda clay, ranging from minimum intervention to full structural bypass. All figures cover 200 km of double-track corridor.

Scenario A: Deep Soil Mixing (DSM) Columns — Ground Improvement

Deep soil mixing injects cement grout into the clay through rotating augers, creating interlocking reinforced columns that stiffen the ground. A load transfer platform (LTP) of compacted fill and geogrid is constructed above the column grid to distribute track loads. This approach does not reach bedrock, it creates a composite ground that is stiffer than untreated clay but remains within the Leda clay mass.

DSM is standard practice for embankment stabilisation in soft ground but carries significant risk for 300 km/h HSR: (a) treated zones remain within the Leda clay, which can fail laterally around the column grid; (b) the columns do not prevent consolidation settlement of the surrounding clay; (c) Transport Canada and international HSR standards do not accept ground improvement alone as the primary foundation system for operations above approximately 200 km/h on quick clay. DSM may be used as a supplementary measure but not as the sole treatment in the highest-hazard zones.

Scenario B: Pile-Supported Slab Track — Piled Foundation

CFA (continuous flight auger) concrete piles are bored through the Leda clay to bedrock or dense glacial till, typically at 20–25 m depth. A reinforced concrete pile cap and load transfer slab distribute track loads directly to the piles, completely bypassing the Leda clay. The track sits on the pile-supported slab at grade level. This is the minimum technically credible solution for 300 km/h HSR in quick clay zones.

This approach is proven in Chinese HSR practice (Harbin–Dalian: pile-supported slab track on permafrost and expansive soils) and is standard on soft ground sections of European HSR. It eliminates the quick clay from the load path entirely. Carbon is concentrated in the large number of concrete pile shafts and the continuous reinforced concrete slab.

Scenario C: Full Elevated Viaduct — Structural Bypass

A continuous reinforced concrete viaduct carries the track on a deck supported by pier columns, each founded on deep pile caps (typically a 4×4 or 4×5 pile group at 25–30 m depth). The viaduct completely eliminates ground contact; no load is transmitted to the Leda clay at all. This is required in the highest-hazard zones where Leda clay thickness exceeds 30–40 m, where lateral spreading risk is high (river floodplains, valley margins), or where the critical speed on pile-supported slab track would still be insufficient.

Viaduct construction generates the largest carbon cost of any HSR treatment option by a significant margin, due to the very large volume of concrete in deck structures, pier columns, abutments, and pile cap foundations. The UIC data shows that per-metre viaduct construction requires approximately 32.1 m³ of concrete and 3.51 tonnes of structural steel per linear metre (double track), compared to roughly 2.5 m³ of concrete for a piled slab section.

3.4 Carbon Calculation Methodology

The following calculations apply published concrete and steel carbon emission factors to the estimated material volumes for each scenario. Concrete emission factor: 371 kg CO_2/m³ (C40 grade; PMC/NCBI railway construction database). Steel emission factor: 1,900 kg CO_2/tonne (World Steel Association). Equipment diesel surcharge: +15% on material carbon total (consistent with HS2 A5 stage data).

Parameter	Scenario A DSM Ground Improvement	Scenario B Pile-Supported Slab Track	Scenario C Full Elevated Viaduct
Treatment width (double track)	12 m	12 m	Deck width ~14 m
Foundation element	DSM columns 600mm × 12m depth	CFA piles 400mm × 20m depth	Bored piles 800mm × 25m depth
Spacing	2.0 m grid across 12 m width	2.5 m × 2.5 m grid	Piers at 32 m centres; 4×4 pile group per pier
Number of foundations (200 km)	~72 million DSM-m (total)	~384,000 CFA piles	~6,250 piers × 16 piles = ~100,000 piles
Concrete — foundations (m³)	~1,440,000 m³ (grout)	~965,000 m³	~3,140,000 m³ (piles + caps)
Concrete — deck / slab (m³)	~480,000 m³ (LTP slab)	~800,000 m³ (track slab)	~9,400,000 m³ (box girder deck)
Total concrete volume	~1,920,000 m³	~1,765,000 m³	~12,540,000 m³
Structural steel (tonnes)	~50,000 t (rebar only)	~130,000 t (rebar + couplers)	~2,100,000 t (structural + rebar)
CO_2 — concrete (@ 371 kg/m³)	~713,000 t	~655,000 t	~4,652,000 t
CO_2 — steel (@ 1,900 kg/t)	~95,000 t	~247,000 t	~3,990,000 t

Parameter	Scenario A DSM Ground Improvement	Scenario B Pile-Supported Slab Track	Scenario C Full Elevated Viaduct
Equipment diesel surcharge (+15%)	~122,000 t	~135,000 t	~1,297,000 t
TOTAL CO_2e — Leda clay treatment	~0.93 Mt	~1.04 Mt	~9.94 Mt

NOTE ON SCENARIO A	
	Scenario A (DSM ground improvement) produces a higher concrete volume than Scenario B because the dense DSM column grid across the full 12 m embankment width requires a larger total volume of grout than the pile shafts in Scenario B. However, Scenario A is unlikely to be accepted as the primary treatment for 300 km/h HSR on quick clay, making Scenario B the effective minimum.

3.5 Budget Ranges Adopted for Alto’s Construction Carbon Estimate

The three scenarios bracket the credible range of Leda clay treatment emissions. For the purposes of Alto’s construction carbon budget, the following ranges are adopted:

- Low estimate (0.3 Mt): Optimistic scenario assuming approximately 75 km of deep ground improvement (DSM) in lower-hazard sections at shallower clay depths (≤15 m), and 125 km of piled slab at full depth. Assumes significant bedrock outcrop sections reduce treatment length from 200 km to an effective 150 km requiring active foundation work.
- Central estimate (0.8 Mt): Pile-supported slab track across the full 200 km effective treatment length, 20 m average pile depth, standard rebar intensity. This is the minimum technically credible approach for 300 km/h in Leda clay.
- High estimate (4.5 Mt): Mixed treatment — approximately 50 km of elevated viaduct in the highest-hazard zones (Ottawa floodplain, South Nation valley crossings, Vaudreuil sector near Montréal) and 150 km of pile-supported slab. Viaduct sections dominate the total due to the volume of deck concrete.

CENTRAL CALCULATION BASIS	
	200 km double track | 400mm CFA piles, 20m average depth | 2.5m × 2.5m grid | Treatment width 12m | Piles: (12/2.5) × (200,000/2.5) = 4.8 × 80,000 = 384,000 piles | Concrete per pile: π × 0.2^2 × 20 = 2.51 m^3 | Pile concrete: 965,000 m^3 | Track slab: 200,000 m × 4.0m wide × 0.3m deep = 240,000 m^3 per track = 480,000 m^3; add pile caps and blinding: ~800,000 m^3 total | Steel rebar: ~130,000 t | CO_2: ~0.8 Mt (central)

3.6 What Alto Has Not Disclosed About Leda Clay

As of March 2026, Alto's public consultation materials contain no reference to Leda clay, quick clay, sensitive marine clay, or Champlain Sea deposits. The McGill TRAM financial analysis contains no geotechnical contingency for soft ground treatment. The AtkinsRéalis corridor study has not publicly identified Leda clay as a design constraint.

This is a material omission. The Leda clay ground treatment cost for 200 km of the Ottawa–Montréal corridor has been independently estimated at C$800 million to C$3.5 billion in financial terms (Alto HSR Citizen Research Initiative, Leda Clay Brief, 2026). The associated construction carbon cost of 0.3–4.5 Mt CO_2e has no counterpart anywhere in Alto's public environmental documentation.

The omission matters for two reasons. First, it means Alto's published cost and carbon figures are systematically understated for the Ottawa–Montréal segment. Second, the choice of treatment method — whether ground improvement, piling, or viaduct — is itself a carbon-significant design decision that should be subject to public scrutiny and environmental assessment before route selection is finalised.

- If Alto adopts pile-supported slab track across all 200 km: adds ~1.0 Mt CO_2e (central), pushing the project's base construction carbon from ~7 Mt to ~8 Mt at the low end
- If Alto uses elevated viaduct for 50 km of the highest-hazard zones: adds ~4.5 Mt CO_2e at the high end, pushing total construction carbon from ~20 Mt to ~24.5 Mt
- If the full 200 km requires viaduct (worst case): adds ~9.9 Mt, pushing the high estimate above 30 Mt CO_2e

4. Revised Estimated Total Construction Emissions

The following table updates the original construction carbon estimate to incorporate the Leda clay ground treatment penalty. Low and high ranges are shown for both the base construction and the Leda clay addition.

Emission Category	Low Estimate	Central Est.	High Estimate	Notes
Embodied carbon (concrete, steel, track, electrification)	2.5 Mt	5.4 Mt	10.0 Mt	Largest single category; 40–60% of total
Heavy machinery / on-site construction (A5)	1.25 Mt	2.1 Mt	3.3 Mt	~25% of total; HS2 benchmark
Material transport to site (A4)	0.8 Mt	1.7 Mt	2.5 Mt	~17% of total

Emission Category	Low Estimate	Central Est.	High Estimate	Notes
Tunnels (varies by route)	0.4 Mt	1.25 Mt	2.5 Mt	Critical variable; not yet disclosed
Bridges and elevated structures	0.25 Mt	0.8 Mt	1.7 Mt	Major river and terrain crossings
Land clearing / deforestation	0.08 Mt	0.17 Mt	0.33 Mt	~2% of total; Frontenac Arch
Debris and waste disposal	0.08 Mt	0.17 Mt	0.42 Mt	~1–3% of total
Wetland / peatland disturbance	Unknown	Unknown	Unknown	Material but unquantified in any HSR LCA
Stream / watercourse diversion	Unknown	Unknown	Unknown	Unquantified
BASE CONSTRUCTION SUBTOTAL	~5.4 Mt	~11.6 Mt	~20.8 Mt	Excl. wetlands, Leda clay, cold climate; scaled to 1,000 km
Cold-climate construction premium (Harbin–Dalian practices, full 1,000 km)	1.2 Mt	2.3 Mt	4.4 Mt	Subgrade depth, insulation, cement, drainage, A5 premium
Leda clay ground treatment — Ottawa–Montréal (200 km)	0.3 Mt	0.8 Mt	4.5 Mt	Fixed 200 km segment; pile-supported slab to partial viaduct
REVISED TOTAL (incl. Leda clay + cold climate)	~6.9 Mt	~14.7 Mt	~29.7 Mt	Excl. wetlands

These estimates are derived by applying per-kilometre emission rates from international projects to Alto's 1,000 km corridor (scaled proportionally from original 1,200 km estimates), adding the cold-climate construction premium derived from Harbin–Dalian HSR design practice (Section 2.9), and adding the Leda clay ground treatment estimate for the fixed 200 km Ottawa–Montréal segment (Section 3). The cold-climate premium applies across the full 1,000 km; the Leda clay treatment covers the 200 km Ottawa–Montréal segment only. Categories marked "Unknown" indicate that no published HSR carbon assessment has quantified these impacts, underscoring the need for Alto to commission and publish its own comprehensive LCA.

5. Carbon Payback Period: When Does HSR Become 'Green'?

The central environmental argument for HSR is that operational emission savings from displaced car and air travel eventually "pay back" the construction carbon debt. The published evidence suggests this payback is far from guaranteed, and the addition of the Leda clay treatment further extends the payback timeline:

- Chester and Horvath (UC Berkeley, 2010) estimated California HSR would require 71 years of operation at medium occupancy to offset its construction-related greenhouse gas emissions.
- The Spanish Basque Y project, with high tunnel/viaduct proportions, was projected to never achieve carbon payback over its entire lifecycle.
- HS2's own 2016 sustainability statement modelled scenarios over a 60-year assessment period, with construction emissions of 5.5–6.2 million tonnes against uncertain modal shift savings.
- The Chang and Kendall (2011) California study found a more optimistic 2–6 year payback — but only with high ridership assumptions, and their construction estimate (2.4 Mt) was less than one-quarter of Chester and Horvath's figure for a similar route.
- A Chinese ex-post study found that the Beijing–Shanghai HSR initially increased emissions because too much traffic was diverted from conventional rail (which was already low-carbon) rather than from cars and planes.

The payback calculation is critically sensitive to three variables: ridership levels; the electricity generation mix powering the trains; and the counterfactual — whether displaced trips would have been by car, plane, or existing rail.

Relevance to Alto: The Toronto–Québec City corridor's ridership projections have not been subjected to independent review. The corridor already has VIA Rail service — diverting passengers from existing rail to new HSR may produce minimal net emissions benefit while generating enormous construction emissions. Canada's trend toward electric vehicle adoption further reduces the carbon advantage of HSR over driving. With a revised construction carbon figure of 6.9–29.7 Mt CO_2e, the payback period under realistic ridership assumptions extends well beyond 50 years, and may never be achieved under pessimistic scenarios.

COLD CLIMATE + LEDA CLAY PAYBACK EFFECT

Adding 2.3 Mt (central) in cold-climate construction premium to the base total is equivalent to approximately 7–10 additional years of carbon payback at medium ridership. Adding 0.8 Mt for Leda clay treatment adds a further 2–4 years. Together, these two previously undisclosed categories add approximately 10–14 years to the central payback timeline. At the high end (4.4 Mt cold climate + 4.5 Mt Leda clay), these categories alone exceed the entire base construction subtotal and make lifecycle carbon payback within any realistic operating horizon essentially impossible.

6. Critical Gaps in Alto’s Environmental Disclosure

Based on this analysis, Alto has failed to publish the following essential information:

- A lifecycle carbon assessment (LCA) for the construction phase, using recognised standards such as PAS 2080 or ISO 14040/14044
- The proportion of the route requiring tunnels, bridges, and elevated structures — the single most important variable in determining construction carbon
- Embodied carbon estimates for materials (concrete, steel, electrification systems)
- Carbon costs of wetland drainage, peatland disturbance, and riparian corridor destruction
- A carbon payback analysis based on realistic, independently verified ridership projections
- Assessment of the counterfactual, including the accelerating transition to electric vehicles and potential improvements to existing VIA Rail service
- Comparison of construction carbon between the northern and southern route options through Eastern Ontario
- ANY acknowledgement of cold-climate design requirements: enhanced subgrade depth (3.1 m vs. 1.5 m standard), XPS/EPS insulation boards, cement-stabilised surface layers, enhanced drainage infrastructure, and cold-weather construction premiums — all mandatory for HSR operating in Eastern Ontario winters, all documented from the Harbin–Dalian HSR precedent
- ANY acknowledgement that Leda clay (quick clay, sensitive marine clay, Champlain Sea deposits) underlies approximately 200 km of the Ottawa–Montréal corridor and requires significant engineering treatment at 300 km/h
- The proposed geotechnical treatment method (ground improvement, pile-supported slab, or viaduct) for Leda clay sections, and its associated construction cost and carbon implications

7. Methodology and Sources

This analysis draws on published data from lifecycle carbon assessments, environmental impact statements, government reports, and peer-reviewed academic research from the following projects and sources:

- UIC (International Union of Railways): Carbon Footprint of High Speed Rail (2011)
  https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/15009/Carbon%20Footprint%20of%20High-Speed%20Rail%20UIC%202011.pdf
- UIC (International Union of Railways): High Speed Rail and Sustainability
  https://uic.org/sustainability/
- UK HS2: Phase 1 Environmental Statement
  https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents
- UK HS2: HS2 Learning Legacy publications
  https://www.hs2.org.uk/building-hs2/learning-legacy/
- UK HS2: Station lifecycle assessments
  https://oneclicklca.com/en/resources/case-studies/london-euston-railway
- Chinese HSR: Life Cycle Cost, Energy and Carbon Assessments of Beijing–Shanghai High-Speed Railway
  https://www.mdpi.com/2071-1050/12/1/206
- Chinese HSR: Lifecycle Assessment of High Speed Rail in China
  https://www.sciencedirect.com/science/article/abs/pii/S1361920915001571
- Chinese HSR: Embodied GHG emissions of high speed rail stations: Quantification, data-driven prediction and cost-benefit analysis
  https://www.sciencedirect.com/science/article/abs/pii/S0959652622025987
- California HSR: Life-cycle assessment of high-speed rail: the case of California
  https://iopscience.iop.org/article/10.1088/1748-9326/5/1/014003/pdf
- California HSR: 2024 Sustainability Report
  https://hsr.ca.gov/communications-outreach/reports/sustainability-reports/
- Spanish HSR: Madrid–Toledo lifecycle (ScienceDirect 2023)
  https://www.sciencedirect.com/science/article/abs/pii/S0048969723051689
- Spanish HSR: Dataset for the life-cycle assessment of the Basque Y high-speed rail line in Spain
  https://www.sciencedirect.com/science/article/pii/S2352340924004414
- Track Maintenance: Krezo et al. (2018) Evaluation of CO_2 emissions from railway resurfacing maintenance activities
  https://www.sciencedirect.com/science/article/abs/pii/S1361920916307684
- Track Maintenance: Life cycle optimization in railway infrastructures
  https://www.voestalpine.com/railway-systems/en/services/life-cycle-cost-optimization/
- Track Maintenance: Greenhouse gas emissions from high-speed rail maintenance: A comparative case study for five major high-speed lines
  https://www.sciencedirect.com/science/article/pii/S2666188825003223
- Winter Operations: The physics of icing drops under complex conditions
  https://link.springer.com/article/10.1007/s10409-025-25318-x
- Winter Operations: Zhou et al. (2022) A review of snow melting and de-icing technologies for trains
  https://journals.sagepub.com/doi/abs/10.1177/09544097211059631
- Winter Operations: Kloow (2011) High-speed train operation in winter climate
  https://bibliotek.vti.se/bib/278045
- Winter Operations: Railway Supply (2026) Winter conditions for Canada’s high-speed rail network
  https://www.railway.supply/winter-conditions-for-canadas-high-speed-rail-network-readiness/
- Ontario Grid: CER Province and Territory Energy Profiles (2022 data)
  https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/index.html
- Ontario Grid: GTHA Carbon Emissions Inventory (2024)
  https://carbon.taf.ca/2024/?v=1

- Ontario Grid: IESO Annual Planning Outlook
  https://www.ieso.ca/en/Sector-Participants/Planning-and-Forecasting/Annual-Planning-Outlook
- Lifecycle Methodology: Frontiers in Built Environment LCA (2021) Embodied GHG Emissions of Wooden Buildings
  https://www.frontiersin.org/journals/built-environment/articles/10.3389/fbuil.2021.729096/full
- Lifecycle Methodology: Rungskunroch et al. Life cycle assessment of ground borne vibration mitigation strategies
  https://pure-oai.bham.ac.uk/ws/portalfiles/portal/53927224/Rungskunroch_et_al_Life_cycle_assessment_INCE_2018.pdf
- Lifecycle Methodology: Carbon Management in Buildings and Infrastructure — PAS 2080
  https://www.bsigroup.com/en-GB/insights-and-media/insights/brochures/pas-2080-carbon-management-in-infrastructure-and-built-environment/
- Lifecycle Methodology: Soroosh Ataee (2025) Life cycle assessment and material flow analysis of road and rail infrastructure assets — A critical review
  https://www.sciencedirect.com/science/article/pii/S2666789425000054
- Decommissioning: SNCF rolling stock recycling data
  https://www.groupe-sncf.com/en/commitments/sustainable-development/our-trains-second-life
- Decommissioning: Okon Recycling locomotive studies
  https://www.okonrecycling.com/specialty-equipment-recycling/locomotives/

Alto HSR Citizen Research Initiative

altohsrcitizenresearch.ca — Glenburnie, Ontario