Research on Non-Energy Sources of Greenhouse Gas Emissions in Water Systems Operation: Improvements and Innovation

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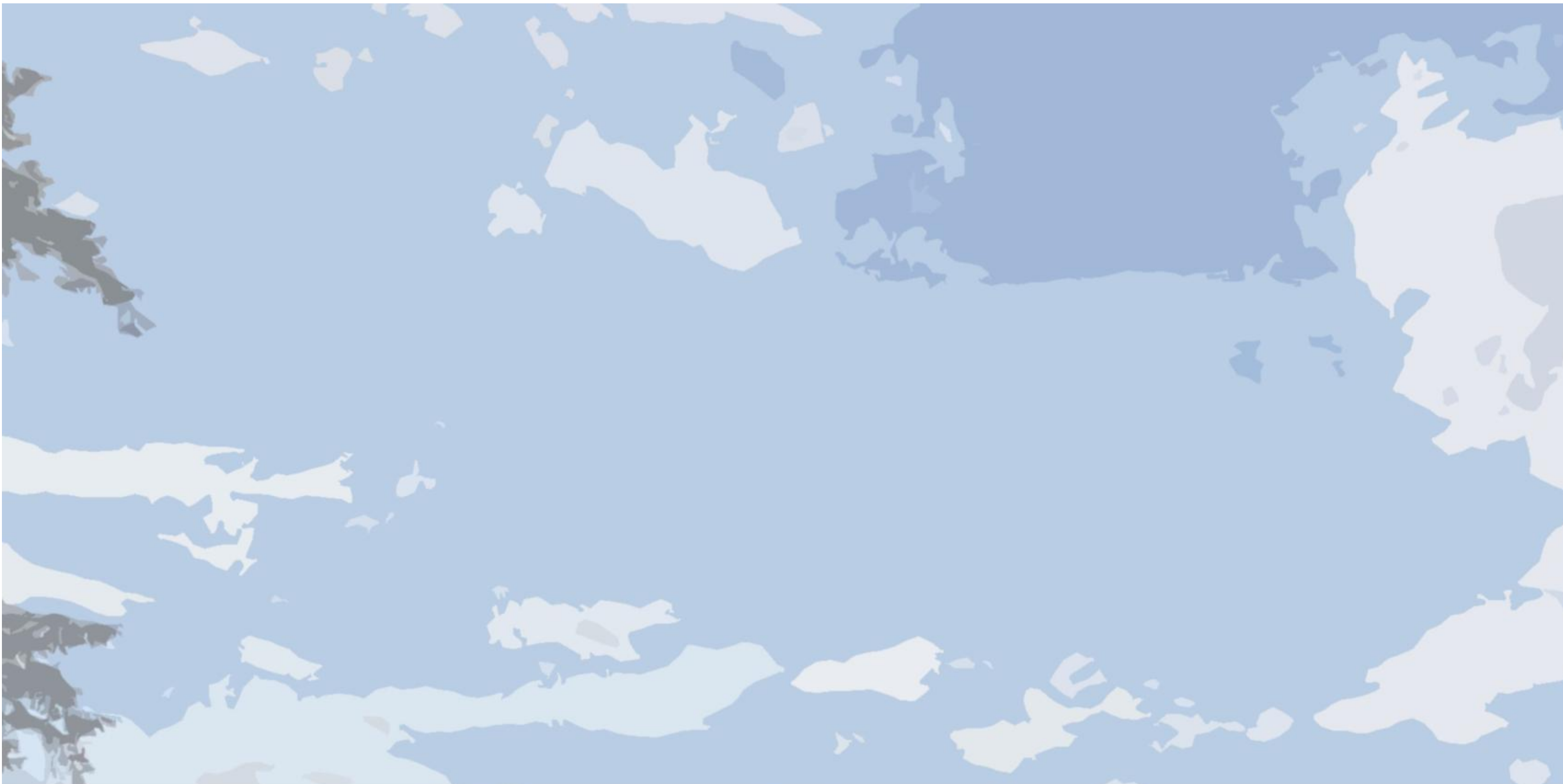

Disclaimer

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Executive Summary

This project explores opportunities to reduce non-energy-related (indirect and process) greenhouse gas (GHG) emissions within Metro Vancouver's drinking water treatment and transmission systems, which are not completely understood and reported in conventional inventories. A problem-driven, section-by-section jurisdictional scan was conducted by narrowing the research to four operational domains with the highest potential for meaningful GHG reductions: chemical use, residuals handling, filter media selection, and UV disinfection systems. This project includes both treatment and transmission systems, and it is found that embodied GHG emissions in transmission are minimal and primarily tied to construction, pipe replacements, and leak repairs, which are areas outside the scope of this study. In chemical sourcing, most treatment chemicals such as coagulants, lime, and disinfectants, have limited substitution potential due to their process-critical roles and stable, inorganic composition. However, GHG performance can still be influenced through supplier choices informed by accessing Life Cycle Assessment (LCA) data. Future efforts should explore integrating these tools into procurement to support low-carbon alternatives. Drinking Water treatment residuals, which are currently diverted to landfills when co-processing options are unavailable, offer substantial room for improvement. Alternatives like blending with green waste for landscaping applications show promise, especially for non-agricultural uses. While drinking water treatment residuals have lower methane generation potential than biosolids, diverting them from landfill still offers moderate climate benefits and aligns with circular economy principles. Emerging filter media such as recycled glass, biochar, and zeolite present environmentally preferable options to anthracite, which is mined and incinerated after use during disposal. These alternatives have lower embodied emissions, longer lifespans, and eliminate disposal-related carbon impacts. In UV disinfection, innovations such as mercury-free UV-C LED technology and real-time smart UV control systems can reduce environmental and energy impacts. While still scaling for large systems, these options show strong potential and align with broader sustainability goals. With the knowledge of chemical usage, the current residuals management practices and their estimated carbon footprints, a simplified calculation projects the potential of about 20% annual decrease in GHGs (embodied and waste handling processes). This calculation is based on the replacement of PACl (Polyaluminium Chloride, currently used coagulant) for a lower footprint variant, the substitution of anthracite filters, and exploration of more diverse routes for residuals beneficial use, such as backfilling. Together, these findings highlight clear pathways for Metro Vancouver to advance indirect GHG reductions by improving procurement practices, adopting circular waste strategies, and piloting sustainable technologies across key operational processes.

1. Introduction

The intensifying concerns around climate change have encouraged global commitments for the reduction of greenhouse gas (GHG) emissions. Through the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), Canada, alongside over 140 nations, has pledged to achieve net-zero emissions by 2050. While direct GHG emissions (Scope 1) from drinking water treatment plants (DWTPs) such as those from fuel combustion in backup generators or fleet vehicles are well tracked, a growing focus is on indirect or Scope 3 emissions, which remain less visible. These include emissions embedded in purchased goods and services such as chemicals, refrigerants, treatment media, and beneficial use practices.(Zhang et al.)

Various initiatives across different departments at Metro Vancouver are underway as a collective effort towards corporate-wide decarbonization, with success reported in the context of energy management. However, there is growing interest in addressing non-energy emissions, those tied to embodied carbon and downstream processes like waste disposal. These sources are inadequately quantified and hard to compare across systems. The goal of this project is to create a targeted approach to exploring jurisdictional innovations and sustainable alternatives relevant to water utilities, particularly focused on indirect emission sources. This is approached by identifying high-impact areas and exploring jurisdictional examples of alternative materials, practices, and technologies that could inform more sustainable procurement and operational decisions. This work aligns with Metro Vancouver's corporate goals towards emission reduction and provides a pathway to integrate embodied emissions into broader decarbonization strategies.

2. Non-energy emission sources within the Greater Vancouver Water District (GVWD)

Non-energy GHG emission intensive sources within Metro Vancouver's drinking water treatment system were identified by process reviews of the Coquitlam Water Treatment Plant (CWTP) and Seymour Capilano Filtration Plant (SCFP), coupled with insights from operational and transmission staff, and subject matter experts (SMEs). Staff from Corporate Climate Action Services were also consulted for information on fugitive emissions and refrigerant-related impacts.

Four operational areas were identified as potential sources of non-energy GHG emissions, and where mitigation opportunities through material choices or reasonable operational changes could be explored. These areas are:

1. Process chemicals
2. Residuals management
3. Filter media choices and disposal
4. UV disinfection equipment

These areas were selected after narrowing down from a broader set of materials (**Table A1**, appendix) and processes. Replacement of commonly used chemicals such as hydrated lime, carbon dioxide, sodium hydroxide, and sodium hypochlorite were not investigated due to their relatively low embodied carbon or lack of viable substitutes without significantly altering treatment processes. For these chemicals, the recommendation towards mitigating embodied GHG is to focus on supplier selection, guided by life cycle assessment (LCA) data sourced from their environmental product declarations (EPDs).

Additionally, other emission sources, such as vehicle fleets, internal energy recovery systems, and infrastructure material disposal were interesting areas for exploration but were deemed out of scope considering our specific focus on non-energy sources or are currently being addressed through broader sustainability initiatives led by other departments at Metro Vancouver. In the case of transmission specifically, process chemical usage is negligible except for leak detection chemicals, which are included in the exploration. The primary sources of embodied carbon here stem from the construction, replacement, or disposal of infrastructure, such as aging or leaking pipes. These are areas that fall under the purview of the engineering and construction group and are outside the scope of this project. Another area that is scoped out is GHG emissions related to activities within the Watersheds operations because of the lack of comparability with most jurisdictions that do not have watersheds as part of their operations.

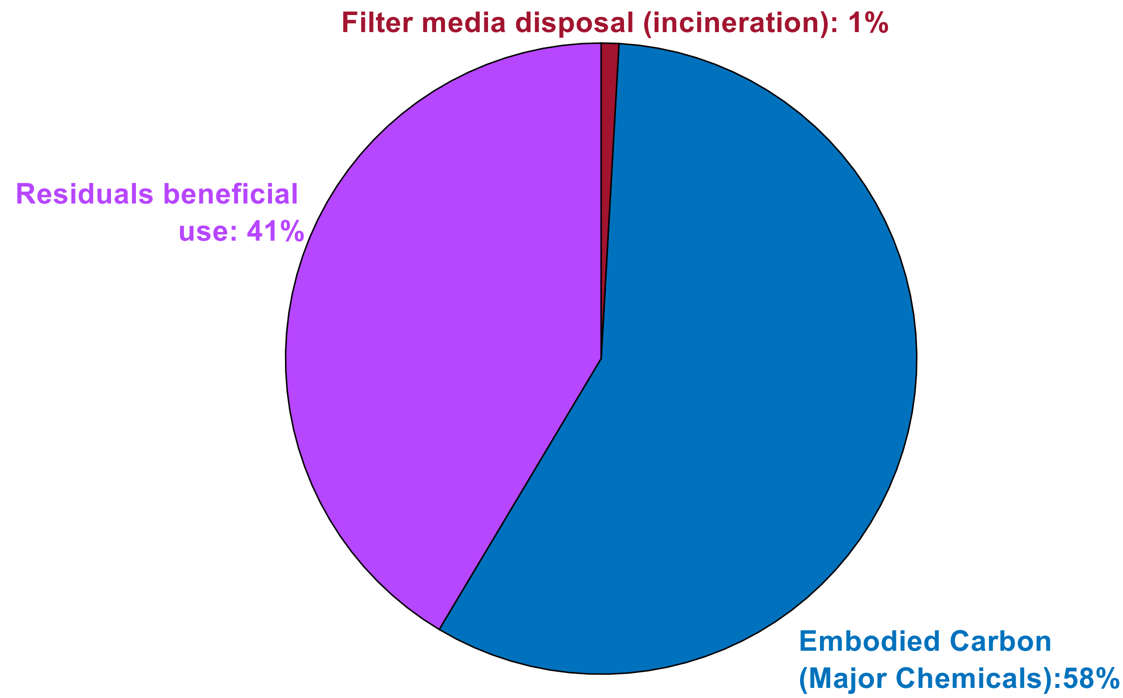

Figure 1 Major identified areas of non-energy emissions at Coquitlam Water Treatment Plant (CWTP) and Seymour Capilano Filtration Plant (SCFP) and their estimated fractional contributions. *Note: Emissions from UV disinfection systems and refrigerants are not included in this breakdown due to limited data availability but are assumed to be minor compared to the sources above, based on process review*

Process fugitive emissions in treatment and transmissions were assessed to be negligible based on SME insights. Refrigerant-related emissions were scoped out due to the prevalence of water-cooled systems in treatment processes in both treatment plants and transmission units. Ethylene glycol is used as a heat transfer fluid in closed-loop (reused continuously and has minimum consumption) heat exchanger systems, and no significant greenhouse gas emissions from refrigerants were identified. This is likely linked to electric chillers utilizing water sourced from mains and geothermal systems (at approximately 9.4°C), reducing reliance on refrigerants commonly associated with high GHG emissions. Emissions from HVAC systems (containing refrigerants), where applicable, are currently under assessment for inclusion in Metro Vancouver's broader GHG inventory and were therefore not included in this report. **Figure 1** presents a simplified breakdown of major contributors to indirect GHG emissions: treatment chemicals: ~58% and Residuals management: ~42%.

2.1 Currently used process chemicals and associated indirect emissions

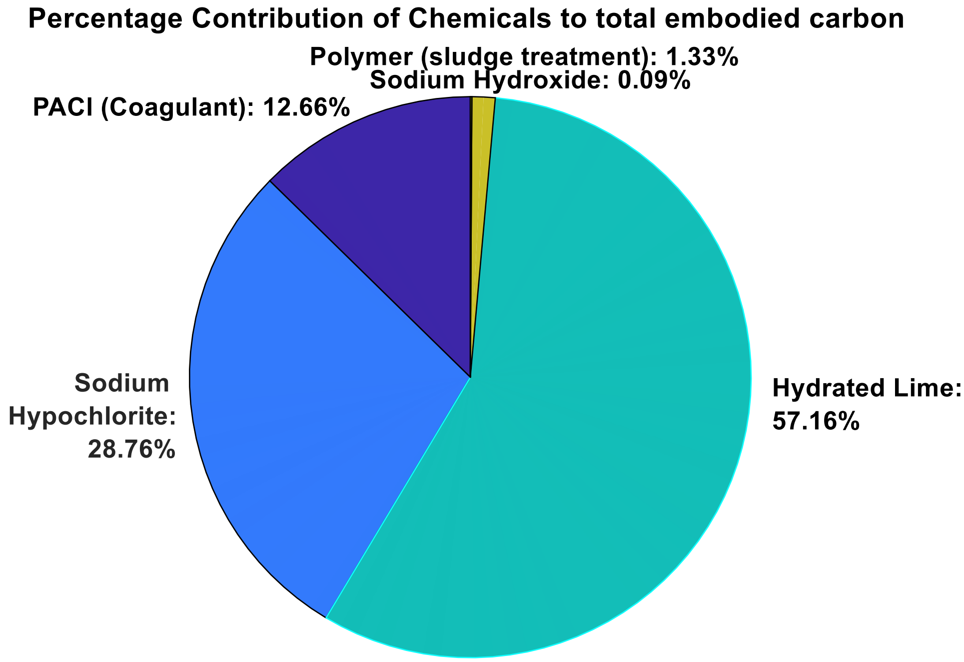

Figure 2 Relative CO_2e contribution of a few major treatment chemicals based on available data. Certain treatment chemicals (proprietary) are excluded from this chart due to limited carbon footprint information; the intent is to highlight the major contributors.

In drinking water treatment, chemicals are found to represent the largest source (as illustrated in **Figure 1**) of indirect (embodied) GHG emissions. While electricity (Scope 2) is often prioritized in indirect emissions inventories, chemical-related emissions are frequently overlooked due to the complexity of tracking embodied emissions across supply chains.(Stokes and Horvath) Reports from literature identify these chemicals as a major contributor to a drinking water treatment plant's total climate footprint, and therefore, an opportunity for decarbonization.(Racoviceanu et al.; Li et al.)

Table A1 (Appendix) lists the major treatment chemicals used at the Seymour Capilano Filtration Plant (SCFP) and the estimated embodied GHG (based on literature or supplier data). In contrast, the Coquitlam Water Treatment Plant (CWTP) uses fewer chemicals due to the current process design which does not include a flocculation and filtration unit. Most treatment chemicals overlap between SCFP and CWTP, except liquid oxygen, which is used in CWTP and cannot be easily substituted. This would also not be practical if substitution is solely driven by the purpose of carbon footprint reduction, because ozone-based disinfection relies on high-purity O_2, and few alternatives exist. PAX-15, an aluminum-based coagulant, is currently used at the Seymour Capilano Filtration Plant (SCFP). This Polyaluminum Chloride (PACl) consists of a high embodied carbon footprint due to the energy-intensive processes involved in aluminum production and chemical manufacturing. As shown in **Figure 2**, sodium hypochlorite and hydrated lime also contribute significantly to the plant's embodied emissions profile, indicating additional targets for emissions reduction. With the currently available data, we identify these chemicals as the most carbon-intensive inputs in the treatment process, making them a strategic focus for decarbonization. On the transmission side, Sodium sulfite and ascorbic acid-based chemicals are used during leak events (which are infrequent) to neutralize residual chlorine. Due to their occasional use and essential role in emergency response, they were not prioritized for embodied carbon reduction.

2.2 Current residuals management practices and associated indirect emissions

Metro Vancouver's Water Treatment Operations' current practice is to dewater the sludge and beneficially use the residuals in two sectors: cement manufacturing and agricultural land application. The majority are transported to a local cement plant for the replacement of virgin materials such as red shale, offering high GHG reduction potential. While this approach aims to leverage the residuals' energy and mineral content, it requires further assessment regarding the embodied emissions from transportation and the cement manufacturing process. As another alternative, portions of the residuals are directed towards the agricultural sector for land application to aid in phosphorus management. When a beneficial use site is not available, the residuals are landfilled.

2.3 Current filter media usage and associated indirect GHG emissions

Metro Vancouver currently uses anthracite filter media, which generates anthracite fines (2-3 40-yard bins) that are incinerated every two years. This process indirectly contributes to commonly overlooked GHG emissions due to combustion. Additionally, Anthracite, being a high-carbon mineral coal, carries substantial embodied emissions from processes such as mining, processing, and transportation.(Schobert and Schobert) This lifecycle presents multiple opportunities for emission reduction through material substitution and waste recovery.

2.4 Current practices regarding refrigerant and UV disinfection equipment and associated indirect GHG emissions

Metro Vancouver's current GHG inventory does not fully capture fugitive refrigerant emissions (Scope 1), which, despite their often small volume, can possess very high Global Warming Potentials (GWPs), making them impactful. Due to limited data availability, these emissions are not further examined in this report. As depicted earlier, the examined areas in treatment and transmission systems predominantly use water-cooled setups (with ethylene glycol in closed loops), making refrigerant-related indirect emissions minimal in water utility operations. The traditional UV disinfection systems used at CWTP, while effective, can lead to energy overuse due to less efficient lamp technology. These lamps are mercury-based, which have environmental implications in disposal that might not be directly related to GHG emissions. Addressing these areas could present additional opportunities for GHG reduction, along with benefits that are indirectly tied to other environmental implications.

3. Jurisdictional Review

Jurisdictions were reviewed according to key operational areas listed in the last section: For each area, multiple jurisdictions were scanned to identify where sustainable alternatives or process innovations for non-energy GHGs have been implemented, revealing mitigation opportunities compatible with the GVWD context.

The decision criteria also considered regulatory and geographical comparability, particularly with other North American or Canadian contexts, as well as technical relevance to Metro Vancouver's operations. A summary of the rationale for including each case or alternative is provided in **Table A2** (Appendix).

3.1 Chemicals

Iron-based coagulants have lower embodied carbon than aluminum-based options (Iron Chlorides and sulphates around 0.7–1.3 kg CO_2-eq per mole of Fe, compared to 1.5–4.5 kg CO_2-eq per mole of Al for aluminum-based coagulants, see **Table A3**). Polymeric ferric sulfates (PFS) offer improved NOM removal, better dewatering, lower dosing needs, and a wider pH range than conventional iron salts. Usage of the iron-based variants have shown additional operational benefits, such as algae control or improved sludge characteristics.(Chen et al.; Xu et al.) Natural coagulants (e.g., Moringa, chickpeas, cacti) are renewable and effective at small scales but face regulatory and infrastructure barriers in large urban systems, making compatibility a concern for the Metro Vancouver context. Sodium hypochlorite and Hydrated lime, which seem to be major contributors to embodied emissions (**Figure 2**) lack viable chemical substitutes, but emissions can be reduced by sourcing from suppliers that may have a lower carbon energy mix and production efficiency. In conclusion, procurement practices could improve to prioritize suppliers with low-carbon production pathways and provide LCA or EPD documentation for informing decisions.

A detailed overview of all alternatives for coagulant chemicals from the jurisdictional review, including their GHG reduction potential and the associated pros and cons, is provided in **Table A3** in the Appendix.

3.2 Residuals Management

GVWD beneficially uses drinking water treatment residuals, and diversifying options could potentially ensure multiple low-carbon alternatives when others are unavailable. The typical residuals composition is suitable for non-agricultural compost use (e.g., mine reclamation, landfill cover). Lower organic content in drinking water residuals leads to comparatively less methane generation, but composting is a better alternative than landfilling, particularly when diversion to the cement industry is unavailable. Al Hoceima, Morocco, exemplifies successful reuse of drinking water residuals by recycling streams and blending with biosolids for composting.

A detailed overview of all residuals beneficial use alternatives from the jurisdictional review, including their GHG reduction potential and the associated pros and cons, is provided in **Table A4** in the Appendix.

3.3 Filter Media

To reduce high embodied GHG emissions and incineration needs of anthracite filter media, several lower-carbon alternatives have been studied. Recycled glass media, made from used glass, is chemically inert and effective in filtration but may be abrasive for some systems. Studies have been limited to pilot scale in Roslyn, Washington. They confirm its viability in slow sand filtration setups. While full-scale adoption has been limited in North America, early pilot testing, such as the 2002 study at the Orangedale treatment plant in Nova Scotia demonstrated technical feasibility in drinking water applications.(Rutledge et al.) Certified options such as NatureWorks (www.natureworks.es) (e.g., NSF/ANSI 61-compliant glass media) are now available, improving the case for regulatory acceptance. Biochar, produced by pyrolyzing organic materials, acts as a carbon sink with high contaminant adsorption and has been explored at PacifiCorp, USA. The use in drinking water is limited due to leaching concerns. Zeolite offers a low carbon footprint, a long lifespan, is NSF/ANSI 61 certified for potable water. It is chemically stable and reusable. It has been explored in India and China, but uses in North America have been limited. These alternatives vary in technical compatibility and performance but can lower GHG emissions and entirely avoid end-of-life incineration requirements. The major challenge remains compliance and regulatory issues in North America.

A detailed overview of all filter media alternatives from the jurisdictional review, including their GHG reduction potential and the associated pros and cons, is provided in **Table A5** in the Appendix.

3.4 UV Disinfection Equipment

Key findings indicate the need to transition to more energy-efficient UV lamps produced using lower-carbon intensity processes. Assessment of Life Cycle Assessment (LCA) data for lamps when considering replacements or new process designs is strongly recommended. UV-C LEDs provide benefits like enhanced durability, instant power cycling without warm-up, and lower fouling and maintenance needs. Despite these advantages, UV-C LED technology is still in its early stages for high-flow water treatment, limiting widespread adoption currently. Pilot projects, such as Glitrevannverket in Norway using AquiSense PearlAqua Kilo UV-C LED units, demonstrate potential for scalable mercury-free UV disinfection. Smart UV control systems dynamically adjust UV intensity based on real-time water quality and flow, preventing energy overuse and reducing indirect GHG emissions (Xylem's Wedeco TAK Smart UV systems incorporate these features and are also deployed at Glitrevannverket). The progression toward mercury-free, energy-efficient, and smart-controlled UV systems indicates potential improvements while transitioning to more sustainable water disinfection techniques.

A detailed overview of all potential innovations and alternatives regarding the UV disinfection units from the jurisdictional review, including their GHG reduction potential and the associated pros and cons, is provided in **Table A6** in the Appendix.

4. Key findings:

The following is a summary of the findings derived from the background research, jurisdictional review, external subject matter expert (SME) interviews and exchanges with water utilities in jurisdictions similar (regulatory or geographical context) to Metro Vancouver, including Portland, Seattle, and Toronto:

- **Seattle**: Derives water from watersheds, with both filtered and UV-disinfected systems (Tolt and Cedar), similar to Metro Vancouver's approach.
- **Portland**: Also situated on the U.S. West Coast, is constructing a new filtration facility and has explored GHGs during land use approval but has yet to integrate embodied emissions into chemical selection.
- **Toronto**: Relevant in terms of Canadian policy and procurement context. They suggested strong emphasis on documenting supplier Environmental Product Declarations (EPDs), and have developed an open-source Scope 1–3 GHG inventory tool (OWWA/WEAO Greenhouse Gas Emissions Inventor Tool), which is being referenced and explored by Metro Vancouver.

4.1 Chemicals

Lessons from other jurisdictions indicate that while core treatment chemicals offer limited opportunities for substitution due to performance and operational requirements, their associated climate impacts can still be mitigated through procurement strategies that prioritize lower-carbon supply chains and production methods.

LCA-informed chemical sourcing: Environmental Product Declarations (EPDs) to compare the embodied GHGs of equivalent chemicals (for standard non-complex chemicals such as bleach, soda ash, etc).

Application at Metro Vancouver: Important for improving Scope 3 tracking, especially when GHG reduction potential is small; key for mature processes where redesign is not feasible.

Feasible action: Integrate LCA/EPD screening into procurement, particularly for common chemicals.

Information from SME (Toronto): Toronto Water is actively promoting EPD literacy and disclosure for suppliers and staff, even when full implementation of a chemical alternative is not immediately feasible. Product Category Rule (PCR) limitations, especially for polymers, are cited as the main barriers.

Exploration of alternative coagulants:

Polymeric ferric sulphate (PFS) variants are gaining traction due to potential LCA advantages.

Application at Metro Vancouver: Currently, PACl is chosen over ferric chloride due to better pH and NOM performance despite higher embodied carbon in the former. Internal SME insights at Metro

Vancouver raised valid concerns regarding iron-based coagulants, which are associated with undesirable colour, taste, and odour in treated water.

Feasible action: Future projects should assess Ferric chloride/PFS options during the process design stage.

Information from SME (Toronto & Seattle):

Both jurisdictions use ferric chloride as a coagulant and do not raise concerns regarding NOM removal, pH windows, or aesthetics of water (odour, taste). Toronto's RC Harris plant, additionally, was reported to have achieved ~40% drinking water sludge reduction with ferric chloride, underscoring process and downstream carbon benefits.

Takeaway: Chemical selection (in the case of complex chemicals such as blended polymers, coagulants, etc) must balance treatment efficacy and carbon impact. Emerging options such as PFS may fit better in early-stage design by replacing higher carbon counterparts.

4.2 Residuals Management

Innovative or diverse ways of residuals recycling or utilization are of importance in circular systems globally. Most GHG reductions can be traced to diverting residuals from landfilling.

Landscaping and reclamation: Jurisdictions like Sydney and Melbourne use treated water treatment sludge in non-agricultural applications.

Application at Metro Vancouver: Metro Vancouver's Utility Residuals Management group already manages similar biosolids-containing soil products. Nutrifor™ landscaping soil is one of those products..

Challenge: Drinking water treatment residuals may have lower nutritive value for direct incorporation in options like Nutrifor™ landscaping soil.

Feasible Action: Exploring options similar to Nutrifor™ landscaping soil, by co-blending with biosolids.

Information from SME (overall):

While a variety of alternative residual beneficial use options have not yet been explored in many jurisdictions, experts expressed support for them, provided they are technically and economically feasible.

4.3 Filter Media

Multiple jurisdictions are phasing out anthracite in favor of recyclable or regenerative alternatives.

Alternatives such as glass, biochar, and zeolite show strong embodied carbon benefits and lower end-of-life emissions.

Application at Metro Vancouver: Filter media replacement is relatively low-effort and can be scheduled into maintenance cycles.

Feasible action: Future design standards should evaluate media options for life-cycle carbon cost along with performance or ease of availability.

Information from SME (Seattle and Toronto):

No formal disposal protocol for anthracite exists, as loss is incremental. They periodically top up media, instead of replacement. This may be suggestive of opportunities to test alternatives during top-ups or study the reuse potential for anthracite fines.

4.4 UV Disinfection Equipment

While current UV systems are effective, emerging technologies may improve environmental performance.

UV-LED disinfection: Pilots in Norway (AquiSense) and EPA studies show scalability potential for large flow systems. Automated power regulation based on flow or turbidity helps reduce energy use.

Application at Metro Vancouver: Current processes at CWTP are very energy efficient, and the processes are not GHG intensive, leaving little room for improvement. Upgrades in the UV systems might be a major area to focus on.

Feasible action: Conducting cost-benefit analysis for LED retrofits and smart controls in future upgrades.

Information from SME (Seattle):

Current upgrades focus on higher efficiency medium-pressure mercury lamps, not LEDs (which are not yet suitable for their design). Nevertheless, they expect considerable energy savings and doubled lamp lifespan—key operational and GHG benefits.

Information from SME (Portland):

Currently, chloramination with soda ash and CO_2 is used instead of UV treatment. No flocculants are used currently, but this could change with the upcoming filtration facility.

As part of an exploratory analysis using literature-derived emission factors and simplified assumptions, the impact of substituting PAX-18 (an aluminum-based coagulant) with a ferric-based alternative, shifting 50% of landfilled residuals to lower-emission backfilling (for land reclamation), and replacing anthracite used in filtration with biochar was explored. While actual systems are more complex, this example, based on similar mass balances used at the SCFP and CWTP, demonstrates overall GHG emissions by approximately 20% annually, considering just these three key changes.

5. Conclusions and Recommendations

Based on the analysis of Metro Vancouver's drinking water supply system, coupled with learnings from other jurisdictions, there may be several opportunities for GHG emission reduction. The following are some actionable recommendations to reduce non-energy GHG emissions from Metro Vancouver's drinking water operations:

1. Prioritizing EPDs and LCA familiarity in chemical procurement

Opportunity: Promoting verified Environmental Product Declarations (EPDs) and Scope 3 carbon awareness to reduce chemical-related embodied emissions. City of Toronto's GHG inventory, especially considering indirect scopes, is a promising model.

Challenges: Cost, data availability (supplier-specific), and the complexity of retrofitting existing processes.

Recommendations: Incorporate EPDs for common chemicals and encourage LCA-based procurement on upcoming projects where redesign is feasible. Consider the development of an in-house Scope 2 and 3 inventory tool using Toronto's framework. External SMEs emphasized the importance of credible, independently (third-party) verified EPDs.

2. Diversifying residuals management options

Opportunity: Reuse of low-organic drinking water residuals in landscaping, soil blends, or construction aligns with circular economy goals.

Challenges: Finding viable end uses for low-organic content residuals and ensuring waste product acceptance.

Recommendations: Diversify residuals beneficial use options by identifying local non-food applications (e.g., mine reclamation) and assessing co-blending potential with biosolids for landscaping applications. Request and assess LCA data of chosen routes before scaling up to ensure net environmental benefit. Consider performing LCA at Metro Vancouver or collaboratively if information is not available.

3. Exploring filter media Replacements

Opportunity: Recycled glass and zeolite present lower embodied carbon alternatives to anthracite and offer operational benefits.

Challenges: Most options seem to be restricted to pilot scales, giving rise to issues with regulatory approval in large North American systems.

Recommendations: Evaluation of technical feasibility from pilot testing of zeolite or recycled glass in small-scale filters. Explore the reuse of anthracite fines in construction (or other beneficial uses) if the usage of anthracite filters is continued.

4. Refrigerants

Opportunity: Fugitive refrigerant emissions (from chillers, HVAC) can be significant due to their high global warming potential (GWP).

Challenges: These emissions are currently awaiting inclusion in Metro Vancouver inventories.

Recommendations: Conduct refrigerant inventory and emissions audit. Prioritize leak detection, repair programs, and phase-out of high-GWP refrigerants.

5. Assess UV disinfection upgrades

Opportunity: UV-C LEDs and smart UV systems (like Xylem's TAK Smart) reduce operational emissions and eliminate mercury use.

Challenges: LEDs may not be viable for high-flow systems due to limited output. SME inputs suggested limitations regarding the scalability of LED setups.

Recommendations: Conduct a feasibility study focused on smart control retrofits and high efficiency mercury lamp upgrades. Continuously reassess UV-C LED viability as the technology matures.

In conclusion, incorporating Environmental Product Declarations (EPDs) into the procurement process for improved understanding of carbon footprints could yield emission reduction from chemicals, particularly as chemicals represent a major source of embodied carbon with promising reduction potentials. Furthermore, beneficial use option diversification beyond the currently limited methods could help achieve further GHG reductions in downstream processes and advance Metro Vancouver towards a more sustainable and climate-resilient water system.

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Appendix

Table A1 Approximate annual CO_2 emissions (embodied) from indirect (non-energy) sources, focusing on process chemicals, considering embodied carbon emissions.

Treatment Chemical(s)	Environmental Implications (GHG)	Estimated CO_2e / kg (and sources)	Interesting finds/notes
Aluminium-based coagulant	No fugitive emissions; Scope 3 embodied energy only	0.537-0.773 1. Older, 2. Modified INCOPA LCA Reports)	Embodied GHG emissions vary by coagulant. Alternative Fe-based coagulants can go as low as ~ 0.03 CO_2e / kg
Coagulant Aid Polymer	High embodied GHG is expected	-	Literature lacks embodied CO_2 data
Sodium hypochlorite (NaOCl)	Fugitive emissions (GHG or otherwise) - Negligible from a bleach source[11]	~0.92 - City of Winnipeg, Euro Chlor EPD 2013 (2011)	-
$Ca(OH)_2$	No fugitive emissions; CO_2-intensive calcination	~0.8 (Cradle to gate) - 2022 research paper, US EPA SEFA 2016, Ecoinvent data V2.2, 2010 (2007)	Energy mixes in supplier's production pathway might be crucial for overall footprint.
Sludge Polymer	As above: high embodied GHG	~ 3.5 Research paper	-
Dewatering Polymer	Same as above	-	Literature lacks embodied CO_2 data
CO_2 (industrial)	Potential (but minor) fugitive emissions. No evidence (from SME interviews) of leaks/degassing, however.	Literature lacks embodied CO_2 data	By-product streams of production: low attributed emissions, the majority of embodied GHG is because of the compression being energy (electricity) intensive. Energy mixes in the supplier's production pathway might be crucial for the overall footprint.

Table A2 List of jurisdictions with justification for choice

Innovation / Jurisdiction	Reason for Inclusion	Justification Type*
Philadelphia Water Department	Demonstrates a shift from aluminum-based to iron-based coagulants with reduced sludge generation, directly relevant for carbon footprint reduction.	Technical relevance
Toronto (R.C. Harris Plant)	Canadian context (regulatory and operational similarities with Metro Vancouver). Demonstrated 40% sludge reduction after switching from Al-based to Fe- based coagulants.	Geographic/regulatory similarity + Technical relevance
Ethiopia	low-carbon, low-cost biodegradable alternatives in coagulation with easy-to-process waste	Innovation potential
Al Hoceima, Morocco	Innovative approach to reusing sludge in construction. Relevance to Metro Vancouver's existing cement production partnerships.	Technical relevance
Sydney, Melbourne (Australia)	Implementation ease as a novel 'landscaping soil alternative' (similar to Nutrifor™ landscaping soil, produced by Metro Vancouver)	Regulatory + technical relevance
Roslyn, WA (USA)	Pacific Northwest context: similar water treatment conditions and regulatory environment. Glass (material) is widely available locally.	Geographic, regulatory similarity + technical relevance
PacifiCorp, USA	Represents use of carbon-sequestering material (biochar) with potentially high adsorption capacity.	Technical relevance + Innovation potential
India, China	Demonstrates widespread adoption of low-embodied carbon materials (Zeolite)	Innovation potential
Glitrevannverket (Norway)	Transition to LED based setups for UV disinfection can lead to reduced energy and mercury use.	Innovation potential
Norway (xylem)	Intelligent controls: relevant to optimizing existing UV systems.	Technical relevance

*Legend for justification types:

- **Technical relevance** – Proven or applicable improvements to process performance and operations.
- **Geographic/regulatory similarity** – Similar climate, water quality water treatment context, or policies.
- **Innovation potential** – Emerging solutions with future application potential.
- **Regulatory relevance** – Aligns with or supports existing/emerging policies or compliance in the Canadian (BC) context. (https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/drinking-water-quality/drinking-water-officers-guide)

Table A3 Jurisdictional innovations in coagulant choices, usage, and associated GHG emissions information. The currently used option (at SCFP) is shown in orange and alternate options from jurisdictional scan is shown in green.

Choice of Coagulant	Main Driver / Description	Notes relevant for GHG Reduction Potential	Pros	Cons	Example Jurisdictions
Aluminum-based Coagulants (Current Practice) 'PAX-18'	Traditional Al based chemical coagulants used for NOM removal.	1.5-4.5 kg CO_2-eq/mole Al -	Conventional option, effective for NOM removal	High embodied carbon from production and transportation; potential human health concerns (neurotoxicity, Alzheimer's, cancer), generates a large volume of toxic residuals.(Liang et al.)	-
Iron-based Coagulants (e.g., Ferric Chloride, Ferric Sulfate, PFS)	Fe based chemical coagulants, often produced from Alternative Raw Materials (ARMs) / industrial by-products.	Generally lower carbon footprint per mole of active ingredient (0.7-1.3 kg CO_2-eq/mole Fe) compared to aluminum-based (1.5-4.5 kg CO_2-eq/mole Al). (~ 70% GHG reduction potential)	Lower embodied carbon. PFS variants shown improved sludge dewatering(Liang et al.; Mohamad et al.)	Can result in low pH water, high dissolved iron, and increased conductivity; may have lower Natural Organic Matter (NOM) removal and a narrower optimal pH window for some applications.(Koul et al.) PFS variants is a possible alternative for these issues.	Philadelphia Water Department (uses ferric chloride)(https://www.waterworld.com/home/article/16192085/streaming-current-monitor-used-to-optimize-coagulant-dosages) ; Toronto (R.C. Harris Plant) demonstrated reduction of sludge volume by 40% after replacing Al-based coagulants.(https://pmarket-research.com/chemi/ferric-chloride-liquid-market/) Bangladesh incorporated $FeCl_3$ to address arsenic contamination in 120 new

					plants(https://pmarket-research.com/chemi/ferric-chloride-liquid-market/)
Natural/Bio-Coagulants (e.g., *Moringa oleifera*, Chickpea, Peanut)	Plant-based materials used for coagulation.	Not explicitly quantified, but inherently lower values are expected due to natural origin and associated preparation methods.	Biodegradable, reduced sludge volume; cost-effective; safer for human health; comparable turbidity removal (e.g., 97% for *Moringa oleifera*); better heavy metal removal than chemical coagulants.	Feasibility in incorporation (e.g., for undesirable amine levels in treated water) requires further investigation for widespread adoption and commercialization.	Rural communities in Ethiopia (pilot studies using *Moringa stenopetala*, aloe vera, cactus leaves); various studies on plant-based coagulants for different wastewaters.(Maurya et al.; Koul et al.)

Table A4 Jurisdictional innovations in residuals management and associated GHG emissions information. The currently used option (at SCFP) is shown in orange and alternate options from jurisdictional scan is shown in green.

Innovation Type	Description of Innovation	Notes relevant for GHG Reduction Potential	Pros	Cons	Example Jurisdictions
Cement (local cement plant), landfilling, nutrient recovery (Current Practice)	A portion of the residuals (filter cake) is sent to a local cement kiln to replace virgin materials (e.g., red shale). When they are unable to accept it, the residuals are landfilled. Another part (unquantified fraction) is directed for agricultural reuse (e.g., phosphorus binding).	Avoids virgin extraction when used in cement; landfilling results in methane and lost resource opportunity.	Enables circular reuse in construction materials. Reduces extraction of raw shale. Potential for nutrient management in agriculture.	Inconsistent uptake by the cement plant can lead to landfill disposal, when agricultural sector is unavailable due to seasonal restrictions for use.	-
Treatment residuals Reuse	Reuse of treated Drinking water treated residuals	Displaces virgin materials with high embodied carbon; reduces landfill disposal.	Diverts and recycles sludge to inlet process stream.	Depending on concentration, recycling the sludge might not be feasible after a few cycles; Process redesign.	Al Hoceima, Morocco(Bensitel et al.)

Composting	Mixing filter cake with green waste or biosolids to produce compost for non-food land uses (e.g., landscaping).	Reduces landfill when other beneficial use options are not available	Does not require technological investments, encourages beneficial use	Aesthetic: Odour/pathogen control measures needed. Cannot be used for agricultural lands.	Australia: Sydney, Melbourne(https://www.sydneywater.com.au/education/wastewater-recycling/solids-recycling.html; https://wastemanagementreview.com.au/biosolids)

Table A5 Jurisdictional innovations in filter media options and associated GHG emissions information. The currently used option (at SCFP) is shown in orange and alternate options from jurisdictional scan is shown in green.

Innovation Type	Description of Innovation	Notes relevant for GHG Reduction Potential	Pros	Cons	Example Jurisdictions
Anthracite – Dual media filters (Current Practice)	Traditional coal-derived filter media used in dual media filter systems	High embodied carbon, and is subjected to direct incineration as a part of the process, thus evolving CO_2	High porosity of filter media, making it effective and resulting in less material usage	Low reusability, sourced through mining	-
Glass filter media	Use of crushed recycled glass as a replacement for sand or anthracite in water filtration systems	Recycled material, low embodied carbon expected because of sourcing from recycling products	Recycled, sustainable, inert to most systems	May be abrasive to certain systems	Roslyn, WA slow sand pilot (US EPA / Clean Washington Center); Nova Scotia town(https://www.osti.gov/etdeweb/biblio/20941459) incorporated in drinking water pilot (low flow rate); emerging drinking water options with compliance such as NatureWorks (certified to NSF/ANSI/CAN 61)

Biochar filter media	Carbonized organic material (e.g., wood) , often as a by-product	Sequesters carbon, incineration not required (Low disposal emissions).	Green, high adsorbing capabilities for inorganic/organic pollutants.(https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/hydro/klamath-river/khsa-implementation/technical-documents/2021-11-15_Biochar-filter-final-rpt.pdf)	Limited applications explored in the drinking water context, possibility of leaching.	PacifiCorp, USA(https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/hydro/klamath-river/khsa-implementation/technical-documents/2021-11-15_Biochar-filter-final-rpt.pdf)
Zeolite filter media	Naturally occurring mineral used as a filter medium to replace anthracite/sand	Low embodied carbon, incineration not required (Low disposal emissions).	Stable material, high reusability. Long lifespan and highly reusable. Certified to NSF/ANSI 61 for safe use in drinking water processes.	Needs greater depth because of smaller pore size (Than anthracite). Not very effective for organics removal.	India, China, less popular as of now in North America(admin)

Table A6 Jurisdictional innovations in UV lamp setups and associated GHG emissions information. The currently used option is shown in orange (at CWTP) and alternate options from jurisdictional scan is shown in green.

Innovation Type	Description of Innovation	GHG Reduction Potential/Other benefits	Pros	Cons	Example Jurisdictions
UV lamps (Custom made, mercury lamps, about 40 lamps are used in CWTP and replaced every 13 k hours) (Current Practice)	Conventional practice, effective and reliable for microbial disinfection	Standard practice, no clearly understood GHG implications	Proven disinfection performance; works across flow variability.	Contains mercury (a hazardous material); high energy consumption; warm-up time needed.	-
UV-LED technologies	Transition from mercury-vapor UV lamps to mercury-free UV-C LED technology.	Eliminates mercury-related environmental risks (embodied benefit); enhanced durability; instantaneous power cycling; reduced fouling/maintenance.	Mercury-free; scalable modules; long lifespan; lower warm-up/wait time.	Not extremely developed for high flow setups yet.	Glitrevannverket (Norway, piloting AquiSense PearlAqua Kilo UV-C LED units).(mitchelhansen) US EPA studies (Development)
Smart UV Control	Systems that dynamically adjust UV output based on real-time water conditions.	Prevents energy overuse, leading to significant energy savings.			Xylem (Wedeco TAK Smart UV systems(https://www.xylem.com/en-us/products--services/treatment-products-systems/disinfection-and-oxidation/uv-disinfection-systems/tak-smart-uv-disinfection-system/); Glitrevannverket