Assessment of Nitrogen Dioxide Emissions from Boilers and Generators on Neighboring High-Density Residential Buildings

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Executive Summary

Metro Vancouver (MV) regulates the discharge of air contaminants, such as nitrogen oxides (NOx), which have been shown to have adverse health and environmental impacts. One source of NOx in the MV region is from buildings. Most buildings are heated by natural gas-fired boilers and heaters, which emit NOx when operating. Given MV's population densification, the NOx from buildings is of special concern when emission stacks from one building may be located near windows or intake vents of a nearby building. Currently, this problem of stack placement is not addressed by local policy. Thus, MV is interested in investigating how other jurisdictions manage NOx emissions from boilers and heaters and also how they manage stack placement and ensure adequate dispersion of NOx emissions.

The following report examines other jurisdictions across the US, Canada, and Europe that are comparably or more dense than MV- called "peer jurisdictions"- by reviewing policies, programs, and codes from these jurisdictions that pertain to NOx emissions from buildings and stack placement. Interviews were conducted with employees of peer jurisdictions to gain more information about policies and employees' experience creating and implementing them. 12 peer jurisdictions were identified as having relevant policies and programs, and summaries of each are provided. Key themes across peer jurisdictions are discussed, ranging from policy similarities to processes for creation and implementation.

Finally, recommendations are offered, given the themes and lessons provided by peer jurisdictions. Strategies outlined in MV's Clean Air Plan 2021 and Climate 2050 Buildings Roadmap are compared to similar initiatives in peer jurisdictions, such that MV might look to the peer jurisdictions for extant models of the proposed strategies. Models for addressing some of the barriers to MV's proposed goals for buildings are also offered. Four recommendations are provided, which range in scope from being short-term to long-term term strategies. These include working with regional government partners to:

1. Reduce NOx limits for boilers, heaters and generators
2. Revise building codes and bylaws to consider stack placement
3. Increase data collection and emissions modeling, towards planning-based approaches
4. Electrify heating systems

These options offer opportunities to improve NOx emissions and dispersion outcomes, alongside potential environmental and health benefits. Electrification offers the highest return on investment in terms of co-benefits with these goals plus climate mitigation and adaptation. MV can consider the exemplars set by peer jurisdictions and work with regional partners to implement these recommendations in the MV area.

Introduction

Problem Overview

Within Metro Vancouver (MV), there is a growing, intersecting problem of building densification and nitrogen dioxide (NO_2) emissions. Many buildings in the area, especially mid- and high-rise buildings, have boilers, heaters and generators to provide heat, hot water, and emergency power that emit nitrogen oxides (NOx) while operating. In MV, 9% of NOx emissions come from buildings' heating and hot water systems (Metro Vancouver 2021b). These nitrogen oxides may present health and environmental concerns (Marks et al. 2010; Mullen et al. 2016). In such dense urban environments, the issue of NOx emissions from buildings intersects with where those emissions are being vented, in proximity to neighboring buildings. Without proper controls, one building's emissions can drift into the intake vents or open windows of an adjacent building – creating possible health risks for the occupants of that building. While MV considers NOx emissions from boilers and heaters in its bylaws, it does not specifically address the effects of emissions on neighboring structures. This project examines how other jurisdictions have endeavored to tackle either or both dimensions of the problem: NOx emissions from gas heating equipment and their relationship to nearby buildings.

Metro Vancouver's Role

Metro Vancouver regulates the discharge of air contaminants to preserve environmental and human health and plays a unique regional role in this endeavor. In Section 31 of British Columbia's Environmental Management Act, Metro Vancouver is delegated the authority to provide the service of air pollution control and air quality management. Under the umbrella of Metro Vancouver Air Quality Management Bylaw 1082, MV regulates several Criteria Air Contaminants (CACs) that affect air quality, but this project focuses on nitrogen oxides, specifically nitrogen dioxide. NO_2 is known to cause adverse respiratory and cardiovascular effects, with emerging science of impacts on other bodily systems (Boyd 2015; Curtis et al. 2006; Trasande and Thurston 2005). It also contributes to ground-level ozone and haze, which pose additional risks. Because of these risks, MV manages NO_2 through its own Ambient Air Quality Objectives (2020) which are equivalent to the Canadian Ambient Air Quality Standards (CAAQS) (Metro Vancouver 2020). Both MV's Objectives and the CAAQS set limits for ambient NO_2 on a 1-hour and an annual averaging time basis. Additionally, MV may consider and implement various rules and programs to manage NOx emissions to meet these standards.

Given its unique and substantial task of managing regional air quality, MV has a significant role in the regulation of boilers and their NOx emissions. However, it is important to note the authority

retained by the province of British Columbia and that of municipalities within Metro Vancouver. Most applicably for this project, the province governs building codes, while municipalities create zoning and building bylaws. These powers have important implications, especially as this research considers overall building and city design (see Discussion and Recommendations).

Current Landscape of Compliance and Policies in Metro Vancouver

Currently, Metro Vancouver does not meet the 2020 CAAQS for NO2 at all of its monitoring stations. Further reductions to emissions to meet the 2025 CAAQS will be necessary, as these are more stringent than current 2020 guidelines. While there are several sources of NOx in MV, and therefore several opportunities for reduction, modifying policies for boilers and heaters can offer substantial reductions, as heating contributes 8.7% of MV's total NOx emissions (Metro Vancouver 2018). There are two main bylaws related to boilers in MV: the Agricultural Boilers Emission Regulation (Bylaw No. 1098, 2008, Amendment No. 1109, 2009) and the Boilers and Process Heaters Emission Regulation (Bylaw No. 1087, 2008, Amendment No. 1190, 2013). The latter is most relevant for this study, as it regulates new or modified boilers and heaters in non-agricultural areas, requiring them to adhere to "low-NOx" emission limits (meaning they do not exceed 60 mg/m³ NOx of flue gases) (Metro Vancouver 2013).

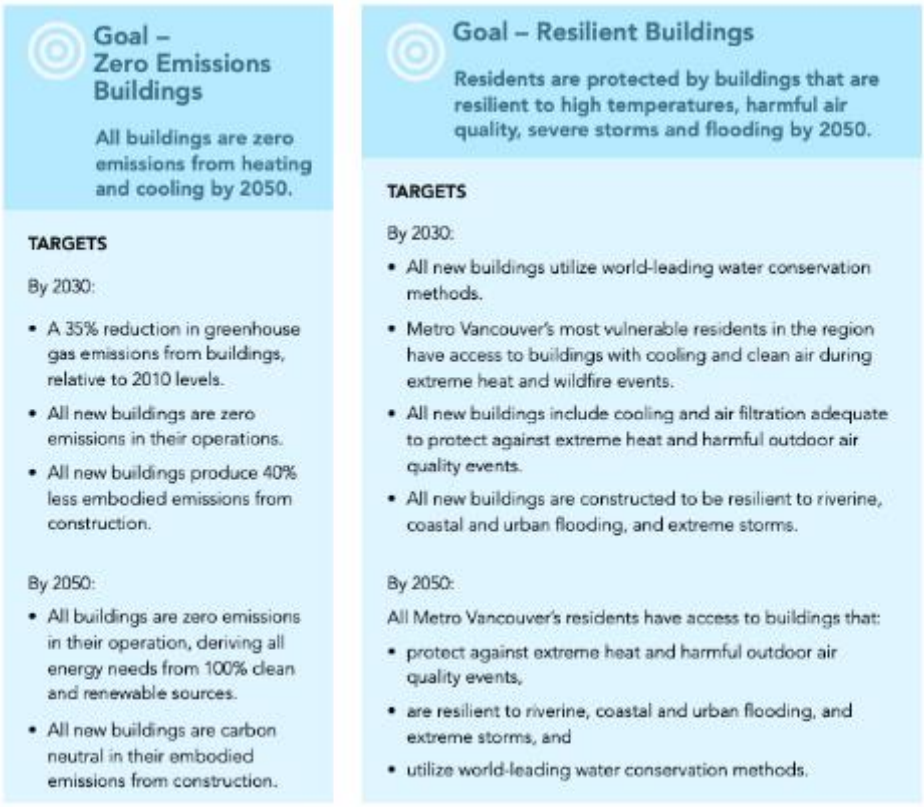
In terms of stack design and buildings, ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) guidelines are widely adopted across jurisdictions in the US and Canada, including BC's building codes (BC Publications 2018). The guidelines are comprehensive in most respects but do not consider the proximity of nearby buildings when recommending building intake placement and exhaust designs (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 2019). Accordingly, the BC Building Codes do not consider stack placement with regards to neighboring buildings, and thus it is not yet accounted for in Metro Vancouver.

Proposed Plans in Metro Vancouver

Climate 2050 Buildings Roadmap and Clean Air Plan 2021

The Climate 2050 Buildings Roadmap ("Buildings Roadmap") is a buildings-oriented subsection of Metro Vancouver's overall Climate 2050 plan, aiming to reduce emissions by 45% from 2010 levels by 2030 and achieve carbon neutrality by 2050. The Clean Air Plan 2021 similarly supports the overall Climate 2050 plan, with an additional focus on air contaminants, supporting a 15% reduction in NOx from 2020 levels. The Buildings Roadmap focuses on seven strategies to help achieve the Climate 2050 goals by reducing emissions from buildings, which currently account for 25% of GHG emissions in the region (Metro Vancouver 2021b). The Clean Air Plan 2021 identifies

six strategies that share overlapping items with those in the Buildings Roadmap to reach climate goals and improve air quality (Metro Vancouver 2021a). These strategies will be analyzed in the context of this research (see Table 3: MV Plan Strategies and Recommendations).



Goal – Zero Emissions Buildings

All buildings are zero emissions from heating and cooling by 2050.

TARGETS

By 2030:

- A 35% reduction in greenhouse gas emissions from buildings, relative to 2010 levels.
- All new buildings are zero emissions in their operations.
- All new buildings produce 40% less embodied emissions from construction.

By 2050:

- All buildings are zero emissions in their operation, deriving all energy needs from 100% clean and renewable sources.
- All new buildings are carbon neutral in their embodied emissions from construction.

Goal – Resilient Buildings

Residents are protected by buildings that are resilient to high temperatures, harmful air quality, severe storms and flooding by 2050.

TARGETS

By 2030:

- All new buildings utilize world-leading water conservation methods.
- Metro Vancouver's most vulnerable residents in the region have access to buildings with cooling and clean air during extreme heat and wildfire events.
- All new buildings include cooling and air filtration adequate to protect against extreme heat and harmful outdoor air quality events.
- All new buildings are constructed to be resilient to riverine, coastal and urban flooding, and extreme storms.

By 2050:

All Metro Vancouver's residents have access to buildings that:

- protect against extreme heat and harmful outdoor air quality events,
- are resilient to riverine, coastal and urban flooding, and extreme storms, and
- utilize world-leading water conservation methods.

Figure 1: Central goals (Climate 2050 Buildings Roadmap, page 13)

Research Objectives

To improve local air quality, Metro Vancouver seeks to examine the multi-faceted problem of NOx emissions from boilers and buildings and learn how peer jurisdictions have addressed it. Accordingly, the following research question was studied:

> *How do different jurisdictions use policy (or other) tools to address (NOx) emissions from high-density buildings?*

To investigate the research question and provide insights, the following objectives were specified:

1. Identify successful building codes, bylaws, programs, etc. in other jurisdictions, including their characteristics, pathways to implementation, and creation.
2. Identify key opportunities where other jurisdictions' best practices can be translated into the MV context. Similarly, identify potential barriers.

3. Provide recommendations based on research findings.

Methodology

Reviewing peer jurisdictions was approached via two primary strategies: interviews with staff and literature reviews of jurisdictions' documents, policies, and programs.

Identifying Peer Jurisdictions

First, "peer" jurisdictions were identified. "Peer" was defined as jurisdictions with similar or higher population densities than Metro Vancouver. According to the Canadian Census, there are approximately 900 people per square kilometer in MV (Government of Canada 2017). However, this is unevenly distributed – with the City of Vancouver having ~5500 people/sq km and many rural areas having ~100 people/sq km or fewer. Because this project is concerned with high-density zones, a range between the average of the five and seven densest municipalities in MV was calculated. The five densest are Vancouver, Burnaby, Surrey, Richmond, and Coquitlam, which average ~2500 people/sq km; the seven densest are these plus Delta and Langley, which altogether average ~1900 people/sq km. Thus, the resulting range of population densities was ~1900-2500 people/sq km. With this range, a search for similarly dense jurisdictions (jurisdictions with population densities between 1900 and 2500 people/sq km) began, spanning the US, Canada, and Europe (see Appendix 1: Detail methods for finding peer jurisdictions). For considering jurisdictions with higher population densities, jurisdictions with reputations for action on air pollution or general sustainability initiatives were prioritized for review. All jurisdictions identified as "peers" were added to a list of candidates to be examined through literature review and interview where available.

The subsequent list of peer jurisdictions was composed of nearly 150 cities. From this list, jurisdictions in Canada were first prioritized for review, then jurisdictions with similar densities and positive sustainability reputations, then others. As a result, 21 jurisdictions were reviewed.

Literature Review

For each of the 21 jurisdictions, the codes, rules, regulations, policies, and otherwise programs were reviewed, particularly those related to boilers, heaters, generators, and buildings. These documents were mainly found on the jurisdictions' websites.

Interviews

All 21 jurisdictions were contacted for more information and/or an interview with staff members. For jurisdictions where the types of literature sought for review, as described above, did not appear to be available on their website, jurisdiction staff members were contacted seeking additional information and resources. For jurisdictions with relevant information, staff members were contacted and asked if they would be willing to meet remotely and share more about the relevant policy or program and their experience implementing it. Staff who responded and were willing to be interviewed resulted in the final sample of 10 interviews, with staff members from eight jurisdictions (see Table 1). Within the remaining 13 jurisdictions reviewed, four had sufficient relevant information on their website and are discussed, while nine did not (and are therefore not discussed at length).

Following the interview methodology literature of Schensul et al. (1999) and Kvale and Brinkmann (2009), it was determined that a semi-structured interview method would be most appropriate for interviewing staff members from peer jurisdictions. Correspondingly, an interview instrument was developed and used as a guide when conducting interviews, but conversations were also allowed to flow organically and as the staff member's experience dictated. Interviews were conducted via Zoom and recorded with interviewees' permission. Recordings and interviewees' identities are protected under BC's Freedom of Information and Protection of Privacy Act (British Columbia 1996). Some interviewees allowed their identities to be shared and others preferred to remain confidential. Recordings were referenced to extract quotes, but interviews were not additionally processed, as they were primarily used for information gathering or clarification.

Results

Through the literature reviews and interviews, jurisdictions were considered a member of one of three categories, as it relates to this project:

1. "Jurisdictions with Boiler Programs": jurisdictions that have codes, policies, programs, etc. targeting boilers, heaters, and/or NOx from buildings. Because boilers and similar technologies are the primary focus of this research, these jurisdictions are examined and described in the greatest depth.
2. "Jurisdictions with Building-Only Programs": jurisdictions that do not explicitly address boilers, but they employ codes, policies, programs, etc. that target building emissions generally, from which MV can extract lessons that may apply to reducing NOx.

3. "Jurisdictions with Neither Type of Program": jurisdictions that do not have any apparent boiler- or building-relevant policies, and their staff members did not respond to emails seeking clarification. As a result, they are not discussed further.

Table 1: Categories of Jurisdictions

JURISDICTIONS WITH BOILER PROGRAMS	JURISDICTIONS WITH BUILDING-ONLY PROGRAMS	JURISDICTIONS WITH NEITHER TYPE OF PROGRAM[1]
London, UK	Boston, MA (US)*	Calgary, AB
California, US	Cambridge, MA (US)*	Düsseldorf, DE[2]
Bay Area Air Quality Management District (BAAQMD), CA (US)*	Winnipeg, MB[3]	Münster, DE
San Francisco, CA (US)*	Montreal, QC[4]	Québec City, QC
South Coast Air Quality Management District (SCAQMD), CA (US)*		Valenciennes, FR
Seattle, WA (US)*		Vicenza, IT
City of Vancouver, BC*		Verona, IT
New York City (NYC), NY (US)*		
Toronto, ON		
Paris, FR		

*Interviewed staff member(s)

Results are organized according to these three categories and are loosely sorted by the programs considered most comprehensive or stringent discussed first in each class, ending with the least extensive.

[1] Some of these, most notably Calgary, Münster, and particularly Düsseldorf, did have detailed climate or sustainability plans available online. However, they did not appear to consider buildings as part of those plans. For all but Calgary, there were various barriers to translating jurisdictions' websites and policies to English, and it is possible that relevant policies or programs were missed on account of these issues.

[2] The state of North-Rhine Westphalia, where Düsseldorf is located within Germany, has a Sustainability Strategy that proposes an energy-efficient building standard, focused on decarbonizing technologies, but it is unclear (perhaps because of translation) whether this is binding yet.

[3] Winnipeg has a Green Building Policy for new and existing City-owned buildings (requiring benchmarking and the equivalent of LEED certifications and the like), and Manitoba has similar but less stringent guidelines for government property, published in the Green Building Program Guidelines (Winnipeg 2018; Province of Manitoba Department of Finance n.d.). Because of these policies' limited scope (only pertaining to government-owned property), they are not discussed.

[4] Personal correspondence with a City of Montreal employee indicated that a building policy may exist, but was not within the purview of their department, and relevant employees were unavailable to provide further information.

Jurisdictions with Boiler Programs

London, UK

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The City of London has one of the most comprehensive and stringent sets of air quality policies and programs reviewed. The City wants "the best air quality of any major world city by 2050" (City of London 2018) and works towards this goal through various approaches. Unlike most other cities reviewed, rather than focusing on individual technologies or even independent buildings, the landscape of NOx emissions across the City is considered as a whole. To address this landscape, emissions are modeled on a granular, yet city-wide scale, and areas where concentrations of contaminants – namely NOx and particulate matter – are exceptionally high are identified (City of London 2020). In those areas of higher concentrations, "Low- [and] Ultra-Low Emission Zones" (LEZ and ULEZ, respectively) can be established, which sets additional restrictions on emission sources. Restrictions mainly apply to transit, but some apply to buildings as well (City of London 2018).

Further, for large developments (150+ residential units), developers must prove that the construction is "air quality neutral" – that is, that it "will not lead to further deterioration of existing poor air quality" as measured against building and transportation benchmarks (City of London 2015). In March 2021, the Mayor of London and Greater London Authority published a draft plan to push this idea further and revise the requirement to be "air quality positive," meaning a development is "making an active contribution to improving air quality in and around a site or masterplan area and minimizing exposure to existing sources of poor air quality" (City of London 2021). If finalized, developments will be required to compile and submit an Air Quality Positive Statement (somewhat similar to an Environmental Impact Statement) at the planning application stage detailing the measures that will be taken to contribute to better air quality. Not only does The London Plan consider developments' effect on air quality overall, but also the vulnerabilities of people who may use the development. Especially in poorer air quality zones, developers are encouraged to implement design solutions, buffer zones, and transportation

solutions to minimize increased exposure to contaminant hazards, particularly where building occupants are members of vulnerable populations (City of London 2016).

For all developments (not only large ones), additional policies require all boilers installed in commercial and residential buildings alike to be rated for low-NOx emissions (47 mg/m^3). In the part of the City with the highest ambient NOx concentrations, the City Corporation of London, ultra-low NOx boilers are encouraged, but not required (18 mg/m^3) (City Corporation of London 2020). While the low-NOx boiler requirement is the most applicable targeted policy for this research, London implements numerous others related to particulates, volatile organic compounds, and further indoor and outdoor air quality considerations. Each borough of London that is non-attained for air quality standards must create its own Air Quality Strategy in addition to London's overall measures, which can include more building and/or NOx policies (City of London 2014).

Finally, the UK Clean Air Act of 1993 sets chimney height requirements, specifying a number of criteria, including "the position and descriptions of buildings near [a chimney]" as a required consideration for stack height and placement (United Kingdom 1993). There is not a quantitatively defined standard for stacks' relationship to other buildings in the Act. Rather, it is required for agencies approving building plans to consider "the position and descriptions of buildings near [stacks]" before approval, alongside compliance with the UK Building Codes, which have more specific guidance on stack placement (HM Government, UK 2010). The UK policies are the only country-wide policies for stack design and placement found during the literature review.

California, US

To understand the actions on NOx taken by jurisdictions in California, it is essential to contextualize their backdrop: the state itself. California is internationally recognized as a leader in sustainability and climate action, and this reputation is realized in its policies and buildings-oriented programs. Most notably, the California Green Building Standards

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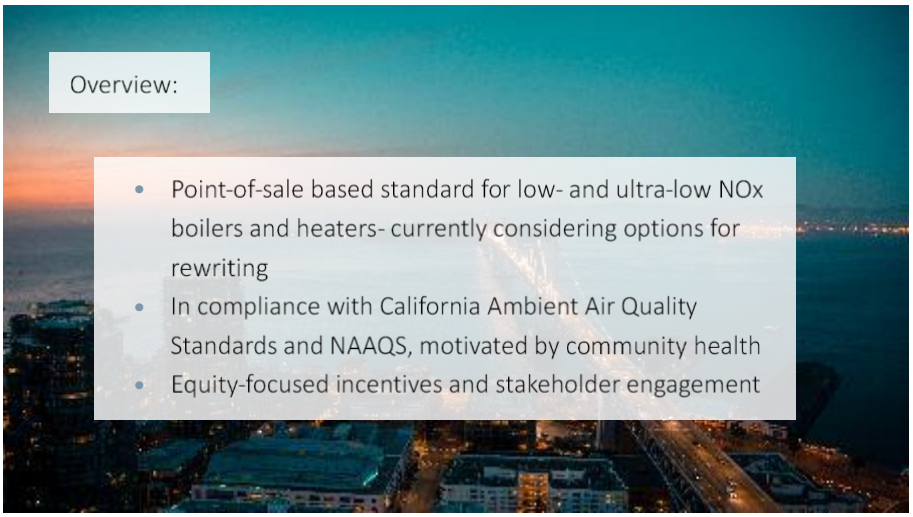
(CALGreen) Code was the first mandatory green buildings state code in the US. It mainly supports the state's greenhouse gas (GHG) reduction programs, but it also includes measures for indoor and outdoor air quality (State of California 2019). Although not yet in place, it has been proposed to update the CALGreen Code to include a preference for electric (rather than fossil fuel) infrastructure (BAAQMD employee 2021). In tandem, the California Environmental Quality Act (CEQA) regulates a host of environmental issues, including processes that emulate the US federal government's Environmental Impact Statements (under the National Environmental Policy Act), but with those under CEQA usually being more stringent than national counterparts (State of California 2018). For certain developments across California, Environmental Impact Reports must be prepared under CEQA, and in some cases, these can reflect air contaminants as part of the environmental impact. Finally, underpinning innumerable policies and programs across the state is the California Ambient Air Quality Standards. These function much like the Canadian Ambient Air Quality Standards, except that they are legally binding and even more stringent than the National Ambient Air Quality Standards (NAAQS) in the US, which are also binding (California Air Resources Board 1995). As a result, municipalities may be motivated to implement programs in the interest of public health, but there is also a legal obligation to deliver on air quality outcomes.

While California's state-wide measures on air pollution are already some of the most progressive in the world, the state additionally encourages its municipalities to create policies beyond the base state codes. This program, called "Reach Codes," connects municipalities to each other and technical expertise to develop policies of various types more ambitious than that of the state (California Codes and Standards Program, Reach Codes Subprogram n.d.; California Air Resources Board n.d.). As they pertain to buildings and NOx, 46 municipalities across California have implemented at least one policy to reduce natural gas infrastructure within their jurisdiction – in many cases, phasing out new gas infrastructure entirely - and the number is growing (Gough 2021). Of the jurisdictions and states reviewed, California's approach is the most wide-reaching and formalized in its support of ambitious codes from its member jurisdictions.

Bay Area Air Quality Management District (BAAQMD), CA, US

The (San Francisco) Bay Area comprises several municipalities, including San Francisco, San Jose, Oakland, and many smaller jurisdictions. The BAAQMD operates as a partner to jurisdictions and a regional backstop for air quality within this densely populated area, managing many projects and policies. Despite its dense population, the region consistently complies with the NAAQS and California Ambient Air Quality Standards. This is partly due to the BAAQMD and member jurisdictions generally adopting a proactive posture; revising and implementing rules to improve air quality in the interest of community health - before bordering on the thresholds on noncompliance (BAAQMD employee 2021).



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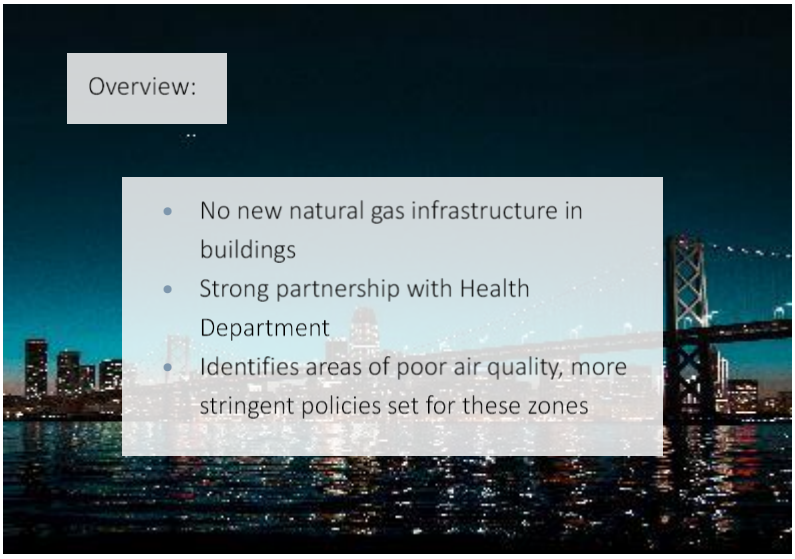
As such, the rules for boilers and heaters are currently being updated, and one interviewee shared their experience with the process. Already, the standards for boilers and heaters range from ultra-low NOx (9 mg/m³) to low-NOx (56 mg/m³), based on the type of appliance, with some standards allowed to reach 104 mg/m³ (Bay Area Air Quality Management District 2007, 6; 2011, 7). Now, the BAAQMD is considering, alongside stakeholders, how these rules might be revised (Bay Area Air Quality Management District 2021). Namely, the conversation focuses on how to decarbonize technologies (and, in tandem, reduce NOx) on a time scale that is equitably affordable for everyone, but is also soon enough that undue pollution and negative health effects therefrom are avoided. As part of this conversation, there is some debate about whether the rules should transition to ultra-low NOx more broadly first and then move to electric technologies (like electric heat pumps), or if moving straight to electric is the better mode. The BAAQMD is engaging a variety of stakeholders in an effort to elicit equitable outcomes, ranging from affordable housing groups and environmental activists to regional organizations and developers (BAAQMD employee 2021).

Given their focus on equity and health, the BAAQMD employee describes the District's desire to consider the bidirectional interaction between buildings and their environment. That is, not only thinking about how buildings impact the environment (as CEQA and other types of

environmental impact assessments typically conceptualize the interaction) but also how the environment impacts building occupants, like accounting for vulnerable populations in more polluted areas with improved building design (such as in London's Air Quality Positive Statement). However, they found considering the latter to be illegal under CEQA - CEQA only operates in the direction of building's impacting the environment. Thus, although California's rules often set an ambitious floor for jurisdictions, they can also present a perhaps unintended ceiling, limiting jurisdictions' scope.

San Francisco, CA, US

San Francisco, CA, is part of the BAAQMD and is therefore subject to the rules put forth by the BAAQMD. However, the City has created several policies and programs which go further than that of the BAAQMD, including a recently passed rule prohibiting any new natural gas infrastructure from being included in buildings and a long-standing rule requiring enhanced ventilation in areas of poorer air quality. The effectiveness of these policies is amplified by a long-standing relationship between the City's Health and Environment Departments, which collaborate on air contaminant rules.



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One of California's Reach Code initiatives, the All-Electric New Construction Ordinance, was ratified in November 2020 and came into effect June 1, 2021. It affects all new buildings, both residential and non-residential (San Francisco 2021). Arising from consultations with their stakeholders in the New Construction Workgroup, the measure ultimately received unanimous support when voted on by the Board of Supervisors (California Codes and Standards Program, Reach Codes Subprogram 2021). Because boilers and heaters are powered by gas, this effectively proscribes natural gas boilers and heaters (and the NOx therefrom) from new construction in San Francisco.

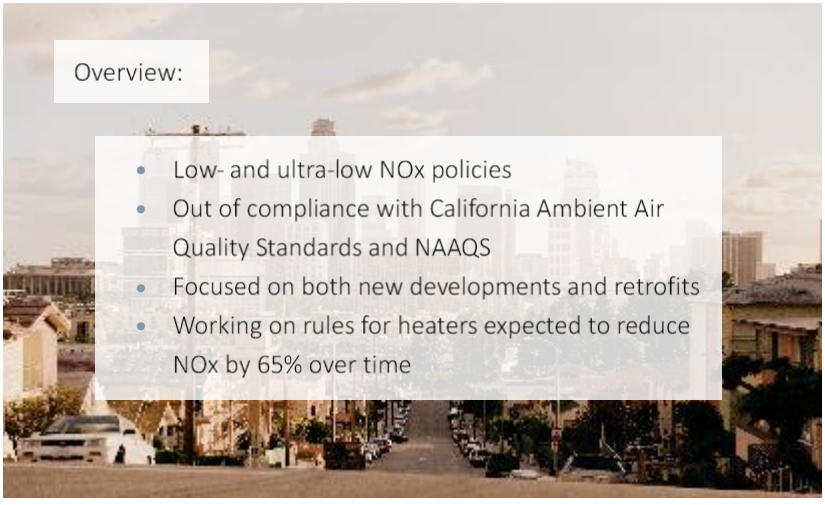
Although the All-Electric New Construction Ordinance holds promise to reduce NOx over time, there are still areas within the City that have higher ambient concentrations currently. Like London, the City undertakes an extensive contaminant modeling process, identifying where the

highest risk areas in the City are on a granular scale. This modeling results in the Air Pollutant Exposure Zone (APEZ) map, identifying zones where concentrations are high, particularly on the east side and main driving corridors of Downtown. Within the APEZ, several more stringent policies become active, such as Article 38 of the San Francisco Health Code (administered by the Department of Health). The Article requires new construction within the APEZ to install enhanced ventilation systems (design features, MERV 13 filters, etc.) to protect occupants from the health effects of pollution (San Francisco 2008; Callewaert 2021).

Interviewee Jennifer Callewaert, the Principal Environmental Health Inspector in San Francisco, spoke of her experience administering Article 38, focusing on the health-focused outlook, interdepartmental partnerships, extensive stakeholder engagement, and strength of the policy language that propels the Article to success. She noted that the APEZ modeling is conducted in collaboration with the Planning and Building Departments in San Francisco, alongside funding for modeling from the state and BAAQMD, so despite its exhaustive nature, there are many supporting departments to help bring it to fruition. In tandem, it was critical to engage stakeholders from affected communities living in the APEZ, who wanted to see these types of measures implemented, as well as builders, who were concerned about costs – both from an early point in the process of developing the Article. Because of the early engagement with builders, for example, the Department was able to minimize costs as much as possible and streamline the application process. Finally, because of the policy language and its functions, the Department of Health effectively acts as a backstop on developments in the APEZ: developments cannot go forward unless they have approval from the Department under Article 38.

South Coast Air Quality Management District (SCAQMD), CA, US

The South Coast Air Quality Management District (SCAQMD) includes major population centers such as Los Angeles, San Bernardino, and Santa Ana, California, and extends East to encompass the Coachella Valley and several miles beyond. Numerous areas of the District are consistently out of compliance with California's Ambient Air Quality Standards and the NAAQS, with designated "extreme ozone" areas in two zones. This is partly due to the



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geography of areas within the District (valleys), but also because of population centers and legacies of high pollution, particularly of NOx (South Coast Air Quality Management District 2012). Accordingly, SCAQMD implements a wide swath of rules, policies, and programs in an attempt to come into compliance and improve public health outcomes.

Only London rivals SCAQMD's broad swath of rules, policies, and programs in terms of sheer number. Many of them were the first of their kind, originating earlier in the 1980s and 90s, compared to several other jurisdictions' more recent interest in controls on air contaminants. Only a few programs will be discussed here, but future research may consider the SCAQMD's host of Clean Air Plans, for example, for questions about other types of contaminants or mitigation efforts (South Coast Air Quality Management District n.d.; n.d.).

Rule 1146 and its subsections are the central policies for boilers, setting limits on NOx ranging from ultra-low NOx (9 mg/m³) to low-NOx (56 mg/m³). Limits are set based on unit type, with most units falling into categories for which ultra-low limits apply (South Coast Air Quality Management District 2018). Rule 1121 targets water heaters, and sets a low-NOx limit (28 mg/m³) for most water heater types (South Coast Air Quality Management District 2020a). Rule 1111 concerns furnaces and has a somewhat less stringent NOx limit for units concerned at 38 mg/m³, although this is a recent and substantial reduction from the previous (pre-2019) limit of 104 mg/m³ (South Coast Air Quality Management District 2020b).

Because of the substantial reduction from previous levels, the update to Rule 1111 and its corresponding measures stand to reduce NOx by 65% over 25 years from the 2018 inventory (SCAQMD 2022 AQMP Residential and Commercial Buildings Working Group 2021). The update to Rule 1111 and others are being discussed by the SCAQMD Residential and Commercial Buildings Working Group, a public group contributing to the 2022 South Coast Air Quality Management Plan. The 2022 South Coast Air Quality Management Plan is "a regional blueprint for achieving air quality standards and healthful air. The 2022 AQMP will represent a comprehensive analysis of emissions, meteorology, regional air quality modeling, regional growth projections, and the impact of existing and proposed control measures." (SCAQMD 2022 AQMP Residential and Commercial Buildings Working Group 2021). The 2022 plan targets the issues of non-attainment for standards and extreme ozone in particular.

At a June 17, 2021 meeting of the Residential and Commercial Buildings Working Group, some debate emerged about whether it was sensible to maintain low- and ultra-low NOx standards for boilers, heaters, and furnaces, given the region's extreme noncompliance, especially when peers such as San Francisco are "leapfrogging" to zero-NOx/electric standards. Notably, these comments came from attendees representing developers and related technology companies.

SCAQMD staff responded that zero-NOx technologies manufacturers might not be able to meet the demand that would arise from a mandatory standard; bolstering their incentive programs for purchasing zero-NOx appliances (as they plan to do) will better manage the demand over time.

According to interviewees Gary Quinn, Program Supervisor, and Yanrong Zhu, Air Quality Specialist, SCAQMD Planning and Rules Division employees and members of the Residential and Commercial Buildings Working Group, there are perhaps two primary factors that make SCAQMD a leader in air pollution control. First, it is their unique focus on existing sources as much as on new sources (where many jurisdictions concentrate more on new sources). For new emissions sources, they implement Best Available Control Technology (BACT) rules. For existing sources, they have a different, but sometimes similarly stringent set of rules called Best Available Retrofit Control Technology (BARCT). In many respects, SCAQMD can often implement rules applying to BARCT on a more streamlined basis than for BACT. By focusing on retrofits rather than merely new sources, there are fewer opportunities for highly polluting appliances to remain in operation. Second, the interviewees emphasized the Division's dedication to constantly reviewing and learning from policies in other jurisdictions. This practice is one of Yanrong's job functions, alongside examining the technological and economic feasibility of proposed rules and plans. On a few occasions - including for the boiler rule (Rule 1146) - peer jurisdictions in California have had more stringent regulations than SCAQMD, and because of the occupational capacity of positions like Yanrong's (and Gary's in a supervisory role), they were able to consider whether those rules may be feasible in SCAQMD and work to apply them if so. Similarly, they can share their best practices with peer jurisdictions that often follow SCAQMD's lead, such as BAAQMD.

One potential obstacle to further progress towards an all zero-emission regulation is that SCAQMD has a "fuel-neutral" policy, meaning that they support all forms of technology regardless of fuel type if it reduces air pollution emission. The use of (renewable) electricity could be one type of technology. However, like with any regulated new technology, any future mandates for electrical appliances will be evaluated for technologically feasible, cost effectiveness, and any other factors such as legal authority (Quinn and Zhu 2021).

Seattle, WA (US)

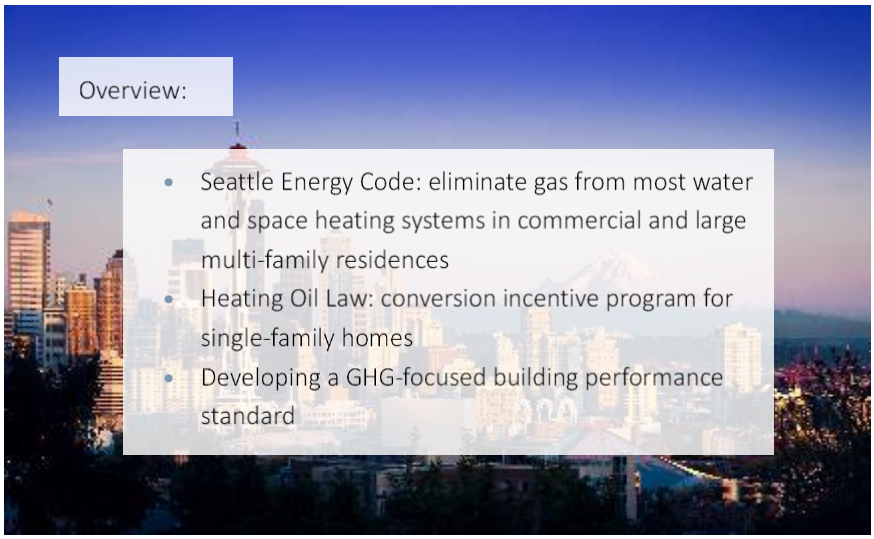

Photo by Thom Milkovic on Unsplash

Seattle is similar to Metro Vancouver in many ways relevant to this research; primarily its focus on climate in its policies and its ability to (relatively) cleanly electrify due to its electrical grid being predominantly powered by hydropower. Seattle has recently (effective March 2021) updated its Energy Code to eliminate gas from water and space heating in larger buildings (commercial and large multi-family). The revised Energy Code applies to new construction and also "when buildings are undergoing major renovations, or when space and water heating systems are being replaced" (City of Seattle 2021). Seattle's primary goal with this update was towards climate change mitigation, but it does help address the ground-level pollutants from fossil fuels and the inequitable impacts of those pollutants on vulnerable communities.

For smaller residences, particularly single-family homes, the Seattle Heating Oil Law exists to implement a tax on heating oil and offer incentives to switch to electric heat pumps. Residents can apply for rebates on heat pumps or free heat pumps in low-income cases. Through these programs, the City's goal is to phase out heating oil entirely by 2028 (City of Seattle n.d.; Seattle employee 2021).

Finally, the City is developing Building Performance Standards for large buildings (over 50,000 square feet), where energy use intensity is measured against benchmarks and must meet certain targets by 2026 and 2028. Incentives are available for early adopters starting in 2021, but it is acknowledged that these standards will not be sufficient to decarbonize buildings and must be used in conjunction with other policies, such as the Energy Code (City of Seattle n.d.).

City of Vancouver, BC

Photo by Mike Benna on Unsplash

As part of Metro Vancouver's jurisdiction, the City of Vancouver is subject to MV's rules and policies. However, the City implements various programs of its own, which will be briefly described. Overall, the City's plans are mostly targeted at buildings and the GHG emissions therefrom, stemming from the City's overarching Climate Emergency Action Plan. While targeting GHGs, particularly while promoting and requiring electric alternatives to gas boilers and heaters, NOx reductions are also achieved.

Most notably, the Vancouver Buildings Bylaw was recently amended to require zero-emissions equipment for space and water heating in low-rise (1-3 stories) residential buildings, while still allowing gas appliances such as stoves (Vancouver 2019). This rule is expected to significantly impact GHG and air contaminant emissions in Vancouver; however, it does not (yet) address larger boilers in mid- and high-rise residential buildings, as concerns this research. The Zero Emissions Building Plan promotes the use of electric heat pumps and has broad support from stakeholders, including developers. Finally, within the Green Buildings Policy, there is a requirement for indoor air quality testing, but NOx is not one of the contaminants tested under this policy (formaldehyde, particulates, ozone, VOCs, and carbon monoxide are tested) (Vancouver 2016).

Dave Ramslie, Vice President of Innovation and Sustainability at Concert Properties and former City of Vancouver employee, spoke of how developers in Vancouver are already integrating sustainability into their construction, design, and certification processes – they are ready for more stringent standards. To meet the company's own climate goals, for example, they already try not to install any further natural gas appliances in buildings and install electric or hybrid devices wherever possible. During retrofits or construction, they also take the opportunity to review ventilation and install additional control technologies, such as MERV filters.

New York City (NYC), NY, US

Within New York City (NYC), there are numerous programs and policies stretching across several departments within the City Government that target air pollution. For purposes of this research, the Department of Environmental Protection is central in that it created and administers the Air Pollution Control Code and tangentially relates to the Construction Codes.

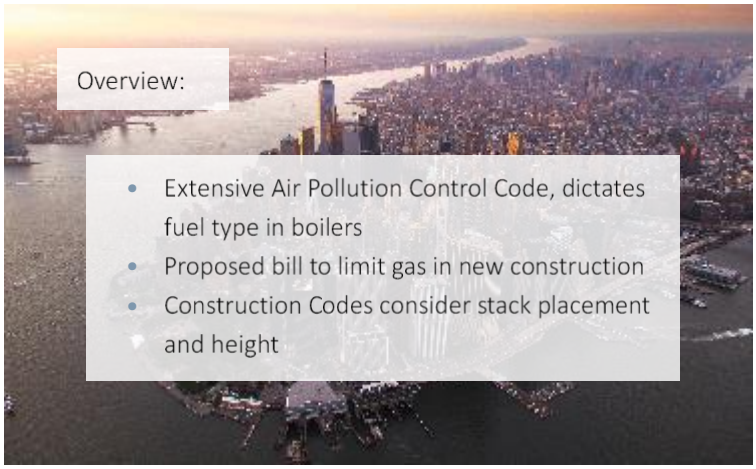

Photo by Brandon Jacoby on Unsplash

Within New York City (NYC), there are numerous programs and policies stretching across several departments within the City Government that target air pollution. For purposes of this research, the Department of Environmental Protection is central in that it administers the Air Pollution Control Code and worked with City Council to update the Air Code, which also relates to the Construction Codes.

The Air Pollution Control Code is a sweeping policy primarily aimed at reducing particulate matter, and also other contaminants. Its main effect on boilers is requiring operators to use #2 fuel oil or natural gas instead of the dirtier #4 fuel oil (phased out by 2030) or #6 fuel oil (already phased out) (New York City 2016). According to interviewees, this transition from #6 fuel oil was unpopular with developers and operators, but received accolades from the public, who reported that they enjoyed no longer seeing the "black smoke" coming from chimneys burning #6 oil. These benefits were not only anecdotally appreciated by members of the public; the Department of Health installed air quality monitoring networks in neighborhoods before the switch off of #6 occurred, then values were compared before and after the transition. Significant reductions in various contaminants were documented through this data collection (NYC Environmental Health 2019). Still, the Code was unpopular with developers during stakeholder engagements, mainly because of the price volatility of natural gas at the time and because of the high cost of replacement (some heating systems had to be replaced entirely). The City of New York and the Department of Environmental Protection alleviated some stressors by allowing flexible timelines for implementations, facilitating grants to help offset costs, and more (New York City employees #2 2021).

Outside of the Air Pollution Control Code, representatives in NYC City Council have proposed a bill to limit natural gas in new construction and in major renovations, called "Use of substances

with certain emissions profiles." It focuses on carbon dioxide, proposing to prohibit "the combustion of a substance that emits 50 kg of carbon dioxide per million Btu within a building" (New York City Council 2021). As the proposed bill is recent (May 2021), it is unclear whether it will be passed.

Finally, NYC has the most direct and explicit guidelines on stack placement of any jurisdiction reviewed. Scattered across the 2014 NYC Construction Codes, especially within the Building, Fuel Gas, and Mechanical Codes, there are abundant rules relating to stack placement and design. For example, Section 503.5.4 of the NYC Fuel Gas Code sets specific parameters for chimney terminations as they relate to the building of origin and neighboring structures (certain temperatures translate to designated minimum distances). Section 802.2 of the NYC Mechanical Code outlines parameters for vents from oil-burning appliances as well (New York City Buildings 2014). However, Chapter 2 of Title 15 of the Rules of the City of New York, called "Engineering Criteria for Fossil Fuel Burning Boilers and Water Heaters," offers the most direct guidance, featuring a table of permissible stack heights given the distances to nearby building's intakes (The Rules of the City of New York, Department of Environmental Protection 2014, 2). An NYC employee summarizes the Codes this way: "If I build a tall building and the existing building next to me is shorter, then I have to pay to run that shorter building's stack upward so that it's high enough to not affect my building" (New York City employee #1 2021). This concept is captured in the Engineering Criteria and Construction Codes but involves many steps in practice, including air dispersion modeling for large projects, stack certifications by engineers, and more. As part of planning these large projects, the employee's team is sometimes able to encourage the use of low-NOx boilers (56 mg/m^3) but cannot require it.

Toronto, ON

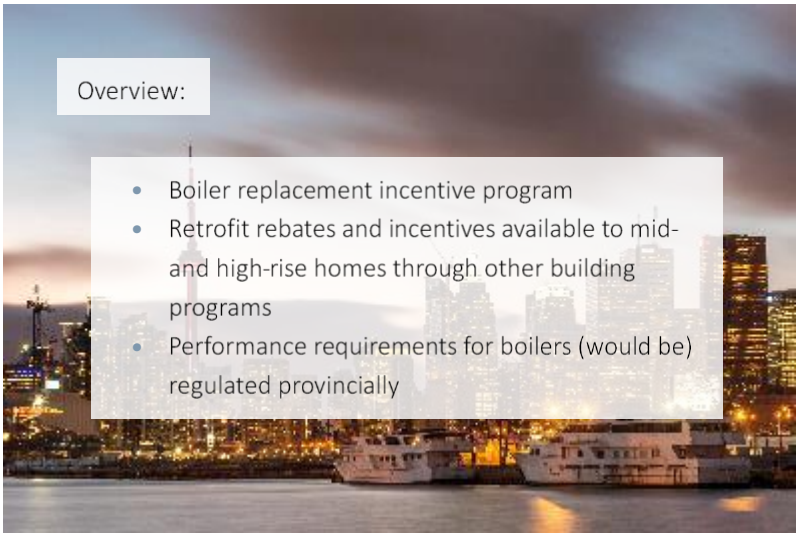

Photo by Alex Shutin on Unsplash

The City of Toronto's buildings and boilers programs center upon financial incentives to replace less efficient or dirtier technologies. Partnering with Enbridge Gas, the City offers a rebate of up to $750 for single-family homes to replace their boilers with a more efficient option (City of Toronto 2017a). Toronto's website also links the Canadian federal home retrofit rebate, which offers up to $5000 for efficiency-increasing retrofits (Canada 2021). These incentives are the programs most directly relevant to boilers. Still, a few buildings policies offer incentives for general emissions reductions retrofits, of which boiler replacement can be a part. Of these, the Net Zero Existing Buildings Strategy (which requires energy and emissions performance reporting) and the High-rise Retrofit Improvement Support (Hi-RIS) are most applicable, offering incentives for retrofits to multi-family residential buildings (City of Toronto 2017b). The Toronto Green Standards are tangentially relevant, targeting GHG emissions in a limited capacity, but not boilers or NOx (City of Toronto 2021).

According to one city employee, "municipalities in Ontario do not have the authority to implement step codes" (personal correspondence) – step codes being optional codes for municipalities to adopt that go above the requirements of the provincial base codes, similar to the California Reach Codes concept. Thus, equipment performance standards (like NOx limits for boilers) would be provincially regulated rather than municipally. Some exceptions have been made, such as for the Net Zero Existing Buildings Strategy, but the ability to regulate boilers in such a way would require an additional solicitation from the provincial government.

Paris, FR

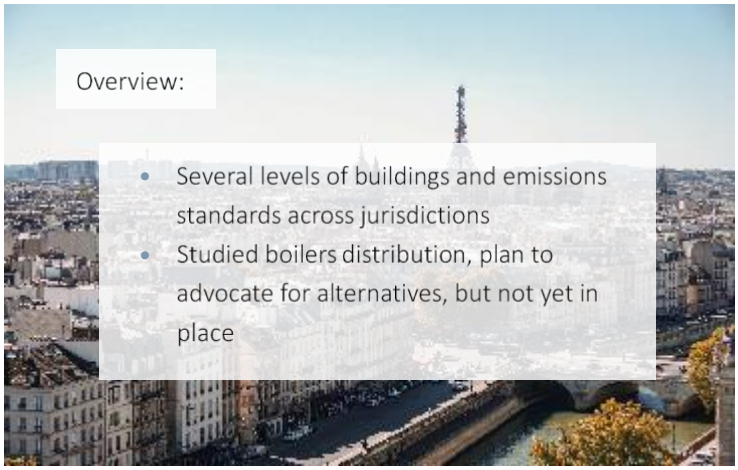

Photo by Alexander Kagan on Unsplash

For Paris, France, somewhat limited data is available. First, there is a clear, comprehensive jurisdictional hierarchy over emissions and building standards at the EU, national, regional, and city levels. Particularly the EU- and national-level standards are more extensive than in many other jurisdictions reviewed. Individual municipalities (like Paris) have fewer responsibilities over creating policy and are more responsible for administering it and meeting emissions targets (Ministére de la Transition Écologique 2021). Like London, the City has a Low Emission Zone, where there are added restrictions on polluting activities due to existing higher levels of contaminants, but it appears that most of the restrictions are oriented towards transportation (City of Paris 2021b). In terms of boilers, the City website mentioned an incentive to replace fuel oil burners (like that in Seattle), but the documentation for the policy could not be located, perhaps because of language translations (City of Paris 2021a). In 2018, a local study found that 10% of NOx emissions in the City come from boilers, which are found in 45,500 homes, and a plan was developed to advance natural gas or district energy systems as alternatives, but this plan is not yet binding (Parisian Climate Agency 2019).

Jurisdictions with Building-Only Programs

Boston, MA (US)

The City of Boston faces unique challenges in its exceptionally high proportion of emissions stemming from buildings, especially from large facilities and labs. The policies aimed to reduce emissions focus on GHGs, but emphasize retrofits targeting boilers and reducing NOx in parallel.

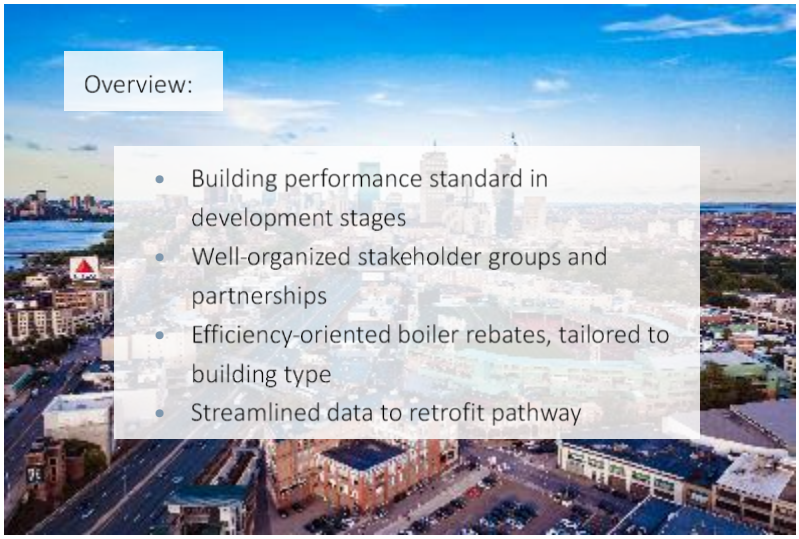

Photo by todd kent on Unsplash

For purposes of this research, one of the most important policies is the proposed Building Performance Standard, under the 2019 Climate Action Plan Update. The Performance Standard targets large buildings, responsible for half of the carbon emissions in Boston, and mainly concentrates on GHG emissions, given its Climate Action Plan mandate. Critically, to set its parameters, the standard uses existing data about large buildings, gathered through the Building Energy Reporting and Disclosure Ordinance (BERDO), which requires large buildings to submit data on annual energy usage. Given the historical data, Boston partnered with experts, consultants, and advisory groups to understand the specific opportunities to reduce carbon emissions in these building types (Boston employee 2021; City of Boston 2020a).

These partnerships also included a Climate Working Group, the Green Ribbon Commission (a group of some of the largest businesses in Boston working together on climate), Resident Advisory Group (composed of renters and homeowners), building owners, and more, across a diverse spectrum of interests ("Boston Green Ribbon Commission" n.d.). According to a Boston employee, groups were well-organized and facilitated throughout the consultation processes, which helped minimize pushback from building owners that may be opposed. Once building owners understood where they stood concerning the standard, its timelines, and how it impacted them in concrete terms, skepticism seemed to be reduced (Boston employee 2021). In conjunction with the standard, there are proposed financing programs to help building owners reach their goals, workforce training programs, and a special focus on low-income multi-family residences. Pilot projects have been conducted examining feasibilities for a "cookie-cutter deep retrofit": a set of retrofits that can be widely applied to different buildings and manufactured on a less customized (and therefore less expensive) basis. These "cookie-cutter deep retrofits"

usually include mechanical pods with ventilation and electric heat pump packages. Finally, the Boston interviewee believes that flexibility is a crucial component of the proposed standard: building owners have the option to purchase an "alternative compliance payment" instead of doing retrofits, and funds from this payment go into an equitable emissions investment fund, used to reduce emissions in environmental justice communities and low-income buildings. However, owners are ultimately disincentivized from the alternative compliance payment, as it is set at a level equivalent to the expected cost of retrofits. This helps to prevent owners from simply purchasing the alternative compliance payment every year.

Separately, the City partners with its leading energy utility, Eversource, to provide incentives and opportunities for buildings of all sizes to perform retrofits. Single-family homeowners can apply for rebates through the Mass Save program for upgrading to more efficient appliances (including boilers). The Building Energy Retrofit Resource Hub is essentially similar but is targeted at large- and medium-sized buildings (City of Boston 2020b). Instead of simply applying to Mass Save online, building owners/operators are invited to contact an Energy Efficiency Consultant at Eversource, such as Steven Miller, who works with customers to identify opportunities for retrofits and direct them to resources within Eversource and the City to help facilitate those retrofits. In an interview with Mr. Miller, he highlighted the effort to make rebate programs accessible for everyone, including energy-intensive labs, among the Boston area's biggest emitters. Eversource receives bonuses from the state for facilitating efficiencies like those made possible through building retrofits, but conversely, this means that every dollar spent on rebates must be justified through the lens of efficiency - claiming reductions in NOx alone, without significant energy savings benefits, is not sufficient, in other words (Miller 2021). As a result, sometimes retrofits for lower NOx boilers are not done in favor of other types of retrofits that deliver higher energy efficiency returns.

Cambridge, MA (US)

Photo by Deval Parikh on Unsplash

The programs in Cambridge, MA, are quite similar to those in Boston, and thus will be described briefly, but there are a few key differences integral to Cambridge's policies and process. First, citizens demanded the City's Net Zero Action Plan – it was created following a citizen referendum in 2015. It is currently being updated to reflect the necessary emissions cuts to reach its goal of carbon neutrality by 2050 (City of Cambridge, Massachusetts 2021). The Net Zero Action Plan functions similarly as Boston's Building Performance Standard but considers a broader swath of buildings (not exclusively large ones) and utilizes building benchmarking to measure progress (Boston's version uses a form of data collection and benchmarking, but Cambridge's version is more comprehensive) (City of Cambridge, Massachusetts 2014). According to a Cambridge employee, Cambridge similarly benefitted from a well-organized coalition of stakeholders, marked by the expertise of top universities in the area, and received very little pushback from these stakeholders. The employee hypothesized that this comparatively little pushback was partly a function of the plan's origin: by definition, as a citizen referendum, the City had a mandate to create and administer the plan. They also noted that Cambridge was watching the nation- and state-wide electrification effort, as some places have been successful (cities in California), but other efforts by towns in Massachusetts have been shut down in court by the Attorney General (Cambridge employee 2021). Just as in Boston, the Mass Save program connects building owners of all types to rebates and the opportunity to consult with an Energy Efficiency Consultant and engineers at Eversource.

Discussion

Summary of Findings

London, BAAQMD, SCAQMD, and NYC are the main jurisdictions that target boilers, heaters, and NOx explicitly, whether they are concerned with stack placement (London and NYC) and fuel types (as in NYC), more driven by NOx emissions outcomes on a per-boiler basis (as in London,

BAAQMD, and SCAQMD), or outcomes on a building- and city-planning basis (London). Other jurisdictions reviewed either have relatively small-scale programs (like boiler replacement incentives), as in Seattle, Boston, Cambridge, and Toronto, or can be considered approaching the issue in a roundabout way - that is, moving off of fossil fuel infrastructure or reducing emissions generally as motivated by climate targets, which carries boilers along with it (San Francisco, Seattle, City of Vancouver, Boston, and Cambridge).

Table 2: Jurisdictions by Policy Type

BOILER AND HEATER NOX LIMITS	ELECTRIFYING HEATING SYSTEMS	STACK DESIGN POLICIES	BOILER REPLACEMENT INCENTIVES
London (low-NOx required, ultra-low NOx recommended)	San Francisco (all buildings)	London	Seattle
BAAQMD (ultra-low NOx and low-NOx required, depending on unit type [limited exceptions])	City of Vancouver (low-rise buildings)	NYC	Toronto
SCAQMD (ultra-low NOx and low-NOx required)	Seattle (large buildings)		Boston and Cambridge (Mass Save)
			SCAQMD

Key Themes

Policy

The movement to electrify buildings is fast-growing, but contextually nuanced and focused on new sources

Jurisdictions are increasingly opting to "leapfrog" past standards requiring more efficient or lower emissions fossil fuel technologies and towards electrification. From the jurisdictions reviewed, it seems the decision to "leapfrog" is based only partially on the availability or feasibility of technologies and is influenced by political, cultural, and legal conditions. For example, given that 46+ jurisdictions in California have already passed legislation to limit gas infrastructure in

buildings, there is clearly not a state-level obstacle to doing so (as there purportedly is in Massachusetts). Yet, despite being a global leader in air quality, SCAQMD has not pushed for electrification standards (besides offering incentives for heat pumps) for itself or its member municipalities (Los Angeles is not among these 46 jurisdictions in California). This could be because of jurisdictional limitations, although these could be circumvented via reducing ultra-low NOx requirements to zero-NOx (effectively an electric transition policy), or because of the SCAQMD's "fuel neutral" approach, which prohibits them from advocating for any one particular fuel type.

Additionally, most electrification policies focus on new sources, whether it includes all or some new buildings, and whether or not it includes renovations. In other words, these policies affect new construction and sometimes require electric heat pumps to be installed when boilers are being replaced, but critically, they do not affect extant, working gas boilers. This gap means that the extant, working gas boilers, which often have a 10-20 years+ life span, will continue to operate and emit NOx and other contaminants for years to come. Correspondingly, the total potential benefits from these policies will be realized over long time horizons.

Data facilitates specialized policies

Granular, building-level data is an asset to creating policy, especially ones that allow for different standards in different parts of the jurisdiction. In London, the best case of highly granular data used for policy creation, NOx concentrations are modeled throughout the City and used to create Low-Emission and Ultra-Low-Emission Zones, where standards are more stringent and targeted. San Francisco does this on a smaller scale, modeling the Air Pollutant Exposure Zone, and similarly creates more stringent rules for that area (like Article 38). Even where concentrations are not modeled, jurisdictions like London, Boston, and Cambridge benefit from detailed building data, in the form of benchmarking energy usage over time. Benchmarking data allows the Cities to create specific targets for reductions on a per-building basis. Overall, while Jennifer Callewaert (San Francisco interviewee) noted the significant time and expense of modeling emissions in this way, it appears that increased, granular data collection allows more targeted (and perhaps more effective) policies.

Incentives precede standards where capacity is limited

In jurisdictions where the capacity to create, facilitate, or enforce a standard is purportedly limited, financial incentives are commonly offered to building owners to replace dirtier technologies. In SCAQMD, the SCAQMD employees at the Residential and Commercial Buildings Working Group meeting said that zero-NOx standards were not feasible because the manufacturing could not meet the demand that such a standard would create. Consequently,

they offer financial incentives to allow a more gradual transition. In Boston and Cambridge, where Cambridge has looked at electrification standards but noticed the hostile legal landscape on the state level, the two cities continue to offer rebates to all building owners through the Mass Save program (partnered with Eversource). Seattle demonstrates a case where both incentives and now standards exist, targeting different populations – incentives exist for fuel oil burner replacements and primarily focus on single-family homes, while the new electrification standard reaches larger commercial and residential buildings.

Equity-centered action

Several jurisdictions' programs dedicate attention to the equity implications of the policy. In Boston, Cambridge, Seattle, and San Francisco, equity is continually referenced as a critical motivating factor for both why their policies are necessary and how dimensions of their program ensure that the policy is delivered equitably. For example, in Boston and Cambridge, interviewees highlighted the extended consultations with low-income housing groups. Especially in areas like Boston (and many of the other jurisdictions reviewed), where housing is expensive, the prospect of "renovictions" and increased housing costs due to emissions-reducing retrofits is a real threat. To combat this, Boston integrated the "alternative compliance payment," which helps fund retrofits in environmental justice and low-income communities. Seattle notes contaminants' disparate impacts on communities of color and vulnerable populations throughout their programs and offers the opportunity for low-income families to apply for free heat pumps. Many other jurisdictions consulted with low-income housing during the policy creation process, but the cases of Boston and Seattle have perhaps the clearest practical applications in policy.

Process

Partnerships with and the backdrop of higher levels of government

It is essential to acknowledge that the jurisdictions reviewed do not operate in isolation, and many of their activities are enabled and supported by higher levels of government (regional, state, national, and international). Many of the policies described in California were encouraged by the California Reach Codes program, with support from the California Air Resources Board (CARB) and state funding. Both the City of Vancouver and London were able to create programs by receiving special exceptions from respective higher levels of government; the City of Vancouver was able to develop its own Building Bylaw (an addition to the BC Building Code that is Vancouver-specific), and London similarly worked with the British government to enact its own air quality goals and controls (Vancouver 2019; City of London 2015). Facilitating relationships with higher levels of government opens opportunities for funding, receiving additional jurisdictional powers, and advocacy outside of the jurisdiction.

Public support

Intuitively, public support is necessary for government programs to succeed, and a spectrum of support is represented by the reviewed jurisdictions' experiences. Cambridge represents the ultimate showing of public support, with its citizen referendum demanding action on climate, which was borne out partly through its buildings policies. New York City's Air Pollution Code was successful but controversial, and although interviewees did not discuss this controversy in the context of the proposed new bill to limit gas in new construction, it is speculative whether it will meet similar obstacles. In areas where policies did enjoy public support, interviewees emphasized the engaged and knowledgeable support of the public, helping to advance the policy through Councils, Boards, and public hearings.

Stakeholder engagement

Interviewees continually underscored the need to engage stakeholders early in the policy creation process and in an organized manner that connects similar interests. The numerous advocacy, consultant, business, and advisory groups organized for Boston's Building Performance Standard and SCAQMD's Residential and Commercial Buildings Working Group represent just some of the groups organized by jurisdiction's departments to facilitate feedback on policies. According to several interviewees, the engagement process allowed the agencies to educate relevant stakeholders on what was proposed, allowing those stakeholders to prepare and understand the program in advance of its implementation. In other words, successful stakeholder engagements were only partly focused on debating the particulars of a program, and more centered on preparation.

Dedicated staff deliver results

The number of coordinated staff within a jurisdiction specifically tasked with facilitating a given policy appears to be a loose proxy for the comprehensiveness and progressiveness of that policy. In San Francisco, interviewee Jennifer Callewaert underscored the diverse, coordinated team across departments dedicated to different aspects of air pollution monitoring, health monitoring, and policy implementation. In SCAQMD, interviewees detailed the highly focused roles and departments within the District, organized by sources of contaminants. Interviewees from Boston and Cambridge also spoke of the high number of staff working on the projects, who facilitate stakeholder groups, consult peer jurisdictions, and more. As jurisdictions work with limited budgets and parameters, the allocation of focused staff demonstrates the prioritization of a project, and their dedication helps deliver sound programs.

Recommendations

Overview

Metro Vancouver's Climate 2050 Buildings Roadmap and Clean Air Plan 2021 already contain most of the strategies necessary to move forward on air quality and climate change action in lockstep. Several of the strategies are reflected in extant policies in other jurisdictions. Where applicable, specific applications of strategies are suggested, based on parallels in peer jurisdictions. If all or targeted parts of these plans are finalized and translated into binding actions, Metro Vancouver can expect positive results insofar as peer jurisdictions have experienced the same for similar actions. However, the opportunities potentially enabled by increased data collection and especially emissions modeling are largely missing from these plans and should be added. Recommendations, ranging from a few shorter-term options like reducing NOx limits for boilers and heaters and revising stack design policies, to longer-term options such as implementing planning-based approaches and electrification standards, are further discussed. Barriers identified in the Buildings Roadmap are discussed through the lens of peer jurisdictions.

Table 3: MV Plan Strategies and Recommendations

MV PLAN STRATEGY	PEER JURISDICTION PARALLEL	RECOMMENDATION
Clean Air Plan Strategy 2.1.1: "Greenhouse Gas Performance Requirements for Existing Large Buildings. Develop regulatory requirements for existing large buildings to meet greenhouse gas emission performance targets, which would reach zero carbon emissions before 2050. Requirements would apply to all existing large commercial and large residential buildings, and would include energy consumption benchmarking, reporting and performance requirements, in coordination with BC Government regulatory requirements. Any regulation should also require that emissions from large buildings would not lead to local air quality that exceeds Metro Vancouver's ambient air quality objectives, when also considering background levels."	Boston Building Performance Standard, Cambridge Net Zero Action Plan, The London Plan (Policy 7.14); Air Quality Positive Guidance draft	Strategy 2.1.1 aligns with Boston and Cambridge's experience with benchmarking and creating performance requirements accordingly, as well as London's requirement for buildings being air quality neutral (against historic benchmarks). For crafting the exact logistics of the performance requirements, MV can look to these cities, but the important first step is to begin requiring benchmarking buildings in a systematic and detailed methodology. MV can improve upon the strategy by partnering with cities to include positive environmental contributions as a requirement for buildings, akin to London's Air Quality Positive Statement.
Climate 2050 Buildings Roadmap Strategy 1.3: "New Buildings are Highly Efficient and	Seattle Energy Code, San Francisco	As far as San Francisco created its electrification plan as a function of

MV PLAN STRATEGY	PEER JURISDICTION PARALLEL	RECOMMENDATION
Electric. Work with the BC Government to establish greenhouse gas performance requirements for new buildings, through the BC Energy Step Code or other legislation, reaching zero emissions by 2030. These requirements should allow local governments to voluntarily adopt zero emissions targets earlier. These requirements would apply to new homes, townhomes, and large commercial and residential buildings. Public sector organizations could play a leadership role by establishing zero emissions targets for their own new buildings earlier."	All-Electric New Construction Ordinance, Vancouver Buildings Bylaw, Vancouver Zero Emissions Buildings Plan, The London Plan, London Sustainable Design and Construction SPG, California Reach Codes	California's Reach Codes, much the same is suggested by Strategy 1.3, wherein MV and member municipalities work with BC Step Codes to advance efficiency and electrification (Building and Safety Standards Branch 2017). Although London does not have an electrification policy, their system of having each borough in non-attainment maintain its own, more ambitious Air Quality Strategy may offer guidance for how local governments can adopt zero emissions targets earlier.
Climate 2050 Buildings Roadmap Strategy 1.2: "Greenhouse Gas Performance Requirements for Existing Houses and Townhomes. Develop regulatory requirements for existing homes and townhomes to meet greenhouse gas emission performance targets, which would reach zero carbon emissions before 2050 in coordination with BC Government regulatory requirements. These requirements would help to achieve Metro Vancouver's air quality objectives."	San Francisco All-Electric New Construction Ordinance, Vancouver Buildings Bylaw	San Francisco and Vancouver's electrification efforts include homes and contribute to climate goals, although this does not include embodied emissions, and is less a "building performance standard" than an electrical mandate. Further research is necessary to seek peer jurisdictions' approach to performance standards for houses and townhomes.
Clean Air Plan Strategy 2.1.7: "Locate Exhausts to Minimize Local Air Quality Impacts. Work with member jurisdictions, the BC Government and health authorities to establish more stringent exhaust requirements for building boilers and heaters, and restaurants. This would include updating municipal development and building permits, and the BC Building Code so that exhausts are located to minimize impacts on local air quality and human health."	UK Clean Air Act and Building Regulations, NYC Construction Codes; BAAQMD Regulation 9 Rule 6 and 7, SCAQMD Rule 1146, 1121, and 1111, London Sustainable Design and Construction	The aspect of locating exhausts in Strategy 2.1.7 aligns with the stack design policies of London/UK and NYC. However, there is also the charge of establishing more stringent exhaust requirements, which (if only considering gas boilers) is paralleled in the low- and especially ultra-low NOx requirements of BAAQMD and SCAQMD. The scale of stack placement considerations depends at least in part on efforts to electrify (see electrification recommendations).
Climate 2050 Buildings Roadmap Strategy 1.10: "Building Electrification Mandate for BC Hydro. Advocate to the BC Government to direct BC Hydro and the BC Utilities Commission to promote and accelerate building electrification and to reduce emissions. A clear mandate could also support the development of electricity rates	Boston and Cambridge (Mass Save)	The closest analog to directing local utilities towards emissions reductions is the case of Eversource partnering with the state of Massachusetts and Boston and Cambridge. However, that public-private relationship is notably different, and Eversource is not pushing for electrification. BC and Metro Vancouver have a unique opportunity with BC

MV PLAN STRATEGY	PEER JURISDICTION PARALLEL	RECOMMENDATION
that support residents who wish to switch to electricity. "		Hydro to advocate for an electrification mandate, and should.
Climate 2050 Buildings Roadmap Strategy 1.4: "Require Greenhouse Gas Reductions During Renovations. Advocate to the BC Government to establish the BC Retrofit Code with increasingly stringent greenhouse gas performance requirements for buildings undergoing significant renovations."	SCAQMD BARCT policies	SCAQMD's Best Available Retrofit Control Technology policies are the closest analogs to this approach. This strategy must be emphasized as a central pillar; although it faces significant obstacles, (since retrofit standards are more difficult than the same for new construction) it holds some of the greatest potentials for air quality gains because of the inefficiencies of old equipment and buildings.
Clean Air Plan Strategy 2.2.5: "Energy Advisor Services for Homes and Large Buildings. Work with the BC Government to enhance energy advisor services for home and large building owners. The expansion would help simplify the customer journey for home and building owners considering retrofits, so they can more easily access technical support and financial incentives through Action 2.2.4."	Boston and Cambridge (Mass Save consultant)	The Energy Efficiency Consultant available through the Mass Save program is analogous to the services proposed by Strategy 2.2.5. This consultancy program is widely used and helps pair interested building owners with the proper strategies and financial incentives available. If sufficient incentives exist within BC Hydro, for example, MV could partner with them to create such a position, and then vigorously market the consultancy to the public, ensuring that the service will be used.

Reducing NOx Limits for Boilers and Heaters

One measure that falls within the purview of MV's jurisdiction is revising Bylaw 1087 to lower NOx emissions from boilers and heaters, updating it from current low-NOx limits to ultra-low NOx limits. First, further research should be conducted to test the difference in NOx emissions as reported by manufacturers versus post-installation in buildings. Following this research, MV may redefine “low-NOx” and “ultra-low NOx” if there is a significant disparity between the values reported by manufacturers and those measured post-installation. Once MV begins redesigning the bylaw NOx limits can be stratified based on unit type, building setting, energy input and output, etc. The updated limit should be required for all new sources (new buildings plus major retrofits). Additionally, the registration fees for different technologies could be modified to act as incentives and disincentives, similar to the the Non-Road Diesel Engine Bylaw (Bylaw 1161) in

terms of fee structure and categorization of emitters, for example. Modeling requirements could also be expanded in the bylaw, such that natural gas boilers and heaters are required to model their emissions, alongside the current rules compelling modeling emissions for biomass boilers and heaters. In conjunction with regional partners, MV can conduct stakeholder consultations with building owners and especially local suppliers of boilers, heaters and generators to gauge (manufacturing) capacity and willingness to adopt. Where capacity is limited, MV can encourage municipalities to implement incentive programs for building owners to install lower-NOx options. Regardless of capacity, MV should encourage municipalities to offer equity-based grants and incentives to low-income housing and similar groups to make lower-NOx options more accessible. Before and after the revision of the bylaw, MV should consider partnering with universities or research groups to study NOx emissions and concentrations before and after the revision, to study its efficacy, as NYC did.

Stack Placement and Design

Policies targeting stack placement and design will likely require revisions to municipalities' building bylaws and/or the BC Building Code. As such, MV plays a role in educating, supporting, and coordinating these actors to facilitate stack design policy. Perhaps the most basic policy opportunity is for BC to mirror London's approach of including stack placement considerations as part of the approval process for buildings, with engineers evaluating the stack's placement relative to neighboring buildings. Higher-level approaches, like including the requirement in a Clean Air Act (as in the UK) or attaching specific, quantitative parameters to it (as in NYC), may prove to be longer-term goals. MV can work with these regional partners, alongside research institutions where applicable, to model the emissions from the stacks of larger developments and design those stack placements accordingly. Prioritizing large developments for modeling and stack design may help to reduce the scope of the overall policy project. Further research is necessary to evaluate how to retrofit existing ill-placed stacks, and how electrification can indirectly solve problems from these ill-placed stacks (i.e., where might it be more effective to replace a gas-fired boiler with an electric option, thereby reducing the NOx emissions from combustion, instead of gutting and replacing a ventilation system).

Increased Data Collection and Emissions Modeling; Planning-based Policy

Increased data collection and emissions modeling

While Strategy 2.1.1 of the Clean Air Plan 2021 mentions the need for increased data collection like benchmarking for buildings, the Roadmap and the Clean Air Plan are missing a strategy for comprehensive, granular modeling of the MV region. Improved granular data, as provided by

increased quantities of monitors and periodic modeling, could allow for more targeted policies like in London and San Francisco. This possibility is particularly relevant when considering the jurisdictional parameters of Metro Vancouver. Given the ability to observe where NOx reductions are most necessary in the region, MV can prioritize working with those municipalities. Similarly, if disproportionately large amounts of NOx are found to be emitted from certain building types or ages of buildings, MV can work with municipalities and the province to revise building bylaws or codes to address these large emitters more directly. Finally, improved modeling could help identify where hazards such as wildfire smoke settle and concentrate, and policies could accordingly target buildings in these areas for improved ventilation standards and/or incentives for filtration systems, like San Francisco's Article 38. Monitors and modeling are significant investments but can be done in partnership with non-government actors, such as universities and NGOs. Overall, increased data collection and modeling open numerous possibilities that allow MV to be more targeted and deliberate with partnerships, resources and policies.

Planning-based policy

Increased data collection and emissions modeling are helpful on their own for a variety of functions as described, but they are also necessary precursors to planning-based policy. Metro Vancouver could work with regional partners to model the comprehensive, planning-based approach taken in London. As described, the London model integrates hyper-detailed data and modeling, additional borough-level policies on top of stringent London policies, an "air quality neutral" requirement, a proposed update to require Air Quality Positive statements, stack placement policies, and all of this is thoroughly integrated with transportation systems on top of building considerations. It does not involve electrification, and yet, because of its comprehensiveness and ambitious targets, dramatic decreases in NOx and other contaminants have been achieved. There are many moving parts within the “London approach”, and several outside of MV’s jurisdiction. As such, MV’s role would likely be mostly supportive in coordinating and educating municipalities, working with universities and NGOs for research and other types of support, and/or encouraging the province to expand the BC Step Codes where applicable. MV may implement a planning-based approach in addition to electrification, and this would be perhaps the most comprehensive possible option towards climate and air quality gains, but a planning-based approach may also include reductions in NOx limits for boilers and/or stack design policies.

Building Electrification

Electrifying buildings- as applied through heating and cooling systems by installing electric heat pumps- is the simplest path forward that simultaneously meets NOx reduction goals, assuages

the stack placement problem, and brings climate mitigation and adaptation benefits along with it. Electrification cuts NOx and GHG emissions drastically, especially given Metro Vancouver's relatively clean electrical grid. Because of this, the problem of where emissions stacks terminate in relation to other buildings is effectively bypassed. Finally, not only does it offer climate mitigation in the form of reducing GHGs, but electric heat pumps additionally provide climate adaptation strategies in that they are also cooling systems, which MV acknowledges as vital in the presence of increasingly frequent and intense heat waves in the region. Since vulnerable populations disproportionately suffer under conditions like heat waves, cooling systems can deliver equity benefits as well. This combination of emissions reductions and adaptation benefits serves MV's goal for "zero emissions resilience" called for in the Climate 2050 Buildings Roadmap. Thus, following peer jurisdictions, an electrification standard mandating no new natural gas infrastructure is recommended. Barring a total-building electrification standard, a "heat pump standard" is possible, mandating new buildings and retrofits be constructed using electric heat pumps.

As peer jurisdictions did during their policy creation processes, it is vital to consider the manufacturing, technological, and electrical capacities, cost, and the largest emitters when formulating an electrification standard in MV. For example, following Seattle's approach, MV may encourage local and provincial government partners to select large buildings for the standard, given their higher emissions. If the region has adequate capacity, partners may follow San Francisco's example and target all buildings. There are also models in terms of the standard targeting only new construction, or new construction plus major renovations, which can again follow capacity considerations. Perhaps an early approach could be for MV to partner with municipalities in the region to help them to simply replicate the City of Vancouver's new electrification policy (targeting low-rise buildings). In summary, an electrification standard of some kind is recommended, but the exact facilities it should target and when is subject to further research on the various capacities of the region.

Addressing Barriers

Peer jurisdictions offer several lessons applicable to addressing the barriers to zero emissions resilient buildings, as outlined in the Climate 2050 Buildings Roadmap.

Low public awareness of problems and opportunities

The Climate 2050 Buildings Roadmap describes the generally low public awareness of the problems associated with gas infrastructure and the opportunities and benefits of zero-emissions standards (page 30). Low awareness is indeed a significant barrier, as peer jurisdictions stressed that the informed public and stakeholders were crucial levers in propelling policies and programs

to success (see public support). While communities can be educated during the policy creation process and stakeholder consultations to some extent, some resources should be dedicated to public education on the front-end, before progressions meaningfully begin. This can be done through marketing campaigns, social media engagement, and partnering with realtors, contractors, and developers to connect with users when opportunities for retrofits arise (purchasing, selling, constructing a building a home, etc.).

Complexity and cost of decision-making

In conjunction with low public awareness, the Buildings Roadmap cites the potentially overwhelming nature of decisions like switching to heat pumps, which can carry some co-requirements alongside the transition, whereas replacing a gas boiler with another is perhaps a known, simpler switch (page 30). Here, improvements to public awareness and online resources are again useful, but the presence of an Energy Efficiency Consultant (like Mass Save's in Boston and Cambridge) also becomes an essential tool. This position allows building owners to save significant time and effort themselves and simply follow the advice of a trusted engineer evaluating their specific needs and capacities.

Costs of retrofitting to zero emissions

Like many other sustainable retrofits, the upfront cost of heat pumps can be high, with savings and benefits realized over a longer term, and increased costs can put pressure on renters in particular (Buildings Roadmap, page 30). As the Roadmap suggests, incentives may need to be explored to help offset these costs. Many models of incentives are discussed, as they have been implemented in peer jurisdictions. Depending on the funding available for incentives, the capacity of local manufacturers, and more, different models can be applied to the MV context.

Existing buildings

The Buildings Roadmap delineates challenges with existing buildings, such as the lack of requirements in BC encouraging building owners to implement sustainable retrofits during renovations and the aforementioned long life span of boilers and furnaces (page 29). As the Roadmap mentions, the proposed BC Retrofit Code could help address the former problem by creating such a standard for retrofits during renovations. Additionally, SCAQMD's BARCT policies may offer useful guidance in developing this code or others further. However, the long life span of gas appliances (up to 20 years) is an ongoing issue mostly unaddressed by peer jurisdictions. The fact remains that it is inequitable to require building owners to replace technologies before they are defunct, especially given the high cost of these appliances. Consequently, recently replaced gas boilers can remain operable and emitting for many years to come. This point underscores the importance of creating an electrification standard as quickly as possible; new gas infrastructure

installed today can continue emitting NOx and other contaminants into the 2030s and 2040s, assuming a life span of 10-20 years. If MV is to deliver the goal of all buildings being zero emissions by 2050, and building owners will not be asked to replace gas infrastructure prematurely, then an electrification standard must be in effect by 2030 at the latest (taking a furnace's 20-year life span into account).

Jurisdictional limits

The parameters of what is within the jurisdiction of Metro Vancouver's power are not discussed as a barrier in the Climate 2050 Buildings Roadmap but should be considered as a caveat to all of the recommendations above. Many of the proposed strategies and recommendations are not within MV's purview, or not within it entirely. As a result, MV will need to operate as an advocate, partner, and/or liaison to other levels of government, whether municipalities, BC, or the federal government, to enact the proposed changes. MV is experienced in facilitating these partnerships, especially local ones, and should continue cultivating relationships to foster the outlined strategies. However, it is important to note that the policy creation process can be less streamlined and stretch over extended periods with these additional partnerships. Still, peer jurisdictions like London, San Francisco, and Boston and Cambridge offer lessons in working across broad coalitions and multiple departments to advance common goals. MV can follow similar models in working with partners in government.

Conclusion

In conclusion, this research identified 21 peer jurisdictions of similar or higher population densities and reviewed their policies on boilers and heaters and stack placements. In doing so, 12 jurisdictions were identified as having policies directly or indirectly relevant for boilers and stack placement. These jurisdictions offer a wide diversity of policies and perspectives on endeavoring toward improved air quality. Several apply to the context of Metro Vancouver and the goals outlined in Metro Vancouver's proposed plans, the Clean Air Plan 2021 and Climate 2050 Buildings Roadmap. Ultimately, a suite of policy and program options are available to Metro Vancouver and its municipal and provincial partners. Four key recommendations are proposed, with options available in the shorter term, such as reducing NOx limits for boilers and heaters and implementing stack design policies, as well as longer term opportunities, like data-driven planning-based approaches and creating a building or appliance electrification standard. All of these have the potential to improve air quality, but the most comprehensive, sustainable path forward, reaping the most co-benefits, is creating a building or appliance electrification standard. Each recommendation should be developed in tandem with other programs, such as increasing

public awareness, offering consultant services, and increased air quality monitoring and modeling. Further research is needed to identify electrical and manufacturing capacities and the highest priority buildings, regions, and stakeholders for each recommendation.

References

American Society of Heating, Refrigeration, and Air-Conditioning Engineers. 2019. "Read-Only Versions of ASHRAE Standards." 2019. https://www.ashrae.org/technical-resources/standards-and-guidelines/read-only-versions-of-ashrae-standards.

BAAQMD employee. 2021. Interview with Bay Area Air Quality Management District employee. Zoom Conference Software.

Bay Area Air Quality Management District. 2007. "Reg 9 Rule 6 Nitrogen Oxides Emissions from Natural GasFired Water Heaters." November 7, 2007. https://www.baaqmd.gov/rules-and-compliance/rules/reg-9-rule-6-nitrogen-oxides-emissions-from-natural-gasfired-water-heaters.

———. 2011. "Reg 9 Rule 7 Nitrogen Oxides And Carbon Monoxide from Industrial Institutional and Commercial Boiler." May 4, 2011. https://www.baaqmd.gov/rules-and-compliance/rules/reg-9-rule-7-nitrogen-oxides-and-carbon-monoxide-from-industrial-institutional-and-commercial-boiler.

———. 2021. "Reg 9 Rule 6 Nitrogen Oxides Emissions from Natural GasFired Water Heaters: 2021 Amendment (Under Development)." 2021. https://www.baaqmd.gov/rules-and-compliance/rules/reg-9-rule-6-nitrogen-oxides-emissions-from-natural-gasfired-water-heaters?rule_version=2021%20Amendment.

BC Publications. 2018. "BC Building Code 2018, Division B: Acceptable Solutions." 2018. https://free.bcpublications.ca/civix/content/public/bcbc2018/?xsl=/templates/browse.xsl&xsl=/templates/browse.xsl.

Boston employee. 2021. Interview with Boston employee. Zoom Conference Software.

Boston Green Ribbon Commission. n.d. Boston Green Ribbon Commission. Accessed July 25, 2021. https://www.greenribboncommission.org/.

Boyd, David R. 2015. *Cleaner, Greener, Healthier: A Prescription for Stronger Canadian Environmental Laws and Policies*. Law and Society. Vancouver ; Toronto: UBC Press.

BREEAM Refurbishment- Domestic Buildings. 2016. "Calculations." February 29, 2016. https://www.breeam.com/domrefurbmanual/content/13calculations/08pol01.htm.

British Columbia. 1996. "Freedom of Information and Protection of Privacy Act." 1996. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96165_02#section22.

Building and Safety Standards Branch, Government of British Columbia. 2017. "Energy Step Code." March 7, 2017. https://energystepcode.ca/.

Bureau, US Census. n.d. “Historical Population Density Data (1910-2020).” Census.Gov. Accessed July 26, 2021. https://www.census.gov/data/tables/time-series/dec/density-data-text.html.

California Air Resources Board. 1995. “California Ambient Air Quality Standards.” 1995. https://ww2.arb.ca.gov/resources/california-ambient-air-quality-standards.

———. n.d. “Beyond Code.” Accessed July 26, 2021. https://ww2.arb.ca.gov/our-work/programs/building-decarbonization/beyond-code.

California Codes and Standards Program, Reach Codes Subprogram. 2021. “Frontrunner: City & County of San Francisco.” 2021. https://localenergycodes.com/content/city-county-of-san-francisco/.

———. n.d. “Statewide Reach Codes Program.” Accessed July 26, 2021. https://localenergycodes.com/content/about-us/.

Callewaert, Jennifer. 2021. Interview with Principal Environmental Health Inspector, Environmental Health Branch, Population Health Division, San Francisco Department of Health. Zoom Conference Software.

Cambridge employee. 2021. Interview with Cambridge employee. Zoom Conference Software.

Canada, Natural Resources. 2021. “Make Your Home More Energy-Efficient.” Natural Resources Canada. March 17, 2021. https://www.nrcan.gc.ca/energy-efficiency/homes/canada-greener-homes-grant/make-your-home-more-energy-efficient/23443.

City Corporation of London. 2020. “Air Quality Supplementary Planning Document.” City of London. September 21, 2020. https://www.cityoflondon.gov.uk/services/environmental-health/air-quality/air-quality-supplementary-planning-document.

City of Boston. 2020a. “Developing Carbon Targets for Existing Large Buildings.” Boston.Gov. May 11, 2020. https://www.boston.gov/building-carbon-standard.

———. 2020b. “Building Energy Retrofit Resource Hub.” Boston.Gov. September 8, 2020. https://www.boston.gov/departments/environment/building-energy-retrofit-resource-hub.

City of Cambridge, Massachusetts. 2014. “Building Energy Use Disclosure Ordinance - CDD.” 2014. https://www.cambridgema.gov/cdd/zoninganddevelopment/sustainablebldgs/buildingenergydisclosureordinance.

———. 2021. “Net Zero Action Plan - CDD.” 2021. https://www.cambridgema.gov/CDD/Projects/Climate/NetZeroTaskForce.

City of London. 2014. “Sustainable Design and Construction.” London City Hall. April 2014. https://www.london.gov.uk//what-we-do/planning/implementing-london-plan/london-plan-guidance-and-spgs/sustainable-design-and.

———. 2015. “The London Plan: Chapter 7 - London’s Living Spaces and Places. Policy 7.14 Improving Air Quality.” London City Hall. October 23, 2015. https://www.london.gov.uk//what-we-do/planning/london-plan/past-versions-and-alterations-london-plan/london-plan-2016/london-plan-chapter-seven-londons-living-spac-16.

———. 2016. “Housing Supplementary Planning Guidance.” London City Hall. March 2016. https://www.london.gov.uk//what-we-do/planning/implementing-london-plan/london-plan-guidance-and-spgs/housing-supplementary.

———. 2018. “London Environment Strategy.” London City Hall. May 25, 2018. https://www.london.gov.uk//what-we-do/environment/london-environment-strategy.

———. 2020. “Air Pollution Monitoring Data in London: 2016- 2020.” London City Hall. February 20, 2020. https://www.london.gov.uk//WHAT-WE-DO/environment/environment-publications/air-pollution-monitoring-data-london-2016-2020.

———. 2021. “Air Quality Positive Guidance Pre-Consultation Draft.” London City Hall. March 18, 2021. https://www.london.gov.uk//what-we-do/planning/implementing-london-plan/london-plan-guidance-and-spgs/air-quality-positive-guidance-pre-consultation-draft.

City of Paris. 2021a. “État de La Qualité de l’air à Paris.” May 1, 2021. https://www.paris.fr/pages/etat-des-lieux-de-la-qualite-de-l-air-a-paris-7101.

———. 2021b. “La Zone à Faibles Émissions (ZFE).” May 31, 2021. https://www.paris.fr/pages/la-zone-a-faibles-emissions-zfe-pour-lutter-contre-la-pollution-de-l-air-16799.

City of Seattle. n.d. “Building Performance Standards- Environment.” Seattle.Gov. Accessed July 25, 2021a. http://www.seattle.gov/environment/climate-change/buildings-and-energy/building-performance-standards.

City of Seattle, Office of Sustainability and Environment. 2021. “Seattle Energy Code.” March 2021. http://www.seattle.gov/environment/climate-change/buildings-and-energy/seattle-energy-code.

———. n.d. “Seattle’s Heating Oil Law.” Seattle.Gov. Accessed July 26, 2021b. http://www.seattle.gov/environment/climate-change/buildings-and-energy/seattles-heating-oil-law#resourcesforalloilheatedhouseholds.

City of Toronto. 2017a. “Energy Efficiency Incentives for Homeowners.” City of Toronto. City of Toronto. Toronto, Ontario, Canada. November 15, 2017. https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/energy-efficiency-incentives-for-homeowners-2/.

———. 2017b. “Hi-RIS Program Overview.” City of Toronto. City of Toronto. Toronto, Ontario, Canada. November 18, 2017. https://www.toronto.ca/community-people/community-partners/apartment-building-operators/hi-ris/program-overview/.

———. 2021. “City Council Approves Bold Strategy to Reduce Emissions from Existing Buildings to Net Zero by 2050, Updates Toronto Green Standard.” City of Toronto. City of Toronto. Toronto, Ontario, Canada. July 14, 2021. https://www.toronto.ca/news/city-council-approves-bold-strategy-to-reduce-emissions-from-existing-buildings-to-net-zero-by-2050-updates-toronto-green-standard/.

Curtis, Luke, William Rea, Patricia Smith-Willis, Ervin Fenyves, and Yaqin Pan. 2006. “Adverse Health Effects of Outdoor Air Pollutants.” *Environment International* 32 (6): 815–30. https://doi.org/10.1016/j.envint.2006.03.012.

Gough, Matt. 2021. "California's Cities Lead the Way to a Gas-Free Future." Sierra Club. July 22, 2021. https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-gas-free-future.

Government of Canada, Statistics Canada. 2017. "Population and Dwelling Count Highlight Tables, 2016 Census." February 8, 2017. https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/hlt-fst/pd-pl/Tables.cfm?Lang=Eng&T=300.

HM Government, UK. 2010. "Building Regulations and Approved Documents Index; The Building Regulations 2010: Combustion Appliances and Fuel Storage Systems." GOV.UK. 2010. https://www.gov.uk/guidance/building-regulations-and-approved-documents-index.

Kvale, Steinar, and Svend Brinkmann. 2009. *InterViews: Learning the Craft of Qualitative Research Interviewing*. SAGE.

Maciag, Mike. 2013. "Population Density for U.S. Cities Statistics." Governing. October 1, 2013. https://www.governing.com/archive/population-density-land-area-cities-map.html.

Marks, Guy B., Wafaa Ezz, Nathan Aust, Brett G Toelle, Wei Xuan, Elena Belousova, Carmen Cosgrove, Bin Jalaludin, and Wayne T. Smith. 2010. "Respiratory Health Effects of Exposure to Low-NOx Unflued Gas Heaters in the Classroom: A Double-Blind, Cluster-Randomized, Crossover Study." *Environmental Health Perspectives* 118 (10): 1476–82. https://doi.org/10.1289/ehp.1002186.

Metro Vancouver. 2013. "Boilers and Process Heaters Emission Regulation Bylaw 1087-Consolidated," no. 1087: 15.

———. 2018. "2015 Lower Fraser Valley Air Emissions Inventory and Forecast."

———. 2020. "Ambient Air Quality Objectives." January 2020. http://www.metrovancouver.org/services/air-quality/about/air-quality-monitoring/ambient-air-quality-objectives/Pages/default.aspx.

———. 2021a. "Clean Air Plan." 2021. http://www.metrovancouver.org/services/air-quality/engagement/clean-air-plan/Pages/, http://www.metrovancouver.org:80/services/air-quality/engagement/clean-air-plan/Pages/default.aspx.

———. 2021b. "Climate 2050 Roadmap | Buildings: A Pathway to Zero Emissions and Resilient Buildings," 52.

Miller, Steven. 2021. Interview with Energy Efficiency Consultant, Eversource. Zoom Conference Software.

Ministére de la Transition Écologique. 2021. "Politiques Publiques Pour Réduire La Pollution de l'air | Ministère de La Transition Écologique." June 11, 2021. https://www.ecologie.gouv.fr/politiques-publiques-reduire-pollution-lair.

Mullen, N. A., J. Li, M. L. Russell, M. Spears, B. D. Less, and B. C. Singer. 2016. "Results of the California Healthy Homes Indoor Air Quality Study of 2011–2013: Impact of Natural Gas Appliances on Air Pollutant Concentrations." *Indoor Air* 26 (2): 231–45. https://doi.org/10.1111/ina.12190.

New York City Buildings. 2014. "Buildings- 2014 Construction Codes." 2014. https://www1.nyc.gov/site/buildings/codes/2014-construction-codes.page#fuel.

New York City Council, Committee on Environmental Protection. 2021. "Use of Substances with Certain Emissions Profiles." May 27, 2021. https://legistar.council.nyc.gov/LegislationDetail.aspx?ID=4966519&GUID=714F1B3D-876F-4C4F-A1BC-A2849D60D55A&Options=&Search=.

New York City employee #1. 2021. Interview with New York City employee #1. Zoom Conference Software.

New York City employees #2. 2021. Interview with New York City employees #2. Zoom Conference Software.

Parisian Climate Agency. 2019. "Paris Veut Dire Adieu Au Chauffage Au Fioul !" Agence Parisienne Du Climat. April 26, 2019. https://www.apc-paris.com/actualite/paris-veut-dire-adieu-chauffage-fioul.

Province of Manitoba Department of Finance. n.d. "Manitoba Green Building Program." Province of Manitoba- Finance. Accessed July 25, 2021. https://www.gov.mb.ca/finance/.

Quinn, Gary, and Yanrong Zhu. 2021. Interview with Air Quality Specialist and Program Supervisor, Planning and Rules Division, South Coast Air Quality Management District. Zoom Conference Software.

San Francisco. 2008. "ARTICLE 38: ENHANCED VENTILATION REQUIRED FOR URBAN INFILL SENSITIVE USE DEVELOPMENTS." American Legal Publishing Corporation. 2008. https://codelibrary.amlegal.com/codes/san_francisco/latest/sf_health/0-0-0-6054.

———. 2021. "All-Electric New Construction Ordinance | Department of Building Inspection." 2021. https://sfdbi.org/AllElectricNewConstructionOrdinance.

SCAQMD 2022 AQMP Residential and Commercial Buildings Working Group. 2021. "2022 AQMP Residential and Commercial Buildings Working Group: June 17, 2021 Presentation." June 17, 2021. http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/2022-aqmp-residential-and-commercial-buildings-working-group.

Schensul, Stephen L., Jean J. Schensul, Margaret Diane LeCompte, and Margaret Diane LeCompte Ph.D M. A. 1999. *Essential Ethnographic Methods: Observations, Interviews, and Questionnaires*. Rowman Altamira.

Seattle employee. 2021. Interview with Seattle employee. Email.

Smith, D A. n.d. "Mapping Population Density Across the Globe." Accessed July 25, 2021. http://luminocity3d.org/WorldPopDen/.

South Coast Air Quality Management District. 2012. "Vision for Clean Air." 2012. https://www.aqmd.gov/home/air-quality/clean-air-plans/vision-for-clean-air.

———. 2018. "Rule 1146.2- Emissions of Oxides of Nitrogen from Large Water Heaters and Small Boilers and Process Heaters." December 7, 2018. http://www.aqmd.gov/home/rules-compliance/rules/support-documents/rule-1146-2-details.

———. 2020a. "Rule 1121- Control of Nitrogen Oxides from Residential-Type, Natural Gas-Fired Water Heaters." July 31, 2020. https://www.aqmd.gov/home/rules-compliance/rules/support-documents/rule-1121.

———. 2020b. “RULE 1111. REDUCTION OF NOx EMISSIONS FROM NATURAL-GASFIRED, FAN-TYPE CENTRAL FURNACES,” September. http://www.aqmd.gov/docs/default-source/rule-book/reg-xi/rule-1111.pdf.

———. n.d. “About RECLAIM.” Accessed July 26, 2021a. http://www.aqmd.gov/home/programs/business/about-reclaim.

———. n.d. “Clean Air Plans.” Accessed July 26, 2021b. http://www.aqmd.gov/home/air-quality/clean-air-plans.

State of California. 2018. “CEQA: The California Environmental Quality Act- Office of Planning and Research.” December 28, 2018. https://opr.ca.gov/ceqa/.

———. 2019. “2019 California Green Building Standards Code, Title 24, Part 11 with Jan 2020 Errata | ICC Digital Codes.” July 2019. https://codes.iccsafe.org/content/CGBC2019P3/copyright.

The Rules of the City of New York, Department of Environmental Protection. 2014. “Chapter 2: Engineering Criteria for Fossil Fuel Burning Boilers and Water Heaters.” American Legal Publishing Corporation. 2014. https://codelibrary.amlegal.com/codes/newyorkcity/latest/NYCrules/0-0-0-24125.

Trasande, Leonardo, and George D. Thurston. 2005. “The Role of Air Pollution in Asthma and Other Pediatric Morbidities.” *Journal of Allergy and Clinical Immunology* 115 (4): 689–99. https://doi.org/10.1016/j.jaci.2005.01.056.

United Kingdom. 1993. “Clean Air Act 1993, Section 15.” Text. Statute Law Database. 1993. https://www.legislation.gov.uk/ukpga/1993/11/part/II/crossheading/height-of-chimneys.

Vancouver, City of. 2016. “Zero Emissions Buildings.” July 12, 2016. https://vancouver.ca/green-vancouver/zero-emissions-buildings.aspx.

———. 2019. “Energy Requirements, Forms, and Checklists for All Buildings.” 2019. https://vancouver.ca/home-property-development/large-building-energy-requirements-forms-checklists.aspx.

Winnipeg, City of. 2018. “Green Buildings - Sustainability - City of Winnipeg.” May 31, 2018. https://winnipeg.ca/sustainability/GreenBuildings.stm.

Appendices

Appendix 1: Methods for finding peer jurisdictions

Canada

The Canadian Census online platform allows users to easily sort jurisdictions by density. Doing so, Montreal and Toronto were identified as the primary cities with similar densities (Government of Canada 2017). Quebec City, Winnipeg, and Calgary were included in the list, although their densities are less than that of MV, in an effort to obtain a more holistic perspective from Canada.

Europe

Several cities throughout Europe were identified as being similarly dense as Metro Vancouver. These were identified using the World Population Density Map (Smith n.d.) and checking figures from this map against other sources, such as census data. While many European cities have reputations for action on air pollution, London and Paris were identified as the priority jurisdictions to review among denser jurisdictions.

United States (US)

Similarly, many cities throughout the US were identified as being similarly dense as Metro Vancouver and were identified using density lists (Maciag 2013) and cross-referencing US Census data (US Census Bureau 2020). For larger jurisdictions, New York City was added because of a hypothesized attention to building problems related to its high density, and Los Angeles was added because of its reputation on air pollution and history of high NOx emissions. San Francisco was also added because of positive air quality and sustainability reputations.

Appendix 2: NOx unit conversions

Nanograms/joule (ng/J)	Parts per million (ppm)	Milligrams per cubic meter (mg/m^3)
	5	9
	9	17
10	15	28
14	20	38
20	30	56
40	55	104

References:

Environmental Protection Agency. 1998. "Air Emissions Factors and Quantification: External Combustion Sources, Section 1.4 Natural Gas Combustion."

RTP Environmental Associates, Inc. 2013. "Ambient Ratio Method Version 2 (ARM2) for Use with AERMOD for 1-Hr NO2 Modeling."

BREEAM Refurbishment- Domestic Buildings. 2016. "Calculations." February 29, 2016. https://www.breeam.com/domrefurbmanual/content/13calculations/08pol01.htm.