

Multi-Factorial Respiratory Disease Etiology, Environmental Exposures, and Corporate Footprint: An Epidemiological and Regulatory Assessment of Saint John, New Brunswick

Executive Summary and Epidemiological Landscape

Evaluating the etiology of respiratory disease—specifically primary bronchogenic carcinoma—in industrial urban environments requires navigating complex exposure pathways and multi-source environmental dynamics. Saint John, New Brunswick, presents an unusually complex environmental health setting where heavy industrial operations, commercial transportation, residential combustion, geological hazards, and behavioral risk factors intersect within a compact geographic area.

A fundamental methodological distinction must be maintained when evaluating population health in multi-source industrial settings:

$\text{Emission} \neq \text{Ambient Exposure} \neq \text{Biological Dose} \neq \text{Epidemiological Association} \neq \text{Causation} \neq \text{Corporate Legal Responsibility}$

Demonstrating that an industrial facility releases a contaminant establishes an emission source, and detecting that contaminant at a monitoring station establishes an ambient concentration.

However, ambient monitoring alone does not determine the specific share of an individual's lifetime biological dose attributable to a single facility, nor does it establish legal causation for individual health outcomes.

Historical research, such as a 2009 study by the Conservation Council of New Brunswick, identified historical lung cancer incidence rates in Saint John that were 40% to 50% higher than in Moncton and Fredericton during the period examined. To maintain scientific rigor, these historical comparisons must be presented with their specific temporal and demographic parameters rather than as static current statistics. Contemporary surveillance data from the New Brunswick Health Council indicate that in 2024–2025, 39.2% of lung cancer cases in Health Zone 2 (Fundy Shore and Saint John Area) were diagnosed at Stage IV, compared to 40.7% provincially. This statistic reflects stage at diagnosis rather than elevated disease incidence or environmental causation.

The available evidence supports a multi-exposure environment containing measurable petroleum-related volatile organic compounds (VOCs), fine particulate matter, residential radon, and commercial tobacco exposure. While corporate entities operate key industrial facilities and commercial retail networks in the region, current evidence does not permit assigning a specific percentage of the community's cancer burden to any single corporation. Determining source-specific contributions requires source-apportioned exposure modeling and longitudinal epidemiological research.

Health Indicator / Environmental Metric	Regional Baseline (Saint John / Zone 2)	Provincial Benchmark (New Brunswick)	Comparative Baseline / Guidelines	Primary Source / Context
Historical Lung Cancer Rate Comparison	40% to 50% higher than Moncton/Fredericton (1989–2005)	Baseline provincial incidence	National average (NB males +20%, females +10%)	Conservation Council 2009 Study
Ambient Benzene Concentration (Champlain Heights, 2024)	0.528 ppb (estimated annual mean)	Unregulated under Clean Air Act	0.14 ppb Ontario Comparison Benchmark	GNB 2024 Air Quality Report
Short-Duration Benzene Peak (Champlain Heights, 2024)	2.1 ppb max (39.1% exceedances of 0.71 ppb benchmark)	Unregulated under Clean Air Act	0.71 ppb Ontario 24-hr Comparison Benchmark	GNB 2024 Air Quality Report (4-hr canister draw)
Residential Indoor Radon Exceedance (>200 Bq/m ³)	21% to 25% of tested homes	~21% to 25% provincial average	10% National Exceedance Average	Cross-Canada Radon Survey
Adult Daily Smoking Prevalence	~14% (2021 daily smokers)	~14% provincial daily rate	16% National Average	New Brunswick Health Council

Industrial Emissions and Atmospheric Exposure Profile

The Multi-Source Airshed of Saint John

Saint John is New Brunswick's primary industrial center, hosting a concentration of heavy manufacturing, energy production, and logistics infrastructure. Major point sources include the Irving Oil Refinery (Canada's largest petroleum refinery), J.D. Irving Pulp and Paper Ltd., Irving Paper Ltd., and NB Power's Coleson Cove Generating Station. The local airshed is further influenced by the Canaport marine terminal, deep-water port activity, cruise ships, railway transport, road traffic, commercial heating, and regional long-range transport.

Because these multiple source categories emit overlapping contaminants into the same geographic area, local air quality cannot be treated as a single-source phenomenon. Facilities release criteria air pollutants—such as fine particulate matter (PM_{2.5}), sulphur dioxide (SO₂), and nitrogen dioxide (NO₂)—alongside volatile organic compounds (VOCs) like benzene and reduced sulphur compounds. Coastal meteorological conditions and marine boundary layer dynamics further influence contaminant dispersion across residential neighborhoods.

Benzene Monitoring Data and Regulatory Benchmarks

Benzene is monitored at select stations in Saint John due to the presence of refining and petroleum handling infrastructure. The 2024 provincial air quality monitoring report recorded the following annual average benzene concentrations across monitoring sites:

- **Saint Andrews (Background Site):** 0.049 ppb
- **Forest Hills:** 0.136 ppb
- **Champlain Heights:** 0.528 ppb

Because New Brunswick's Clean Air Act does not currently include a statutory ambient objective for benzene, the province compares measured values against Ontario's Ambient Air Quality Criterion (AAQC) of 0.14 ppb. The estimated annual concentration at Champlain Heights (0.528 ppb) exceeded the Ontario comparison benchmark by approximately 3.77 times.

Important methodological parameters govern the interpretation of these data:

1. **Sampling Methodology:** The provincial monitoring report explicitly notes that annual benzene averages are approximations derived from periodic canister sampling rather than continuous 365-day monitoring.
2. **Comparison vs. Risk:** Exceeding Ontario's 0.14 ppb comparison benchmark by 3.77 times represents a benchmark comparison exceedance; it does not equate to a 3.77-fold increase in individual cancer risk. Ontario's AAQC is set at a conservative level to keep lifetime excess cancer risk below one in one million exposed individuals.
3. **Short-Duration Sampling:** At Champlain Heights, 39.1% of collected VOC samples exceeded Ontario's 24-hour comparison criterion of 0.71 ppb, with a maximum measured sample concentration of 2.1 ppb in 2024. The sampling draw time was four hours rather than a full 24 hours. Short-duration peak values cannot be directly compared against annual standards, nor do they prove an annual average exceedance on their own.

Carcinogenicity and Epidemiological Context

Benzene is classified by the International Agency for Research on Cancer (IARC) as a Group 1 known human carcinogen, with the strongest causal evidence established for acute myeloid leukemia (AML) and other hematological malignancies.

Regarding lung cancer, contemporary epidemiological research indicates a supportive association, particularly in occupational settings:

- A 2024 systematic review and meta-analysis examining occupational benzene exposure across 13 studies (comprising 366,975 participants) identified a pooled relative risk (RR) of 1.14 (95% CI: 1.03–1.27) for ever-exposed workers, alongside a positive exposure-response trend, though study heterogeneity was substantial.
- A pooled analysis of 14 case-control studies similarly observed increased lung cancer odds across occupational benzene exposure categories after adjusting for smoking and other occupational carcinogens.

While these findings support an association between occupational benzene exposure and lung cancer risk, occupational exposure levels generally exceed residential ambient levels.

Converting ambient community concentrations into precise numbers of local cancer cases requires formal, source-resolved exposure-response modeling.

Criteria Air Pollutants: PM_{2.5}, SO₂, and NO₂

Particulate matter and criteria gases represent distinct biological exposure pathways:

- **Fine Particulate Matter (PM_{2.5}):** Outdoor particulate matter is classified by IARC as carcinogenic to humans. In New Brunswick, the Canadian Ambient Air Quality Standards (CAAQS) for PM_{2.5} are set at 8.8 µg/m³ (three-year average of annual averages) and 27 µg/m³ (24-hour metric). However, CAAQS serve as national management goals rather than binding provincial standards. Annual PM_{2.5} averages at monitored Saint John

stations, such as Champlain Heights (3.3 to 6.8 $\mu\text{g}/\text{m}^3$), remained within CAAQS target thresholds during 2024.

- **Nitrogen Dioxide (NO₂) and Sulphur Dioxide (SO₂):** All monitored Saint John locations met applicable provincial objectives for NO₂ in 2024 (e.g., Castle Street recorded an annual average of 3.8 ppb). For SO₂, while stations generally achieved provincial objectives, certain locations like Grandview West received higher CAAQS management classifications, and temporary SO₂ spikes can occur during industrial upset events or adverse meteorology.

Behavioral, Geological, and Environmental Co-Exposures

Tobacco Consumption and Retail Determinants

Cigarette smoking remains the primary direct cause of primary lung carcinoma. Health Canada estimates that approximately 72% of lung cancer cases in Canada are directly attributable to smoking.

The commercial infrastructure through which tobacco products are sold—including gas stations, travel plazas, and convenience outlets operated by regional entities—represents an aspect of the commercial tobacco environment. Evaluating retail availability and outlet density is part of analyzing commercial determinants of health. However, retail presence alone does not establish that a specific commercial network caused a measurable fraction of local cancer cases.

Demonstrating such a connection requires empirical analysis of historical outlet density, sales volumes, demographic variables, pricing, and cessation patterns relative to competing retail channels.

Daily adult smoking prevalence in New Brunswick has declined from historical highs, reaching approximately 14% in 2021 (below the national average of 16%), with recent self-reported survey models estimating further decreases. Because lung cancer typically involves a 20-to-40-year latency period between exposure and clinical diagnosis, historical smoking rates remain a key variable in contemporary epidemiological assessments.

Geological Radon Gas (Radon-222)

Indoor Radon-222 (^{222}Rn) is an independent environmental risk factor that must be accounted for in regional lung cancer studies. Radon is a naturally occurring radioactive gas formed by the decay of uranium and radium in soil and bedrock, which accumulates inside enclosed residential spaces. Health Canada identifies radon as the leading cause of lung cancer among non-smokers, recommending remediation when long-term indoor levels exceed the national guideline of 200 Bq/m³.

Data from the Cross-Canada Survey of Radon Concentrations in Homes show that New Brunswick has elevated geological exposure, with a provincial geometric mean indoor level of 99.4 Bq/m³. Approximately 21% to 25% of homes across the province exceed the 200 Bq/m³ action threshold, compared to 10% nationally, with certain geological zones reaching exceedance rates of up to 40%. An additional 24.2% of residences fall within the moderate-risk range between 100 Bq/m³ and 199 Bq/m³. Because indoor radon levels vary considerably from home to home, epidemiological studies require participant-level long-term testing or validated

historical exposure reconstructions.

Multi-Exposure Interaction Models

The biological risk profile of Saint John reflects a multi-exposure environment where individuals may concurrently experience tobacco smoke, indoor radon, fine particulate matter, and ambient VOCs.

In environmental toxicology, co-exposures do not automatically translate into simple multiplicative or universal numerical multipliers (such as an assumed "50-fold" increase). While the interaction between radon and tobacco smoke is well-documented as multiplicative—where radioactive alpha particles from radon progeny induce double-strand DNA breaks while smoke carcinogens impair cellular repair—the overall combined effect of ambient industrial pollutants, radon, and smoking must be modeled empirically.

Depending on exposure levels and physiological pathways, joint effects may follow additive, multiplicative, or submultiplicative statistical models. Determining true cumulative risk requires field measurements and empirical exposure-response modeling rather than assumed mathematical constants.

Regulatory Framework: Current Status vs. Modernization Proposals

Operative Law Under the Clean Air Act

As of September 2026, New Brunswick's statutory air quality enforcement framework is grounded in the Clean Air Act (enacted in 1997) and its associated Air Quality Regulation. The province formally regulates Maximum Permissible Ground Level Concentrations for five criteria air pollutants:

1. Carbon monoxide (CO)
2. Hydrogen sulphide (H₂S)
3. Nitrogen dioxide (NO₂)
4. Sulphur dioxide (SO₂)
5. Total suspended particulate matter (TSP)

Volatile organic compounds—including benzene and formaldehyde—are not currently subject to legally binding ambient standards under provincial regulation. While New Brunswick reports monitoring data against the Canadian Ambient Air Quality Standards (CAAQS) for PM_{2.5}, ozone, NO₂, and SO₂, CAAQS serve as non-binding national management goals rather than statutory requirements in the province.

Regulatory Parameter	Operative Framework (Clean Air Act)	Proposed Modernization Framework (Under Review)	Operational Impact on Airshed Oversight
Regulated Ambient Objectives	5 criteria pollutants (CO, H ₂ S, NO ₂ , SO ₂ , TSP)	Proposed expansion to ~60 pollutants including VOCs	Would bring benzene, formaldehyde, and heavy metals under direct regulation
Benzene Standard	Unregulated; compared	Proposed enforceable	Would establish a

Regulatory Parameter	Operative Framework (Clean Air Act)	Proposed Modernization Framework (Under Review)	Operational Impact on Airshed Oversight
	to Ontario AAQC (0.14\text{ ppb})	Ambient Air Quality Objective	statutory compliance target for local emitters
CAAQS Implementation	Non-binding national planning benchmarks	Proposed integration into provincial objective framework	Clarifies regulatory status of national benchmarks in approvals
Public Transparency	Annual static summary reports & online data portal	Proposed real-time online permit and enforcement databases	Expands public access to industrial compliance records

Modernization Roadmap (2024–2026)

The Department of Environment and Local Government (DELG) has undertaken a comprehensive review to update the Clean Air Act and Clean Water Act. The proposed modernization framework includes:

- Expanding regulated ambient air quality objectives from 5 to approximately 60 pollutants.
- Establishing legally binding provincial objectives for previously unregulated substances, including benzene and formaldehyde.
- Enhancing public access to monitoring data, industrial permits, and enforcement records.
- Updating approval-to-operate frameworks and compliance tools.

Amendments to the Air Quality Regulation are targeted for 2026, with broader legislative updates targeted for implementation by fall 2027. Until these amendments receive legislative approval and take effect, the 60-pollutant framework represents proposed policy rather than operative law.

Attribution Framework and Methodological Research Roadmap

Six-Level Attribution Framework

To avoid oversimplification, evaluating corporate environmental impact requires a structured attribution framework spanning six distinct analytical levels:

1. **Level 1 — Facility Existence:** Identifying the presence and operating history of industrial facilities within the airshed.
2. **Level 2 — Emissions Quantification:** Documenting contaminant release rates through national pollutant inventories and stack testing.
3. **Level 3 — Environmental Transport & Dispersion:** Modeling how atmospheric emissions disperse under local meteorological and topographic conditions.
4. **Level 4 — Population Exposure Assessment:** Measuring ground-level contaminant concentrations at residential monitoring stations.
5. **Level 5 — Epidemiological Association:** Determining whether higher exposure zones correlate with increased disease incidence after controlling for confounders.
6. **Level 6 — Causal Attribution:** Quantifying the specific fraction of disease burden

attributable to a given source.

Establishing Levels 1 and 2 confirms the presence of industrial emissions but does not satisfy Levels 5 or 6. Complete causal attribution requires integrating source-apportionment models with longitudinal epidemiological data.

Recommended Source-Apportionment Study Design

A rigorous epidemiological investigation of respiratory risk in Saint John should integrate the following components:

- **Integrated Environmental Monitoring:** Continuous, high-frequency tracking of benzene, BTEX compounds, PM2.5, SO2, NO2, polycyclic aromatic hydrocarbons (PAHs), and reduced sulphur species across dense spatial networks.
- **Chemical Source Apportionment:** Utilizing trace chemical signatures, wind-direction correlations, and receptor modeling to separate petroleum refining, pulp processing, marine shipping, rail transport, and traffic contributions.
- **Participant Exposure Reconstruction:** Gathering detailed residential address histories, employment records, indoor radon test results, lifetime smoking pack-years, and secondhand smoke exposures for study participants.
- **Controlled Epidemiological Modeling:** Conducting retrospective cohort and case-control analyses that adjust for age, sex, socioeconomic status, occupational exposures, and residential mobility.

Strategic Policy Options

The following evidence-based policy options offer pathways to reduce exposure uncertainty and strengthen environmental oversight:

1. **Establish Provincial Ambient Objectives for Volatile Carcinogens:** Codify enforceable ambient air quality objectives for benzene and formaldehyde under the Clean Air Act, backed by clear compliance protocols for Class 1 industrial facilities.
2. **Implement Cumulative Exposure Assessments:** Require environmental assessments and facility renewal approvals to evaluate cumulative pollution loads, incorporating background emissions, transport traffic, and local geological risks.
3. **Expand Real-Time Continuous VOC Monitoring:** Augment canister-based VOC sampling with continuous monitoring near industrial fence-lines to capture short-duration emission spikes and operational upsets.
4. **Fund Targeted Residential Radon Remediation:** Provide testing and mitigation assistance prioritized for high-risk geological areas across Health Zone 2 to reduce non-industrial background risks.
5. **Publish Centralized Environmental and Health Data:** Develop open-access databases integrating real-time air quality metrics, facility emission reports, permit conditions, and aggregated health surveillance indicators.

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