RESEARCH REPORT

Life-cycle Environmental Impacts of the Canadian Residential Sector

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– Final Technical Report –

Submitted to:
Canada Mortgage and Housing Corporation (CMHC)

Submitted by:
Marbek Resource Consultants
in association with
Athena Sustainable Materials Institute
and
Jane Thompson Architect

August 31, 2007

This study was funded by Canada Mortgage and Housing Corporation (CMHC). The contents, views and editorial quality of this report are the responsibility of the authors and CMHC accepts no responsibility for them or any consequences arising from the reader's use of the information, materials and techniques described herein.

Marbek Resource Consultants Ltd.
222 Somerset Street West, Suite 300
Ottawa, Ontario, Canada K2P 2G3
Tel: 613-523-0784 Fax: 613-523-0717
www.marbek.ca

Athena Sustainable Materials Institute
28 St. John Street, Box 189
Merrickville, Ontario, Canada K0G 1N0
Tel: 613-269-3795 Fax: 613-269-3796
www.athenaSMI.ca

Jane Thompson Architect
1 Middleton Drive
Ottawa, Ontario, Canada K1M 1B8
Tel: 613-747-8104 Fax: 613-747-8396
jtarch@cyberus.ca

Table of Contents

List of Exhibits

EXECUTIVE SUMMARY

Many aspects of the residential built environment—where we live, what we build, how we build and operate our buildings, and how we move—have environmental impacts through their life cycles. Approximately 80 per cent of Canadians now live in urban areas, where development patterns include continued low-density development and increased densification. By 2025 Canada's expected population will require an estimated four million new dwelling units and incremental infrastructure. This study aimed to quantify and describe the life cycle resource use, environmental outputs and resulting environmental impacts of Canada's residential sector.

Approach

Life Cycle Stages and Relation to the Environment

This study analyzed the following life cycle stages:

- Extraction and manufacturing (non-operating): resource extraction—mining, harvesting—and transportation; refining or manufacturing of materials into components; and embodied impacts;
- On-site construction (non-operating): component transportation to building site, construction and embodied impacts;
- Indirect operating: upstream impacts of supplying operating services, such as extracting, refining, and delivering fuels and electricity for use during operation; and treating and delivering potable water for use during operation;
- Direct operating: direct impacts of operating a housing unit, such as energy and water use and production of wastewater and solid waste;
- Maintenance and replacement (non-operating): manufacturing, transport and on-site construction effects for materials and activities involved in the maintenance and replacement of a housing unit over its life (for example, repainting, window replacement, roofing replacement); and
- End-of-life (non-operating): deconstruction and demolition; reuse, recycling and disposal of materials.

Figure 1: Life cycle stages and relation to the environment

Figure 1 shows that each residential structure and activity in each life cycle stage:

- Requires resource use—resources such as primary fuels (that is, fossil fuels, nuclear fuels, biomass), water, land, and solids (that is, organics, minerals, metals);

- Releases environmental outputs—emissions and pollutants released into the air (such as. greenhouse gases [GHG], air contaminants), pollutants released into water (such as solids, chemical compounds), and soil (such as organic, mineral); and
- Results in environmental impacts—at the local, regional, and global scales, such as climate change and loss of habitat.

Scope and Exclusions

The study team developed a research and analysis framework, then modelled and analyzed the results for a 2004 and a 2025 scenario. The scope of analysis included:

- Residential sector structures and activities*:* existing, renovated, and new dwellings, by dwelling type; existing and new neighbourhood infrastructure, such as roads and waterworks; and residential transportation, by private vehicle and urban public transit;
- Life cycle stages: operating (both direct and indirect) and non-operating activities (extraction, manufacturing, transportation, construction, maintenance and replacement);
- Environmental impacts: resource use, environmental outputs, and resulting environmental impacts, attributed to the residential sector, where possible;
- Estimated impacts in 2004 and potential impacts by 2025 through a business-as-usual (BAU) scenario, utilizing national dwelling stock projections and intensification plans of three high-growth regions in Canada;
- End-use categories for energy and water (heating/cooling, domestic hot water); and
- Neighbourhood types.

There were numerous exclusions because of a lack of available, reliable data. The non-operating impact analysis excluded assessment of:

- Life cycles of existing dwellings and neighbourhood infrastructure, because non-operating environmental impacts had already been incurred when the elements were first constructed;
- Maintenance and replacement impacts for existing dwellings, buildings, and infrastructure;
- Dwelling or infrastructure renovation impacts;
- Demolition and reuse/recycling/disposal impacts; and
- Regional variations.

The operating impact analysis excluded assessment of:

- Consumer goods and services (for example, food, non-food items, packaging);
- Certain pollutants from dwellings (for example, daily solid waste production); and
- Certain residential transportation vehicles and transportation modes.

Areas of Analysis

The study used a wide range of methodologies and models within the following areas:

- Dwelling stock: This analysis developed a portrait of dwelling stock, by four dwelling types: single-detached, row/town, low-rise multi-unit residential building (MURB) units, and high-rise MURB units. The portrait was based on stock projections from Natural Resources Canada's (NRCan) *Canada's Energy Outlook: The Reference Case 2006* [1]—

[1] Natural Resources Canada, *Canada's Energy Outook: The Reference Case 2006,* English and French, retrieved July 2008 from http://www.nrcan-rncan.gc.ca/com/resoress/publications/peo/peo-eng.php

the best available source of data at the time of the study—and Statistics Canada's 2001 Census data, as well as regional data where possible.

- Neighbourhoods: This analysis characterized physical attributes of three neighbourhood archetypes that best represented most existing and new Canadian neighbourhoods (*see* table 1). Key data sources were: Statistics Canada's 2001 Census, interviews with municipal planners in three high-growth regional areas and Ottawa municipal land use data.

Type	Location	Density	Green space
Inner city	Core	High (35–46 dwellings/ha)	Limited
Inner suburb	Around core	Medium (16–19 dwellings/ha)	Moderate
Outer suburb	Perimeter	Low (4–5 dwellings/ha)	Considerable

Table 1: Summary of neighbourhood-type definitions

- Neighbourhood infrastructure: Using the three neighbourhood archetypes, the analysis calculated the amount of residential road and accompanying in-ground water infrastructure required to increase density in existing neighbourhoods and build new neighbourhoods. Key data sources were CMHC's *Life Cycle Costing Tool* [2] and background report, as well as a road construction consultant who prepared material quantity dimension estimates and construction-related energy use by activity for various infrastructure elements.
- Non-operating effects from new dwellings and linear infrastructure (roads, water, sanitary and storm sewer): Using the ATHENA Institute's ATHENA® *Impact Estimator for Buildings* [3]and supporting life cycle data, the analysis developed resource use and environmental output indicators by dwelling and by length of infrastructure, for each non-operating stage, based upon four dwelling archetypes and four infrastructure archetypes. The analysis then multiplied these per-dwelling and per-kilometre figures by the total number of new dwellings (by dwelling type) and total kilometres of new neighbourhood infrastructure (by infrastructure type).
- Municipal water system demand to service dwellings: This analysis used Marbek's *Residential Sector Water End-use Model* to estimate annual water use and wastewater production resulting from daily habitation and operation of dwellings, including activity and market penetration levels for water-using technologies for different end uses, and resulting water use per dwelling, by dwelling type. Key data sources were NRCan and Statistics Canada water use data from Canadian and North American surveys and audits, as well as Marbek's in-house database of residential water use characteristics.
- Direct operating energy for dwellings: Using NRCan's *Comprehensive Energy Use Database,* this analysis was based upon a similar Marbek model and completed in a similar fashion to the water analysis.

[2] For more information, see "Life Cycle Costing Tool for Community Infrastructure Planning," CMHC socio-economic series Research Highlight 08-001.

[3] ATHENA Institute, *The Impact Estimator for Buildings* English, retrieved July 2008 from http://www.athenasmi.org/tools/impactEstimator/index.html

- Direct operating energy for municipal water systems: Based upon municipal energy use statistics, this analysis used energy intensities by fuel type to determine energy used by municipal water systems to treat and distribute potable water to dwellings and to collect and treat dwelling wastewater.
- Direct operating energy for residential transportation: Using CMHC's *Greenhouse Gas Emissions from Urban Travel Tool,*[4] the 2001 Toronto *Transportation Tomorrow Survey* [5] and Transport Canada's 2004 *Canadian Vehicle Survey,* [6] this analysis estimated vehicle kilometres travelled per dwelling for personal vehicles and passenger kilometres travelled per dwelling for public transportation, all by neighbourhood types. NRCan's 2006 *Canada's Energy Outlook* was then used to identify total annual operating energy in Canada by fuel type for Light Duty Vehicles and Public Transit, to determine private vehicle and public transit fuel use per dwelling by neighbourhood type.
- Indirect effects of operating energy use: Again, using the ATHENA Institute's ATHENA® *Impact Estimator for Buildings* life cycle assessment model, this analysis estimated the indirect resource use and environmental outputs from extracting, refining, and delivering operating energy (that is, refined petroleum products, electricity). It developed coefficients of resource use and environmental outputs to provide each fuel used to operate dwellings, municipal water systems, and residential transportation, which were then multiplied by total operating fuel use to calculate the indirect effects of using fuels.
- Resulting environmental impacts: This analysis relied on a qualitative approach informed by the study's quantitative results and supported by data in available literature, to attribute—as much as possible—environmental impacts to the residential sector.

Framework of Analysis

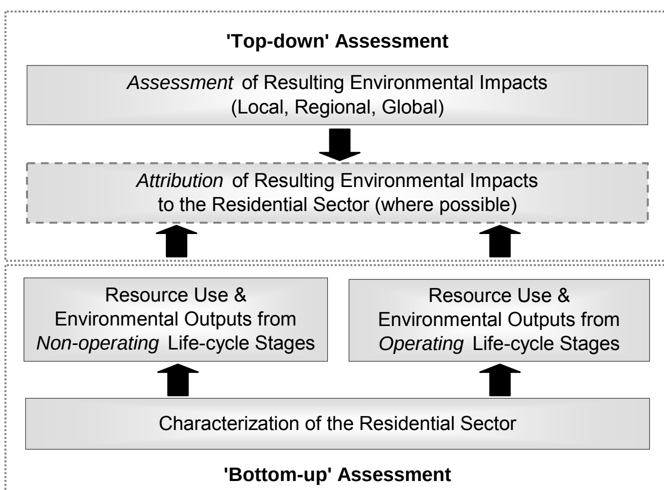

Figure 2: Overall study approach

[4] For more information, see "Greenhouse Gas Emissions from Urban Travel: Tool for Evaluating Neighbourhood Sustainability / Émissions de gaz à effet de serre attribuables aux déplacements urbains: Outil d'évaluation de la durabilité des quartiers" CMHC Research Report, Ottawa, 2000

[5] Transportation Tomorrow Survey at http://www.jpint.utoronto.ca/ttshome/. English, retrieved July, 2008.

[6] Transport Canada, *Canadian Vehicle Survey,* English and French, retrieved July 2008 from http://www.tc.gc.ca/pol/en/aca/cvs/menu.htm

The bottom-up assessment of resource use and environmental outputs profiled the physical characteristics of the residential sector during the study period, including required dwellings and neighbourhood infrastructure. This assessment then calculated resource use and environmental outputs for operating and non-operating life cycle stages.

A more qualitative top-down assessment descriptively bridged the gap between the analytical results (that is, resource use and environmental outputs) and the resulting environmental impacts seen locally, regionally, and globally. Attribution at these scales was challenging, due to the complex, inter-related, non-linear nature of environmental impacts, which are difficult to attribute to individual sectors or sources.

Building the Business-as-Usual (BAU) Scenario to 2025

The study built a BAU scenario to reflect anticipated patterns of urban development using established projections of number and type of new dwellings and their associated land use. The BAU scenario merged national dwelling projections with intensification plans of high-growth Census Metropolitan Areas (CMAs). However, high-growth CMAs had different visions of future development patterns than those of independently determined dwelling stock projections.

The study incorporated municipal planners' expectations of neighbourhood development patterns in three of Canada's highest-growth CMAs: British Columbia's lower mainland (including Metro Vancouver/Greater Vancouver Regional District) and Vancouver Island; the Calgary–Edmonton corridor; and Ontario's Golden Horseshoe. [7] Intensification plans for these CMAs had begun to be implemented to a greater extent than in the past, as evidenced by an increasing percentage of low-rise and high-rise condominiums being built in existing neighbourhoods during 2003 to 2007.

This study's BAU scenario assumed that these intensification plans will be fully met. The implication of such an assumption is that urban areas in Canada would become intensified in terms of population density, housing density, efficiency of infrastructure provision and other factors. More specifically, discussion with municipal planners in the high-growth CMAs indicated expected densification of existing urban areas through:

- Significant low-rise and high-rise multi-unit construction;
- Conversion of some existing urban green space to housing; and
- Redevelopment of some brownfields to dense housing.

The study used the best available long-term housing stock projection, at its time: Canada's *Canada's Energy Outlook: The Reference Case 2006*. It shows a higher share of single-detached houses being built during 2004–2025 than is anticipated by Canada's high-growth CMAs. These projections are driven by assumptions of economic growth, but do not adequately reflect the likely evolution of urban intensification in Canada's CMA growth clusters or the resulting growth in construction of the higher-density dwelling types (that is, low-rise and high-rise MURBs) required to meet these expected intensification plans.

[7] The Golden Horseshoe is the area around the western end of Lake Ontario, stretching from Niagara Falls to Hamilton at the west end of Lake Ontario and east through the Greater Toronto Area to Oshawa. The population of the area is 8.1 million.

Results

The study's findings and implications attempt to answer the three high-level questions for the 2004–2025 study period:

- Which residential sector life cycle stages would have the greatest environmental impact?
- How would housing and neighbourhood development patterns be expected to evolve?
- How would choices of neighbourhood, dwelling, and dwelling operation affect the environment?

Key Findings

The following are the five most significant study findings.

- Operating stage would dominate overall environmental impacts. When total resource use and environmental outputs are taken into account, the operating stage of the housing life cycle would produce 60 to 95 per cent of total life cycle energy use, water use, greenhouse gas emissions (*see* figure 3), air contaminants, water pollution, and solid waste.

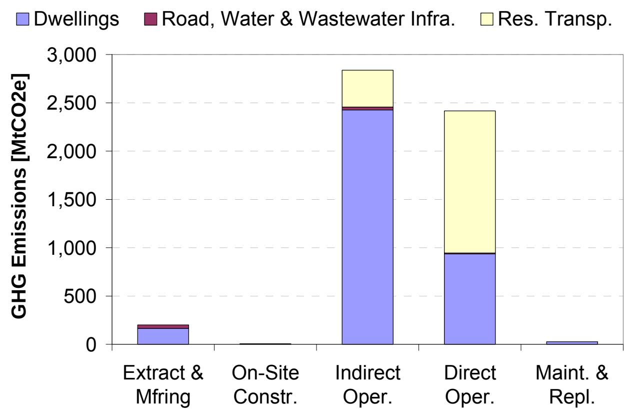

Figure 3: Life cycle greenhouse gas emissions by the residential sector 2004–2025, by life cycle stage and structure/activity

- Compared to other dwelling types, single-detached houses would have significantly higher environmental impacts, per dwelling. On a per-dwelling basis, a new single-detached house would require 1.3 to 2 times the life cycle resources (*see* figure 4). It would also produce 1.5 to 4 times the life cycle emissions and pollutants of other dwelling types. These environmental outputs could be assumed to result in higher environmental impacts than other dwelling types.

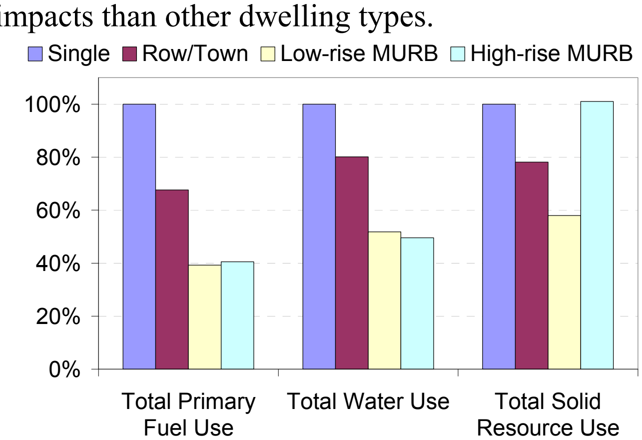

Figure 4: Life cycle resource use per new dwelling 2004–2025, by dwelling type, normalized to single detached

- Compared with other neighbourhood types, outer suburbs would have significantly higher environmental impacts, per dwelling. On a per-dwelling basis, an average new dwelling in an outer suburb would require 1.2 to 2.5 times the life cycle resources (*see* figure 5). It would also produce 1.1 to 2 times the life cycle emissions and pollutants of an average new dwelling in other neighbourhood types. Considering the number of dwellings per neighbourhood and the number of neighbourhoods of each type in Canada, outer suburbs would require about five times the life cycle resource use, and produce about five times the environmental outputs as inner suburbs and inner city neighbourhoods combined.

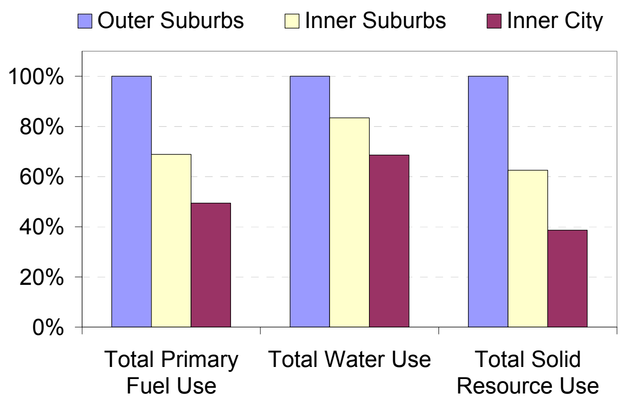

Figure 5: Life cycle residential sector resource use per average new neighbourhood dwelling 2004–2025, by neighbourhood type, normalized to outer suburbs

- Reductions in environmental impacts would be limited unless existing dwelling stock is addressed. Of the 16 million dwellings projected for 2025, 75 per cent had already been built by 2004. As such, the study results have smaller sensitivity to the possible variations in the distribution of new dwellings by type, since most of the impacts from dwelling operation in 2025 would be from existing, rather than new dwellings.
- Four CMA regional growth clusters would attract most new housing. Most of the new dwellings required would be built in four high-growth regions: British Columbia's lower mainland and Vancouver Island; the Edmonton-Calgary corridor; Ontario's Golden Horseshoe region and the Montréal region. Between 1996 and 2001, population growth was roughly ten times higher in these regions compared to the rest of Canada, resulting in more than 50 per cent of Canadians calling them home in 2001. This trend is expected to continue (see Table 2).

2004–2025 indicator	Neighbourhood type		
	Inner city	Inner suburb	Outer suburb
% Increase in total dwelling stock *	33%	33%	31%
% Increase densification of existing neighbourhoods †	28%	16%	31%
# Existing 50 ha (124 acres) neighbourhoods as of 2004 ‡	619	1,994	47,104
# New dwellings to be built in densified existing neighbourhoods	310,000	250,000	2,930,000
# Remaining new dwellings to be built in dense new neighbourhoods	343,000		
# Resulting new 50 ha neighbourhoods to be built	330		

* Based on methodology in Section 2, using dwelling stock growth from NRCan's *Canada's Energy*

Outlook: The Reference Case 2006
† Based on projections from municipal officials in high-growth regions
‡ Neighbourhood size of 50 ha arbitrarily chosen

Table 2: Comparison of dwelling stock growth to neighbourhood densification 2004–2025, by neighbourhood type

Other Significant Impacts

The following are further major findings and implications.

Residential Dwellings, Neighbourhoods and Neighbourhood Infrastructure:

- Higher-density existing neighbourhoods, especially existing outer suburbs, would absorb most new housing. Assuming intensification plans are realized, the CMA growth clusters expect existing neighbourhoods within their jurisdictions to become 16 to 33 per cent denser, so these neighbourhoods would absorb about 90 per cent of new dwellings. Based on these trends and dwelling stock projections, existing outer suburbs would absorb roughly 75 per cent of 3.8 million new homes built.
- Most new neighbourhood infrastructure would be needed to densify residential areas in existing inner city and inner suburb neighbourhoods. Based on high-growth region densification estimates, over 90 per cent of new road and water infrastructure would be used in existing neighbourhoods, while the remainder would be used to build new neighbourhoods.

Overall Resource Use and Environmental Outputs:

- Operation of dwellings and residential transportation would dominate life cycle energy use. Dwelling operating energy (direct and indirect) would account for over 50 per cent and residential transportation operating energy (direct and indirect) for almost 45 per cent of the total life cycle primary energy use of the residential sector.
- Impacts of dwelling direct operating energy would be exacerbated by upstream environmental impacts. Every unit of fuel or water consumed "inside the meter" at dwelling premises or in vehicles would have already required sizeable upstream energy for extraction, production and delivery of these commodities.

Air

- Dwelling and residential transportation operation would dominate life cycle air emissions. Residential sector life cycle GHG emissions would be roughly 5,500 Mt (5,400,000,000 tons) of carbon dioxide-equivalent ($MtCO_2e$). Over 95 per cent of this (65 per cent for dwelling operation and 35 per cent for transportation operation) would be generated during the operating stage of the life cycle. In contrast, transportation operation would almost entirely dominate criteria air contaminants, due to carbon monoxide emissions from mostly gasoline-powered private vehicles.

Water

- Dwelling water use would continue to dominate life cycle water use. Canada's per-capita annual water consumption is very high, at 65 per cent above the OECD average; so, it is not surprising that dwelling operation would account for over 80 per cent of total life cycle water use of the residential sector.
- Annual water use in existing dwellings would decline, but total water use would still increase. Although existing housing stock would see a decline of 20 per cent with

improved plumbing fixtures due to kitchen and bathroom renovations, the increase in new dwelling stock would more than make up the difference, resulting in a 13 per cent increase.

- Residential sector would have significant impact on aquatic environments. Urban treatment infrastructure, such as sewer systems, only partially address water quality. Secondary treatment is a biological process. It not designed to remove all wastewater contaminants or to address all pollutants associated with the 30 to 50 per cent of urban stormwater and snowmelt converted to surface runoff.

Land and Soil

- Extraction and manufacturing would dominate life cycle solid resource use. About 60 per cent of solids would be used for construction of roads and residential water and wastewater infrastructure, with the remaining 40 per cent going to construction of dwellings.
- Indirect operating stage would dominate life cycle solid waste production. With municipal solid waste from dwelling operation aside, most life cycle solid waste would be generated from indirect operating impacts, from extracting, refining, and combusting coal and other fossil fuels for electricity generation.
- Land impermeability would increase, with implications for air and water quality. As a result of development, roughly 45 per cent of urban land would be classified as impermeable, leading to fundamental urban water cycle changes, as well as exacerbation of the "heat island" effect which, in turn, could produce secondary effects on local wind patterns, clouds and fog, lightning strikes, rates of precipitation, and smog.

Integrated Local, Regional and Global Consequences:

- The magnitude of environmental outputs to air, water, soils and land alterations of the residential sector would be significant enough that they can be expected to contribute to broader environmental impacts including acid rain, smog, climate change, biodiversity decline, and Arctic contamination. Table 3 shows examples of these links. The degree of impact is difficult to assess given the scale and non-linearity of the impacts and interdependent roles of other sectors and activities in contributing to environmental impacts.

Resulting environmental impact	Environmental outputs *causing* the impact			Media and inhabitants *affected*			
	Air emissions	Water pollution	Land alteration and soil pollution	Air	Water	Soil	Biota (living organisms)
Local impacts							
Air quality impairment	√			√			√
Surface water quality impairment		√	√		√	√	√
Ground water quality impairment		√	√		√	√	√
Heat island effect	√		√	√			√
Regional impacts							
Smog	√			√	√		√
Acid rain	√			√	√	√	√
Water ecosystems altered or lost and land ecosystem fragmentation		√	√		√	√	√
Impacts on wildlife	√	√	√				√
Global impacts							

Climate change	√			√	√	√	√
Biodiversity decline	√	√	√				√
Systems response to regional contamination	√	√		√	√	√	√
Note: "√" means a relevant linkage exists							

Table 3: Example linkages between environmental outputs and environmental impacts

This study represents an ambitious first attempt at exploring the use of life cycle principles to assess the environmental impacts of an entire sector, within the Canadian context. Its findings concur with the results anticipated by life cycle assessment practitioners, helping make the concepts of life cycle impacts more accessible by exploring a sector intimately familiar to most: the residential sector. The empirical work from this study will help Canadian and foreign stakeholders plan further research and explore appropriate solutions to address the residential sector's increasing environmental impact.

Résumé

Bien des aspects de l'environnement bâti résidentiel – les lieux où nous vivons, nos types de logements, les modes de construction et d'occupation de nos bâtiments et nos modes de déplacement – ont des répercussions sur l'environnement tout au long de leurs cycles de vie. Environ 80 % des Canadiens vivent maintenant dans des zones urbaines, où les modèles d'aménagement comportent encore des quartiers à faible densité, mais aussi des secteurs à plus grande densification. D'ici 2025, on prévoit qu'il faudra construire quatre millions de nouveaux logements et l'infrastructure d'appoint pour répondre aux besoins de la population du Canada. La présente étude vise à quantifier et à décrire, pour l'ensemble du cycle de vie, l'utilisation qui est faite des ressources, les extrants environnementaux produits et les impacts sur l'environnement qui s'ensuivent dans le secteur résidentiel du Canada.

Méthode

Étapes du cycle de vie et lien avec l'environnement

Les chercheurs ont analysé les étapes du cycle de vie suivantes :

- extraction et fabrication (non liées à l'occupation) : extraction des ressources – exploitation minière et forestière – et transport; raffinage ou fabrication de matériaux à titre de composants; incidences intrinsèques;
- construction sur le chantier (non liée à l'occupation) : transport des composants au chantier, construction et incidences intrinsèques;
- occupation indirecte : incidences en amont de la fourniture de services liés à l'occupation, comme l'extraction, le raffinage et la fourniture des combustibles et de l'électricité qui seront utilisés pendant l'occupation; le traitement et la fourniture de l'eau potable qui sera utilisée pendant l'occupation;
- occupation directe : incidences directes de l'occupation d'un logement, par exemple, la consommation d'eau et d'énergie et la production d'eaux usées et de déchets solides;
- entretien et remplacement (non liés à l'occupation) : incidences de la fabrication, du transport et de la construction sur le chantier liées aux matériaux et activités inhérents à l'entretien et au remplacement d'un logement au cours de sa vie utile (par exemple, nouvelle peinture, remplacement des fenêtres, remplacement de la toiture);
- fin de la durée de vie (non liée à l'occupation) : déconstruction et démolition; réutilisation, recyclage et élimination des matériaux.

(Terms for Figure 1)

extraction & manufacturing	Extraction et fabrication
on-site construction	Construction sur le chantier
operating (direct & indirect)	Occupation (directe et indirecte)
maintenance & replacement	Entretien et remplacement
End-of-life	Fin de la durée de vie
Resource Use	Utilisation des ressources
Emissions & pollutants	Émissions et polluants
Environmental impacts	Impacts environnementaux

Figure 1 : Étapes du cycle de vie et lien avec l'environnement

La Figure 1 illustre que tous les bâtiments résidentiels et toutes les activités qui y sont liées, à chaque étape du cycle de vie :

- consomment des ressources – notamment des combustibles primaires (combustibles fossiles, combustibles nucléaires, biomasse), de l'eau, de la terre et des solides (composés organiques, minéraux, métaux);
- rejettent des extrants dans l'environnement – émissions et polluants rejetés dans l'air (gaz à effet de serre [GES], contaminants atmosphériques), rejets de polluants dans l'eau (solides, composés chimiques) et dans le sol (organiques, minéraux);
- ont des impacts sur l'environnement – à l'échelle locale, régionale et mondiale (changement climatique et perte d'habitats).

Portée et exclusions

L'équipe de chercheurs a élaboré un cadre de recherche et d'analyse, puis a modélisé et analysé les résultats pour un scénario de 2004 et de 2025. L'analyse a porté sur :

- les structures et activités résidentielles : logements existants, rénovés et nouvellement construits, par type de logement; infrastructure des quartiers existants et nouveaux (voies de circulation et réseau de distribution d'eau); transport privé et public des résidents;
- étapes du cycle de vie : activités liées à l'occupation (directes et indirectes) et non liées à l'occupation (extraction, fabrication, transport, construction, entretien et remplacement);
- impacts environnementaux : utilisation des ressources, extrants environnementaux et impacts sur l'environnement attribués au secteur résidentiel, dans la mesure du possible;
- impacts estimés en 2004 et potentiels d'ici 2025, avec un scénario fondé sur le maintien du *statu quo* (MSQ), en utilisant les prévisions nationales relatives au parc de logements et les plans de densification de trois régions du Canada en forte croissance;
- catégories de l'utilisation finale de l'énergie et de l'eau (chauffage/climatisation, chauffe-eau domestique);
- types de quartiers.

Bien des éléments ont été exclus de l'étude, à cause d'un manque de données ou de données fiables. Ainsi, l'analyse des impacts non liés à l'occupation n'a pas tenu compte des éléments suivants :

- les cycles de vie des logements existants et de l'infrastructure des quartiers, parce que les impacts environnementaux non liés à l'occupation s'étaient déjà produits au moment de la construction initiale des éléments;

- les impacts liés à l'entretien et au remplacement pour les logements, les bâtiments et l'infrastructure existants;
- les impacts de la rénovation des logements ou de l'infrastructure;
- les impacts de la démolition et de la réutilisation, du recyclage ou de l'élimination;
- les variations régionales.

L'analyse des impacts liés à l'occupation n'a pas tenu compte des éléments suivants :
- biens et services de consommation (par exemple, aliments, articles non alimentaires, emballages);
- certains polluants provenant des logements (par exemple, la production quotidienne de déchets solides);
- certains véhicules de transport des résidents et certains modes de transport.

Domaines d'analyse

Les chercheurs ont eu recours à divers modèles et méthodes dans les domaines suivants :
- Parc de logements : cette analyse a dressé un portrait du parc de logements divisé en quatre types de logement : maisons individuelles, maisons en rangée, petits collectifs d'habitation et tours d'habitation. Le portrait est basé sur les prévisions de Ressources naturelles Canada (RNCan) quant au nombre de logements, dans son rapport *Perspectives énergétiques du Canada : scénario de référence de 2006* [8] – la meilleure source d'information disponible au moment de l'étude – et les données du Recensement de 2001 de Statistique Canada, de même que diverses données régionales, dans la mesure du possible.
- Quartiers : cette analyse a déterminé les caractéristiques physiques de trois quartiers typiques qui illustrent le mieux la plupart des quartiers nouveaux et existants du Canada (*voir* le tableau 1). Les données analysées proviennent principalement du Recensement de 2001 de Statistique Canada, d'entrevues avec des urbanistes municipaux de trois régions à forte croissance et des données sur l'utilisation du sol de la ville d'Ottawa.

Type	Emplacement	Densité	Espaces verts
Zone centrale	Noyau urbain	Élevée (35–46 logements/ha)	Limités
Banlieue proche	Autour du noyau urbain	Moyenne (16–19 logements/ha)	Modérés
Banlieue lointaine	Périmètre	Faible (4–5 logements/ha)	Considérables

Tableau 1 : Sommaire des définitions des types de quartier

- Infrastructure de quartier : dans le cadre de cette analyse, les chercheurs ont calculé pour les trois types de quartier la quantité de voies de circulation résidentielles et de réseaux d'eau et d'égouts nécessaires pour augmenter la densité de quartiers existants et pour en construire de nouveaux. Les principales données ont été tirées de l'*Outil de calcul des*

[8] Ressources naturelles Canada, *Perspectives énergétiques du Canada : scénario de référence de 2006,* français et anglais, consulté à l'adresse http://www.nrcan-rncan.gc.ca/inter/pdf/outlook2006_f.pdf en juillet 2008.

coûts du cycle de vie [9] de la SCHL et du rapport documentaire connexe, de même que sur les estimations des quantités de matériaux et de la consommation énergétique reliée à la construction, par activité, pour divers éléments d'infrastructure. Ces estimations ont été préparées par un consultant en construction de voies de circulation.

- Les incidences des nouveaux logements et de l'infrastructure linéaire (routes, eau, réseaux d'égouts sanitaires et pluviaux) non liées à l'occupation : cette analyse a été réalisée à l'aide de l'ATHENA® *Impact Estimator for Buildings* [10]de l'ATHENA Institute et des données complémentaires sur le cycle de vie. Elle a permis de créer des indicateurs sur l'utilisation des ressources et les extrants environnementaux, par logement et par longueur de l'infrastructure, pour chaque étape non liée à l'occupation, en fonction de quatre types de logement et quatre types d'infrastructure. Les résultats par logement et par kilomètre ont ensuite été multipliés par le nombre total de nouveaux logements (par type de logement) et le nombre total de kilomètres de nouvelles infrastructures de quartier (par type d'infrastructure).
- Demande en réseaux municipaux d'eau et d'égouts pour desservir les logements : cette analyse a été réalisée à l'aide du *Residential Sector Water End-use Model* de Marbek pour estimer la consommation d'eau et la production d'eaux usées annuelles découlant de l'occupation quotidienne des logements, en tenant compte des niveaux d'utilisation et de pénétration du marché des technologies de gestion de l'eau pour différentes utilisations finales, et de la consommation d'eau correspondante par logement et par type de logement. Les données de cette analyse proviennent principalement de RNCan et des données de Statistique Canada sur la consommation d'eau établies à partir de sondages et de vérifications effectués au Canada et en Amérique du Nord, de même que de la base de données de Marbek sur les caractéristiques de la consommation d'eau en milieu résidentiel.
- Consommation d'énergie des logements liée à l'occupation directe : cette analyse a été réalisée à l'aide de la *Base de données complète sur la consommation d'énergie* de RNCan, et fondée sur un modèle semblable de Marbek. Elle a été réalisée sensiblement de la même façon que l'analyse de la consommation d'eau.
- Consommation d'énergie des réseaux d'eau et d'égouts des municipalités liée à l'occupation directe : à partir de statistiques municipales sur la consommation d'énergie, cette analyse a utilisé les intensités énergétiques par type de combustible pour déterminer la consommation d'énergie des réseaux municipaux d'eau et d'égouts servant à traiter et à distribuer l'eau potable aux logements et à recueillir et à traiter leurs eaux usées.
- Consommation d'énergie liée à l'occupation directe pour le transport des résidents : à l'aide de la publication *Émissions de gaz à effet de serre attribuables aux déplacements urbains : Outil d'évaluation de la durabilité des quartiers,*[11]de la SCHL, de la *Transportation Tomorrow Survey* [12] de Toronto, pour 2001, et de l'*Enquête sur les*

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[9] Pour de plus amples renseignements, voir « Outil d'analyse des coûts du cycle de vie pour la planification d'infrastructures », Le Point en recherche de la SCHL, série socio-économique, 08-001.

[10] ATHENA Institute, *The Impact Estimator for Buildings*, en anglais, consulté en juillet 2008 à l'adresse http://www.athenasmi.org/tools/impactEstimator/index.html

[11] Pour de plus amples renseignements, voir « Émissions de gaz à effet de serre attribuables aux déplacements urbains : Outil d'évaluation de la durabilité des quartiers », Rapport de recherche de la SCHL, Ottawa, 2000

[12] Transportation Tomorrow Survey, à http://www.jpint.utoronto.ca/ttshome/. En anglais, consulté en juillet 2008.

véhicules au Canada [13] pour 2004, de Transports Canada, cette analyse a permis d’estimer le nombre de kilomètres parcourus en véhicule, pour les véhicules personnels, et le nombre de kilomètres parcourus par les passagers du transport public, par logement et par type de quartier pour les deux analyses. Les *Perspectives énergétiques du Canada : scénario de référence de 2006* de RNCan ont ensuite servi à déterminer la consommation d'énergie annuelle totale liée à l’occupation au Canada, par type de combustible, pour les véhicules légers et le transport en commun, afin de déterminer la consommation de combustible, par les véhicules privés et de transport en commun, en fonction du type de quartier.

- Incidences indirectes de la consommation d'énergie liée à l’occupation : cette analyse, qui a également été réalisée à l’aide du modèle d’évaluation du cycle de vie ATHENA® *Impact Estimator for Buildings* de l’ATHENA Institute, a permis d’estimer la consommation indirecte de ressources et les extrants environnementaux liés à l’extraction, au raffinage et à la fourniture de l’énergie d’occupation (c’est-à-dire, les produits de pétrole raffinés, l’électricité). L’analyse a aussi permis d'élaborer des coefficients de l’utilisation des ressources et des extrants environnementaux liés à la fourniture du combustible servant à l’occupation des logements, au fonctionnement des réseaux d'eau et d’égouts et au transport des résidents, qui ont ensuite été multipliés par la consommation totale de combustible liée à l’occupation afin de calculer les incidences indirectes de l’utilisation des combustibles.
- Impacts sur l'environnement : cette analyse s’est basée sur une approche qualitative fondée sur les résultats quantitatifs de l’étude et appuyée par des données puisées dans des documents disponibles, pour attribuer – dans la mesure du possible – les impacts environnementaux au secteur résidentiel.

Cadre de l’analyse

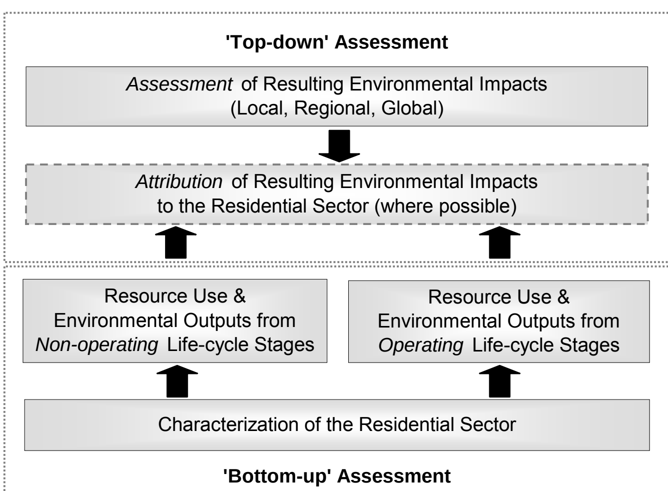

Figure 2 : Méthode d’étude globale

Évaluation « descendante »
Évaluation des impacts environnementaux (locaux, régionaux, mondiaux)

[13] Transport Canada, *Enquête sur les véhicules au Canada,* en français et en anglais, consulté en juillet 2008 à http://www.tc.gc.ca/pol/fr/aca/evc/menu.htm

Attribution des impacts environnementaux au secteur résidentiel (dans la mesure du possible)
Utilisation des ressources et extrants environnementaux des étapes du cycle de vie *non liées à l'occupation*
Utilisation des ressources et extrants environnementaux des étapes du cycle de vie *liées à l'occupation*
Caractérisation du secteur résidentiel
Évaluation « ascendante »

L'évaluation ascendante de l'utilisation des ressources et des extrants environnementaux a permis de déterminer les caractéristiques physiques du secteur résidentiel durant la période étudiée, y compris les logements et l'infrastructure de quartier nécessaires. Cette évaluation a servi ensuite à calculer l'utilisation des ressources et les extrants environnementaux des étapes du cycle de vie liées et non liées à l'occupation.

Une évaluation descendante plus qualitative a permis de combler de façon descriptive l'écart entre les résultats analytiques (c'est-à-dire l'utilisation des ressources et les extrants environnementaux) et les impacts environnementaux qui en découlent à l'échelle locale, régionale et mondiale. L'attribution de ces impacts à des sources ou à des secteurs en particulier et à une échelle donnée a posé de grandes difficultés, en raison de la complexité des impacts environnementaux, de leurs interrelations et de leur nature non linéaire.

Création du scénario de maintien du *statu quo* (MSQ) jusqu'à 2025
Les chercheurs ont créé un scénario MSQ pour tenir compte des modèles prévus de développement urbain en utilisant les prévisions établies concernant le nombre et le type de nouveaux logements et l'utilisation du territoire correspondante. Le scénario MSQ a intégré les prévisions nationales en matière de logement et les plans de densification de régions métropolitaines de recensement (RMR) à forte croissance. Toutefois, les modèles de développement futur prévus par les RMR à forte croissance différaient des prévisions déterminées par les études indépendantes quant au parc de logements.

L'étude a intégré les attentes des urbanistes municipaux par rapport aux modèles de développement des quartiers dans trois des RMR du Canada ayant la plus forte croissance : la vallée du bas Fraser de la Colombie-Britannique (comprenant la grande région de Vancouver) et l'île de Vancouver; le corridor Calgary-Edmonton, et le Golden Horseshoe de l'Ontario[14]. Ces RMR avaient commencé à accélérer la mise en œuvre de leurs plans de densification, comme le démontre le pourcentage plus élevé d'immeubles en copropriété de faible et de grande hauteur construits dans les quartiers existants de 2003 à 2007.

Le scénario MSQ de cette étude est fondé sur l'hypothèse de la mise en œuvre complète de ces plans de densification qui aurait notamment pour conséquence d'accroître la densité de population et de logements et l'efficacité de l'infrastructure en place et d'autres facteurs dans ces régions urbaines. Les urbanistes municipaux des RMR à forte croissance ont indiqué qu'ils prévoyaient une densification des régions urbaines existantes par :

[14] Le Golden Horseshoe est la région située à l'ouest du lac Ontario, qui s'étend de Niagara Falls à Hamilton du côté ouest du lac Ontario jusqu'à la région du Grand Toronto et Oshawa vers l'Est. Cette région compte 8,1 millions d'habitants.

- la construction d’un nombre important de collectifs d'habitation de faible et de grande hauteur;
- la conversion de certains espaces verts urbains en espaces résidentiels;
- le réaménagement de certaines friches industrielles en terrains résidentiels à densité élevée.

Les chercheurs ont utilisé la meilleure source d’information sur les prévisions de logements à long terme disponible au moment de leur étude, à savoir le document du gouvernement du Canada intitulé *Perspectives énergétiques du Canada : scénario de référence de 2006*. Selon ce rapport, il se construira plus de maisons individuelles de 2004 à 2025 que ce que prévoient les RMR à forte croissance du Canada. Ces prévisions sont fondées sur des hypothèses de croissance économique, mais ne rendent pas compte adéquatement de l’évolution probable de la densification urbaine dans les grappes de croissance des RMR du Canada, ni de l’augmentation du nombre de collectifs d'habitation de faible et de grande hauteur qui en découlera pour satisfaire aux plans de densification prévus.

Résultats

Les résultats et les incidences de l’étude tentent de répondre à trois questions d’importance pour la période allant de 2004 à 2025 :

- Quelles étapes du cycle de vie du secteur résidentiel auront le plus grand impact sur l'environnement?
- Comment évolueront les modèles d’habitation et d’aménagement des quartiers?
- Comment les choix en matière d’aménagement de quartiers, de logements et d’occupation de logements influeront-ils sur l’environnement?

Principales conclusions

Voici les cinq principales conclusions de l'étude :

- L'étape de l'occupation est celle qui aura les plus grands impacts globaux sur l'environnement. Lorsque l'on tient compte de la totalité des ressources utilisées et des extrants environnementaux produits, l'étape de l'occupation d'un logement est responsable de 60 à 95 % de la consommation d'eau et d'énergie, des émissions de gaz à effet de serre (*voir* la figure 3), des rejets de contaminants dans l'air, de la pollution de l'eau et de la production de déchets solides de ce logement pour l'ensemble de son cycle de vie.

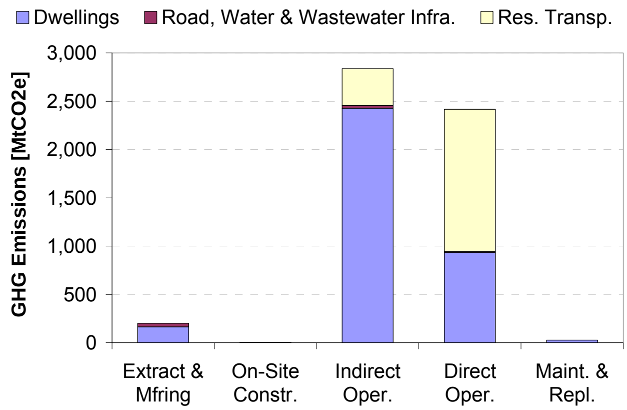

Figure 3 : Émissions de gaz à effet de serre du secteur résidentiel, de 2004 à 2025, par étape du cycle de vie et structure ou activité

Logements Routes, eau et égouts Transport des rés.
Extraction et fabr. Constr. au chantier Occ. indirecte Occ. directe Entr. et rempl.
3 000 2 500 2 000 1 500 1 000 500 0
Émissions de GES [MT éCO_2]

- Par rapport aux autres types de logement, les maisons individuelles auront des impacts beaucoup plus élevés, par logement. Une nouvelle maison individuelle nécessitera de 1,3 à 2 fois plus de ressources sur son cycle de vie (*voir* la figure 4). Elle produira également de 1,5 à 4 fois plus d'émissions et de polluants durant son cycle de vie que les autres types de logement. On peut présumer que ces extrants environnementaux auront des impacts sur l'environnement plus élevés que ceux des autres types de logement.

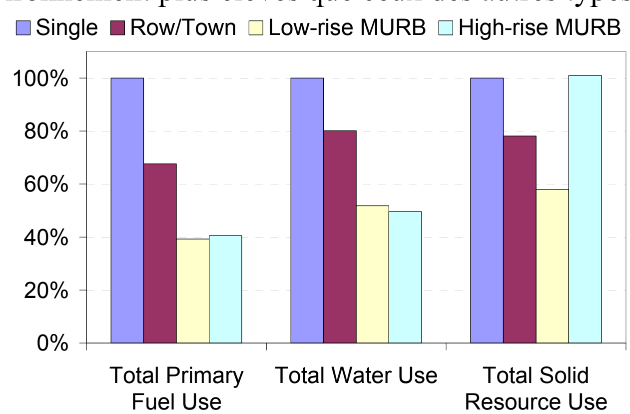

Figure 4 : Utilisation de ressources durant le cycle de vie, par nouveau logement de 2004 à 2025, par type de logement, normalisée par rapport à la maison individuelle isolée

Maison indiv. Maison en rangée Petit collectif Tour d'hab.
Cons. tot. de comb. primaires Cons. d'eau totale Util. tot. de ress. solides
100 % 80 % 60 % 40 % 20 % 0 %

- Par rapport aux autres types de quartier, les banlieues éloignées auront des impacts environnementaux beaucoup plus élevés, par logement. En moyenne, un nouveau logement d'une banlieue éloignée nécessitera de 1,2 à 2,5 fois plus de ressources durant son cycle de vie (*voir* la figure 5). Il produira également de 1,1 à 2 fois plus d'émissions et de polluants durant son cycle de vie que le nouveau logement moyen des autres quartiers. Vu le nombre de logements par quartier et le nombre de quartiers de chaque type au Canada, les banlieues éloignées consommeront environ cinq fois plus de ressources au cours de leur cycle de vie et produiront environ cinq fois plus d'extrants environnementaux que les quartiers des banlieues proches et les quartiers de zone centrale mis ensemble.

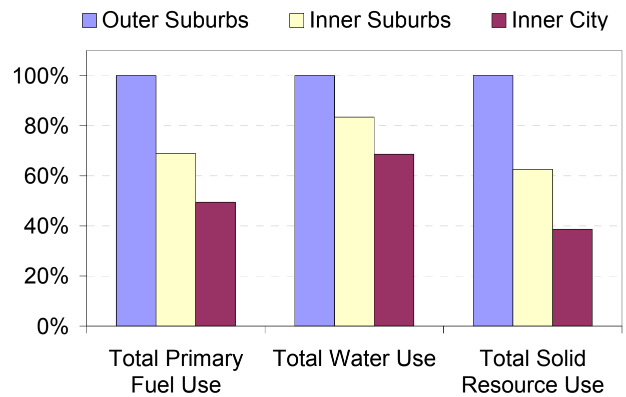

Figure 5 : Utilisation de ressources du secteur résidentiel durant son cycle de vie, par logement d'un nouveau quartier, de 2004 à 2025, par type de quartier, normalisée par rapport aux banlieues éloignées

Quartiers éloignés Quartiers proches Quartiers de zone centrale
Cons. tot. de comb. primaires Cons. d'eau totale Util. tot. de ress. solides
100 % 80 % 60 % 40 % 20 % 0 %

- Les réductions des impacts environnementaux seront limitées, à moins de prendre des mesures par rapport au parc de logements existants. Des 16 millions de logements prévus pour 2025, 75 % étaient déjà construits en 2004. Les résultats de l'étude sont moins sensibles aux variations possibles dans la distribution des nouveaux logements selon leur type, puisque la plupart des impacts découlant de l'occupation des logements en 2025 seront dus à des logements existants et non pas à de nouveaux logements.
- La plupart des nouveaux logements seront vraisemblablement concentrés dans des grappes de croissance régionales de quatre RMR : la vallée du bas Fraser de la Colombie-Britannique et l'île de Vancouver, le corridor Calgary-Edmonton, le Golden Horseshoe de l'Ontario et la région de Montréal. Entre 1996 et 2001, la croissance de la population a été environ dix fois plus élevée dans ces régions que dans le reste du Canada, de sorte que plus de 50 % des Canadiens y vivaient en 2001. On s'attend à ce que cette tendance se maintienne (voir le Tableau 2).

Indicateur 2004–2025	Type de quartier		
	Zone centrale	Banlieue proche	Banlieue éloignée
Augmentation du parc de logements total, en % *	33 %	33 %	31 %
Augmentation de la densification des quartiers existants, en % †	28 %	16 %	31 %
Nombre de quartiers de 50 ha (124 acres) en 2004 ‡	619	1 994	47 104
Nombre de nouveaux logements devant être construits dans des quartiers existants à forte densité	310 000	250 000	2 930 000
Nombre de nouveaux logements devant être construits dans de nouveaux quartiers denses	343 000		
Nombre de nouveaux quartiers de 50 ha devant être construits	330		

* Selon la méthodologie décrite à la section 2, en utilisant les données sur la croissance du parc de logements du document *Perspectives énergétiques du Canada : scénario de référence de 2006* de Ressources naturelles Canada
† Selon les prévisions des urbanistes municipaux des régions à forte croissance
‡ L'étendue physique des quartiers a été arbitrairement établie à 50 ha

Tableau 2 : Comparaison de la croissance du parc de logements par rapport à la densification des quartiers, de 2004 à 2025, par type de quartier

Autres incidences importantes

D'autres conclusions et incidences d'importance ont été tirées de l'étude.

Logements, quartiers et infrastructure de quartier :

- Les quartiers existants à densité plus élevée, particulièrement ceux des banlieues éloignées, accueilleront la plupart des nouveaux logements. En présumant que les plans de densification se réalisent, les grappes de croissance des RMR s'attendent à ce que la densité des quartiers actuels de leur région passe de 16 % à 33 %, de sorte que ces quartiers absorberont environ 90 % de tous les nouveaux logements. Selon ces tendances et les prévisions relatives au parc de logements, les banlieues éloignées existantes absorberont environ 75 % des 3,8 millions de nouveaux logements.
- La plus grande partie de la nouvelle infrastructure de quartier servira à densifier les secteurs résidentiels des zones centrales et des banlieues proches. Selon les estimations de la densification des régions à forte croissance, plus de 90 % des nouvelles voies de circulation et de la nouvelle infrastructure d'eau et d'égouts seront construites dans des quartiers existants, le reste l'étant dans les nouveaux quartiers.

Utilisation globale des ressources et extrants environnementaux :

- L'occupation des logements et le transport des résidents seront les principaux facteurs de consommation énergétique au cours du cycle de vie. L'énergie liée directement et indirectement à l'occupation des logements représentera plus de 50 % de la consommation d'énergie primaire durant le cycle de vie du secteur résidentiel et l'énergie liée directement et indirectement au transport des résidents en représentera près de 45 %.
- Les incidences de l'énergie liée à l'occupation directe des logements seront aggravées par les impacts environnementaux en amont. Chaque unité de combustible ou d'eau consommée par les logements ou par les véhicules aura déjà nécessité une énergie assez considérable en amont pour l'extraction, la production et la livraison de ces matières premières.

Air

- L’occupation des logements et le transport des résidents seront les principaux responsables des rejets atmosphériques durant le cycle de vie. Les émissions de GES durant le cycle de vie du secteur résidentiel seront d’environ 5 500 Mt (5 400 000 000 tonnes) d’équivalent en dioxyde de carbone (Mt éCO_2). Plus de 95 % de ces émissions (65 % pour l’occupation des logements et 35 % pour le transport) seront générées durant l’étape d’occupation du cycle de vie. Cependant, le transport sera presque entièrement responsable de la contamination de l’air, à cause des émissions de monoxyde de carbone des véhicules privés généralement alimentés à l’essence.

Eau

- La consommation d’eau par les logements continuera de dominer la consommation d’eau au cours du cycle de vie. La consommation d’eau annuelle par habitant est très élevée au Canada. Elle est 65 % plus élevée que la consommation moyenne des pays de l’OCDE. Il n’est donc pas étonnant que la consommation d’eau à l’étape de l’occupation des logements représentera plus de 80 % de la consommation d’eau totale durant le cycle de vie du secteur résidentiel.
- La consommation d’eau annuelle dans les logements existants diminuera, mais la consommation totale continuera d’augmenter. Bien que la consommation des logements existants diminuera de 20 % grâce aux rénovations des cuisines et salles de bains et à l’installation d’appareils sanitaires plus performants, l’augmentation du nombre de logements fera en sorte que l’augmentation globale de la consommation s’établira à 13 %.
- Le secteur résidentiel aura des incidences importantes sur les milieux aquatiques. Les installations municipales de traitement de l’eau, comme les réseaux d’assainissement, ne résolvent qu’en partie la problématique de la qualité de l’eau. Le traitement secondaire est un processus biologique. Il n’est pas conçu pour éliminer tous les contaminants des eaux usées ni pour éliminer tous les polluants associés aux 30 à 50 % d’eaux pluviales et d’eaux de fonte urbaines qui se transforment en eaux de ruissellement.

Sol et terrain

- L’extraction et la fabrication seront les principaux facteurs d’utilisation des ressources solides durant le cycle de vie. Environ 60 % des solides serviront à la construction de voies de circulation et d’infrastructure résidentielle d'eau et d’égouts. Le reste (40 %) servira à la construction des logements.
- L’étape de l’occupation indirecte sera la principale responsable de la production de déchets solides au cours du cycle de vie. En faisant abstraction de la production des déchets solides liée à l’occupation des logements, la plupart des déchets solides produits au cours du cycle de vie seront issus des impacts indirects de l’occupation, à savoir l’extraction, le raffinage et la combustion de charbon et d’autres combustibles fossiles servant à produire de l’électricité.
- Les terrains seront moins perméables, ce qui aura des incidences sur la qualité de l’air et de l’eau. Le développement urbain fera en sorte qu’environ 45 % des terres urbaines seront considérées comme imperméables, ce qui amènera des changements fondamentaux dans le cycle de l’eau en milieu urbain et aggravera l’effet d’îlot de chaleur qui, à son tour, pourrait produire des effets secondaires sur la configuration des vents, la nébulosité et le brouillard, la foudre, les taux de précipitation et le smog.

Conséquences intégrées, à l’échelle locale, régionale et mondiale :

- L’importance des extrants environnementaux du secteur résidentiel dans l’air, l’eau, les sols et les terrains sera probablement suffisamment grande pour contribuer aux impacts environnementaux globaux, y compris les pluies acides, le smog, le changement climatique, le déclin de la biodiversité et la contamination de l’Arctique. Le Tableau 3 illustre des liens entre les extrants et les impacts environnementaux. Il est difficile d’évaluer dans quelle mesure les impacts se feront sentir, à cause de l’échelle et de la non-linéarité des impacts et des rôles interdépendants d’autres secteurs et activités qui génèrent également des impacts environnementaux.

Impacts environnementaux	Extrants environnementaux qui *causent* l’impact			Éléments et habitants *affectés*			
	Émissions dans l’atmosphère	Pollution de l’eau	Altération du terrain et pollution des sols	Air	Eau	Sol	Biote (organismes vivants)
Impacts locaux							
Dégradation de la qualité de l’air	√			√			√
Dégradation de la qualité des eaux de surface		√	√		√	√	√
Dégradation de la qualité des eaux souterraines		√	√		√	√	√
Effet d’îlot de chaleur	√		√	√			√
Impacts régionaux							
Smog	√			√	√		√
Pluies acides	√			√	√	√	√
Modification ou perte d’écosystèmes aquatiques et fragmentation des écosystèmes terrestres		√	√		√	√	√
Impacts sur les espèces sauvages	√	√	√				√
Impacts mondiaux							
Changement climatique	√			√	√	√	√
Déclin de la biodiversité	√	√	√				√
Réaction des systèmes à la contamination régionale	√	√		√	√	√	√
Note : le symbole « √ » indique un lien réel							

Tableau 3 : Exemple de liens entre des extrants environnementaux et des impacts environnementaux

Cette étude est le fruit d’une première tentative ambitieuse visant à évaluer les impacts environnementaux d’un secteur dans son ensemble, dans le contexte canadien, à l’aide des principes du cycle de vie. Ses conclusions coïncident avec les prévisions des praticiens de l’évaluation du cycle de vie. L’étude favorise l’utilisation des concepts liés aux impacts sur le cycle de vie en explorant un secteur que la plupart connaissent très bien : le secteur résidentiel. Le travail empirique de cette étude aidera les parties intéressées du Canada et de l’étranger à planifier d’autres études et à explorer des solutions appropriées pour contrer les impacts toujours croissants du secteur résidentiel sur l'environnement.

CMHC SCHL

National Office

700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national

700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

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1. INTRODUCTION

This report estimates the life-cycle environmental impacts of Canada's residential sector, including housing, neighbourhood infrastructure, and residential transportation. The study outcome also includes considerations for addressing data limitations and gaps, considering alternative scenarios, and investigating alternative pathways to improved environmental sustainability. This study is the first of its kind and is a robust, defensible platform from which future research and analysis can be undertaken.

The results highlight the aspects of the residential sector that have the largest influence on the environment at local (urban), regional, and global scales. Indeed, the fundamental ecosystem concept of inter-connectedness is never more relevant than when we consider the relationship of housing and neighbourhood development choices to the broader scales of environmental impact.

1.1 CONTEXT

As Canada's national housing agency, the Canada Mortgage and Housing Corporation (CMHC) works with community organizations, the private sector, non-profit agencies and all levels of government to help create innovative solutions to today's housing challenges, anticipate tomorrow's needs, and improve the quality of life for all Canadians.[15] CMHC's research plays an important role in maintaining and enhancing the high standard of Canada's housing and the current framework guiding CMHC research shows a focus on five broad theme areas: improving the efficiency of housing markets, housing needs of communities, distinct housing needs of individuals, building performance and technology, and improved data on housing issues.

Environmental impacts are relevant to most aspects of CMHC's mandates and, through a life-cycle perspective, this study explores the most relevant dimensions of the residential sector's environmental impact. As of 2004, Canada's 32 million residents lived in 12 million dwelling units; Canada's population is expected to reach 38 million residents by 2025, requiring an estimated 4 million new dwelling units.[16,17] This housing activity is supported by various types of infrastructure, such as roads, pipes, wires, etc. Approximately 80% of Canadians now live in urbanized areas and the patterns of development in cities currently encompass both continued low-density development and increased densification.[18] Where we live, what we build, and where we build have tremendous implications for resource use and environmental impacts during resource extraction, manufacturing, transportation of materials, on-site construction, and operation.

CMHC commissioned this project because there is a growing demand for analysis with which the full environmental impact of housing in Canada can be conveyed. In recent years, CMHC

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[15] Canada Mortgage and Housing Corporation. Accessed May 26, 2007. Website: *What We Do*. http://www.cmhc-schl.gc.ca/en/corp/about/whwedo/index.cfm

[16] United Nations, Department of Economic and Social Affairs, Population Division. 2006. *World Population Prospects: The 2006 Revision — Canada, medium variant*. http://www.un.org/esa/population/publications/wpp2006/wpp2006.htm

[17] Natural Resources Canada. 2006. *Canada's Energy Outlook: The Reference Case 2006*. http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php

[18] Ibid.

and other organizations have conducted a diverse range of applied research to explore the relationship among urban form, dwelling types and various environmental impacts. The residential building sector has a major impact on the natural environment[19]; the purpose of this study is to determine, as best as possible, the nature and extent of this impact.

Environmental integrity is critical to providing and maintaining a good quality of life for Canadians. They are voicing their desires to have quality of life considered in its broadest sense, encompassing ecosystem sustainability[20], health, comfort, and economic viability. In this context, an understanding of Canada's housing environmental impact is a necessary foundation from which housing development in the future can be considered.

1.2 STUDY OBJECTIVES

In approaching the issue of determining the residential sector's environmental impacts, the objectives of this study are to:

- Create an analysis framework and methodology for understanding the relationship and estimating the magnitude of life-cycle environmental impacts from the residential sector;
- Quantify, where possible, and describe the life-cycle environmental impacts of the residential sector in Canada: a) in the base year; and b) in 2025 under a business-as-usual scenario; and
- Identify opportunities for improving the business-as-usual scenario accuracy and for building alternative future scenarios.

The ultimate goal of the study is to assess the environmental impact of the housing sector using an overall methodology and set of analytical tools that are flexible enough to handle future refinements resulting from updated models, input data, and research.

1.3 REPORT STRUCTURE

This report is presented as follows:

- Section 2 presents the framework for understanding the life-cycle residential sector environmental impacts and defines key terminology used in the report. The multi-dimensional framework builds from the logic that residential activities have immediate implications in terms of resource use (inputs) and emissions/pollutants (environmental outputs), from which an extensive array of environmental impacts can be identified.
- Section 3 provides an overview of the study scope, methodology and data used to estimate the environmental impacts of the residential sector.
- Section 4 presents the resulting profile of the Canadian residential sector over the study period. The profile examines the housing and neighbourhood dimensions of the built environment.

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[19] Organisation for Economic Co-operation and Development (OECD). 2003. *Policy Brief: Environmentally Sustainable Buildings: Challenges and Policies*. http://www.oecd.org/dataoecd/23/17/8887401.pdf

[20] While commonly used in relation to residential housing in Canada, there is no generally accepted definition of what "sustainability" means.

- Section 5 presents estimates of the resources used (i.e., energy, water, land, and solids) by the residential sector over the study period.
- Section 6 presents estimates of the environmental outputs (i.e., emissions to air, water and soil) from the residential sector over the study period.
- Section 7 presents estimates of the environmental impacts (i.e., on air, water, soil, and biota) resulting from the residential sector's environmental outputs over the study period.
- Section 8 summarises the key findings and implications from the study and describes the influence of key market drivers on residential sector environmental outputs.
- Section 9 presents key implications and research considerations for the study's data limitations and exclusions, and sets the stage for defining alternative scenarios that could be explored in the future.

The above sections are followed by a glossary of key terms and acronyms.

Appendix A contains a more detailed description of the methodologies used in the study.

2. FRAMEWORK FOR UNDERSTANDING RESIDENTIAL SECTOR ENVIRONMENTAL IMPACTS

This section describes a framework that can used to relate the residential sector to resulting environmental impacts. This section is presented as follows:

- *Overall Analytical Framework*, which presents and describes two schematics that relate residential sector environmental impacts
- *Life-cycle Analysis & Life-cycle Stages*, which characterizes operating and non-operating stages of residential sector activity and impacts
- *Resource Use & Environmental Outputs*, which describes tangible factors that can be measured or estimated in environmental impact assessment
- *Types & Scales of Resulting Environmental Impacts*, which describes less tangible resulting environmental impacts at local, regional, and global scales
- *Summary.*

2.1 OVERALL ANALYTICAL FRAMEWORK

This section provides an analytical framework to relate the residential sector to resulting environmental impacts. The exhibits used illustrate the critical relationships and data flows upon which the analytical approach is based. Each exhibit is described below.

2.1.1 Relationship of Environmental Impacts

Exhibit 2.1, Relationship of the Residential Sector to Environmental Impacts, illustrates the key elements that comprise the research framework:

- Life-cycle stage
- Activities
- Resource use
- Environmental outputs
- Environmental impacts at local, regional and global scales.

Many inter-relationships exist between the elements identified in successive columns of Exhibit 2.1; the large arrows indicate the many direct and indirect relationships within the framework.

Exhibit 2.1 illustrates the five life-cycle stages of the residential sector, beginning with resource extraction and manufacturing for materials used to construct residential sector housing and infrastructure. Other stages include planning and on-site construction; operation of housing and infrastructure; demolition or refurbishment; and, recycling, reuse and disposal (see Section 2.2 for further discussion of life-cycle stages). At each life-cycle stage, two tangible aspects of the residential sector can be considered to produce environmental outputs: 1) dwellings; and 2) neighbourhood infrastructure. Less tangible aspects of the residential sector could also be considered, such as behaviour of residents.

In this framework, each life-cycle stage gives rise to a number of activities with relevance for environmental impact. Activities can be characterized as the range of actions taken to build, occupy and refurbish or remove structures of the residential sector, including housing and associated infrastructure. Exhibit 2.1 is intended to be illustrative of only the activities undertaken from resource extraction through to disposal. Such activities result in resource use at each life-cycle stage. Resources used include energy, water, land, and other resources including, for example, construction materials at the planning and construction life-cycle stage and, in the housing operation stage, chemicals and pesticides used by residents and road salts used for infrastructure maintenance.

Resource use leads to environmental outputs, which are emissions, pollutants, and changes that result directly from the activities of the residential sector (e.g., nitrogen oxides released to air). Outputs can be conceptually grouped in terms of the media to which they are released, including air, water and land/soil. The land/soil group includes pollutants emitted directly to soil, as well as changes in land use and land cover (e.g., increased impervious surface area resulting from road pavement and roof systems).

Environmental impacts result from the environmental outputs. For example, many air pollutants are released during energy use. Each pollutant is an output, while one of the environmental impacts at a local level is air quality impairment. At a regional and global scale, air pollutant outputs result in the environmental impacts of smog, acid rain and global climate change. The distinction between outputs and impacts is one of attribution: outputs can be estimated and can be attributed to the residential sector through the methodology used for this study. The residential sector contributes to these impacts but, due to scale and activities of other sectors, such impacts cannot typically be attributed to the residential sector alone. Estimation of impacts at the local, regional and global scales must rely on scientific research in areas of air quality, water quality, soils quality, and effects identified on biota (i.e., living systems).

It is important to note that resource use can result in environmental outputs (e.g., emissions/pollutants) that affect more than one media, as shown in Exhibit 2.2. For example, activities that use water resources can result in outputs that affect the water media (e.g., pollutants released to water) as well as biota (e.g., changes to water quantity in streams, affecting quality of life for organisms). Exhibit 2.2 demonstrates the most closely linked inter-relationships of the elements described in Exhibit 2.1.

Exhibit 2.1: Relationship of Residential Sector to Environmental Impacts

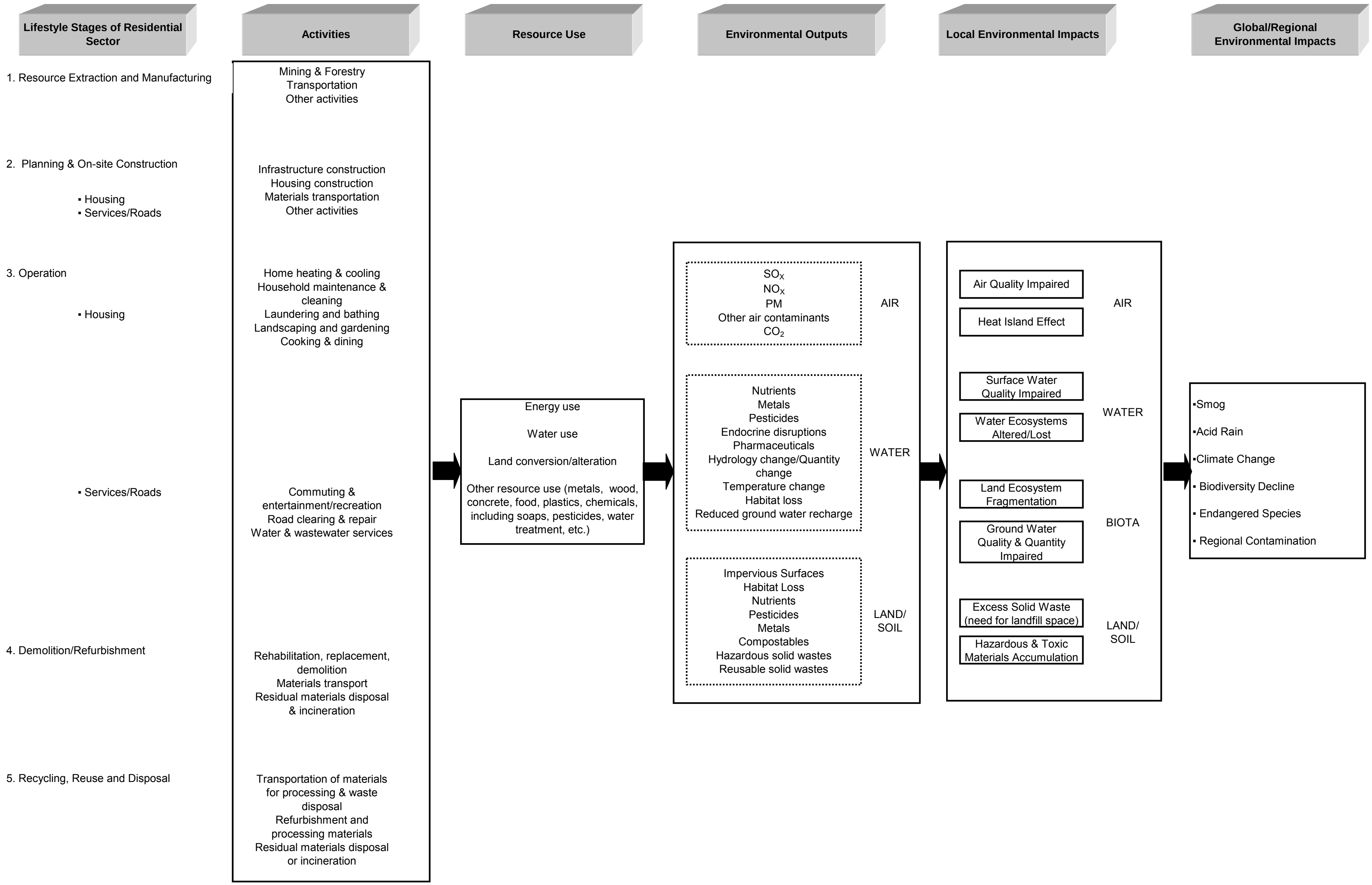

Exhibit 2.2: Linkages between Environmental Outputs & Environmental Impacts

Resulting Environmental Impact	Environmental Outputs Causing the Environmental Impact			Media & Inhabitants Affected by the Environmental Impact			
	Air Emissions	Water Pollution	Land Alteration & Soil Pollution	Air	Water	Soil	Biota (Living Organisms)
Local Impacts							
Air Quality Impairment	√			√			√
Surface Water Quality Impairment		√	√		√	√	√
Ground Water Quality Impairment		√	√		√	√	√
Heat Island Effect	√		√	√			√
Regional Impacts							
Smog	√			√	√		√
Acid Rain	√			√	√	√	√
Water Ecosystems Altered or Lost & Land Ecosystem Fragmentation		√	√		√	√	√
Impacts on Wildlife	√	√	√				√
Global Impacts							
Climate Change	√			√	√	√	√
Biodiversity Decline	√	√	√				√
Systems Response to Regional Contamination	√	√		√	√	√	√

Note: "√" means a relevant linkage exists

2.1.2 Magnitude of Environmental Impacts

Even the most environmentally-friendly homes and neighbourhoods involve activities that result in environmental outputs which, in turn, impact the environment. A key question then is, "What is the magnitude of the impact of various configurations of dwellings and neighbourhoods on the environment?"

Before answering this question, let us first look at relevant market drivers for the residential sector. Exhibit 2.3 lists *market drivers* (i.e., patterns, trends, issues and circumstances) that are expected to influence the environmental impacts of the residential sector. The exhibit also summarizes the relative data availability, market impact, and government influence.

Exhibit 2.3: Residential Sector Market Drivers

Market Driver	Data Availability	Market Impact		Government Influence
		Demand	Supply	
Key Market Drivers				
Resource Use, Availability & Price — Types, amount, and price of available resources (land uses prior to residential development, fuels, water sources, raw materials, etc.)	H	H	M→H	M
Socio-Demographics, Culture & Consumer Preferences — Residential population and their preferences, such as population (birth rate, health, immigration), age, income, debt ratio, health, mobility, living location, quality of living, size of home, stock growth by dwelling type, renovations[21], consumerism[22], recreation, etc.	H	H	n/a	L
Urban Planning & Project Financing — Urban planning, greyfield or brownfield redevelopment vs. greenfield development, related public and private sector investments, etc.	M	L	H	L
Other Market Drivers				
Policies & Regulations — Policies and regulations relating to building design and construction (building codes), land use, energy, water, emissions, etc.	M	M	M	H
Economy & Trade — Interest rates, inflation, GDP, regional economies, globalization, import/export, etc.	M	L	L→M	M
Environmental Factors — Climate change, weather, air quality, water quality, soil quality, related migration, etc.	M	L→M	M	M
Telecommunications — Wireless, internet access, security, privacy, building operation, integrated supply chains (building and transportation energy), telecommuting, etc.	L	L	L	L
Materials & Manufacturing Technology — Nanotechnology, robotics, composite materials, etc.	M	n/a	M	L
Design & Construction — Design and construction practices of residential dwellings, neighbourhoods, and infrastructure; contractor skills; etc.	M	M	M→H	M

Note: H = high; M = medium; L = low; n/a = not applicable

Various driver elements exert different pressures on the market that can result in competing influences on resources consumed. For example, limitations placed on land available by municipalities through their ‘Official Plans’ may conflict with consumer preferences for single detached housing. Essentially, market drivers determine not the relationship, but the magnitude of environmental impacts by the residential sector.

To further understand how market drivers influence the magnitude of residential sector environmental impacts, Exhibit 2.4 further explores select key drivers that were also highlighted at the top of Exhibit 2.3. Exhibit 2.4 shows how decision outcomes on the location, size and type of homes built and occupied have significant implications for resource use (energy, water, land) by the sector and, thus, can be key determinants of the magnitude of environmental impacts.

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[21] CMHC, Market Analysis Products & Services. Spring 2007 (target). *Annual Renovation Expenditure Survey*.

[22] Market penetrations of air conditioning, dishwashers, etc. by dwelling type:
Statistics Canada. December 12, 2006. *Survey of Household Spending*. http://www.statcan.ca/english/sdds/3508.htm

Exhibit 2.4: Factors Affecting Magnitude of Residential Sector Environmental Impacts

Drivers	Driver Elements	Decision Outcomes	Framework Inputs
Resource Availability & Price	▪ Land use & availability ▪ Energy sources & availability ▪ Water sources & availability ▪ Raw material sources & availability	▪ Home building locations ▪ Materials for construction ▪ Neighbourhood density ▪ Servicing costs ▪ Cost of home	▪ Life-cycle resource inputs ▪ Neighbourhood archetypes ▪ Residential servicing
Urban Planning & Financing	▪ Land use & availability ▪ Existing infrastructure & feasibility of extension ▪ Public & private sector risk (e.g., Brownfield cleanup) ▪ Influence of income on planning (e.g., wealthy buying lots outside urban area)	▪ Use of brownfields, infill, redevelopment, etc. ▪ Intensification or sprawl ▪ Servicing costs	▪ Neighbourhood archetypes ▪ Financing models
Socio-demographics, Culture & Consumer Preferences	▪ Birth rate & immigration ▪ Age of population ▪ Employment and income ▪ Debt ratio ▪ Health & mobility ▪ Consumerism	▪ Buy new or renovate ▪ Size of home ▪ Type of housing ▪ Type of neighbourhood ▪ Use of vehicle ▪ Use of transit ▪ Type & size of vehicle	▪ Residential archetypes ▪ Operating & maintenance resource inputs ▪ Transportation use & energy

The exhibit identifies the three key drivers, but can also be used for other drivers that have not been explicitly noted. The second column of the exhibit illustrates elements of these drivers. For example, *Resource Availability and Price* includes elements such as land availability, fuel sources (i.e. types of fuel) and water availability. Taken together, the driver elements result in decisions, identified as *Decision Outcomes* in column three of the exhibit, that determine the life-cycle resources used, neighbourhood design, residential servicing, types of residences built, and operation and maintenance of water servicing and transportation systems. These factors can be used as inputs to analyses on the environmental outputs and impacts of the residential sector.

2.2 LIFE-CYCLE ANALYSIS & LIFE-CYCLE STAGES

2.2.1 Life-cycle Analysis

Life-cycle assessment (LCA), and especially its most developed component, life-cycle inventory (LCI) analysis, is a methodological tool that provides quantitative analyses of the environmental impacts of products and production systems. LCA studies involve the collection, assessment and interpretation of environmental data over a product's life-cycle (production, use, and end-of-life). These studies can evaluate entire product life-cycles, (referred to as cradle-to-grave or cradle-to-cradle), or focus on parts of a product life-cycle, (referred to as cradle-to-gate or gate-to-gate).

The application of LCA and its numerous components is governed by an International protocol as set out in the ISO 14040 document series. It was developed with international experts on LCA from more than fifty countries over a period of more than 15 years.[23] A life-cycle inventory involves compiling an inventory of relevant inputs and outputs of a product system, comprising resource flows (e.g., mass and energy) that contribute to various environmental outputs (emissions and pollutants). The data inventory is carried out for each process step defined in the product system.

2.2.2 Life-cycle Stages

The environmental impacts of the residential sector can be assessed for the full life-cycle of housing and the supporting municipal infrastructure to ensure that transportation, energy, and water services at the dwelling level would be met. The key stages of the housing life-cycle considered in this study are described below.

Non-Operating Stages

- **Extraction & Manufacturing,** which includes: 1) resource extraction (e.g., mining, harvesting), 2) resource transportation, and 3) refining or manufacturing of specific materials, products, or building components. This stage occurs before a physical structure is built.
- **On-site Construction,** which includes: 1) product/component transportation from the point of manufacture to the building site, and 2) on-site construction of a physical structure. This stage occurs mostly while a physical structure is being planned and built.
- **Maintenance & Replacement**, which includes the manufacturing, transport and on-site construction effects for materials and activities involved in the maintenance and replacement of a physical structure over the life of the structure. Maintenance and replacement materials and activities include repainting, window replacement, roofing replacement, etc. This stage occurs after a physical structure is built.

Note: The first two of the non-operating life-cycle stages (Extraction & Manufacturing and On-site Construction) are sometimes referred to as the *embodied* impacts of a structure or commodity. For example, the *embodied* energy of a house includes the end-use fuel needed to extract all the raw materials from the earth, refine and manufacturer those raw materials into usable products, transport those products to the construction site, and construct the house, as well as all of the energy needed to extract and refine the crude oil (or other raw energy sources) needed to provide end-use fuels for all those tasks.

[23] ISO 14040. 2006. *Environmental Management – Life-cycle Assessment – Principles & Framework*
ISO 14044. 2006. *Environmental Management – Life-cycle Assessment – Requirements & Guidelines*.

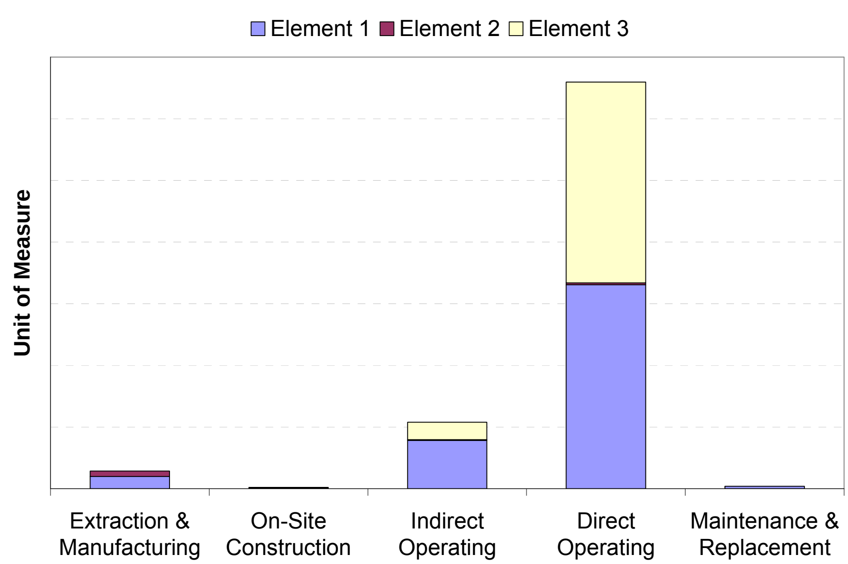
Operating Stages

- **Indirect Operating,** which includes the indirect/upstream impacts of supplying the operating services to a physical structure. This includes such things as: 1) the impacts of extracting, refining, and delivering fuels for use during operation (e.g., refined petroleum products, electricity), and 2) the impacts of treating and delivering potable water for use during operation. This stage occurs while a physical structure is being used. The Indirect Operating stage is not really a "stage", per se, but is shown separately to clearly illustrate the additional impacts that occur from every unit of operating services (e.g., energy or water) used during operation of the physical structure (e.g., dwelling, vehicle).

- **Direct Operating,** which includes the direct impacts of occupying and operating a physical structure, such as energy and water use and production of wastewater and solid waste. This stage occurs while a physical structure is being used.

Life-cycle assessment results can be summarised in graphical form using formats such as that shown in Exhibit 2.5, which is used in this report. This chart format shows a unit of measure on the Y-axis (e.g., gigajoules of energy), life-cycle stages along the X-axis, and data displayed for various elements of a product system (e.g., dwellings, neighbourhood infrastructure, and residential transportation). In such a comparison by life-cycle stage, the direct and indirect operating impacts shown are the sum of the annual operating results over the defined period (e.g., the study period or an element's start to end of life).

Exhibit 2.5: Sample Illustration of Measured Units by Life-cycle Stage over a Defined Period



2.3 RESOURCE USE & ENVIRONMENTAL OUTPUTS

As described in the analytical framework in Section 2.1, resource use creates environmental outputs (emissions and pollutants) that result in environmental impacts. Resource use and environmental outputs can be estimated or measured using modelling techniques, extrapolated from direct measurement in the field, or a combination of these approaches. Exhibit 2.6 identifies typical measures of resource use and environmental outputs for the residential sector.

Exhibit 2.6: Typical Measures of Resource Use & Environmental Outputs

Resource Use		Emissions & Other Outputs	
Primary Fuels	**Solids**	**Air Emissions**	**Water Pollutants**
Fossil Fuels	*Organic Solids*	*Greenhouse Gases (GHG)*	Suspended Solids
Heavy Fuel Oil	Wood Fiber	Carbon Dioxide, CO_2 from non-biomass	Dissolved Solids
Diesel	*Minerals*	Nitrous Oxide, N_2O	Oil & Grease
Gasoline	Limestone	Methane, CH_4	Sulphates
Liquid Petroleum Gas	Clay & Shale	*Criteria Air Contaminants (CAC)*	Sulphides
Other Oil-related Fuels	Sand	Sulphur Oxides, SO_x	Nitrates & Nitrites
Natural Gas	Gypsum	Nitrogen Oxides, NO_x	Dissolved Organic Compounds
Coal	Aggregates	Total Particulate Matter, TPM	Metals
Feedstock Fuels	*Metals*	Non-Methane Volatile Organic Compounds, NMVOC	Biological Oxygen Demand, BOD
Other Fuels	Iron Ore	Carbon Monoxide, CO	Chemical Oxygen Demand, COD
Nuclear	*Other Resources*	*Other Air Emissions*	**Land Alterations**
Wood	Other	Carbon Dioxide, CO_2 from biomass (biogenic/neutral)	Impervious surface area
Water		Metals	**Soil Pollutants**
Water			Organic Waste
Land			Mineral Waste
Land			Other Solid Waste

2.4 TYPES & SCALES OF RESULTING ENVIRONMENTAL IMPACTS

Exhibit 2.1 identifies two groups of Environmental Impacts: local; and, regional and global. In considering the environmental impacts of housing, it is evident that some effects, such as habitat reduction and ecosystem fragmentation, are virtually imperceptible at the scale of incremental housing development and operation. For example, the contributions of one dwelling's GHG emissions are immeasurable in their direct effects on the surface temperature of the planet. Similarly, the incremental increase of impervious surface area due to a house roof and laneway are immeasurably related to biodiversity decline in the aquatic environment. However, the cumulative effect of development begins to have ecosystem health implications, at local, regional and global scales, some of which are enormous (such as global climate change).

The environment functions as a system and therefore seemingly disparate factors can combine to create non-local, unexpected and/ or non-linear impacts. Broader environmental impacts are not necessarily directly attributable to the residential sector, but the sector contributes to these impacts.

It is possible to explore potential environmental impacts starting at the local scale and progressing to the larger scales. In doing so, we notice two major effects: 1) broad, cumulative effects; and 2) non-linear effects where, at any of these scales, there may be a threshold, or 'tipping point' at which significant and unpredictable outcomes would occur.

Therefore, the resulting environmental impacts of resource use, emissions, and other quantitative impacts can be described at the following scales:

- *Local impacts* that affect mostly the environment on a site, in the surrounding community or in a city;
- *Regional impacts* that affect a geographic region, determined by connectedness through air flow, water flow/watershed, wildlife habitats, etc.;
- *Global impacts* that affect a global aspect of the earth's ecosystem.

2.5 SUMMARY

This section was intended to describe the important aspects of an analytical framework that can be used to assess the environmental impacts of the residential sector. There are many complex and inter-related aspects to assessing environmental impacts, including the scale of the impact in question. The disconnect between local activities, such as heating a home, and larger scale environmental impacts, such as climate change, has resulted in only a slow realization by societies of the implications of the collective actions of economic sectors, including the residential sector. The framework presented can be used to generate quantitative results up to the environmental output level, but then must rely on a combination of qualitative and quantitative results found in scientific literature to describe and assess the environmental impacts. At the broadest scale, these impacts can only be understood from a top-down, systems-level analysis, such as for climate change, Arctic contamination, and species extinction.

3. STUDY SCOPE & METHODOLOGY

This is a study of considerable complexity, employing several analytical techniques, models and extensively varied data sets. This section describes the scope of this study and summarizes the data sources, models, and methodologies used to assess the Canadian residential sector's environmental impacts during the study period of 2004–2025.

This section is organized as follows:

- *Study Scope*, which defines the study period and scope inclusions and exclusions;
- *Overall Approach*, which describes the bottom-up and top-down assessments used;
- *Summary of Methodologies*, which summarises the key data sources, assumptions, models, and methodologies used in the analysis; and
- *Constructing the BAU Scenario to 2025*, which comments on some of the underlying methodological and data challenges in building a credible business-as-usual (BAU) scenario to 2025.

Appendix A provides extensive details on the data sources, assumptions, models, and methodologies used.

Section 9 presents implications and recommendations on resolving key data limitations and gaps.

3.1 STUDY SCOPE

3.1.1 Study Period

A *scenario* is a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g., technology changes, energy prices).[24] *A scenario is neither a prediction nor a forecast.*

This study estimates the resource use, environmental outputs, and resulting environmental impacts of the residential sector in Canada based on a scenario resembling recent business-as-usual trends. This study includes analysis of the current status in the base year and of the contributions from changes in the residential sector through a business-as-usual (BAU) scenario:

- **Current Status in Base Year (2004)**: The base year analysis addresses the question of "Where are we now?" in terms of the residential sector's impact on the environment. It is a static examination of key environmental performance indicators resulting from the operation of the housing stock as it currently exists. The year 2004 has been selected as the base year because it is the last year for which historical energy use data is available. The base year analysis is confined to the operation of dwellings and, therefore, does not include the life-cycle analysis; life-cycle effects are

[24] Natural Resources Canada. October 2006. *Climate Change Impacts and Adaptation: A Canadian Perspective* — Scenarios section. http://adaptation.nrcan.gc.ca/perspective/directions_3_e.php

assumed to be "sunk" costs in the base year since they have already been incurred during the construction of this stock.

- **Contributions from Changes during BAU Scenario (2004–2025)**: The BAU scenario analysis addresses the question of "Where are we going?" The BAU scenario assumes *no significant paradigm shift in dwelling construction practices and neighbourhood infrastructure needs*, but assumes *significant paradigm shifts in neighbourhood densification and land development practices*, based on information from municipal officials in high-growth areas of Canada. In addition to operating impacts of the existing and new dwelling stock, the BAU scenario also estimates the life-cycle environmental impacts of the new dwelling stock and required new neighbourhood infrastructure during the study period.

3.1.2 Scope Inclusions & Exclusions

The scope of this study is captured in Exhibits 3.1 and 3.2, with a particular focus on key exclusions. The scope exclusions were reviewed and approved by CMHC and are primarily due to: 1) lack of available, reliable data; and 2) project budget limitations. The key exclusions are reiterated in Section 9, which recommends specific areas in which data limitations and gaps can be addressed.

Exhibit 3.1 profiles the study scope for the *non-operating* impact analysis, of which the life-cycle analysis is a major component. As noted, the key exclusions were:

- No life-cycle analysis conducted for existing dwellings and neighbourhood infrastructure because the non-operating environmental impacts were already incurred when these elements were constructed. The life-cycle analysis focuses on newly constructed buildings and neighbourhood infrastructure, with a few exceptions shown in Exhibit 3.1.
- No maintenance and replacement impacts assessed for existing dwellings, buildings, and infrastructure.
- No dwelling or infrastructure renovation impacts assessed.
- No regional variations assessed.

Exhibit 3.2 profiles the study scope for the *operating* impact analysis. For dwellings and neighbourhoods, the analysis of certain pollutants (e.g., dwelling solid waste production) was excluded due to limitations of what could be addressed within the study budget. In addition, the analysis excludes certain types of vehicles and transportation modes for residential transportation.

Exhibit 3.1: Study Scope for *Non-Operating* Impact Analysis

Non-Operating Impact Analysis		
Existing	**New**	**Renovated / Renewed / Densified**
Dwellings & Buildings		
Excluded: • Maintenance & Replacement effects of existing dwellings and buildings • Extraction & Manufacturing and On-site Construction effects of existing dwellings and buildings, since impacts were incurred when constructed • Life-cycle effects of consumer goods and services (aside from household energy and water) • Demolition and Recycling & Disposal effects	**Included:** • Extraction & Manufacturing, On-site Construction, and Maintenance & Replacement effects of new occupied dwellings (presented as Single Detached; Row/Town; Low-rise MURB, and High-rise MURB) • High-rise MURB underground parking **Excluded:** • Dwelling driveways, parking, and 'hardscaping' (decks, fencing, etc.), aside from high-rise MURB underground parking • New *unoccupied* and seasonal dwellings[25] • New commercial and institutional buildings in residential neighbourhoods • Life-cycle effects of consumer goods and services (aside from household energy and water) • Demolition and Recycling & Disposal effects	**Excluded:** • Renovated dwellings • Life-cycle effects of consumer goods and services (aside from household energy and water) • Demolition and Recycling & Disposal effects
Neighbourhoods		
Excluded: • Existing neighbourhoods since impacts were incurred when constructed	**Included:** • New inner city, inner suburb, and outer suburb neighbourhoods **Excluded:** • New seasonal home neighbourhoods • New rural settings	**Included:** • Densified inner city, inner suburb, and outer suburb neighbourhoods **Excluded:** • Densified seasonal home neighbourhoods • Densified rural settings
Neighbourhood Infrastructure		
Excluded: • Maintenance & Replacement effects of existing infrastructure • Extraction & Manufacturing and On-site Construction effects of existing infrastructure, since impacts were already incurred when constructed • Demolition and Recycling & Disposal effects	**Included:** • Extraction & Manufacturing and On-site Construction effects of new neighbourhood roads for personal vehicles or public transit, and accompanying in-ground water and wastewater infrastructure **Excluded:** • Maintenance & Replacement effects, since new infrastructure would not require significant maintenance during the study period, aside from annual maintenance (e.g., street sweeping and snow clearing) • Residential driveways and service laneways/alleys • Centralized facilities, such as fuel refineries, electricity generation plants, fuel stations, water purification plants, wastewater treatment plants, and water pumping stations • Energy distribution networks, such as electricity transmission lines, natural gas pipelines, etc. • Public transit non-road infrastructure, such as railway tracks, subway tracks and tunnels, cable car lines, transit stations • Solid waste management infrastructure • Infrastructure to service commercial and institutional buildings in residential neighbourhoods • Demolition and Recycling & Disposal effects	**Excluded:** • Neighbourhood roads used for personal vehicles or public transit • Accompanying in-ground water supply and wastewater infrastructure in neighbourhoods • Residential driveways and service laneways/alleys • Centralized facilities, such as fuel refineries, electricity generation plants, fuel stations, water purification plants, wastewater treatment plants, and water pumping stations • Energy distribution networks, such as electricity transmission lines, natural gas pipelines, etc. • Public transit non-road infrastructure, such as railway tracks, subway tracks and tunnels, cable car lines • Water infrastructure • Solid waste management infrastructure • Infrastructure to service commercial and institutional buildings in residential neighbourhoods • Demolition and Recycling & Disposal effects
Residential Transportation		
Excluded: • Existing vehicles since impacts were incurred when constructed	**Excluded:** • New vehicles	**Excluded:** • Renewed/Rebuilt vehicles

25 The actual dwelling stock is comprised of dwellings that are either occupied or unoccupied. Unoccupied dwellings form about 5% of the total stock. The occupied housing stock was chosen for analysis because the behavioural and lifestyle characteristics of the dwelling occupants drive operation of the dwelling stock.

Exhibit 3.2: Study Scope for *Operating* Impact Analysis

Operating Impact Analysis		
Existing	**New**	**Renovated / Renewed / Densified**
Dwellings & Buildings		
Included: • Direct and Indirect Operating effects of existing occupied dwellings (presented as Single Detached; Row/Town; Low-rise MURB, and High-rise MURB) **Excluded:** • Existing unoccupied dwellings[26] • Existing seasonal dwellings • Existing commercial and institutional buildings in residential neighbourhoods • Effects of providing consumer goods and services (aside from household energy & water) • Water pollutants from dwelling wastewater production • Water use for dwellings with groundwater supply • Municipal solid waste production	**Included:** • Direct and Indirect Operating effects of new occupied dwellings (presented as Single Detached; Row/Town; Low-rise MURB, and High-rise MURB) **Excluded:** • New *unoccupied* and seasonal dwellings[26] • New commercial and institutional buildings in residential neighbourhoods • Effects of providing consumer goods and services (aside from household energy & water) • Water pollutants from dwelling wastewater production • Water use for dwellings with groundwater supply • Municipal solid waste production	**Excluded:** • Direct and Indirect Operating effects of renovated *occupied* dwellings[26] **Excluded:** • Renovated *unoccupied* dwellings • Renovated seasonal dwellings • Renovated commercial and institutional buildings in residential neighbourhoods • Effects of providing consumer goods and services (aside from household energy & water) • Water pollutants from dwelling wastewater production • Water use for dwellings with groundwater supply • Municipal solid waste production
Neighbourhoods		
Included: • Existing inner city, inner suburb, and outer suburb neighbourhoods **Excluded:** • Existing seasonal home neighbourhoods • Existing rural settings	**Included:** • New inner city, inner suburb, and outer suburb neighbourhoods **Excluded:** • New seasonal home neighbourhoods • New rural settings	**Included:** • Densified inner city, inner suburb, and outer suburb neighbourhoods **Excluded:** • Densified seasonal home neighbourhoods • Densified rural settings
Neighbourhood Infrastructure		
Included: • Direct and indirect (upstream) effects of municipal water supply and wastewater system treatment and pumping energy to service dwellings **Excluded:** • Water pollutants from municipal water and wastewater treatment • Water pollutants from storm water run-off	**Included:** • Direct and indirect (upstream) effects of municipal water supply and wastewater system treatment and pumping energy to service dwellings **Excluded:** • Water pollutants from municipal water and wastewater treatment • Water pollutants from storm water run-off	**Excluded:** • Direct and indirect (upstream) effects of municipal water supply and wastewater system treatment and pumping energy to service dwellings • Water pollutants from municipal water and wastewater treatment • Water pollutants from storm water run-off
Residential Transportation		
Included: • Private vehicles (cars & light-duty trucks) • Urban public transit (buses, streetcars, trains, subways) **Excluded:** • Personal use of off-road and heavy-duty vehicles and long distance air, bus, rail, marine	**Included:** • Private vehicles (cars & light-duty trucks) • Urban public transit (buses, streetcars, trains, subways) **Excluded:** • Personal use of off-road and heavy-duty vehicles and long distance air, bus, rail, marine	not applicable

26 The actual dwelling stock is comprised of dwellings that are either occupied or unoccupied. Unoccupied dwellings form about 5% of the total stock. The occupied housing stock was chosen for analysis because the behavioural and lifestyle characteristics of the dwelling occupants drive operation of the dwelling stock.

For each of the life-cycle stages analysed in this study, the resource uses and environmental outputs from the residential sector are estimated through modelling. The models and methodologies used are described in subsequent sub-sections. The quantified data in this study includes the indicators of resource use and environmental outputs (i.e., emissions, pollutants, and land use changes) listed in Exhibit 3.3. This exhibit is identical to Exhibit 2.6 and is meant to illustrate that this study comprehensively estimates a wide breadth of resource uses and environmental outputs possible for such analysis.

Exhibit 3.3: Resource Use & Environmental Output Indicators Estimated in this Study

Resource Use		**Emissions & Other Outputs**	
Primary Fuels	**Solids**	**Air Emissions**	**Water Pollutants**
Fossil Fuels	*Organic Solids*	*Greenhouse Gases (GHG)*	Suspended Solids
Heavy Fuel Oil	Wood Fiber	Carbon Dioxide, CO_2 from non-biomass	Dissolved Solids
Diesel	*Minerals*	Nitrous Oxide, N_2O	Oil & Grease
Gasoline	Limestone	Methane, CH_4	Sulphates
Liquid Petroleum Gas	Clay & Shale	*Criteria Air Contaminants (CAC)*	Sulphides
Other Oil-related Fuels	Sand	Sulphur Oxides, SO_x	Nitrates & Nitrites
Natural Gas	Gypsum	Nitrogen Oxides, NO_x	Dissolved Organic Compounds
Coal	Aggregates	Total Particulate Matter, TPM	Metals
Feedstock Fuels	*Metals*	Non-Methane Volatile Organic Compounds, NMVOC	Biological Oxygen Demand, BOD
Other Fuels	Iron Ore	Carbon Monoxide, CO	Chemical Oxygen Demand, COD
Nuclear	*Other Resources*	*Other Air Emissions*	**Land Alterations**
Wood	Other	Carbon Dioxide, CO_2 from biomass (biogenic/neutral)	Impervious surface area
Water		Metals	**Soil Pollutants**
Water			Organic Waste
Land			Mineral Waste
Land			Other Solid Waste

In addition to the *quantitative* measures listed above, this study also *qualitatively* assesses the following local, regional, and global environmental impacts that result from the residential sector's environmental outputs:

- *Local impacts*, such as air quality, surface and groundwater quality, and heat island effect;
- *Regional (including national) impacts*, such as smog, acid rain, and water and land ecosystems fragmented, altered or lost, and impact on wildlife; and
- *Global impacts*, such as climate change, biodiversity decline and ecosystem services, and systems responses to regional contamination (e.g., arctic).

The quantitative and qualitative analyses are further described under Overall Approach in the following sub-section.

3.2 OVERALL APPROACH

The overall approach employed to estimate the environmental impacts of Canada's residential sector combines what are referred to as *'bottom-up'* and *'top-down'* approaches, which are described in the following sub-sections and illustrated in Exhibit 3.4 below.

3.2.1 Bottom-up Assessment of Resource Use & Environmental Outputs

Most of the quantitative analysis employed in the study utilises a bottom-up analysis to establish the cause and affect relationships discussed in Section 2. The bottom-up analysis first profiles the physical characteristics of the residential sector during the study period, and then calculates the resulting *resources use* (i.e., energy, water, land, solids) and *environmental outputs* (i.e., emissions/pollutants to air, water, and soil) resulting from various life-cycle stages in constructing and operating the residential sector (i.e., dwellings, neighbourhood infrastructure, and residential transportation systems) over the study period. As discussed in Section 2, the residential sector is analysed by various life-cycle stages that can be grouped as *operating* and *non-operating*; this distinction is used in the following elaboration of the bottom-up approach.

- **Characterization of the Residential Sector** — This characterization establishes the foundation upon which the analysis is conducted. The defining characteristics of the residential sector, in terms of dwelling stock, infrastructure and neighbourhood, drive resource use and environmental outputs.

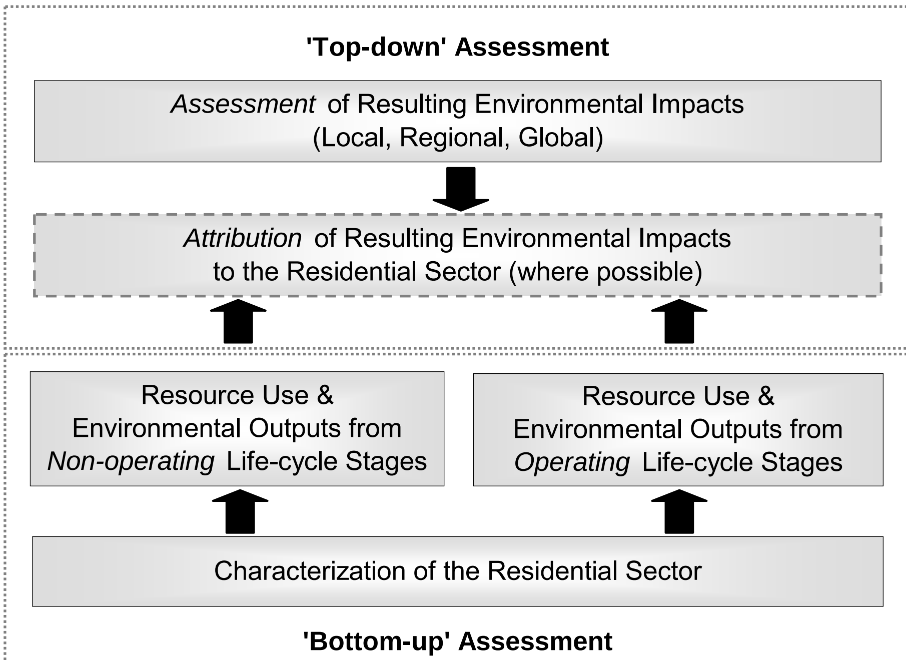
- **Resource Use & Environmental Outputs from *Non-operating* Life-cycle Stages** — The analysis estimates the resources used and environmental outputs produced from the residential sector lifecycle as defined in Section 2. For dwelling non-operating effects, per-dwelling coefficients were derived for resource use and environmental outputs. These coefficients are then multiplied by the new dwelling stock from the characterization of the residential sector. Similarly, for neighbourhood roads and water infrastructure, per-kilometre coefficients were derived for resource use and environmental outputs for each infrastructure type, and these coefficients were multiplied by the required new infrastructure identified by the characterization of the residential sector.

- **Resource Use & Environmental Outputs from *Operating* Life-cycle Stages** — This analysis estimates the resources used and environmental outputs produced from operating Canadian dwellings and some of the municipal infrastructure required to service these dwellings. Specifically, this area of analysis includes: i) dwelling operating energy; ii) dwelling potable water consumption; iii) dwelling operating wastewater production; iv) municipal water system operating energy associated with providing treatment and pumping of supply water and wastewater for dwellings; v); operating energy used by residential transportation (i.e., private vehicles and public transit); and vi) the indirect (upstream) resource use and environmental outputs needed to extract, refine, and distribute operating fuels to their point of use. For the upstream effects of operating energy use, per-gigajoule (GJ) coefficients were derived for resource use and environmental outputs for each fuel, and these coefficients were multiplied by the annual fuel use estimated in the analysis.

3.2.2 Top-down Assessment & Attribution of Resulting Environmental Impacts

A more qualitative approach is taken in a 'top down' fashion to describe the possible implications of the residential sector life-cycle at the local, regional, and global scales. A recurring theme in this report is the challenge of attribution at these scales, recognizing that complex, inter-related, non-linear environmental impacts (responses) are difficult to attribute to individual sectors or sources. Regardless, the top-down qualitative assessment attempts to bridge the gap between the measurable environmental outputs from the residential sector (e.g., emissions/pollutants to air, water and soil) and the resulting environmental impacts experienced locally, regionally, and globally.

Exhibit 3.4: Schematic of Overall Study Approach



3.3 SUMMARY OF METHODOLOGIES

Following is a brief description of the methodologies and models used for the areas of analysis included in this study:

- **Dwelling Stock** — The dwelling stock analysis develops a portrait of the Canadian dwelling stock during 2004-2025. The dwelling stock projections were drawn from *Canada's Energy Outlook, 2006* (Natural Resources Canada, based on their *Maple C* model with data from Informetrica) — the best available source of data at the time of this study — and from Statistics Canada's 2001 Census data. Dwellings were categorized into four dwelling types: *Single Detached, Row/Town, Low-rise Multi-Unit Residential Building (MURB) units, and High-rise MURB units*. The analysis employs regional data where possible.

- **Neighbourhoods** — The neighbourhood analysis develops a portrait of three neighbourhood types that best represent the majority of existing and new Canadian neighbourhoods: *Inner City, Inner Suburbs, and Outer Suburbs*. The key data sources are the Statistics Canada 2001 Census, interviews with municipal planners in three high-growth regional areas of Canada[27], and municipal land use data from Ottawa, ON. As a result, three composite neighbourhood archetypes were developed, representing the physical attributes of the three neighbourhood types.

- **Neighbourhood Infrastructure** — This analysis was used to calculate the amount of residential road and accompanying in-ground water infrastructure required during 2004–2025: 1) to densify existing neighbourhoods; and 2) to build new neighbourhoods. The key data sources were: 1) CMHC's recently-developed Sustainable Community Infrastructure Costing Tool and background report; and 2) a road construction consultant[28] who prepared material quantity take-offs and construction-related energy use by activity for various infrastructure elements. The resulting infrastructure needs per area of neighbourhood were characterized in the neighbourhood archetypes mentioned above.

- **Non-Operating Effects from New Dwellings & Infrastructure** — This analysis used the Athena Institute's Environmental Impact Estimator model and its wealth of supporting life-cycle data to develop resource use and environmental output (emissions) indicators per dwelling and per length of infrastructure. These indicators were developed for the non-operating stages of Extraction & Manufacturing, On-site Construction, and Maintenance & Replacement. Development of these indicators required characterizing four dwelling archetypes and four infrastructure archetypes, each which included the amount and type of materials used in their construction. To calculate the aggregate resource use and environmental outputs for all dwellings and all neighbourhood infrastructure, these values were multiplied by the total number of dwellings (by dwelling type) and total number of kilometres of new infrastructure (by infrastructure type).

- **Municipal Water System Demand to Service Dwellings** — This analysis estimated the annual water use and wastewater production resulting from the daily habitation and operation of dwellings. Marbek's Residential Sector Water End-use Model was used for the analysis, which included water-using technologies for different end uses, activity levels (e.g., litres/capita/day) for these technologies, penetration levels of these technologies, and the resulting water use per dwelling, by dwelling type. The key data sources were: 1) water use data from surveys and audits conducted in Canada and North America, compiled by NRCan and Statistics Canada; and 2) Marbek's in-house database of water use characteristics in the residential sector. This analysis also included changes in water use per dwelling due to renovations of existing stock from 2004.

- **Direct Operating Energy for Dwellings** — As with the water analysis mentioned above, the dwelling energy analysis was completed with a similar Marbek model and in a

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[27] As discussed further in Section 3.4 and Appendix A, four high-growth Census Metropolitan Areas (CMAs) attract the majority of new dwellings built in Canada — the Greater Vancouver Regional District, Calgary–Edmonton, the Greater Toronto Area, and Montreal. City planners from Montreal were not interviewed due to study resources and the assumption that growth trends in Montreal are a composite of growth trends in the other three high-growth CMAs.

[28] Degmar Construction. Markham, Ontario

similar fashion. The main data source for this analysis was the NRCan Comprehensive Energy Use Database (CEUD).

- **Direct Operating Energy for Municipal Water Systems** — This analysis used energy intensities (megajoules/litre) by fuel type to determine the energy used by municipal water systems to treat and distribute (pump) potable water to dwellings, and to collect (pump) and treat wastewater produced by dwellings. The data source was energy use statistics for different municipalities across Canada.

- **Direct Operating Energy for Residential Transportation** — This analysis used CMHC's *Greenhouse Gas Emissions from Urban Travel Tool*, the Toronto Transportation Tomorrow Survey 2001, and the Canadian Vehicle Survey 2004 from Transport Canada. The data from these sources were used to estimate the vehicle-kilometres travelled (VKT) per dwelling for personal vehicles and the passenger-kilometres travelled (PKT) per dwelling for public transportation, all by neighbourhood type. Canada's Energy Outlook 2006 (NRCan) was then used to identify the total annual operating energy in Canada by fuel type for "Light Duty Vehicles" and "Public Transit". These values were used to determine private vehicle and public transit fuel use per dwelling by neighbourhood type.

- **Indirect Effects of Operating Energy Use** — This analysis estimated the indirect (upstream) resource use and environmental outputs from extracting, refining, and delivering the operating energy (e.g., refined petroleum products, electricity) used during the operating stage of the life-cycle. Again, the Athena Institute's *Environmental Impact Estimator* LCA model was used to develop per-gigajoule coefficients of resource use and environmental outputs for each fuel type used to operate dwellings, municipal water systems, and residential transportation. These per-gigajoule coefficients were then multiplied by the total (direct) operating fuel use to aggregate the indirect effects of using fuel.

- **Resulting Environmental Impacts** — Environmental impacts result from many factors, including the environmental outputs quantified in this study, such as pollutants and land use change, as well as systems level responses, such as changes in biota supported regionally and melting ice due to warmer air temperatures. All sectors of the economy contribute to environmental outputs, including the residential sector, and thus, given the broad nature of environmental impacts, attribution of impacts to a specific sector is problematic. For this reason, the methodology for assessing resulting environmental impacts relies on a qualitative approach that is informed by quantitative data generated by this study and supported by data available in literature.

3.4 CONSTRUCTING THE BAU SCENARIO TO 2025

While data limitations and gaps affecting the analysis are discussed in detail in Section 9, this sub-section provides some elaboration on the issue of constructing a credible scenario for the residential sector to 2025.

One of the most significant challenges in this study was building a business-as-usual (BAU) scenario that reflects anticipated patterns of urban development using established projections of number and type of new dwellings and their associated land use. A defensible and robust approach has been used to characterize the BAU but, as shown in the subsequent sections, the empirical results are not always what one would intuitively expect. Fundamentally, the method employed was to merge national projections of dwelling stock with expectations of neighbourhood development patterns in four high-growth Census Metropolitan Areas (CMAs) in Canada — the Greater Vancouver Regional District, Calgary–Edmonton, the Greater Toronto Area, and Montreal.

In short, the BAU scenario developed in this study was an attempt to merge two different, yet legitimate characterisations of how the residential built environment could evolve to 2025:

- **Urban intensification plans for high-growth CMAs** — Municipal officials were consulted from three of the four largest growth clusters in Canada (Vancouver, Calgary-Edmonton, and Toronto). The intensification plans for these CMAs have begun to be implemented to a greater extent than in the past, as evidenced by the increasing percentage of low-rise and high-rise condominiums being built in existing neighbourhoods during 2003 to 2007. This study's BAU scenario assumes the intensification plans of municipalities to 2025 would be fully met by the high-growth CMAs.

- **National dwelling projections** — The national dwelling projections used from Canada's Energy Outlook (NRCan, 2006) were the best available data at the time of this study, but are *not* driven by emerging municipal intensification trends.

The Canadian Urban Institute's paper on *Smart Growth* notes that the term was coined in the United States to suggest an alternative growth paradigm that ultimately became "a magnet for all kinds of proposals to make cities less dysfunctional, more livable, and more economically competitive."[29] Based on the aim to decrease the impacts of low-density regional development on the natural environment, the focus of "Smart Growth" planning is the intensification of both population and physical development in existing urban areas.

Development may be driven by both plans and market demand; in fact, plans may respond to population and economic pressures based upon available literature about how past plans have worked in practice. The main issue that arises from our study approach is that the vision of future development patterns in high-growth CMAs is different from what we see emerging from independently-determined dwelling stock projections. This is particularly true for Toronto and Vancouver, where scarcity of available land and urban intensification policies are providing a

[29] Canadian Urban Institute, *Smart Growth in Canada*, March 2001, p.3. The Institute grouped the main actions with which Smart Growth can be "operationalised" into six categories: 1) Promoting cities as engines of the economy; 2) Containing urban sprawl; 3) Providing transportation alternatives; 4) Providing housing choice; 5) Protecting natural areas and cultural heritage; 6) Creating community.

strong impetus for intensification versus continued suburban, low-density development. The urban intensification paradigm has started to take hold in most of the major Census Metropolitan Areas (CMAs) of Canada as reflected in the most recent official municipal plans, in by-laws and other efforts to slow urban low-density development, and in discussions in this study with city planners from Vancouver, Calgary, and Toronto. The projected mix and type of new dwellings to emerge from the national dwelling projections does not reflect the mix and type of dwelling types that would be required to meet the anticipated implications of urban intensification policies taking hold.

The implication, as best interpreted from these discussions, is that urban areas in Canada are expected to become denser, as measured in terms of population density, housing density, efficiency of infrastructure provision and other factors. More specifically, discussion with these municipal planners indicated that we can expect to see densification of existing urban areas (inner city, inner suburbs, and outer suburbs) through:

- Significant low-rise and high-rise multi-unit residential building (MURB) construction;
- Conversion of some existing urban green space to housing; and
- Redevelopment of some brownfields to dense housing.

This vision of urban development patterns is quite different from that which would result from the national housing projections currently being used by the federal government. These dwelling stock projections show a higher share of single detached houses being built during 2004–2025 than is anticipated by Canada's high-growth CMAs. At the present time, there are simply no credible long-term housing stock projection sources beyond that of Canada's Energy Outlook (2006), which was used in this study. These projections of household formation are driven by assumptions of economic growth but they do not adequately reflect: 1) the likely evolution of urban intensification in Canada's CMA growth clusters; or 2) the resulting growth in construction of the higher-density dwelling types (e.g., low-rise and high-rise MURBs) required to meet these expected intensification plans.

In the final analysis, a robust and defensible method has been employed to generate the BAU scenario. As discussed in Section 9, the data uncertainties mentioned above, as well as throughout the report, do warrant consideration of possible additional analyses in the future. For example, there should be recognition that current residents of low-density suburbs may oppose densification policies strongly. As well, the assumption that redevelopment and densification of existing inner city neighbourhoods will not require upgrading of existing road or water infrastructure could warrant a need to better quantify these requirements, particularly in relation to brownfield redevelopment.

4. PROFILE OF THE RESIDENTIAL SECTOR

As discussed in Section 2, characterizing the residential sector provides a platform to assess its resulting environmental impacts, both quantitatively and qualitatively. This section is organized according to the two key aspects of the residential sector characterization:

- *Dwellings*, which characterizes and projects Canadian dwellings over 2004–2025; and,
- *Neighbourhoods & Infrastructure*, which characterizes and projects Canadian neighbourhoods and supporting residential infrastructure over 2004–2025.

Resource uses (e.g., energy, water, land, and solids) and environmental outputs (e.g., emissions to air, water, and land) are associated with the construction and maintenance of a physical structure (e.g., dwelling, residential road, residential water system infrastructure), while other resource uses are a result of operating those structures and providing operating services (e.g., servicing dwellings with energy and water, residential transportation). Following this profile of the residential sector, sections 5, 6, and 7 present the resource use, environmental outputs and resulting local, regional, and global environmental impacts from the residential sector.

4.1 DWELLINGS

This sub-section categorizes Canadian dwellings into dwelling archetypes and characterizes them sufficiently over the study period of 2004–2025 to allow assessment of their operating and non-operating resource use and environmental outputs. The discussion begins with dwelling types, and proceeds with dwelling stock by dwelling type, region, and neighbourhood type.

4.1.1 Dwelling Types

Canadian dwellings are categorised into the four "archetypes", which are presented in Exhibit 4.1. These archetypes are meant to be representative of the *average*, not of every individual dwelling in Canada (e.g., the high-rise multi-unit residential building (MURB) archetype assumes the *average* new building has underground parking).

Exhibit 4.1: Summary of Dwelling Archetypes Chosen for this Study

Dwelling Type	Dwellings Included	Dwelling Features	Building Features
Single Detached	Single detached houses, Mobile homes	218 m^2 (2,350 sqft), 2-storey, 3-bedroom, 2.5 bathrooms, full basement, 2-car garage	1 dwelling/building
Row/Town	Row & Townhouses, Semi-detached houses, Duplexes	139 m^2 (1,500 sqft), 2-storey, 3-bedroom, 1.5 bathrooms, full basement, 1-car garage	5 dwellings/building
Low-rise MURB	Apartments & condo units in multi-unit buildings less then 5 storeys[30]	84 m^2 (900 sqft); impacts assumed similar to 80% Row/Town (adjusted from 1,500 to 900 sqft) & 20% High-rise MURB unit	6 dwellings/building
High-rise MURB	Apartments & condo units in multi-unit buildings with 5 storeys or more	84 m^2 (900 sqft)	40 dwellings/building, 11-storey complex, 2 levels underground parking, common spaces

[30] Built according to Part 9 of the *National Building Code of Canada 2005* (National Research Council Canada), http://irc.nrc-cnrc.gc.ca/pubs/codes/nrcc47666_e.html

Per-dwelling resource use and environmental outputs are presented in Sections 5 and 6.

4.1.2 Dwelling Stock by Dwelling Type

Exhibit 4.2 presents the actual dwelling stock in 2004 and the estimated stock in 2025, based on the methodology and data sources described in Section 3.

Exhibit 4.2: Total Dwelling Stock in 2004 & 2025, by Dwelling Type

Dwelling Type	# Dwellings (thousands)		% of Total Dwellings	
	Actual **2004**	Est. **2025**	Actual **2004**	Est. **2025**
Total	**12,037**	**15,900**	**100%**	**100%**
Single Detached	6,836	9,000	56.8%	57%
Row / Town	1,809	2,500	15.0%	16%
Low-rise MURB	2,254	2,900	18.7%	18%
High-rise MURB	1,138	1,500	9.5%	9%

The above study results yield the following observations:

- There were 12 million dwelling units in Canada in 2004, of which single detached houses account for about 57% of the total.
- The total number of dwelling units would increase from 12 million to nearly 16 million units by 2025, comprising an additional 3.8 million dwellings, including demolitions and replacements.
- The addition of about 3.8 million new dwellings mean that only 25% of the dwelling stock projected to exist in 2025 would be built after 2004.
- As shown, the dwelling projection from Canada's Energy Outlook (NRCan, 2006) suggests that there would be virtually no change in percentage shares of the major dwelling types between 2004 and 2005. Of course, as mentioned in Section 3.4, this does not mesh entirely with the scenario of urban intensification reported by the high-growth CMAs consulted in this study. And, there exists the potential for leap-frogging development, in which exurban development may take place beyond planning boundaries. These high-growth areas are discussed more in the following sub-section.
- As a result of the above, possible future work could involve assessing the results for a different degree of high-growth CMA intensification coupled with close-matching dwelling projections by dwelling type.

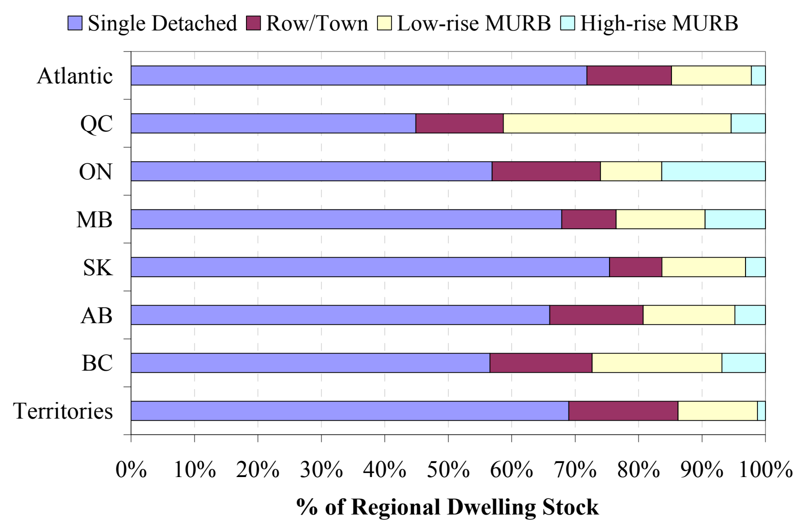
4.1.3 Dwelling Stock by Region

Exhibit 4.3 presents the dwelling stock distribution and growth by region. Exhibit 4.4 presents the 2004 distribution of dwellings by percentage of regional dwelling stock, to show dominant dwelling types.

Exhibit 4.3: Dwelling Stock Distribution & Growth during 2004–2025, by Dwelling Type & Region

Dwelling Type	Territories	BC	AB	SK	MB	ON	QC	Atlantic
	Dwellings (thousands) in 2004							
Single Detached	23	890	760	285	296	2,561	1,379	643
Row/Town	6	253	169	31	37	767	425	120
Low-rise MURB	4	322	167	50	61	434	1,103	113
High-rise MURB	0	108	55	12	41	735	166	20
Regional Total	**33**	**1,573**	**1,151**	**377**	**436**	**4,498**	**3,073**	**895**
% of Canada Total	**0%**	**13%**	**10%**	**3%**	**4%**	**37%**	**26%**	**7%**
	Estimated Growth by 2025							
Single Detached	47%	28%	44%	18%	24%	40%	24%	14%
Row/Town	47%	29%	72%	42%	5%	57%	14%	15%
Low-rise MURB	47%	28%	21%	5%	28%	30%	28%	14%
High-rise MURB	47%	28%	21%	5%	28%	30%	27%	13%
Total	**47%**	**28%**	**44%**	**18%**	**23%**	**41%**	**24%**	**14%**

Exhibit 4.4: Percentage of Regional Stock Distribution in 2004, by Dwelling Type & Region



The above study results yield the following observations:

- Single detached dwellings clearly dominate the dwelling stock in all regions, but there is some interesting variation. For instance, Quebec has a relatively higher percentage of low-rise MURB units, as a result of the many walk-up low-rises in Montreal. Both Ontario and Manitoba have relatively higher percentages of high-rise MURB units. About 63% of the dwellings in 2004 were located in Ontario and Quebec.
- In percentage terms, the Territories, Alberta and Ontario are projected to have the largest growth rates. In terms of volume, about 67% of all new stock would be built in Ontario and Quebec while 25% would be built in Alberta and B.C.

Regional Growth Clusters

In 2001, more than 50% of Canadians lived in four large urban regions:[31]

- British Columbia's lower mainland (including the Greater Vancouver Regional District, GVRD) and southern Vancouver Island;
- Alberta's Edmonton–Calgary corridor;
- Southern Ontario's 'Golden Horseshoe' of densely populated cities near the west end of Lake Ontario, including the Greater Toronto Area; and
- Québec's Montreal region.

Canadian residential growth between 1996 and 2001 was 7.6% in these four regions compared to only 0.5% in the rest of the country, a trend that is expected to continue.[32] The majority of all new Canadian dwellings during 2004–2025 are expected to be built in these four urban growth clusters.

4.1.4 Dwelling Stock by Neighbourhood Type

As noted, three neighbourhood archetypes were developed in this study to represent average neighbourhoods in Canada. Exhibit 4.5 presents the projected Canadian dwelling stock by neighbourhood type.

Exhibit 4.5: Projected Dwelling Stock for 2004–2025, by Dwelling Type & Neighbourhood Type

Neighbourhood & Dwelling Type	% of Total Dwellings in Canada		% of Total Dwellings in Nhood Type		Forecast # Dwellings (thousands)	
	Actual 2004	Est. 2025	Actual 2004	Est. 2025	Actual 2004	Est. 2025
Inner City total	**9.25%**	**10.5%**	100%	100%	**1,113**	**1,486**
Single Detached			15%	15%	167	225
Row/Town			20%	21%	223	319
Low-rise MURB			25%	24%	278	358
High-rise MURB			40%	39%	445	585
Inner Suburbs total	**13.25%**	**14.5%**	100%	100%	**1,595**	**2,124**
Single Detached			40%	40%	638	854
Row/Town			15%	16%	239	341
Low-rise MURB			15%	14%	239	308
High-rise MURB			30%	29%	478	622
Outer Suburbs total	**77.5%**	**75%**	100%	100%	**9,329**	**12,257**
Single Detached			65%	65%	6,031	7,943
Row/Town			14%	15%	1,347	1,875
Low-rise MURB			19%	18%	1,736	2,184

[31] David Suzuki Foundation. *Understanding Sprawl: A Citizen's Guide*. http://www.davidsuzuki.org/files/Climate/Ontario/Understanding_Sprawl.pdf

[32] Ibid.

High-rise MURB		2%	2%	214	255

The above study results show that, for both 2004 and 2025, Canadian neighbourhoods are predominantly low-density and suburban in character, with over 75% of all dwelling units located in outer suburbs.

4.2 NEIGHBOURHOODS & INFRASTRUCTURE

The profile of Canadian neighbourhoods in this sub-section helps capture effects that are greater than the sum of the individual dwelling impacts. Neighbourhoods provide the context within which residents and dwellings operate, and are an appropriate scale to describe changes to land and residential infrastructure, such as roads and water works.

This sub-section defines three representative neighbourhood types, profiles the total number of each type of neighbourhood in Canada over the study period, and characterizes these neighbourhoods by physical attributes and required neighbourhood infrastructure.

4.2.1 Neighbourhood Types

As derived in Section 3, three neighbourhood archetypes are used to characterize existing and new residential development in Canada:

- **Inner City** — This neighbourhood type is representative of the downtown area of major Canadian cities, containing high density development, mixed commercial and residential use, a majority of dwelling units in low or high rise apartment buildings, and a rectangular grid of small blocks with limited green space.

- **Inner Suburb** — This neighbourhood type is representative of the ring of older suburban development surrounding the downtown core of major cities, the central area of smaller centres, and newer suburban development based on "neo-traditional" or "new urbanist" planning principles. The inner suburb is characterized by medium density development with a commercial main street providing neighbourhood services, a relatively even split between detached/semi-detached/row house development and MURBs, longer rectilinear blocks and more generous parkland.

- **Outer Suburb** — This neighbourhood type is representative of suburban or rural areas with low density development, segregated commercial or institutional uses, a majority of units as detached houses, curvilinear street patterns, larger lot sizes, and generous parkland within or surrounding residential development.

4.2.2 Number of Neighbourhoods

Exhibit 4.6 compares the Canadian dwelling stock growth to neighbourhood densification during the study period of 2004–2025. A typical neighbourhood area of 50 hectares was selected to bound neighbourhoods into discrete areas that could be quantified in Canada and used for a comparative analysis on a per-neighbourhood basis.

Exhibit 4.6: Comparison of Dwelling Stock Growth to Neighbourhood Densification during 2004–2025, by Neighbourhood Type

Measure during 2004–2025	Neighbourhood Type		
	Inner City	Inner Suburb	Outer Suburb
% Increase in Total Dwelling Stock[33]	33%	33%	31%
% Increase Densification of Existing Neighbourhoods[34]	28%	16%	31%
# Existing 50-ha Neighbourhoods (as of 2004)	619	1,994	47,104
# New Dwellings to be Built in Densified Existing Neighbourhoods	310,000	250,000	2,930,000
Remaining # New Dwellings to be Built in Dense New Neighbourhoods	343,000		
Resulting # New 50-ha Neighbourhoods to be Built	330		

The above study results yield the following observations:

- In 2004, there were roughly 47,000 neighbourhoods, of 50 hectares each, in Canada. The vast majority of these neighbourhoods are categorized within the Outer Suburb archetype, as defined for this study.
- In terms of dwelling per hectare, the analysis reveals that all neighbourhood archetypes would become considerably denser, ranging from 16% to 31% denser, depending on neighbourhood type.
- Over the study period, the gradual effects of urban intensification taking effect in the large, growth CMAs would constrain the expansion of the urban boundaries. Consequently, the analysis reveals that the gradual densification of existing neighbourhood archetypes would cause these neighbourhoods to absorb about 90% of the new dwellings built in Canada during 2004–2025, amounting to about 3.8 million new dwellings.

4.2.3 Neighbourhood Physical Characteristics

As noted, the BAU scenario reveals that most of the new dwellings built during 2004–2025 would be absorbed by existing neighbourhoods. To densify these existing neighbourhoods, some existing greenspace and vacant and underutilized land (e.g., brownfields, greyfields, shopping malls, etc.) would be developed/redeveloped with residential buildings, including higher density housing (e.g., low-rise and high-rise MURBs). This densification also requires changes to roads, parking, and other residential infrastructure. Exhibit 4.7 presents the estimated share of residential neighbourhood land used for various residential and non-residential purposes in 2004 and 2025.

[33] Based on methodology in Section 3 and Appendix A, using dwelling growth from: Natural Resources Canada. 2006. *Canada's Energy Outlook: The Reference Case 2006*. http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php

[34] Based on projections from municipal officials in regional growth cluster cities

Exhibit 4.7: Estimated Share of Residential Neighbourhood Land in 2004 & 2025, by Neighbourhood Type & Residential/Non-Residential

Res/Non-Res	Area Category	Area Type	Inner City 2004	Inner City 2025	Inner Suburb 2004	Inner Suburb 2025	Outer Suburb 2004	Outer Suburb 2025
Residential	Buildings	Single Detached	8%	8%	11%	11%	8%	10%
		Row/Town	5%	6%	3%	5%	1%	2%
		Low-rise MURBs	2%	3%	1%	1%	0%	0%
		High-rise MURBs	2%	2%	1%	1%	0%	0%
	Paved	Parking	6%	5%	6%	6%	4%	5%
		Roads	11%	11%	10%	10%	12%	14%
		Sidewalks	4%	4%	3%	3%	0%	0%
	Green Space	Parkland	2%	2%	12%	10%	21%	14%
		Lots & Right-of-Ways	34%	33%	32%	32%	31%	31%
Residential Total			**74%**	**74%**	**80%**	**80%**	**77%**	**77%**
Non-Residential	Buildings	Comm, Inst, Ind	10%	10%	5%	5%	5%	5%
	Paved	Roads & Parking	11%	11%	10%	10%	6%	6%
		Sidewalks	2%	2%	1%	1%	2%	2%
	Green Space	Lots, Right-of-Ways, Parkland	3%	3%	4%	4%	9%	10%
Non-Residential Total			**26%**	**26%**	**20%**	**20%**	**22%**	**23%**
Grand Total			100%	100%	100%	100%	100%	100%
*Note: any discrepancies in sub-totals are attributable to the rounding of numbers.								

The above study results yield the following observations:

- Inner City neighbourhoods have significantly less residential green space than the other neighbourhood types.
- When the values for residential "parkland" and "lots & right-of-ways" are combined, it shows that the Outer Suburb archetype has a significant share of residential green space, amounting to over 50% of total neighbourhood area in 2004 and declining to about 45% of the total neighbourhood area in 2025. The decline in the Outer Suburb archetype is likely influenced by expected densification patterns, where some green space would be converted to development.
- These changes in land use convert some existing permeable land (i.e., land that rain water can soak into) to impermeable land. The implications of this are discussed in Section 6.

Exhibit 4.8 summarises some of the major physical characteristics of the three neighbourhood types, resulting from Exhibits 4.5 and 4.7.

Exhibit 4.8: Summary of Neighbourhood Physical Characteristics in 2004 & 2025, by Neighbourhood Type[35]

Physical Indicator	Inner City		Inner Suburb		Outer Suburb	
	2004	2025	2004	2025	2004	2025
Gross Residential Density [dwellings/ha]	35	46	16	18.5	4.0	5.2
Average Building Coverage per Dwelling [ha/dwelling]	0.005	0.004	0.01	0.01	0.02	0.02
Average Paved Area per Dwelling [ha/dwelling]	0.005	0.004	0.01	0.01	0.04	0.03
Average Green Space per Dwelling [ha/dwelling]	0.01	0.01	0.03	0.02	0.12	0.08
Average Road Length per Dwelling [ha/dwelling]	2.9	2.3	6.3	5.9	14.2	12.8

The above study results show that there are significant differences in the type of land use and infrastructure requirements *per dwelling unit* among the three neighbourhood types. For instance, compared to the Inner City neighbourhood type, Outer Suburbs have 4 times the building coverage, 8 times the paved area, 12 times the green space, and 5 times the road and infrastructure length *per dwelling unit*.

4.2.4 Neighbourhood Infrastructure

As described in Section 3 and Appendix A, four residential infrastructure types were defined to characterise the roads and accompanying water supply and wastewater collection infrastructure needed to provide transportation and water services to residential neighbourhoods:

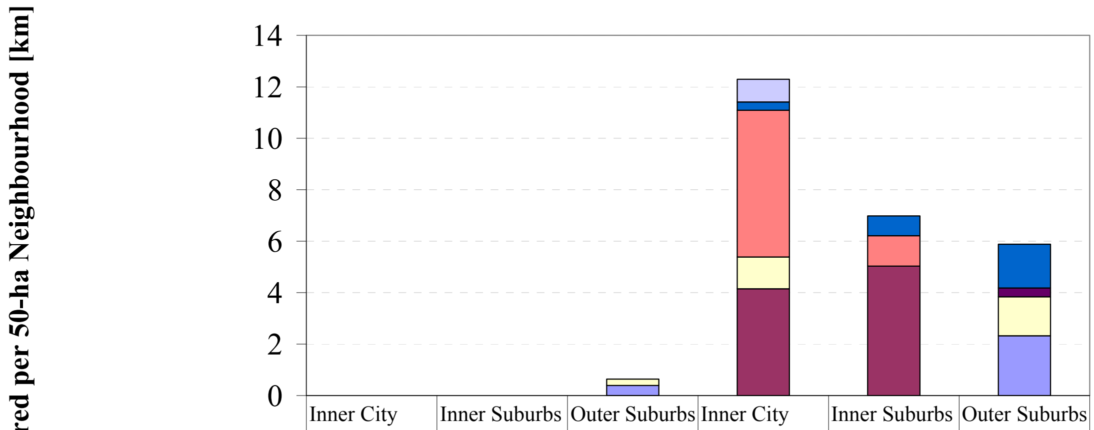
- **Type I: Two-lane Local Road** with total road width of 8 m, no sidewalks, and 8 domestic water and sewer connections per 100 m.
- **Type II: Two-lane Local Road** with total road width of 9 m, total sidewalk width of 3 m, and 15 domestic water and sewer connections per 100 m.
- **Type III: Two-lane Collector Road** with total road width of 11 m, total sidewalk width of 3 m, and 5 domestic water and sewer connections per 100 m.
- **Type IV: Four-lane Collector Road** with total road width of 15 m, total sidewalk width of 5 m, and no domestic water and sewer connections.

According to these four residential infrastructure types, Exhibit 4.9 presents the length of residential road infrastructure required per 50-ha neighbourhood in 2004 and 2005, making a distinction between the implications of building new neighbourhoods versus densification of existing neighbourhoods.

Exhibit 4.10 presents the resulting kilometres of each of the four road infrastructure types required for residential densification and new neighbourhoods during 2004–2025. A typical neighbourhood area of 50 hectares was selected to bound neighbourhoods into discrete areas that could be quantified in Canada and used for per-neighbourhood comparisons.

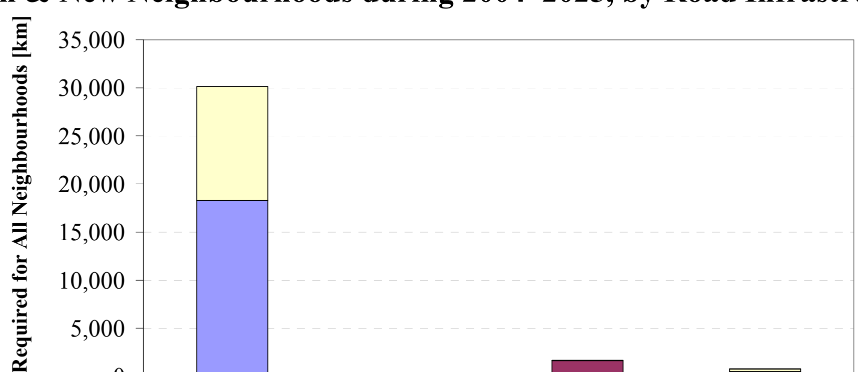
[35] Based on projections from municipal officials in regional growth cluster cities.

Exhibit 4.9: New Road Infrastructure Required *per 50-ha Neighbourhood* for Residential Densification & New Neighbourhoods during 2004–2025, by Neighbourhood Type & Road Infrastructure Type



	Densify Existing Residential Nhood: Inner City	Densify Existing Residential Nhood: Inner Suburbs	Densify Existing Residential Nhood: Outer Suburbs	Build New Dense Residential Nhood: Inner City	Build New Dense Residential Nhood: Inner Suburbs	Build New Dense Residential Nhood: Outer Suburbs
Non-Residential - Type IV	0.0	0.0	0.0	0.9	0.0	0.0
Non-Residential - Type III	0.0	0.0	0.0	0.3	0.8	1.7
Non-Residential - Type II	0.0	0.0	0.0	5.7	1.2	0.0
Non-Residential - Type I	0.0	0.0	0.0	0.0	0.0	0.3
Residential - Type IV	0.0	0.0	0.0	0.0	0.0	0.0
Residential - Type III	0.0	0.0	0.3	1.2	0.0	1.5
Residential - Type II	0.0	0.0	0.0	4.2	5.0	0.0
Residential - Type I	0.0	0.0	0.4	0.0	0.0	2.3

Exhibit 4.10: New Road Infrastructure Required *for All Neighbourhoods* for Residential Densification & New Neighbourhoods during 2004–2025, by Road Infrastructure Type



	Densify Existing Residential Nhoods: Residential	Densify Existing Residential Nhoods: Non-Residential	Build New Dense Residential Nhoods: Residential	Build New Dense Residential Nhoods: Non-Residential
Type IV	0	0	0	24
Type III	11,870	0	34	241
Type II	0	0	1,635	515
Type I	18,276	0	0	0

The above study results yield the following observations:

- As shown, the profile assumes that no new road and water infrastructure are required to densify existing Inner City and Inner Suburb neighbourhoods during 2004–2025 . While this assumption was accepted by CMHC within the scope of this study, it is probably an underestimation of anticipated future infrastructure needs associated with urban core redevelopment.[36]
- The profile also assumes that new housing built in the existing Inner City and Inner Suburb neighbourhoods can be accommodated with existing infrastructure levels.
- Minimal new road and water infrastructure are required to densify each 50-ha Outer Suburb neighbourhood during 2004–2025. However, because of the large *number* of existing Outer Suburb neighbourhoods, this results in 10 times more road and water infrastructure required to densify existing Outer Suburb neighbourhoods than to build all newly needed neighbourhoods (of all types) during 2004–2025. This proportion is shown in Exhibit 4.10 and is a result of most new dwellings fitting inside densified existing neighbourhoods.
- Any new road and water infrastructure required to densify existing neighbourhoods is needed to service *residential* areas within those neighbourhoods, *not non-residential* areas (e.g., commercial areas, schools, etc.).

Section 5 presents the resource use of residential structures (i.e., dwellings and neighbourhood infrastructure) and activities (i.e., servicing dwellings with energy and water, servicing vehicles with energy).

[36] For example, the Le Cours Chaboillez brownfield development in downtown Montreal requires new roads and widening of existing roads.

5. RESOURCE USE

As described in Section 2, residential structures and activities require resource use (e.g., energy, water, land, and solids), which creates environmental outputs (e.g., emissions to air, water, and soil), which results in local, regional, and global environmental impacts.

This section presents the resources required by structures and activities in the Canadian residential sector during the study period 2004–2025. This section is presented as follows:

- Overall Energy Use
- Overall Water Use
- Overall Land Use
- Overall Solid Resource Use
- Comparison by Dwelling Type
- Comparison by Neighbourhood Type.

The first four sub-sections provide "overall" results that do not highlight differences by dwelling type or neighbourhood type.

The results contained in each sub-section highlight differences according to each the following:

- *Element of the residential built environment* — Dwellings, neighbourhood infrastructure, and residential transportation, as defined in Section 1;
- *Life-cycle stage* — Extraction & Manufacturing, On-site construction, Indirect Operating, Direct Operating, and Maintenance & Replacement, as defined in Section 2;
- *Year* (i.e., 2004 & 2025); and
- *Cumulative for all dwellings vs. average per dwelling*, as available and relevant.

Each sub-section begins with an overview of the life-cycle resource use over the study period, followed by results for areas that dominate life-cycle resource use and, therefore, require deeper understanding. Interpretations and observations on the results are discussed throughout.

Following this discussion, Section 6 describes the environmental outputs from using resources for environmental structures, services, and activities.

5.1 OVERALL ENERGY USE[37]

This section presents the overall primary energy use by Canada's residential sector during 2004–2025. Differences by dwelling and neighbourhood type are presented in Sections 5.5 and 5.6.

Before presenting the results, note the difference between primary and secondary energy:[38]

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[37] It should be noted that residential occupants have differing degrees of control over primary and secondary energy use. For example, they cannot determine the generation of the electricity used in their homes.

[38] Environment Canada. Last updated April 2005. *National Environmental Indicator Series*. https://www.ec.gc.ca/soer-ree/English/Indicators/Issues/Energy/Tech_Sup/ecsup1_e.cfm

- **Primary energy** is energy in its original raw resource form, either domestic or imported. Primary energy includes energy used by the final consumer, intermediate uses of energy in transforming one energy form to another (e.g., coal to electricity), and energy used by suppliers in providing energy to the market (e.g., fuel for pipeline compressors). Examples are: fossil fuel hydrocarbons in the form of coal, crude oil, and natural gas; and electricity from nuclear power plants and hydro-electric stations.

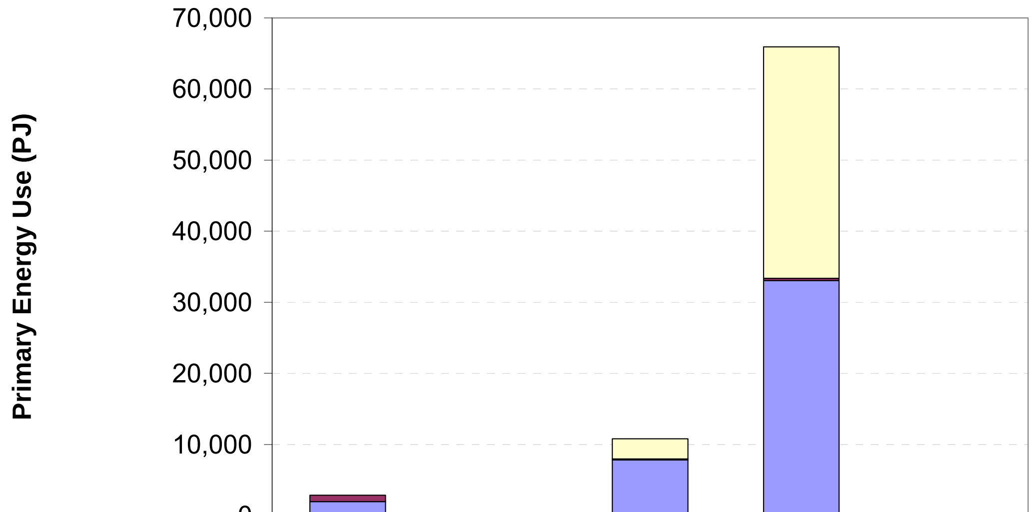
- **Secondary energy** is produced by processing primary energy. It does not include the energy lost in inefficient conversions from one energy form to another, nor does it include intermediate uses of energy for transporting energy to market. Examples are electricity produced from coal, and gasoline produced from crude oil. Together with primary natural gas and electricity, secondary energy is the energy used by final consumers for residential, commercial, industrial and transportation purposes

To better relate the above definitions to this study, secondary energy includes only the energy commodities paid for by end users (e.g., electricity, natural gas, propane, fuel oil, diesel, gasoline, wood, etc.), while primary energy also includes all raw energy resources (e.g., crude oil, coal, etc.) used to produce and distribute that secondary energy.

5.1.1 Life-cycle Primary Energy Use

Exhibit 5.1 presents the life-cycle primary energy use by the residential sector over the study period, by life-cycle stage and structure/activity. The units in the table beneath the chart are expressed in scientific notation, which is useful for displaying a significant number of digits (in this case two digits) for values that are different orders of magnitude. For example, 8.9E+02 represents 8.9 x 10^2, which is 890, and 3.3E+04 represents 3.3 x 10^4, which is 33,000.

Exhibit 5.1: Life-cycle Primary Energy Use by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			2.9E+03	3.3E+04	
Road, Water & Wastewater Infrastructure	8.9E+02	5.9E+01	1.3E+02	3.1E+02	
Dwellings	2.0E+03	1.4E+02	7.8E+03	3.3E+04	3.9E+02

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- Total life-cycle primary energy use of Canada's residential sector over the 21-year study period amounts to about 80,000 PJ. To put this into perspective, if the annual secondary energy consumption in 2004 for *all* sectors in Canada was multiplied by the same 21-year period, the resulting energy consumption would be 178,500 PJ.[39]
- Direct primary operating energy outweighs any other stage of the life-cycle by almost seven times, while the sum of direct and indirect primary operating energy outweighs any other stage of the life-cycle by almost forty times.
- Operating energy use is almost evenly split between dwelling operation (e.g., heating, cooling, etc.) and residential transportation operation (i.e., private vehicles and public transit), with municipal water system operating energy barely visible, in comparison.
- The upstream primary energy use in Extraction & Manufacturing is largely for the production of cement, which is used later in the life-cycle in the concrete elements of dwellings (e.g., high-rise MURBs) and road and water infrastructure.

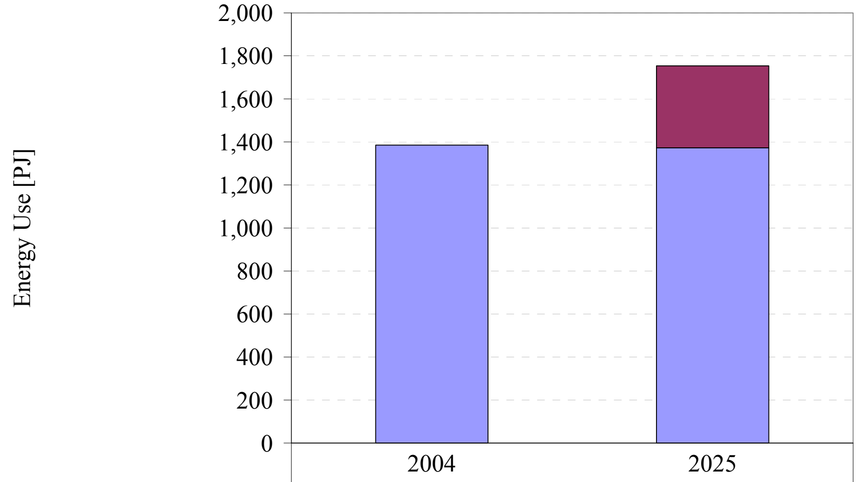
To focus more on the dominant life-cycle stage of "Direct Operating", the following three sub-sections explore the annual operating energy of dwellings, municipal water systems (to service dwellings), and residential transportation.

5.1.2 Annual Dwelling Operating Energy

Exhibit 5.2 presents the annual direct operating energy used by dwellings for all dwellings in 2004 and 2025, highlighting the difference between new housing and existing/renovated housing. Exhibits 5.3 and 5.4 present the same data for 2004 and 2025, except by energy end-use and fuel, respectively. In Exhibit 5.3, the end use category "Other" refers to computers, televisions, and other plug loads.

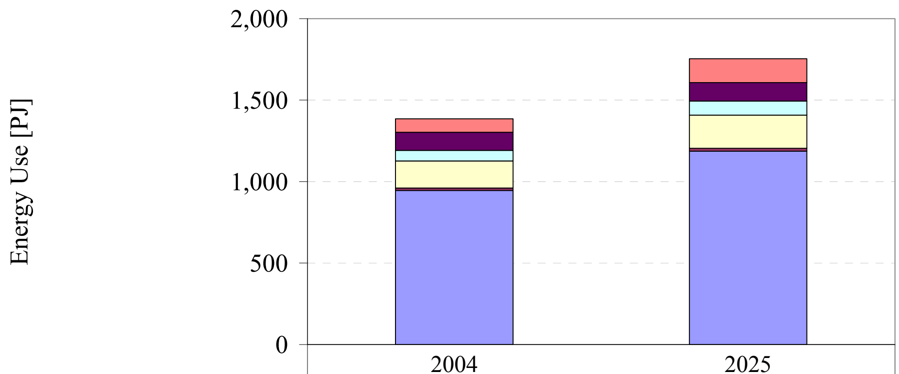
[39] Natural Resources Canada. 2006. *National Energy Use Database (NEUD) – Total End-Use Sector – Energy Use Analysis*. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablesanalysis2/aaa_ca_1_e_4.cfm?attr=0

Exhibit 5.2: Annual Dwelling Direct Operating Energy for All Dwellings in 2004 & 2025, by New vs. Existing & Renovated



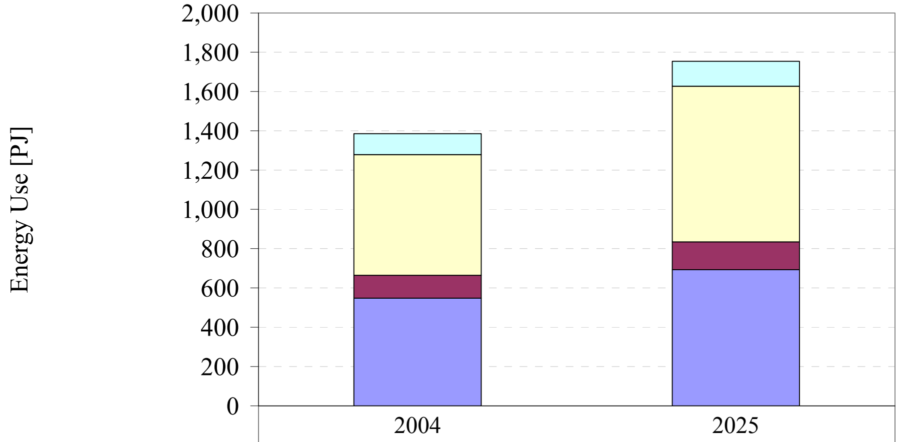
	2004	2025
New	0	381
Existing & Renovated	1,385	1,373

Exhibit 5.3: Annual Dwelling Direct Operating Energy for All Dwellings in 2004 & 2025, by End-Use



	2004	2025
Other	83	147
Major Appliances	111	113
Lighting	64	86
Domestic Water Heating	166	204
Space Cooling	14	17
Space Heating	946	1,187

Exhibit 5.4: Annual Dwelling Direct Operating Energy for All Dwellings in 2004 & 2025, by Fuel



	2004	2025
Wood	106	127
Natural Gas	614	792
Fuel Oil & Propane	117	141
Electricity	548	693

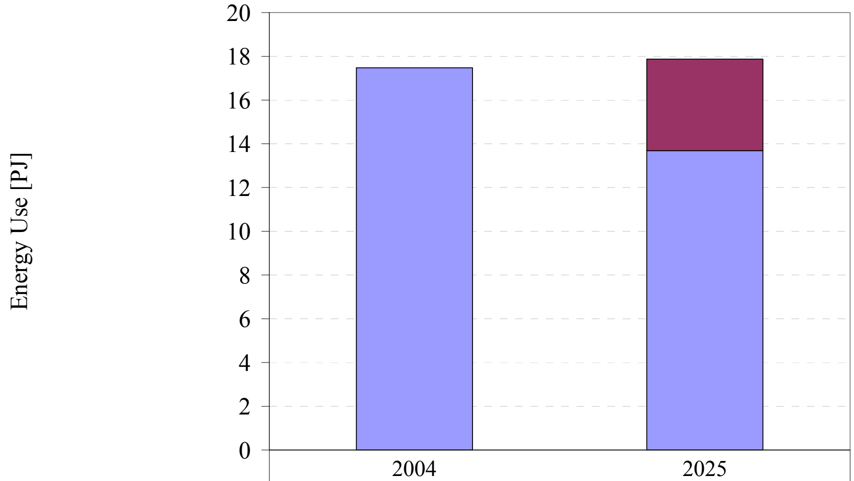
The above study results yield the following observations:

- In 2004, dwellings consumed 1,390 PJ of direct operating energy, which is 16% of total energy use in all sectors in Canada.
- Very little decrease in annual energy use by existing dwellings (built as of 2004) over the study period, since decrease in energy use from energy conservation and efficiency is almost completely countered by increases in renovated dwelling size, increases in renovated dwelling window-to-wall ratio, and increases in the number of electrical devices per dwelling, such as entertainment systems, computers, etc.
- Space heating dominates dwelling end uses due to Canada's northern climate.
- Use of all four major fuels increases over the study period, with natural gas dominating and electricity following closely behind.

5.1.3 Annual Municipal Water System Operating Energy to Service Dwellings

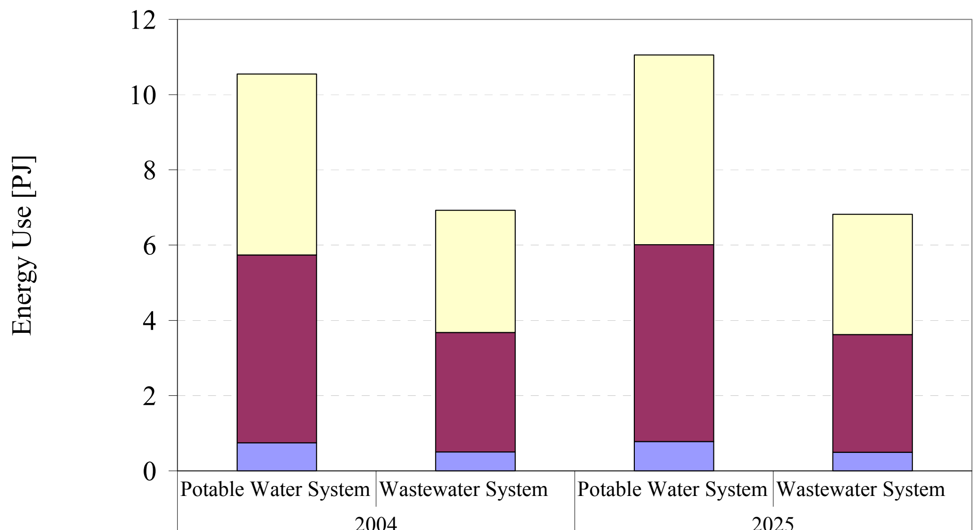
Exhibit 5.5 presents the annual direct operating energy used by municipal water treatment and pumping systems for supply water and wastewater servicing of all dwellings in 2004 and 2025, highlighting the difference between new housing and existing and renovated housing. Exhibit 5.6 presents the same data for 2004 and 2025, except by fuel.

Exhibit 5.5: Annual Municipal Water Supply & Wastewater Treatment & Pumping Direct Operating Energy to Service All Dwellings in 2004 & 2025, by New vs. Existing & Renovated



	2004	2025
New	0	4
Existing & Renovated	17	14

Exhibit 5.6: Annual Municipal Water Supply & Wastewater Treatment & Pumping Direct Operating Energy to Service All Dwellings in 2004 & 2025, by Municipal Water System & Fuel



	2004		2025	
	Potable Water System	Wastewater System	Potable Water System	Wastewater System
Natural Gas	4.8	3.2	5.0	3.2
Electricity	5.0	3.2	5.2	3.1
Diesel	0.7	0.5	0.8	0.5

The above study results yield the following observations:

- Water use improvements are estimated in the existing stock over the study period due to water conservation by residents, increasingly water-efficient products, and increased water efficiency due to renovated water systems in dwellings (e.g., kitchens, bathrooms). This decrease in total annual water use by the existing stock results in decreased water system energy use to service the existing dwellings.

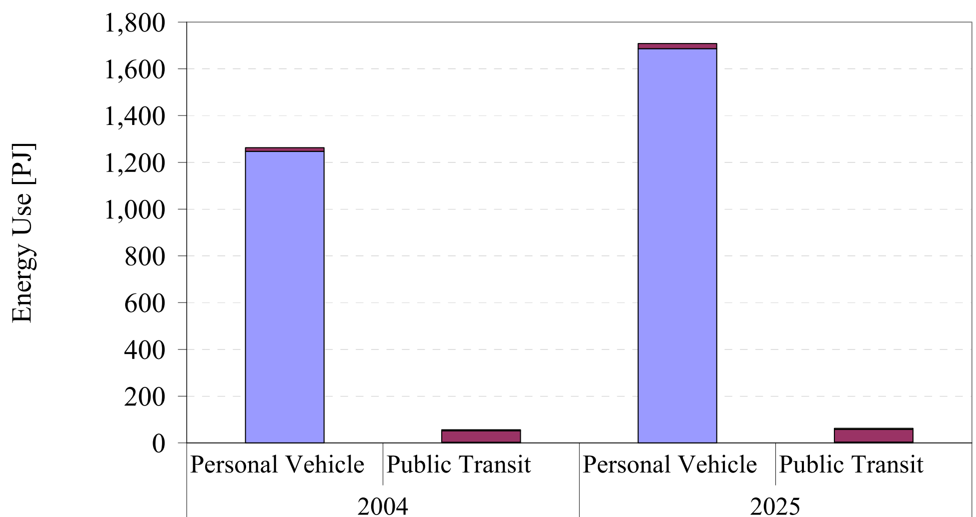
Unfortunately, the additional water demand and resulting municipal water system energy demand for new dwellings more than makes up for the savings in existing dwellings.

- Treatment and pumping of potable water requires about 50% more operating energy than pumping and treatment of wastewater.
- Municipal water system operating energy use is roughly half natural gas for treatment of potable water and wastewater, and half electricity for pumping of potable water and wastewater to and from dwellings.

5.1.4 Annual Residential Transportation Operating Energy

Exhibit 5.7 presents the annual direct operating energy used by all Canadians for residential transportation use in 2004 and 2005, highlighting the difference by end-use (private vehicle and public transit), and showing respective fuels used.

Exhibit 5.7: Annual Residential Transportation Direct Operating Energy for All Dwellings in 2004 & 2025, by End-Use & Fuel



	2004 Personal Vehicle	2004 Public Transit	2025 Personal Vehicle	2025 Public Transit
Electricity	0	4	0	4
Diesel	16	49	22	54
Gasoline	1,247	3	1,686	3

The above study results yield the following observations:

- Annual residential transportation operating energy use is almost the same as annual dwelling operating energy use.
- Personal vehicle operating energy use is more than 20 times that of public transit.
- Gasoline dominates personal vehicle fuel use (~99% of total) and diesel dominates public transit fuel use (~83% of total).
- Gasoline use is estimated to increase by a third over the study period due to national population and other factors included in Canada's Energy Outlook 2006 (NRCan).

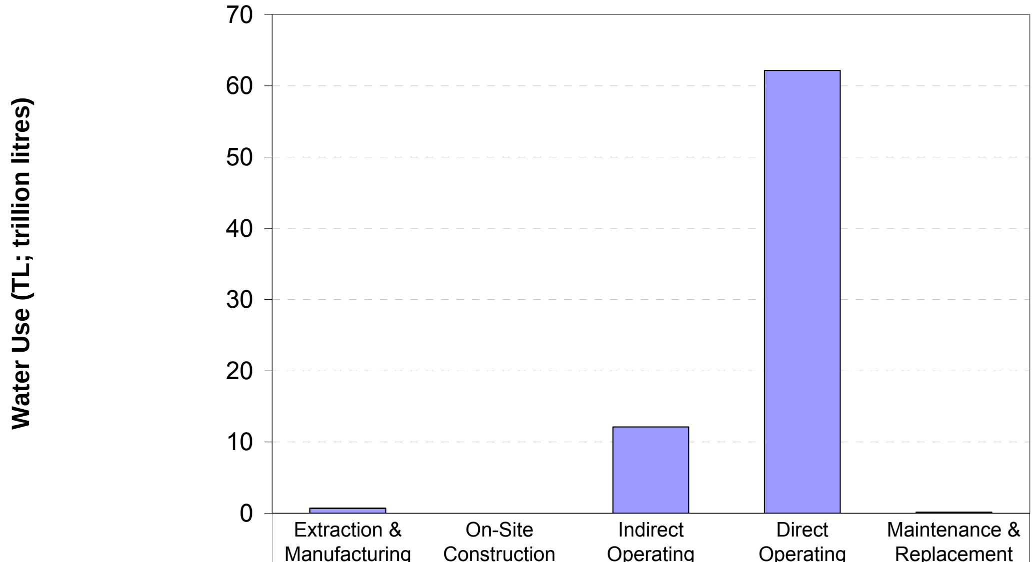
5.2 OVERALL WATER USE

This sub-section presents the overall water use of Canada's residential sector during the study period of 2004–2025. Resource use differences by dwelling type and neighbourhood type are presented later, in Sections 5.5 and 5.6.

5.2.1 Life-cycle Water Use

Exhibit 5.8 presents the life-cycle water use of the residential sector during 2004–2025, by life-cycle stage and structure/activity.

Exhibit 5.8: Life-cycle Water Use by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			0.0E+00	0.0E+00	
Road, Water & Wastewater Infrastructure	2.2E-02	0.0E+00	0.0E+00	0.0E+00	
Dwellings	7.0E-01	0.0E+00	1.2E+01	6.2E+01	1.7E-01

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- The Canadian residential sector would use about 75 teralitres (75 km^3) of water during 2004–2025, which is equivalent to almost a year of water flowing over Niagara Falls.[40]
- Dwelling-related water use, i.e. direct operating use, dominates the entire life-cycle.

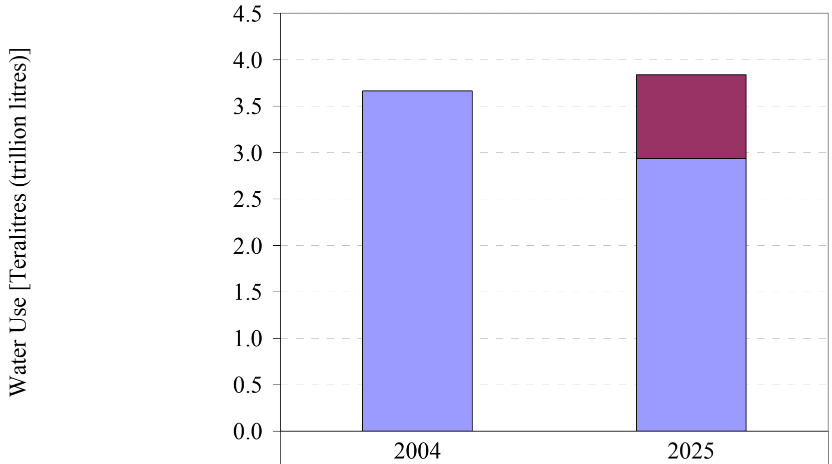
The next sub-section focuses more on the dominance of dwelling operating water use.

[40] Niagara Falls volume of water flow: http://www.niagaraparks.com/nfgg/geology.php

5.2.2 Annual Dwelling Operating Water Use

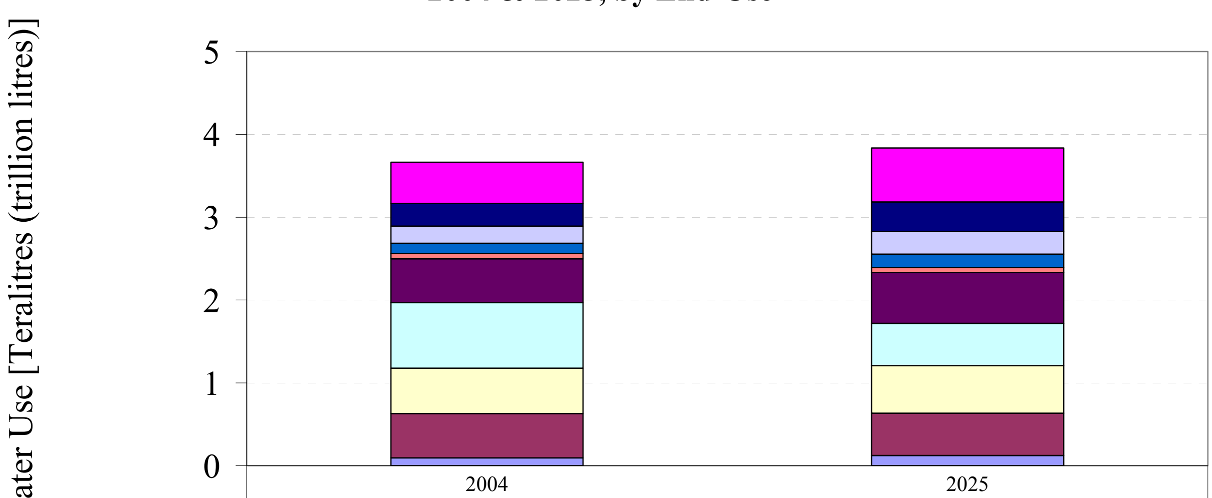
Exhibit 5.9 presents the annual operating water use by all dwellings and the resulting upstream water leaks in 2004 and 2005, highlighting the difference between new housing and existing/renovated housing. Exhibit 5.10 presents the same data by end-use.

Exhibit 5.9: Annual Dwelling Operating Water Use & Upstream Distribution Leaks in 2004 & 2025, by New vs. Existing & Renovated



	2004	2025
New	0.0	0.9
Existing & Renovated	3.7	2.9

Exhibit 5.10: Annual Dwelling Operating Water Use & Upstream Distribution Leaks in 2004 & 2025, by End-Use



	2004	2025
Distr System Leaks	0.50	0.65
Dwelling Leaks	0.27	0.36
Outdoor	0.21	0.27
Other Domestic	0.12	0.16
Dishwasher	0.06	0.06
Clothes Washer	0.53	0.62
Toilets	0.79	0.51
Faucets	0.55	0.57
Showers	0.54	0.51
Baths	0.09	0.12

The above study results yield the following observations:

- There are estimated to be actual water use improvements in the existing stock over the study period due to water conservation by residents, increasingly water-efficient products, and increased water efficiency due to renovated water systems in dwellings (e.g., kitchens, bathrooms). An active water conservation program in the existing stock could largely cover the net requirements of future population and household growth.
- A significant volume of leakage occurs in the distribution system, both within the municipal delivery system and on-site (on the dwelling premises).

5.3 OVERALL LAND USE

This sub-section presents the overall land use of Canada's residential sector during the study period of 2004–2025. According to the residential neighbourhood definitions and densities presented in Section 4, Canada's residential sector occupied about 22,200 km^2 of land in 2004.

As explained in section 4.2.2, the gradual take-up of urban intensification policies and planning would result in increasingly densified neighbourhoods for all three of the archetypes profiled in this study. Existing neighbourhoods would absorb about 90% of the 3.8 million new dwellings built during 2004–2025.

The remaining 10% of new dwellings would be built in new residential neighbourhoods that expand the urban boundary. The analysis reveals that this would subsume an additional 165 km^2 of greenfield land by 2025, representing less than 1% growth in total residential neighbourhood land use in 2004.

5.4 OVERALL SOLID RESOURCE USE

This sub-section presents the "solid resources" use of Canada's residential sector during the study period of 2004–2025. The analysis pertains to the following categories of solid resources such as:

- Organic Solids (wood fibre);
- Minerals (limestone, clay and shale, sand, gypsum, aggregates);
- Metals (iron ore); and
- Other solids.

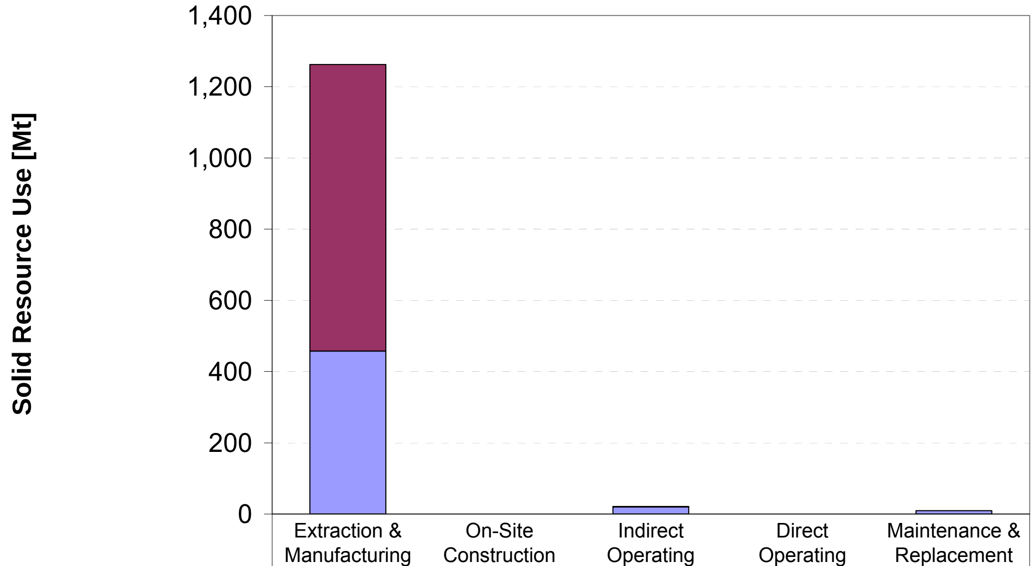
It should be noted that these analyses of resource do not include renovation-related materials, which currently account for a significant portion of annual investment in housing. This exclusion is discussed further in Section 9.

Resource use differences by dwelling type and neighbourhood type are presented later, in Sections 5.5 and 5.6.

5.4.1 Life-cycle Solid Resource Use

Exhibit 5.11 presents the life-cycle solid resource use by the residential sector in units of megatonnes (Mt) of solids, by life-cycle stage and structure/activity.

Exhibit 5.11: Life-cycle Solid Resource Use by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			8.5E-01	0.0E+00	
Road, Water & Wastewater Infrastructure	8.0E+02	2.8E-04	2.5E-01	0.0E+00	
Dwellings	4.6E+02	1.3E-02	2.0E+01	0.0E+00	9.3E+00

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- As expected, almost all solid resources used for the residential sector are used (extracted) during the Extraction & Manufacturing stage, when materials are prepared for construction of dwellings and neighbourhood infrastructure.
- About 60% of solids used are for construction of roads and residential water and wastewater infrastructure, with the remaining 40% going to construction of dwellings.

5.5 COMPARISON BY DWELLING TYPE

This sub-section presents the differences by dwelling type in the energy, water, and solid resource use of Canada's residential sector during the study period of 2004–2025. Where relevant, results are shown as: 1) the aggregate of all dwellings; and 2) the average per dwelling, to gain a better understanding of the consequences of choosing one dwelling type over another. Where appropriate, results are normalised to 100% for single detached dwellings, to show the relative contributions of the other three dwelling types.

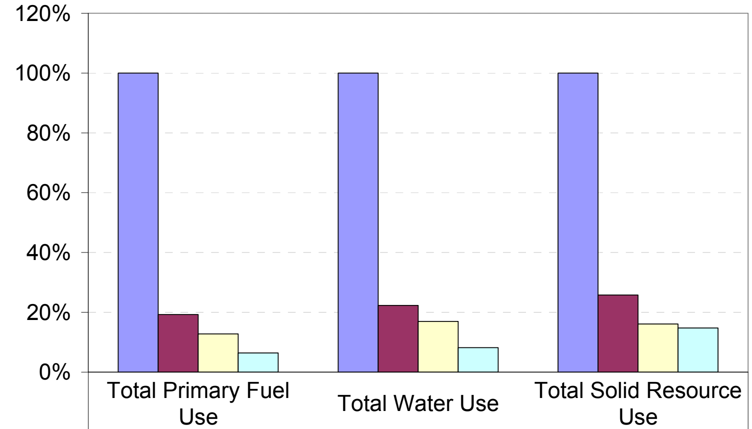
Resource use differences by neighbourhood type are presented later, in Section 5.6.

5.5.1 Life-cycle Resource Use

For All Dwellings

Exhibit 5.12 presents the life-cycle resource use (of primary energy, water, and solids) of *all dwellings*, by dwelling type.

Exhibit 5.12: Life-cycle Resource Use for *All Dwellings* during 2004–2025, by Dwelling Type, Compared (Normalised) to Single Detached



	Total Primary Fuel Use	Total Water Use	Total Solid Resource Use
Single	100%	100%	100%
Row/Town	19%	22%	26%
Low-rise MURB	13%	17%	16%
High-rise MURB	6%	8%	15%

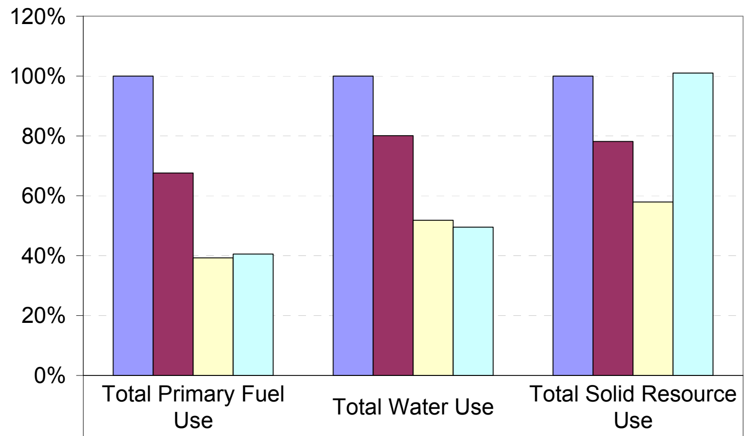
Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The analysis indicates that, in aggregate terms, single detached dwellings have a far greater impact than other dwelling types. This impact is mostly due to the sheer number of dwellings in Canada of each dwelling type.

Per Dwelling

Exhibit 5.13 presents the life-cycle resource use (of primary energy, water, and solids) *per dwelling*, by dwelling type.

Exhibit 5.13: Life-cycle Resource Use *per Dwelling* during 2004–2025, by Dwelling Type, Compared (Normalised) to Single Detached



	Total Primary Fuel Use	Total Water Use	Total Solid Resource Use
Single	100%	100%	100%
Row/Town	68%	80%	78%
Low-rise MURB	39%	52%	58%
High-rise MURB	41%	50%	101%

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

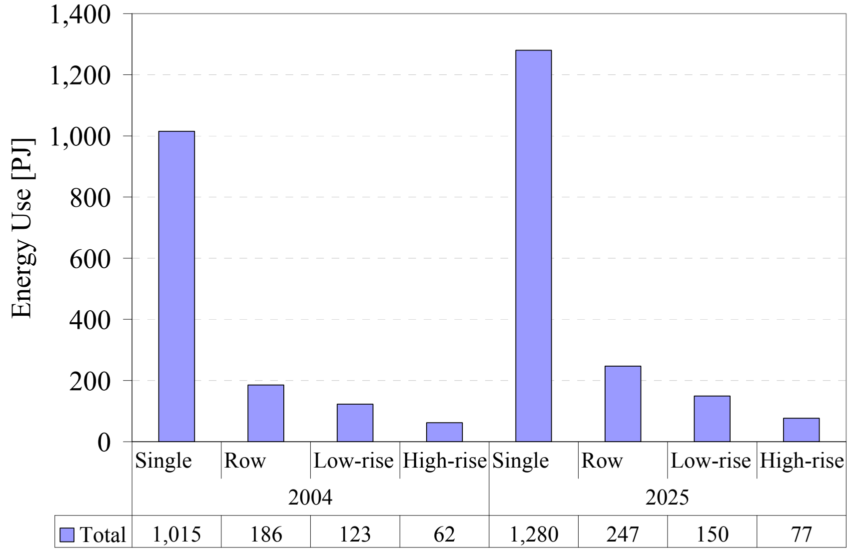
The above study results yield the following observations:

- Single detached houses dominate on a per-dwelling basis, with the largest life-cycle resource use of all the dwelling types. Single detached houses require roughly 1.3 times the life-cycle resources as row/town houses, and roughly 2 times the life-cycle resources as low-rise MURBs.
- For solid resource use, high-rise MURBs require a comparable amount of solids in their construction, per dwelling, compared to single detached houses. This is largely due to the resource intensity of underground parking lots found in high-rise MURBs. Note that, as mentioned under Scope and Methodology in Section 3, the study included high-rise underground parking but excluded all other dwelling driveways, parking, and 'hardscaping' (decks, fencing, etc.).
- Life-cycle resource use for high-rise MURBs is roughly the same as for low-rise MURBs, except high-rise MURBs use significantly more solid resources (e.g., cement and aggregates for concrete).

5.5.2 Annual Dwelling Operating Energy Use

To further understand annual contributions by dwelling type, Exhibit 5.14 presents the annual dwelling direct operating energy use of *all dwellings* for 2004 and 2025.

Exhibit 5.14: Annual Dwelling Direct Operating Energy Use for *All Dwellings* in 2004 & 2025, by Dwelling Type



The analysis indicates that single detached houses consumed (in 2004) and would consume (in 2025) almost 75% of the dwelling operating energy in Canada.

5.6 COMPARISON BY NEIGHBOURHOOD TYPE

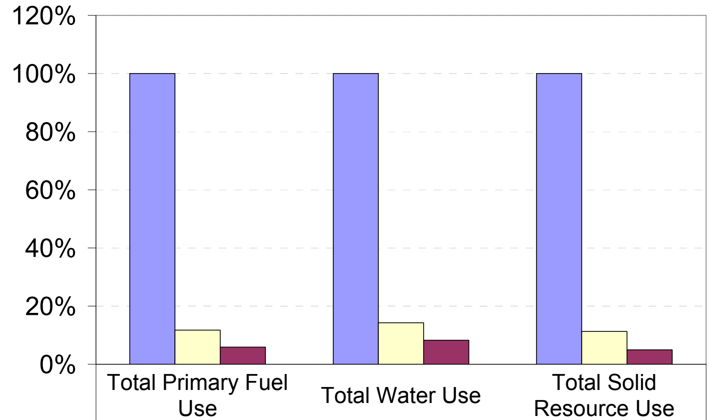
This sub-section presents the differences by neighbourhood type in the energy, water, and solid resource use of Canada's residential sector during the study period of 2004–2025. Where relevant, results are shown as: 1) the aggregate of all dwellings; and 2) the average per average dwelling, to gain a better understanding of the consequences of choosing one neighbourhood type over another. Where appropriate, results are normalised to 100% for outer suburbs, to show the relative contributions of the other two neighbourhood types.

5.6.1 Life-cycle Resource Use

For All Dwellings

Exhibit 5.15 presents the life-cycle resource use (of primary energy, water, and solids) of the residential sector in Canada, by neighbourhood type.

Exhibit 5.15: Life-cycle Resource Use for the Residential Sector during 2004–2025, by Neighbourhood Type, Compared (Normalised) to Outer Suburbs



	Total Primary Fuel Use	Total Water Use	Total Solid Resource Use
Outer Suburbs	100%	100%	100%
Inner Suburbs	12%	14%	11%
Inner City	6%	8%	5%

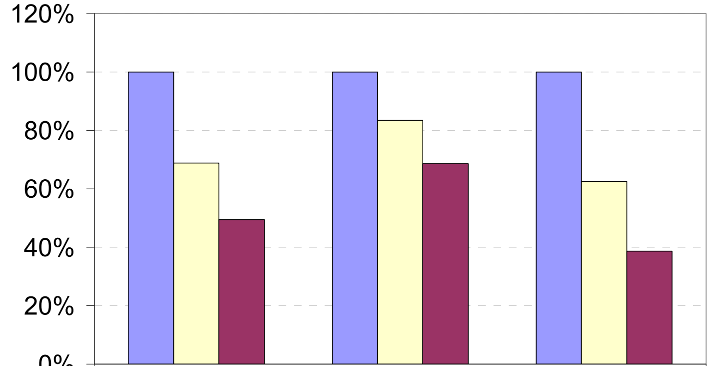
Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The analysis indicates that, in aggregate terms, outer suburbs have a far greater impact than other neighbourhood types. This impact is mostly due to the number of single detached houses contained in outer suburbs and the difference in residential transportation energy use between neighbourhood types.

Per Dwelling

Exhibit 5.16 presents the life-cycle resource use (of primary energy, water, and solids) *per average neighbourhood dwelling*, by neighbourhood type.

Exhibit 5.16: Life-cycle Resource Use *per Average Neighbourhood Dwelling* for the Residential Sector during 2004–2025, by Neighbourhood Type, Compared (Normalised) to Outer Suburbs



	Total Primary Fuel Use	Total Water Use	Total Solid Resource Use
Outer Suburbs	100%	100%	100%
Inner Suburbs	69%	83%	63%
Inner City	49%	69%	39%

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The analysis indicates that outer suburbs dominate on a per-average-dwelling basis, with the largest life-cycle resource use of all the neighbourhood types. Average dwellings in outer suburbs require roughly 33% more life-cycle resources than average dwellings in inner suburbs, and roughly double the life-cycle resources as average dwellings in inner city neighbourhoods. This is, again, largely due to the high percentage of single detached houses in outer suburbs.

5.6.2 Annual Residential Transportation Operating Energy Use

Per Dwelling

Exhibit 5.17 presents the difference in personal vehicle-kilometres travelled (VKT) and public transit passenger-kilometres travelled (PKT) per dwelling, for average dwellings located in each neighbourhood type. As mentioned in Section 3, the VKT and PKT values average per-neighbourhood dwelling were frozen at 2004 levels in this study.

Exhibit 5.17: Estimated Personal Vehicle & Public Transit Use by Neighbourhood Type

Transportation Type	Units	2004			2025		
		Inner City	Inner Suburbs	Outer Suburbs	Inner City	Inner Suburbs	Outer Suburbs
Personal Vehicle	VKT/dwelling/yr	7,450	13,500	25,620	7,450	13,500	25,620
Public Transit	PKT/ dwelling/yr	6,280	5,510	6,460	6,280	5,510	6,460

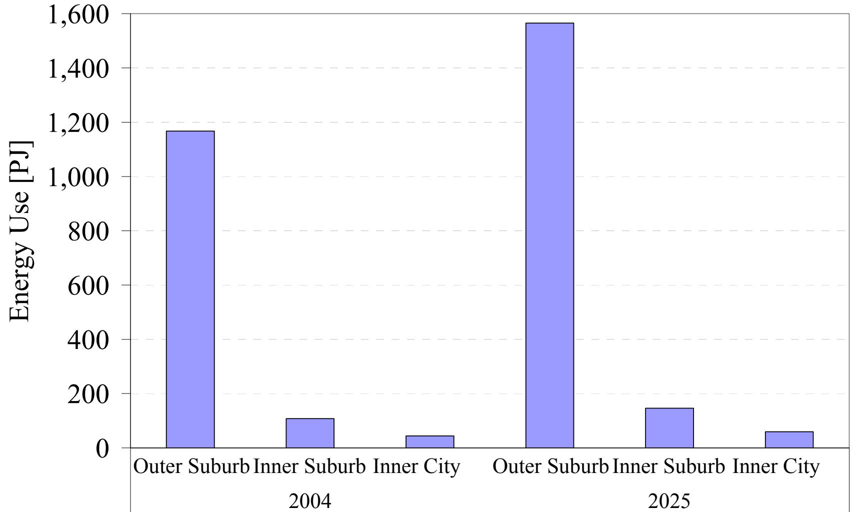
The analysis reveals that occupants in Outer Suburb dwellings use personal vehicles, on average, for almost twice the travel as Inner Suburb dwellings and almost four times the travel of Inner City dwellings. On the other hand, there is not much difference among the neighbourhood types with regard to travel using public transit.

Clearly, neighbourhood type can be a large determining factor of residents' personal vehicle transportation patterns. Inherent in the definition of a neighbourhood are proximity to the workplace, household size and demographics, resident lifestyles, etc.; all of these factors influence vehicle use patterns.

For All Dwellings

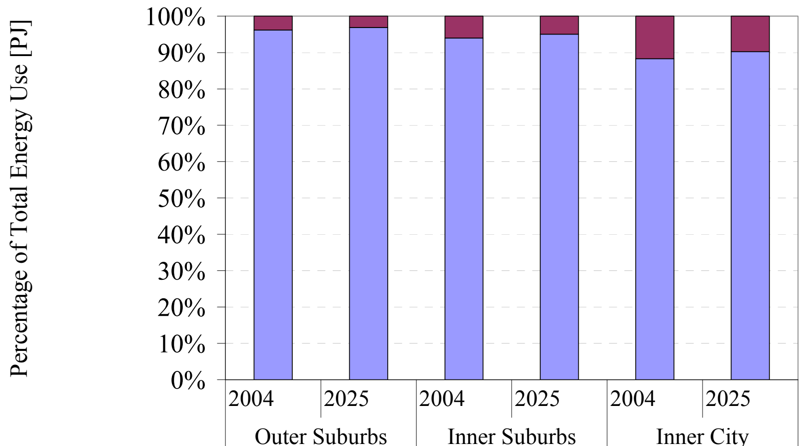
Exhibit 5.18 presents the annual residential transportation direct operating energy use for *all dwellings*, by neighbourhood type, for 2004 and 2025. Exhibit 5.19 presents the share of private vehicle and public transit annual energy use, by neighbourhood type.

Exhibit 5.18: Annual Residential Transportation Direct Operating Energy for *All Dwellings* in 2004 & 2025, by Neighbourhood Type



	2004			2025		
	Outer Suburb	Inner Suburb	Inner City	Outer Suburb	Inner Suburb	Inner City
Total	1,167	108	44	1,565	146	59

Exhibit 5.19: Modal Share of Annual Residential Transportation Direct Operating Energy for *All Dwellings* in 2004 & 2025, by Neighbourhood Type



	Outer Suburbs		Inner Suburbs		Inner City	
	2004	2025	2004	2025	2004	2025
Public Transit	44	49	6	7	5	6
Personal Vehicle	1,123	1,516	101	138	39	53

The above study results yield the following observations:

- Personal vehicle use accounts for 95% of annual residential transportation operating energy in Canada, with the remaining 5% from public transit use.
- Residents of outer suburbs use almost 90% of the annual residential transportation operating energy in Canada, with outer suburbs defined as per Section 4.
- Combining the above, personal vehicle use by outer suburb residents accounts for almost 85% of the annual residential transportation operating energy in Canada.

This section has presented the resources required by structures and activities in the Canadian residential sector during the study period 2004–2025. The following section describes the environmental outputs (e.g., emissions) from using these resources.

6. ENVIRONMENTAL OUTPUTS

As described in Section 2, residential structures and activities require resource use (e.g., energy, water, land, and solids), which creates environmental outputs (e.g., emissions to air, water, and soil), which results in local, regional, and global environmental impacts.

Each form of resource use by the residential sector can, on its own or in combination with other resource uses, result in environmental outputs/emissions to air, water, and soil, such as greenhouse gas (GHG) emissions, criteria air contaminant (CAC) emissions, water pollutants, and solid waste. Land use and the construction of buildings, roads, and parking lots (with solid resources) also result in land alterations such as land impermeability.

This section presents the environmental outputs caused by resource use for Canadian residential sector structures and activities over the study period. This section is presented as follows:

- Overall Air Emissions
- Overall Water Pollutants
- Overall Soil Pollutants
- Comparison by Dwelling Type
- Comparison by Neighbourhood Type.

The first three sub-sections are "overall" in that they do not compare results by dwelling type or neighbourhood type.

The results contained in each sub-section highlight differences according to each the following:

- *Element of the residential built environment* — Dwellings, neighbourhood infrastructure, and residential transportation, as defined in Section 1;
- *Life-cycle stage* — Extraction & Manufacturing, On-site construction, Indirect Operating, Direct Operating, and Maintenance & Replacement, as defined in Section 2;
- *Year* (i.e., 2004 & 2025); and
- *Cumulative for all dwellings vs. average per dwelling*, as available and relevant.

Each sub-section begins with an overview of the life-cycle environmental outputs over the study period, followed by results for dominating factors that warrant deeper understanding. Interpretations and observations on the results are discussed throughout.

Following this discussion, Section 7 describes the local, regional, and global environmental impacts that result from these environmental outputs.

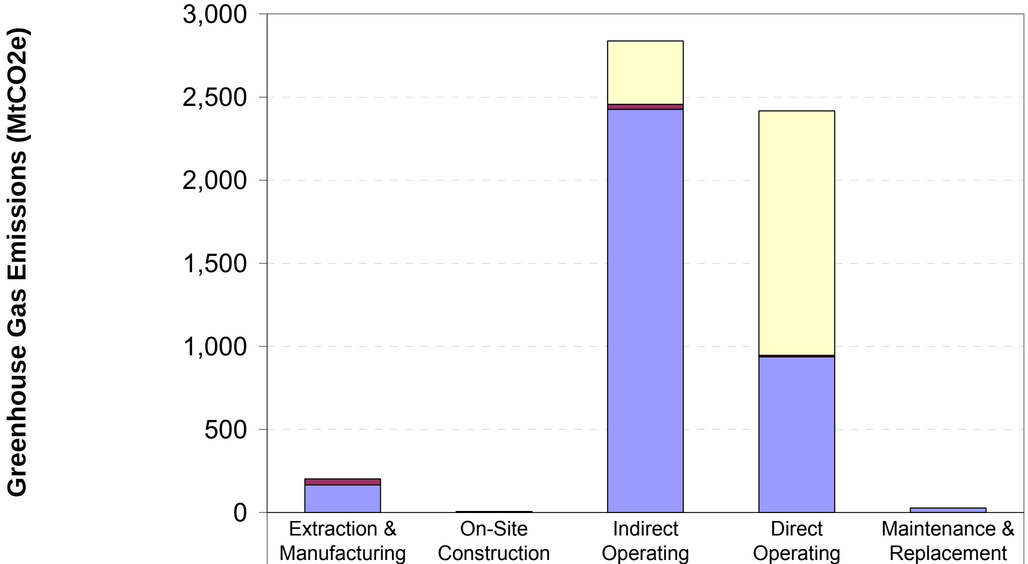
6.1 OVERALL AIR EMISSIONS

This sub-section presents the overall air emissions from Canada's residential sector during the study period of 2004–2025. As described under Scope in Section 3, the analysis in this study included many air emissions, such as greenhouse gas (GHG) emissions, criteria air contaminant (CAC) emissions, and other emissions such as carbon dioxide (CO_2) from biomass (biogenic/neutral), carbon monoxide (CO), and metals. Only GHGs and CACs are presented below, as good indications of overall air emissions.

6.1.1 Life-cycle GHG & CAC Emissions

Exhibit 6.1 presents the estimated life-cycle GHG emissions of the residential sector, by life-cycle stage and structure/activity. The GHG results include carbon dioxide (CO_2) from inorganic sources (e.g., excluding carbon-neutral emissions from, say, combustion of wood), nitrous oxide (N_2O), and methane (CH_4), but exclude water vapour (H_2O).

Exhibit 6.1: Life-cycle Greenhouse Gas (GHG) Emissions by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			3.8E+02	1.5E+03	
Road, Water & Wastewater Infrastructure	3.7E+01	1.0E+00	3.0E+01	8.7E+00	
Dwellings	1.7E+02	4.4E+00	2.4E+03	9.4E+02	2.6E+01

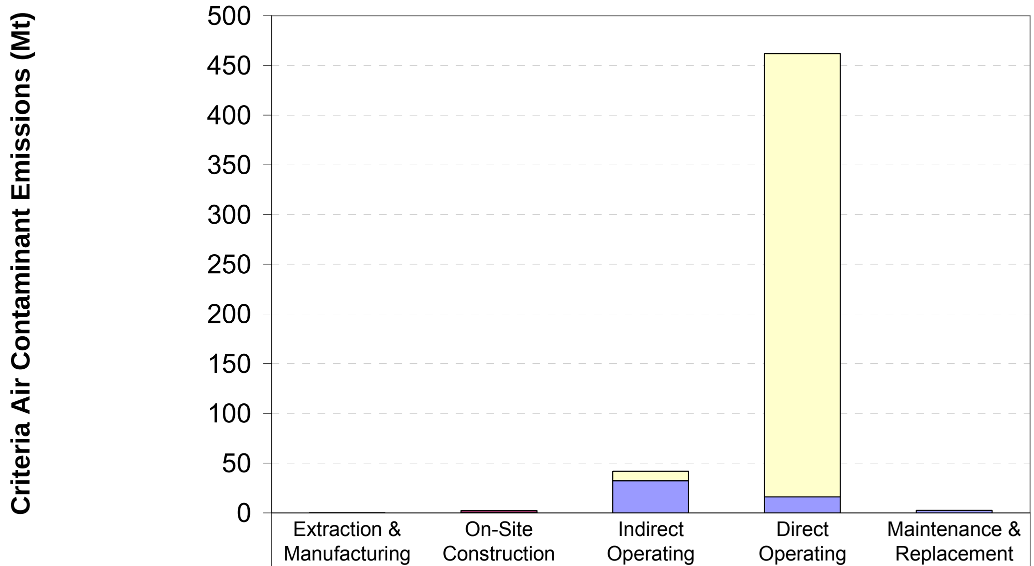
Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- Life-cycle GHG emissions for the residential sector over the study period are roughly 5,500 megatonnes of carbon dioxide-equivalent ($MtCO_2e$).
- Life-cycle GHG emissions are, by far, dominated by direct and indirect emissions from operating energy use.
- While significant GHG emissions are shown as Indirect Operating (e.g., GHG emissions from fuel combusted during electricity generation), these emissions are still associated with the operating stage of dwellings.

Exhibit 6.2 presents the life-cycle criteria air contaminant (CAC) emissions of the residential sector, by life-cycle stage and structure/activity. The CAC results include carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), total particulate matter ($PM_{2.5}$ and PM_{10}), and non-methane volatile organic compounds (VOCs).

Exhibit 6.2: Life-cycle Criteria Air Contaminant (CAC) Emissions by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			9.4E+00	4.5E+02	
Road, Water & Wastewater Infrastructure	1.8E-03	2.0E+00	3.2E-01	3.2E-02	
Dwellings	7.1E-02	2.9E-01	3.2E+01	1.6E+01	2.4E+00

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- Life-cycle CAC emissions are, by far, dominated by direct emissions from residential transportation energy use, which is expected, given the dominance of carbon monoxide emissions from gasoline-powered cars and light-duty trucks.[41]
- While a significant portion of CAC emissions are shown as Indirect Operating (e.g., CACs from fuel combusted during electricity generation), these emissions are still associated with the operating stage of dwellings. If the dwelling and transportation operating demands were not present, these upstream emissions would not occur.
- As stated in Section 3.1, CAC emissions from land modification and road construction are excluded, except for CACs from construction energy use.

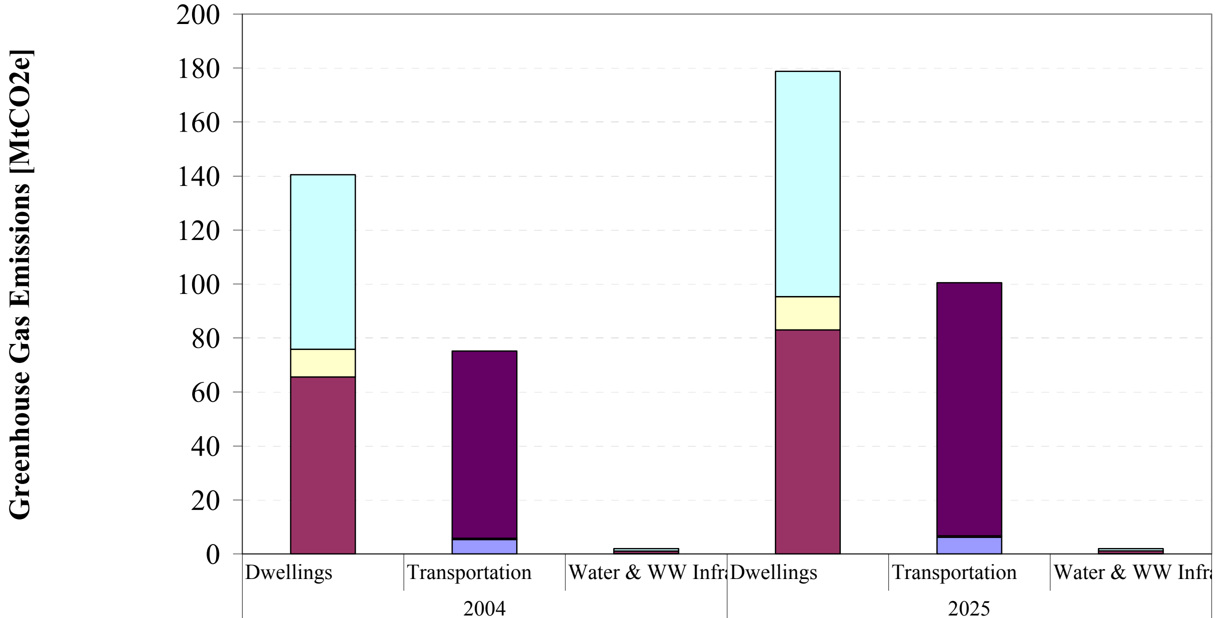
To focus more on the dominant Operating stage for GHG emissions, the following sub-section explores the annual operating energy of dwellings.

[41] Environment Canada. Last updated April 2007. Website: *2005 CAC Emissions for Canada*. http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/EmissionsSummaries/2005_canada_e.cfm

6.1.2 Annual GHG Emissions from Operating Energy

Exhibit 6.3 presents the annual GHG emissions from direct and indirect operating energy used by the residential sector, for all dwellings in 2004 and 2025, by fuel.

Exhibit 6.3: Annual GHG Emissions from Direct & Indirect Operating Energy Use by the Residential Sector in 2004 & 2025, by Fuel



	2004 Dwellings	2004 Transportation	2004 Water & WW Infra	2025 Dwellings	2025 Transportation	2025 Water & WW Infra
Gasoline	0	69	0	0	94	0
Natural Gas	65	0	1	83	0	1
Fuel Oil & Propane	10	0	0	12	0	0
Electricity	66	0	1	83	1	1
Diesel	0	5	0	0	6	0

The above study results yield the following observations:

- Although the operating energy use for dwellings and residential transportation is similar in magnitude, as originally shown under Life-cycle Primary Energy Use in Section 5, the GHG emissions from dwelling operating energy are almost twice as high due to the emissions from generating electricity to power homes. Exhibit 6.3 illustrates that electricity generation is attributable for approximately 47 per cent of the residential sector's GHG emissions from dwellings in both 2004 and 2025, respectively.
- As originally shown in Section 5, water and wastewater infrastructure uses relatively negligible operating energy and, so, produces relatively negligible GHGs compared to dwelling and residential transportation operating energy.

6.2 OVERALL WATER POLLUTANTS

This sub-section presents the overall water emissions from Canada's residential sector during the study period of 2004–2025, as well as dwelling wastewater production.

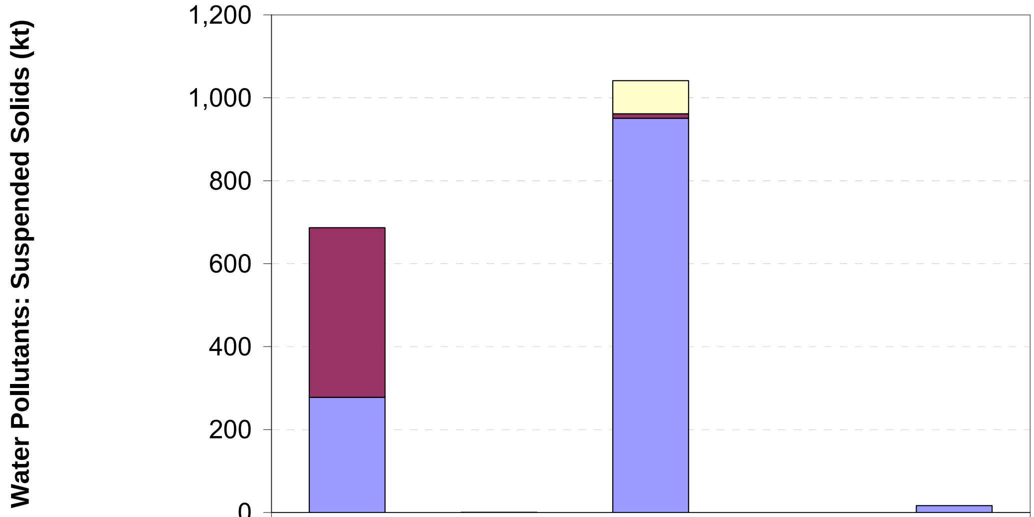
As described under Scope in Section 3, the analysis in this study included many emissions to water, such as suspended solids, dissolved solids, oil and grease, sulphates, sulphides, nitrates and nitrites, dissolved organic compounds, and metals. The analysis also included indicators of water pollutants, such as biological oxygen demand (BOD) and chemical oxygen demand (COD). Due to time and resource limitations in this study, only a sub-set of these results is presented below, where the emissions chosen are good indicators of overall emissions to water.

The life-cycle water use results were presented under Resource Use in Section 5.2.

6.2.1 Life-cycle Water Pollutants

Exhibit 6.4 presents the life-cycle emissions of suspended solids to water from the residential sector, by life-cycle stage and structure/activity.

Exhibit 6.4: Life-cycle Suspended Solid Emissions to Water by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			8.0E+01	0.0E+00	
Road, Water & Wastewater Infrastructure	4.1E+02	2.5E-03	1.1E+01	0.0E+00	
Dwellings	2.8E+02	4.0E-01	9.5E+02	0.0E+00	1.6E+01

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

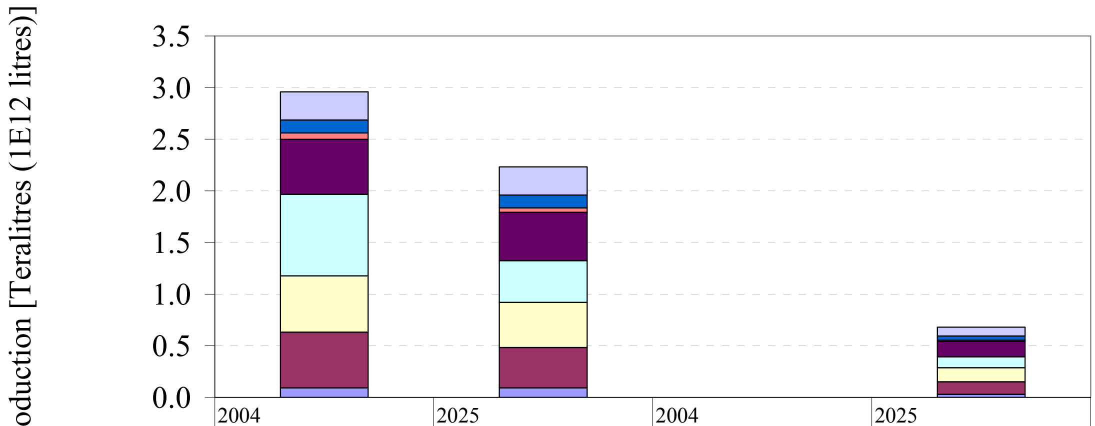
- As stated under Scope in Section 3, emissions to water were estimated for the non-operating life-cycle stages of dwellings and neighbourhood infrastructure, and resulting from the operating energy used in dwellings, municipal water systems, and residential transportation. However, the emissions to water resulting from dwelling wastewater production and municipal treatment have not been accounted for, nor have the emissions to water from storm water run-off from roads. Therefore, the largest contributor to actual water emissions cannot be fairly ascertained.

- Of the water emission sources assessed, the largest contributors are: 1) electricity generation to service dwelling operation (Note: electricity generation is captured under Indirect Operating, since the fuel combustion to produce electricity occurs upstream of the user); and 2) the mining and manufacturing of materials (e.g., cement) used to construct dwellings and neighbourhood infrastructure.

6.2.2 Annual Dwelling Wastewater Production

Although the emissions to water from dwelling wastewater production and treatment were not included in this study, Exhibit 6.5 presents the annual operating wastewater production by all dwellings in 2004 and 2025, by water end-use, to show the relative contributions of various household activities.

Exhibit 6.5: Annual Dwelling Wastewater Production for All Dwellings in 2004 & 2025, by End-Use



	Existing & Renovated		New	
	2004	2025	2004	2025
Dwelling Leaks	0.27	0.27	0.00	0.09
Other Domestic	0.12	0.12	0.00	0.04
Dishwasher	0.06	0.04	0.00	0.01
Clothes Washer	0.53	0.47	0.00	0.15
Toilets	0.79	0.40	0.00	0.11
Faucets	0.55	0.44	0.00	0.14
Showers	0.54	0.39	0.00	0.12
Baths	0.09	0.09	0.00	0.03

The above study results yield the following observations:

- Annual wastewater production by all dwellings in 2004 was 3 teralitres (3 km^3), which is equivalent to more than 12 days of water flowing over Niagara Falls.[42]
- As described in Section 5.2.2, overall water use (and, therefore, wastewater production) is estimated to decrease for existing and renovated dwellings, but go up by almost the same amount for new dwellings built since 2004.
- In contrast to water use by end use in Section 5.2.2, collection system leaks are excluded from wastewater production totals because these cannot be estimated from

[42] Niagara Falls volume of water flow from: http://www.niagaraparks.com/nfgg/geology.php

residential wastewater discharges but rather are dependent on factors such as wastewater collection system integrity and groundwater levels.

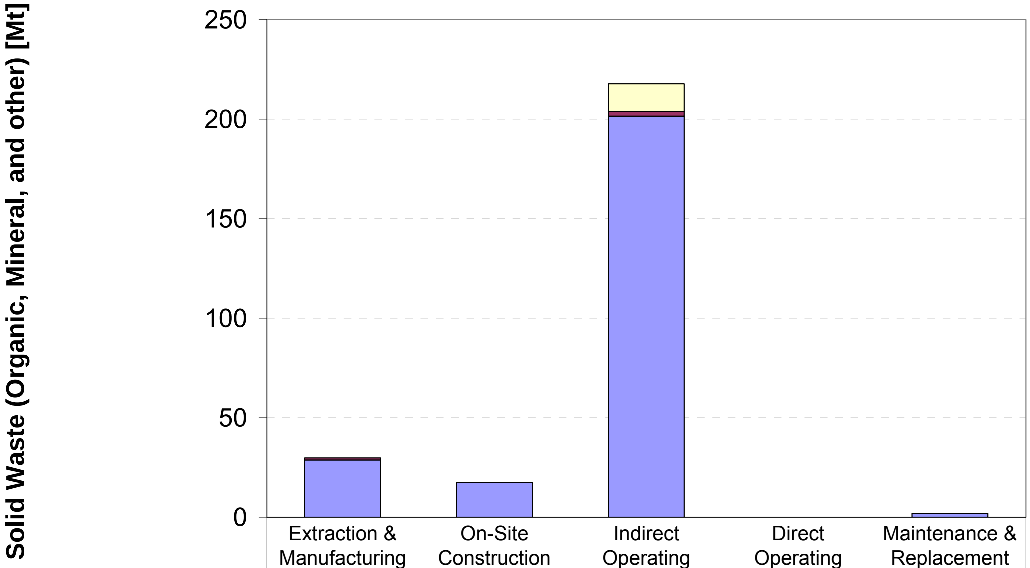
6.3 OVERALL SOIL POLLUTANTS

This sub-section presents the overall emissions to soil from Canada's residential sector during the study period of 2004–2025.

6.3.1 Life-cycle Solid Waste Emissions to Soil

Exhibit 6.6 presents the life-cycle solid waste emissions to soil from the residential sector during 2004–2025, by life-cycle stage and structure/activity (excluding municipal solid waste generated).

Exhibit 6.6: Life-cycle Solid Waste from the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity (excluding Waste from Dwelling Operation)



	Extraction & Manufacturing	On-Site Construction	Indirect Operating	Direct Operating	Maintenance & Replacement
Residential Transportation			1.4E+01	0.0E+00	
Road, Water & Wastewater Infrastructure	1.0E+00	4.9E-03	2.4E+00	0.0E+00	
Dwellings	2.9E+01	1.7E+01	2.0E+02	0.0E+00	1.9E+00

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- Municipal solid waste from dwelling operation was excluded from the study scope because of limited study resources. This is, of course, a significant contributor to life-cycle solid waste from the residential sector and should be included in future work.
- With direct operating waste aside, most of the solid waste generated during 2004–2025 is from indirect operating impacts, such as the solid waste resulting from extracting, refining, and combusting coal and other fossil fuels for electricity generation.

6.4 COMPARISON BY DWELLING TYPE

This sub-section presents the differences by dwelling type in the emissions to air, water, and soil from Canada's residential sector during the study period of 2004–2025. Where relevant, results are shown as: 1) the aggregate of all dwellings; and 2) the average per dwelling, to gain a better understanding of the consequences of choosing one dwelling type over another. Where appropriate, results are normalised to 100% for single detached dwellings, to show the relative contributions of the other three dwelling types.

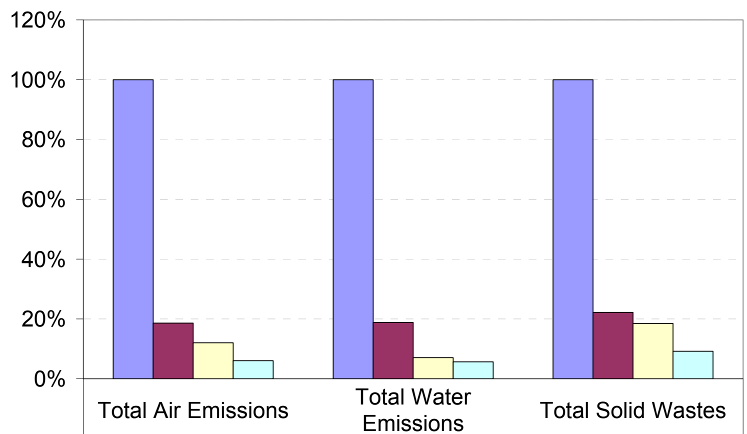
Resource use differences by neighbourhood type are presented in Section 5.6.

6.4.1 Life-cycle Emissions & Pollutants

For All Dwellings

Exhibit 6.7 presents the life-cycle emissions to air, water, and soil of *all dwellings*, by dwelling type.

Exhibit 6.7: Life-cycle Emissions for *All Dwellings* during 2004–2025, by Dwelling Type, Compared (Normalised) to Single Detached



	Total Air Emissions	Total Water Emissions	Total Solid Wastes
Single	100%	100%	100%
Row/Town	19%	19%	22%
Low-rise MURB	12%	7%	19%
High-rise MURB	6%	6%	9%

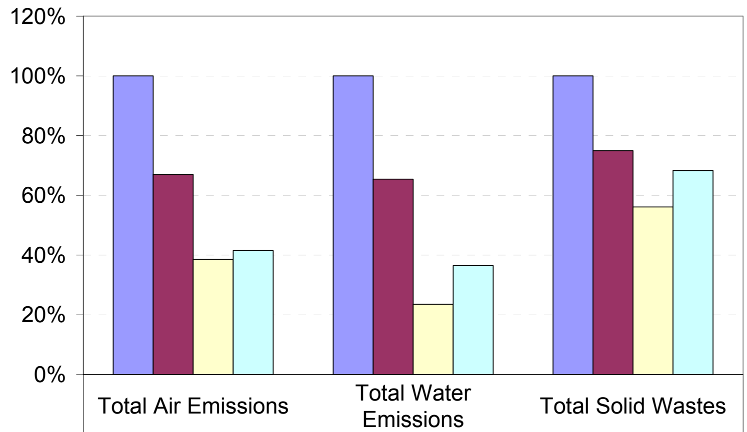
Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results suggest that, in aggregate terms, single detached dwellings have a far greater impact than other dwelling types. This impact is mostly due to the sheer number of dwellings in Canada of each dwelling type.

Per Dwelling

Exhibit 6.8 presents the life-cycle emissions to air, water, and soil *per dwelling*, by dwelling type.

Exhibit 6.8: Life-cycle Emissions *per Dwelling* during 2004–2025, by Dwelling Type, Compared (Normalised) to Single Detached



	Total Air Emissions	Total Water Emissions	Total Solid Wastes
Single	100%	100%	100%
Row/Town	67%	65%	75%
Low-rise MURB	39%	24%	56%
High-rise MURB	42%	36%	68%

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results yield the following observations:

- Single detached houses dominate life-cycle emissions on a per-dwelling basis, although less so than in the aggregate impacts of all dwellings in the previous exhibit. Single detached houses produce roughly 1.5 times the life-cycle emissions as row/town houses, and roughly 2 times the life-cycle emissions as low-rise and high-rise MURBs.
- Per-dwelling life-cycle emissions are 10–30% higher for high-rise MURBs than for low-rise MURBs. While this may seem counterintuitive, these per-dwelling differences are likely explained by the construction materials used for and household types living in low-rise multi-family units.

6.5 COMPARISON BY NEIGHBOURHOOD TYPE

This sub-section presents the differences by neighbourhood type in emissions to air, water, and soil from Canada's residential sector during the study period of 2004–2025. Where relevant, results are shown as: 1) the aggregate of all dwellings; and 2) the average per average dwelling, to gain a better understanding of the consequences of choosing one neighbourhood type over another. Where appropriate, results are normalised to 100% for outer suburbs, to show the relative contributions of the other two neighbourhood types.

6.5.1 Life-cycle Decrease in Permeable Land

As described under Overall Land Use in Section 5, the four regional urban growth clusters expect most of the new dwellings built during 2004–2025 to be absorbed by densified existing neighbourhoods. To densify these existing neighbourhoods, some existing greenspace and vacant and underutilized land (e.g., brownfields, greyfields, shopping malls, etc.) would be developed/redeveloped with residential buildings, including higher density housing (e.g., low-rise and high-rise MURBs). This densification also requires changes to roads, parking, and other residential infrastructure. These changes convert some existing permeable land (i.e., land that rain water can soak into) to impermeable land. Exhibit 6.9 presents the percent impervious area by neighbourhood type in 2004 and 2025, which is an excerpt from Exhibit 4.7.

Exhibit 6.9: Percent Impervious Area per Neighbourhood in 2004 & 2025, by Neighbourhood Type

Neighbourhood Type	2004		2025
	Existing Neighbourhoods	New Neighbourhoods	Existing & New Neighbourhoods
Inner City	61%	0%	62%
Inner Suburb	51%	0%	53%
Outer Suburb	38%	0%	44%

The above study results yield the following observations:

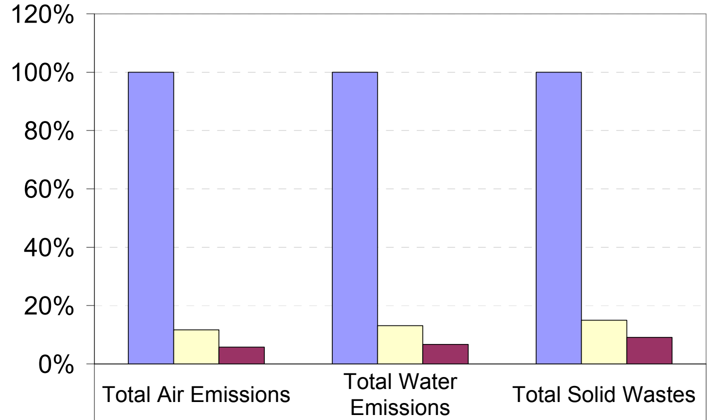
- Existing inner city and inner suburbs in 2025 are expected to have increased impermeable area by only one and two percentage points.
- Existing outer suburbs in 2025 are expected to have increased impermeable area by six percentage points, to 44%.
- New neighbourhoods of all three types in 2025 are expected to have increased impermeable area from 0% (greenfield) to the values shown.
- The environmental impacts resulting from these land changes are discussed in the following chapter.

6.5.2 Life-cycle Air Emissions and Water & Soil Pollutants

For All Dwellings

Exhibit 6.10 presents the life-cycle emissions to air, water, and soil from the residential sector in Canada, by neighbourhood type.

Exhibit 6.10: Life-cycle Emissions from the Residential Sector during 2004–2025, by Neighbourhood Type, Compared (Normalised) to Outer Suburbs



	Total Air Emissions	Total Water Emissions	Total Solid Wastes
Outer Suburbs	100%	100%	100%
Inner Suburbs	12%	13%	15%
Inner City	6%	7%	9%

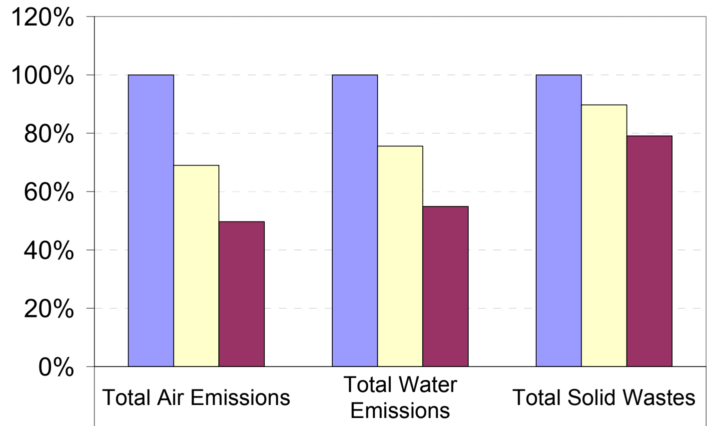
Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

The above study results suggest that, in aggregate terms, outer suburbs have a far greater impact than other neighbourhood types. This impact is mostly due to the number of single detached houses contained in outer suburbs and the residential transportation energy used by residents of outer suburbs.

Per Dwelling

Exhibit 6.11 presents the life-cycle emissions to air, water, and soil *per average neighbourhood dwelling*, by neighbourhood type.

Exhibit 6.11: Life-cycle Emissions *per Average Neighbourhood Dwelling* for the Residential Sector during 2004–2025, by Neighbourhood Type, Compared (Normalised) to Outer Suburbs



	Total Air Emissions	Total Water Emissions	Total Solid Wastes
Outer Suburbs	100%	100%	100%
Inner Suburbs	69%	76%	90%
Inner City	50%	55%	79%

Note: As per the Scope in Section 3, non-operating effects were estimated only for *new* dwellings and neighbourhood infrastructure built since 2004, while operating effects were estimated for all *existing* and *new* dwellings and neighbourhood infrastructure.

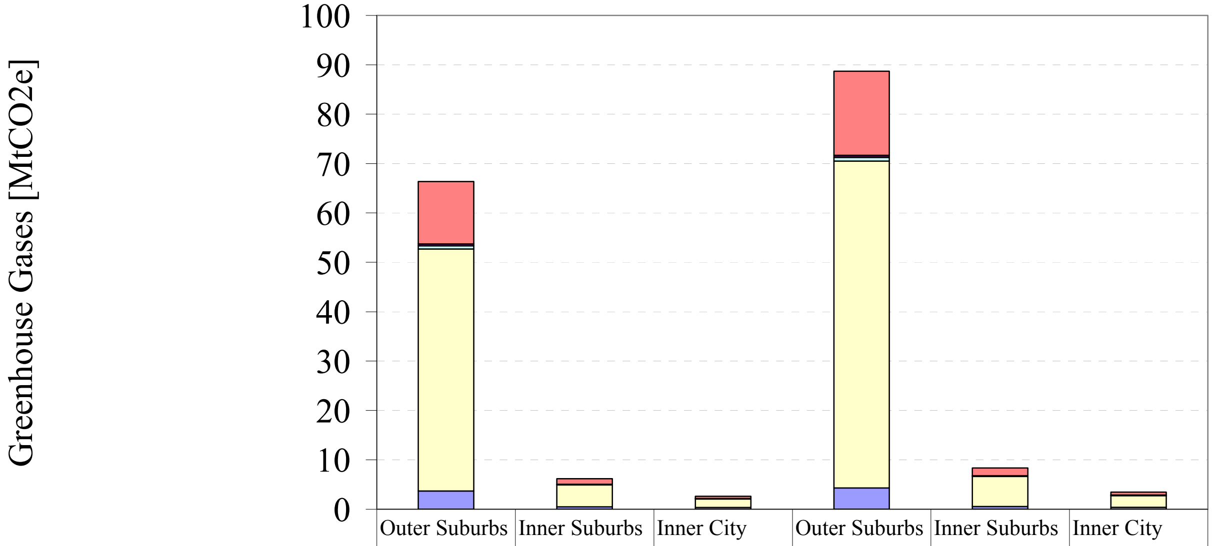
The above study results suggest that outer suburbs dominate on a per-average-dwelling basis, with the largest life-cycle emissions of all the neighbourhood types. Average dwellings in outer suburbs create roughly 25% more life-cycle emissions than average dwellings in inner suburbs, and roughly 50% more life-cycle emissions than average dwellings in inner city neighbourhoods. This is due to: 1) the high percentage of single detached houses in outer suburbs; and 2) the significant difference in annual residential transportation energy used for residents of different neighbourhood types.

6.5.3 Annual Residential Transportation Operating GHG Emissions

For All Dwellings

To further understand annual contributions by neighbourhood type, Exhibit 6.12 presents the annual residential transportation direct and indirect operating GHG emissions for *all dwellings*, by neighbourhood type, for 2004 and 2025.

Exhibit 6.12: Annual Residential Transportation Direct & Indirect Operating GHG Emissions for *All Dwellings* in 2004 & 2025, by Neighbourhood Type & Fuel



	2004			2025		
	Outer Suburbs	Inner Suburbs	Inner City	Outer Suburbs	Inner Suburbs	Inner City
from Indirect Oper E - Gasoline	12.6	1.1	0.4	17.0	1.6	0.6
from Indirect Oper E - Electricity	0.4	0.1	0.0	0.4	0.1	0.0
from Indirect Oper E - Diesel	0.6	0.1	0.1	0.7	0.1	0.1
from Direct Oper E - Gasoline	49.0	4.4	1.7	66.2	6.1	2.3
from Direct Oper E - Electricity	0.0	0.0	0.0	0.0	0.0	0.0
from Direct Oper E - Diesel	3.7	0.5	0.3	4.3	0.6	0.4

The above study results yield the following observations:

- Residents of outer suburbs produce almost 90% of annual residential transportation operating GHGs in Canada.
- Personal vehicle use by residents of outer suburbs accounts for almost 85% of the annual residential transportation operating energy in Canada.

This section has presented the environmental outputs (i.e., emissions to air, water, and soil) resulting from resource use by the Canadian residential sector. The following section describes the resulting environmental impacts of these emissions.

7. RESULTING ENVIRONMENTAL IMPACTS

As described in Section 2, residential development and activities require resource use (e.g., energy, water, land, and solids), which generates environmental outputs (e.g., emissions to air, water, and soil). This section describes the environmental impacts that result from these outputs over the study period of 2004–2025. This section includes qualitative assessment of all impacts noted and quantitative assessment where possible and appropriate.

Each type of environmental output from the residential sector can, on its own or in combination with other environmental outputs, result in local environmental impacts to air, water, soil, and biota (living organisms), many of which ultimately contribute to regional and global consequences such as climate change, biodiversity decline, etc. Exhibit 7.1 repeats the illustration of these linkages as initially presented in Section 2. Building on the linkages conveyed in this table, the discussion will examine how environmental outputs act on air, water, soil and biota and ultimately cause environmental impact (as noted, the impact on human health is outside the scope of this study).

Exhibit 7.1: Linkages between Environmental Outputs & Environmental Impacts

Resulting Environmental Impact	Environmental Outputs Causing the Environmental Impact			Media & Inhabitants Affected by the Environmental Impact			
	Air Emissions	Water Pollution	Land Alteration & Soil Pollution	Air	Water	Soil	Biota (Living Organisms)
Local Impacts							
Air Quality Impairment	√			√			√
Surface Water Quality Impairment		√	√		√	√	√
Ground Water Quality Impairment		√	√		√	√	√
Heat Island Effect	√		√	√			√
Regional Impacts							
Smog	√			√	√		√
Acid Rain	√			√	√	√	√
Water Ecosystems Altered or Lost & Land Ecosystem Fragmentation		√	√		√	√	√
Impacts on Wildlife	√	√	√				√
Global Impacts							
Climate Change	√			√	√	√	√
Biodiversity Decline	√	√	√				√
Systems Response to Regional Contamination	√	√		√	√	√	√

Note: "√" means a relevant linkage exists

The assessment of environmental impact follows a progression from local to global impacts:

- *Local impacts* that affect a neighbourhood or city scale;
- *Regional impacts* that affect a geographic region determined by connectedness through air flow or water flow/watershed at regional and national levels; and
- *Global impacts* that affect a global aspect of the earth's ecosystem.

Consequently, this section is organized by local, regional, and global impacts, concluding with a summary of what all these impacts mean for the residential sector's contribution.

7.1 LOCAL IMPACTS

Local impacts affect mostly the environment on a site, in the surrounding community or in a city.

7.1.1 Local Air Quality

Air pollutant emissions alter ambient air quality either directly, as in the case of particulate matter (PM), or through the secondary formation of PM and Ozone as in the case of NO_x, SO_2 and VOCs. Studies conclude that these ambient air quality changes impact sensitive human and environmental receptors. Exhibit 7.2 presents a simplified typology of air quality impacts which shows the magnitude and depth of possible effects. As we consider the local air quality impacts, it is important to note then, that any level of emission will have a deleterious effect on air quality. In this context then we consider the local impacts from the standpoint of magnitude of emissions and how this magnitude compares with emissions generated by industry.

Exhibit 7.2: Air Quality & Environmental Impacts Attributed to Air Emissions

	Air Emission Impacts		
	Particulate Matter ≤ 2.5 µm diameter ($PM_{2.5}$)	**Ozone**	**Wet/dry Acid Deposition**
Air Quality & Deposition Impacts	• Actual change, for example measured as µg/m^3 of PM; • % change from the base ambient levels;	• Actual change from the base ambient in terms of actual (ppb), • % change from the base ambient levels,	• Deposition measured in kg/ha/yr.
Environmental Impacts *Changes in the incidence of:*	• Deterioration of visibility • Decrease of plant productivity (photosynthesis), • Increased plant susceptibility to disease, • Soil contamination, • Damage to lung tissue, • Effects on wildlife breathing capacity and respiratory systems • Damage to materials through soiling and discoloration (metals, wood, stone, painted surfaces, electronics and fabrics)	• Reduced plant growth • Yield reduction and losses, reduction in annual biomass (trees and crops/fruits) • Greater root to shoot ratio • Shifts in species composition • Leaf physical injury and death (chlorosis, bleaching, bronzing, flecking, mottling, banding, stippling) • Reduced root growth • Inflammatory responses	• Soil nutrient depletion • Decline of sensitive forest • Reduced tree resistance to cold, drought, insects, disease and UV radiation • Acidification of lakes and streams • Nutrient enrichment of coastal waters • Reduced fish population or elimination of species

Under their Canada-Wide Standard (CWS), the Canadian Council of Ministers of the Environment (CCME)[43] set a national benchmark for ambient $PM_{2.5}$ at 30 µg/m^3 over a 24 hour period[44] and a benchmark for ozone at 65 ppb over an 8-hour period.[45] Based on

[43] Canadian Council of Ministers of the Environment. *Canada-Wide Standards*. http://www.ccme.ca/ourwork/environment.html?category_id=108. The CCME manages intergovernmental approaches to existing and new air quality issues in Canada (excluding climate change) to recommend priorities for cooperative action.

[44] To be achieved by the year 2010; achievement to be based on the 98th percentile ambient measurement annually, averaged over 3 consecutive years.

the population of communities where monitoring stations are located across Canada, it has been noted that:[46]

- At least 40% of Canadians live in communities where ambient ozone levels are above the target CWS, and;
- At least 30% of Canadians live in communities where ambient levels for $PM_{2.5}$ are above the target CWS.

In Ontario and British Columbia, in particular, where concentrations approach or exceed the CWS for certain air contaminants during seasonal periods, residential sector contribution are known to drive ambient local air quality over the CWS. For example, southern Ontario suffered 32 "smog days" in 2005 and seven in 2006.[47]

7.1.2 Local Water Quality Impairment

Water quality impairment resulting from the residential sector can occur as a result of potable water treatment and use, wastewater release to the environment and from land use changes (in particular, due to increased non-permeable surface area). However, as noted in Section 3, the life-cycle analysis excluded certain aspects of tracking water contaminants due to data availability and study resources:

- Releases of contaminants (such as coagulant chemical residues) to water from production and distribution of potable water
- Central systems that collect and treat wastewater.
- Releases of wastes and chemicals during operation of homes were not included within the life-cycle analysis.
- Releases of contaminants to water from upstream energy generation activities.

Given these limitations, the assessment of local water quality impacts is more indicative than definitive. Further data gleaned from the literature helps to provide an overview of surface water quality impairment resulting from municipal effluents. Together these data provide information for a qualitative discussion of water quality impacts from the residential sector.

This section uses the following indicators of water quality to provide insight to the local water quality effects from the residential sector:

- Potable water use;
- Wastewater volumes and quality;
- Indirectly, storm water runoff as a function of impermeable area; and
- Nutrient loadings to surface water and groundwater.

[45] By 2010; achievement to be based on the 4th highest measurement annually, averaged over 3 consecutive years

[46] Canadian Council of Ministers of the Environment. November 2006. *Canada-wide Standards for Particulate Matter and Ozone: Five Year Report 200-2005*. PN 1374

[47] CityNews. September 28, 2006. *One Serious Day of Severe: Summer of '06 Review*. http://www.citynews.ca/blogs/citynewsweather_3921.aspx

Potable water consumed results in wastewater discharge and, for the residential sector, the volume discharged as wastewater is roughly equal the volume of potable water consumed.[48] Stormwater runoff volumes can be estimated based on non-permeable surface areas. As elaborated below, both changes in volume and quality of stormwater result in impacts on aquatic environments.

Potable Water Use & Wastewater Production

Exhibit 7.3 profiles annual residential operating water consumption for the portion of the residential dwelling stock that exists in 2004, showing also how much water would be consumed by this stock in the final year of the BAU, 2025. As shown, annual operating water consumption in the base year stock is anticipated to decline due to replacement of less efficient water fixtures at the rate of natural stock turnover, supplemented by more accelerated activities due to renovations and retrofits over the study period. By 2025, the new dwelling stock (built since 2004) is expected to consume approximately the same amount of water per year as would be saved in existing dwellings.

Exhibit 7.3: Annual Water Use in all Existing & New Dwellings

Year	Annual Water Use (Teralitres (10^{12} litres)	Annual Wastewater Production (Teralitres (10^{12} litres)
All Existing Stock from 2004, in 2004	3.7	3.0
All Existing Stock from 2004, in 2025	2.9	2.2
Total (Existing & New) Stock in 2025	3.8	2.9

Despite the anticipated consumption trends, Canada continues to have one of the highest water consumption rates. The 3.7 teralitres of water consumed in 2004 is equivalent to about 15 days of water flow over Niagara Falls.[49] The volume consumed by Canadians is still very high relative to other nations, at 65% above the Organisation for Economic Co-operation & Development (OECD) average in terms of cubic metres per capita per year.[50]

The wastewater implications of this potable water use are also shown in Exhibit 7.3. The wastewater production volumes do not reflect *total* wastewater attributable to the residential sector since water infrastructure inefficiencies (such as infiltration of groundwater into sewers and inflow to sewers from surface runoff) were excluded from the study due to limited data and study resources.

[48] Differences in volumes occur as a result of spring and summer potable water use when a portion of water consumption goes to outdoor use and is not directed to the sanitary sewer system. Estimates of outdoor water use in Canada range from about 4% to 6% of consumption.

[49] Niagara Falls water flow from: http://www.niagaraparks.com/nfgg/geology.php

[50] University of Victoria. 2001. *Canada vs. the OECD: An Environmental Comparison*. http://www.environmentalindicators.com/htdocs/index.html

To put these water use and wastewater production estimates into context, below are some **related research findings**:

Sanitary Sewage

- In 1999, 78% of the municipal population on sewer systems in Canada was serviced by secondary wastewater treatment facilities or better.[51]
- 19% of the municipal population on sewer systems in 1999 was serviced by primary treatment and 3% were not serviced by treatment systems.[52]
- In 1983, 56% of the population on sewer systems had secondary treatment.[53]
- An estimated 4300 million cubic meters of municipal wastewater was discharged in 1991 in Canada.[54]

Combined Sewer Overflows (CSOs)

- Municipalities with CSOs typically experience dozens of CSO events per year[55] although specific systems can experience 100–150 per year.[56]

Relative Volumes of Wastewater

- In a 1997 study of Canadian Areas of Concern in the Great Lakes area, the annual wastewater volumes by type were: 17–65% stormwater runoff; 1–6% CSOs; and 35-80% wastewater treatment plants.[57]

Stormwater

- About 30–50% of stormwater or snowmelt in urban areas is converted to surface runoff; however in downtown areas, the amount may be 90% of higher.[58]

Contaminants

- About 200 chemicals have been identified in municipal sanitary and stormwater discharges.[59]
- Domestic sewage pollutants include biodegradable oxygen-consuming organic matter, suspended solids, nutrients, micro-organisms, metals, organic chemicals,

[51] Environment Canada. 2003. *Environmental Signals: Canada's National Environmental Indicator Series 2003.*

[52] Ibid.

[53] Ibid.

[54] Environment Canada. 2001. *Threats to Sources Drinking Water and Aquatic Ecosystem Health in Canada*. National Water Research Institute, Burlington, Ontario.

[55] Ibid.

[56] Ibid.

[57] Ibid.

[58] Environment Canada. 2001. *The State of Municipal Wastewater Effluents in Canada.*

[59] Environment Canada. 2003. *Environmental Signals: Canada's National Environmental Indicator Series 2003.*

and emerging contaminants of concern such as endocrine disrupting substances, pharmaceuticals and personal care products.

- Stormwater contains substantial amounts of oil, grease, chlorides, toxic metals, organic chemicals, residues of fertilizers, insecticides and herbicides, debris, sand as well as settled air pollutants.
- In a 1995 stormwater study, 28 pollutants and pollutant groups with the potential to affect aquatic life and human health were identified; pollutants identified included total solids, suspended solids, chloride, oxygen depleting substances, micro-organisms, 12 heavy metals, and 9 organic chemicals.[60]
- In 2005, 32% of households used fertilizers on lawns or gardens and 29% used pesticides; 52% of pesticide use was applied as part of a regular maintenance cycle (74% of households had lawns or gardens).[61]

As indicated in above, the quality of wastewater treatment by community infrastructure systems is gradually improving in Canada from primary treatment to secondary treatment; this results in improved removal of suspended solids, oxygen demand and nutrients. However secondary treatment is a biological process and is not designed to remove many of the contaminants in wastewater. Further, removal of contaminants from the water discharged often means the contaminant has been transferred to another medium, such as solids or the air. For example, metals are typically transferred to biosolids, which are disposed of on lands or in landfill sites.

Potable water use can cause local environmental problems where withdrawal rates from surface waters or aquifers exceeds recharge rates, resulting in low flow conditions for surface waters and aquifer depletion.

Surface Water Quality Impairment

The share of non-permeable surface area in cities is projected to increase from 39% to 45% over the study period 2004–2025, which would result in additional storm water volumes under the BAU scenario. In effect, stormwater is surface run-off during precipitation events and it can impair surface water quality in many ways, including chemical contamination, sediment deposition, increased erosion, temperature increase, and oxygen depletion. Temperature increases are often exacerbated by the removal of riparian tree cover, exposing watercourses to increased sun and heat during critical periods in the life-cycle of aquatic species. The larger volumes of water scour land and watercourses, are capable of carrying higher pollutant loads, and result in fundamental changes in aquatic habitat (these impacts are discussed further in Section 7.3 Regional Impacts).

The contextual research findings on the previous page provide quantitative information on wastewater gleaned from literature, including metrics on sanitary wastewater and storm water that can be used to qualitatively assess surface water quality impairment. As indicated in the research findings above, the contribution of pollutants from stormwater

[60] Environment Canada. 2001. *The State of Municipal Wastewater Effluents in Canada.*

[61] Statistics Canada. 2006. *Households and the Environment Survey*.

has been monitored in specific instances and found to be significant relative to other sources. See Relative Volumes on the previous page for literature data on the estimated volumes of various types of discharges from sewer systems. The highly variable range for stormwater reflects the weather-dependent nature of this discharge to the environment.

Local Groundwater Quality Impairment

Groundwater quality impairment in urban areas is of particular concern in the vicinity of brownfield sites and operating industrial sites. The impacts of the residential sector on groundwater quality are not known except on a case-by-case basis, where development conditions (such as development of a brownfield site) or servicing conditions (such as use of groundwater sources for potable water supply) require monitoring and analysis of groundwater quality over time. There is insufficient data on this topic to address this issue either qualitatively or quantitatively.

Nutrient Loadings to Surface & Ground Water

Exhibit 7.4, containing the most recent available data from 1996, provides some insight to the residential sector contribution of nutrient loadings (phosphorous and nitrogen) to surface water and groundwater in Canada. The portion of the residential sector represented in this table is the urban infrastructure required to transport and treat wastewater and to transport storm water. A comparison is made with the industry and agricultural sectors, keeping in mind that data limitations impede a full picture of the loadings due to industry.

Exhibit 7.4: Nutrient Loadings to Surface Water & Groundwater from Various Sources in Canada, 1996[62]

Nutrient Source	Phosphorus (10^3 t/yr)	Nitrogen (10^3 t/yr)
Municipal		
Municipal Wastewater Treatment Plants	5.6	80.3
Sewers (stormwater and Combined Sewer Overflows)	2.3	11.8
Septic systems	1.9	15.3
Industry (value underestimated due to data limitations)	1.9	11.5
Agriculture (residual in the field after crop harvest)	55.0	293.0
Aquaculture	0.5	2.3
Atmospheric deposition	n/a	182.0 (NO_3^- & NH_4^+)

As shown, the activities attributed to the residential sector comprise only a part of the municipal discharges and the proportion would vary from community to community, depending on the presence and activities of other economic sectors in the community. Municipal discharges can include effluents from industrial and commercial dischargers connected to the sanitary sewer system as well as residential sector discharges. Septic systems primarily receive residential effluents and, in terms of phosphorus and nitrogen, the volumes of these effluents are comparable to those from industrial sources.

62 Environment Canada. 2001. *The State of Municipal Wastewater Effluents in Canada*.

Residential sanitary discharges contribute relatively significant loadings of nutrients to surface waters, except in comparison with loadings from agricultural sources.

Exhibit 7.5, containing the most recent available data from 1992–1992, provides a comparison of loadings of polychlorinated biphenyls (PCBs) and mercury to two of the Great Lakes from three types of urban water infrastructure (stormwater runoff, combined sewer overflows, municipal wastewater treatment plants) in comparison with industrial sources. This study indicates that stormwater runoff is the most significant source of PCBs and is also a significant contributor of mercury by comparison with industry and other urban water infrastructure loadings.

Exhibit 7.5: Estimated Loading of PCBs & Mercury to Lakes Superior & Ontario, 1991–1992[63]

Loadings	PCB Loadings (kilograms/year)		Mercury Loadings (kilograms/year)	
	Lake Superior	Lake Ontario	Lake Superior	Lake Ontario
Industry	10	4	39	12
Stormwater runoff	18	83	40	29
Combined Sewer Overflows	2	4	3	2
Municipal Wastewater Treatment Plants	8	15	34	89
Spills	0	0	2	0

Emerging contaminants of concern in wastewater are increasingly gaining attention due to their potentially negative impacts on water ecosystems. Pharmaceuticals, personal care products and other endocrine disrupting chemicals are discharged by wastewater treatment facilities with unknown consequences for aquatic biota. Effects on fish downstream of municipal wastewater treatment facilities in Canada have been documented (for example, male fish carrying egg sacs).

The effects of these contaminants is an emerging area of research in Canada and internationally. For example, results of a recent seven-year study in north-western Ontario found that exposing fish to very low traces of synthetic estrogen used in human birth control pills had catastrophic effects on the minnow population.[64] The added dosage was the same level of the hormone found in water discharged from sewage treatment plants in Canada. After treatment, the lake water had estrogen concentrations of about five parts per trillion (ppm) in the lake, which was about 35 hectares. Within a year of exposure, the minnow population began to crash. The study found dramatic impacts on minnow populations, with male fish showing female characteristics including egg production. Within a few years, the fish population, which at one time was abundant in the lake, had collapsed. The results highlight the need to understand more about the impacts of drug residues in waterways.

[63] Environment Canada. 2001. *The State of Municipal Wastewater Effluents in Canada.*

[64] Karen A. Kidd, Paul J. Blanchfield, Kenneth H. Mills, Vince P. Palace, Robert E. Evans, James M. Lazorchak, and Robert W. Flick, *Collapse of a fish population after exposure to a synthetic estrogen*, PNAS, May 22, 2007 vol. 104 no. 21 8897-8901

Summary

Per-dwelling potable water use is expected to decrease in Canada during the study period due to improved plumbing standards. With this decrease, the volume of wastewater treated may also decrease. At the same time, the rate of secondary wastewater treatment is expected to increase in Canada over the study period, resulting in improved treatment of conventional pollutants. Stormwater quantity and quality is a contributing factor to environmental impacts due to an increase of non-permeable surface area over the study period.

The contribution from urban infrastructure operations of contaminants to Canadian aquatic ecosystems is significant in comparison with other sector sources, a portion of which come from the residential sector (For example, as shown in Exhibits 7.4 and 7.5 above). Data is not available on the specific contribution of the residential sector to contaminant loadings identified from urban or municipal system but a portion of these come from the residential sector.

Limitations

As noted, the discussion on the local environmental impact relating to surface water quality is indicative, rather than definitive. The complete quantifications of loadings of pollutants from wastewater and stormwater from the residential sector have not been estimated in this study. To fully understand these environmental implications would require a thorough correlation relating wastewater and stormwater with potable water consumed and non-permeable surface area respectively.

The highly variable nature of discharges, weather conditions and infrastructure capacity and conditions makes quantitative estimation of contaminant releases problematic. Further, precipitation and melt events are episodic and, although total rainfall can be estimated based on yearly averages, no attempt has been made to extrapolate stormwater volumes or quality based on the impervious surface areas of residential developments. This calculation would be too simplistic for many reasons; for example, stormwater also runs off pervious areas during larger rain events.

7.1.3 Local Heat Island Effect

The final local environmental impact discussed is the Heat Island Effect (HIE), which is defined in terms of the difference in urban temperature relative to its rural surroundings.[65] The HIE is only discussed briefly because there is limited understanding of the phenomenon and its environmental impacts. However, it is believed to be a growing local environmental concern, affected by residential development patterns that reduce permeable surface areas.

Materials commonly used in urban areas, such as concrete and asphalt, have different thermal and surface radiative properties than those used in rural areas, resulting in

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[65] Cuddihy, J.M.M. *Toward Sustainable Urban Design: The Impact of Urban Geometry on the Energy Consumption of Buildings*. M.A.Sc. Thesis, University of Toronto, 2005.

temperature variation within the urban area that are not experienced in surrounding rural areas. Heat islands can exist at the street level or into the urban area's atmospheric boundary layer, which can range from 100 meters at night to two kilometres during the day.[66] Numerous local and regional factors contribute to the individual characteristics of HIE, including topography and water bodies, soil type, vegetation, land-use, characteristics of the built environment, weather (including wind and cloud cover) and city size.[67]

Although many factors contribute to the HIE, indicators of impervious area provide some insight to how the HIE phenomenon might grow over time. As previously discussed, two development factors can drive the increase in impervious area: densification (of existing urban area) and increase in urban area.

One of the important study outputs is impervious surface area, which includes roads, sidewalks, parking, and roof areas. As mentioned in Section 7.1.2, the share of non-permeable surface area in cities is projected to increase from 39% to 45% over the study period 2004–2025. This trend of increased impervious area suggests an increase in the occurrence and extent of the HIE under BAU. These impacts may be exacerbated or mitigated by building materials used and local conditions.

Evidence of and the Effects of Warming

Springtime land surface temperatures in eastern North American cities were on average 2.3°C warmer than surrounding rural areas (NASA 2004). In late autumn to winter, the city temperatures were 1.5°C higher than the surrounding areas. The warming effect of HIE can generate the following types of environmental effects, some positive, others negative:

- Using satellite images, researchers discovered that, in 70 cities in eastern North America, growing seasons were about 15 days longer in urban areas compared to rural areas outside of a city's influence.[68] They also found that for every one degree Celsius rise in temperature during early springtime, vegetation bloomed three days earlier. These higher urban temperatures caused plants to start greening-up an average of seven days earlier in spring. Similarly, in urban heat island areas, the growing season lasted eight days longer in the fall than the rural areas. Noticeable effects were seen up to 10 kilometres from a city's edges, meaning the impact of urban climates on ecosystems in the areas studied extended out 2.4 times the size of a city itself.

- In addition to warming, HIE can produce secondary effects on local wind patterns, the development of clouds and fog, the number of lightning strikes, and the rates of precipitation.[69] Smog is more likely to occur in higher temperatures.[70]

[66] Cuddihy, J.M.M. *Toward Sustainable Urban Design: The Impact of Urban Geometry on the Energy Consumption of Buildings*. M.A.Sc. Thesis, University of Toronto, 2005.

[67] Ibid.

[68] U.S. National Aeronautics & Space Administration (NASA). July 2004. *Urban Heat Islands Make Cities Greener*. http://www.nasa.gov/centers/goddard/news/topstory/2004/0801uhigreen.html

[69] U.S. National Aeronautics & Space Administration (NASA). April 1999. *Science at NASA, Welcome to Thunder Dome*. http://science.msfc.nasa.gov/newhome/headlines/essd26apr99_1.htm

Summary

The HIE experienced in Canadian cities can be expected to continue and to increase under BAU conditions as impervious areas increase and the extent of land area occupied by urban developments increases. The effect potentially has both beneficial and detrimental implications for energy use. Its overall environmental impacts are not well understood, in particular with respect to biodiversity. Further research on the space heating and cooling implications of heat islands could be explored although this is a relatively low priority area since the effect is mixed in terms of increases and decreases in energy use.

Limitations

Significant gaps exist in understanding of the implications of HIE on biodiversity and ecosystem health in urban areas. Similarly, definitive data on the additional cooling energy and reduced heating energy required for building interior spaces is not known. The USEPA concludes, "In general, the harmful impacts from summertime heat islands are greater than the wintertime benefits, and most heat island reduction strategies can reduce summertime heat islands without eliminating wintertime benefits."[71]

7.2 REGIONAL IMPACTS

7.2.1 Smog

As discussed in Section 7.1.1, the contribution of the residential sector to air pollution can be significant enough to affect ambient air quality. The residential sector activities can therefore also be expected to contribute to smog on regional levels.

Generally speaking, smog is formed by four pollutant groups: nitrogen oxides (NO_x), SO_2, volatile organic compounds (VOCs), and particulate matter (PM). However, two of these pollutants, NOx and VOCs, are the primary drivers of smog and are responsible for formation of ground level ozone, a major component of smog. Average ozone levels have remained more or less unchanged from 1991 to 2004, except for New Brunswick where a decreasing trend has been seen.[72] The national average ozone levels have been just above or just below the Canadian Council of the Ministers of the Environment (CCME) Canada-Wide Standards (CWS) over most of the 15-year period.[73] The four western provinces have had regional averages below the CWS but southern and central Ontario has been above the CWS every year.[74] In Ontario and British Columbia, in particular, where concentrations approach or exceed the CWS for certain air contaminants during

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[70] U.S. Department of Energy – Environmental Energy Technologies Division – Heat Island Group. Accessed March 2007. *Air Quality*. http://eetd.lbl.gov/HeatIsland/AirQuality

[71] U.S. Environmental Protection Agency. Accessed March 2007. *Heat Island*. http://www.epa.gov/heatislands/about/index.html

[72] ibid

[73] U.S. Environmental Protection Agency. Accessed March 2007. *Heat Island*. http://www.epa.gov/heatislands/about/index.html

[74] Ibid

seasonal periods, residential sector contribution are know to drive ambient local air quality over the CWS. For example, southern Ontario suffered 32 “smog days” in 2005 and seven in 2006.[75] Transboundary contributions and other events, such as forest fires, contribute to air contaminant levels. The topography of an area influences dispersion of air contaminants.

Smog has detrimental effects on natural vegetation and smog pollutants contribute to the corrosion of materials, such as rubber and stone. Smog may occur locally and it also occurs as a result of regional and transboundary movement of air masses to other regions.

7.2.2 Acid Rain

Similar to the smog phenomenon, acid rain occurs as a result of local conditions and also as a result of air masses transporting pollutants regionally and at the transboundary level. Acid rain results primarily from the transformation of SO_2 and NOx into secondary acidic pollutants such as sulphuric acid and nitric acid. These pollutants can be transported in the atmosphere over distances of hundreds to thousands of kilometres and are removed from the atmosphere in precipitation.[76] Dry deposition can also take place when particles are deposited from the air on land surfaces and converted into acids when they contact water.

The contribution of the residential sector to NOx emissions can be significant enough to affect ambient air quality and, therefore, can be expected to contribute to acid rain on regional levels. The SOx emissions by the residential sector are less significant relative to other sources.

Acid rain is a problem where water and soil systems lack natural alkalinity and therefore cannot neutralize these acidic deposits naturally. Areas of the Canadian Shield, including Ontario, Quebec, New Brunswick and Nova Scotia, are particularly susceptible to acid rain since their water and soil systems lack alkalinity. Overall, more than half of Canada consists of rock areas susceptible to acid rain, including specific areas in western Canada, for example where granite is predominant in the land form.

7.2.3 Water & Land Ecosystems Fragmented, Altered or Lost

At the regional scale, the activities off the residential sector contribute to a category of environmental effect referred to as “water and land ecosystems fragmented, altered or lost”. As discussed below, often dramatic environmental effects take place at this scale and the magnitude of these effects could grow in a future as represented by the BAU. The discussion begins with the regional water ecosystem effects and proceeds to the land ecosystem effects.

Water and land ecosystem alteration and fragmentation are addressed together in one sub-section because the environmental outputs data developed in this study pertaining to these

[75] Toronto CityNews. September 28, 2006. *One Serious Day of Severe: Summer of '06 Review*. http://www.citynews.ca/blogs/citynewsweather_3921.aspx

[76] Environment Canada. Accessed March 2007. Acid Rain. http://www.ec.gc.ca/acidrain/acidfact.html

two environmental impacts are the same. The pertinent indicators are: 1) land area consumed by housing development; and 2) percent impervious area of developed land.

A brief literature review was conducted to supplement the study findings. However, literature providing insight on how development affects either land or water ecosystems, or both, is not available nationally for Canada. Some case study information was identified for wetland development on local or regional scales, as described following.

The land area consumed by housing development between the baseline year of 2004 and 2025 is 165 square kilometres, according to the current and estimated neighbourhood densities and densification levels resulting from this study. Exhibit 6.9 previously presented the percent impervious area by neighbourhood type in 2004 and 2025.

Water Ecosystems Altered or Lost

Watersheds can be analyzed at various scales. There are four major watersheds at the national scale: draining to the Pacific Ocean, the Arctic Ocean, Hudson Bay and the Atlantic Ocean77. Municipalities typically deal with watershed scales of about 1000 km^2 and sub-watershed planning at about 50 to 200 km^2.[78] The levels of impervious area identified in this study are high enough to clearly affect sub-watershed ecosystem quality in urbanized areas. In particular, the core and inner suburban neighbourhoods profiled in the study can be expected to have highly impaired sub-watersheds unless measures to mitigate effects are aggressively applied. This impairment is a current condition that can be expected to worsen under a BAU approach.

According to the Rapid Watershed Planning Handbook79, published by the United States Center for Watershed Protection, the percentage of impervious surface within a watershed has a direct correlation to watercourse quality changes. With increasing imperviousness, certain elements are lost from stream systems with aquatic diversity, habitat quality and water quality being affected. With over 10% impervious cover, sensitive stream elements (such as sensitive invertebrates) are lost from the system. With 25–30% impervious cover, stream quality indicators can be expected to fall in the category of poor. These percent impervious cover thresholds have been used in the Handbook to identify three watercourse categories: sensitive (0–10% impervious), impacted (11–25% impervious), and non-supporting (greater than 25% impervious), each with unique characteristics.

These dramatic changes in water ecosystem quality occur because changes in land use due to urban developments result in changes to the water cycle, summarized as follows:

- Impervious surfaces reduce the water infiltration rate, which reduces groundwater levels. Groundwater and direct surface run-off feed creeks, streams, rivers, and lakes.

[77] A very small portion of western Canada drains to the Gulf of Mexico.

[78] Conservation Ontario. 2003. *Watershed Management in Ontario: Lessons Learned and Best Practices: Newmarket*.

[79] Centre for Watershed Protection, http://www.cwp.org/index.html

- As previously noted, impervious urban land use increases the proportion of surface water runoff relative to groundwater recharge. Increased surface runoff has greater momentum and this increased energy of the water increases scour and erosion of receiving water bodies, eventually changing the cross-sectional area of creeks and rivers. Impervious surfaces allow water to runoff land very quickly relative to meadow and forested areas. This increased speed exacerbates the lack of groundwater recharge.

- Pavements also transfer heat to the water and its speedy deposition to storm sewers and quick conveyance to receiving waters warms up the aquatic environment. Warm water holds less oxygen and supports different biota than cold and cool waters. The disappearance of trout from urban streams is typically not the result of chemical pollution, but the result of fundamental changes in habitat due to warmer waters.

- The loss of wetland areas to urban development has an especially detrimental effect on the water cycle in the area. Wetlands act as sponges, storing water during wet seasons and releasing it during dryer periods. The loss of wetlands thus contributes to both increased flooding and prolonged periods of drought. In addition to effects on water quantity, the loss of wetlands contributes to reduced water quality. Wetlands act as natural water treatment systems, supporting beneficial bacteria and a complex food web that acts to reduce nutrients, settle solids and integrate 'waste' products back into more organized forms by supporting various birds, fish and animals that feed in wetland areas. Wetlands represent critical and highly productive habitat for fish, wildlife and many types of plants.[80]

- There is limited literature data on the magnitude of wetlands lost to urbanization. Exhibits 7.6, 7.7 and 7.8 provide three case study results within three of the urban development areas of particular interest in this study, the greater Vancouver area, the Calgary area and the Toronto area.

[80] Environment Canada. 2004. *Threats to Water Availability in Canada*. http://www.nwri.ca/threats2full/intro-e.html

Exhibit 7.6: Vancouver/Lower Mainland: Encroachment on Fraser Lowland Wetlands[81]

Using a 1989 wetland inventory as a baseline, two Environment Canada researchers demonstrated that urbanization and other human land uses continue to encroach on the wetlands of the Vancouver area. Although agriculture was shown to be the largest single use for converted wetlands, increases in urban land uses (housing and industrial building) and related land uses (i.e. landfills, golf courses) are significant factors, accounting for over 500 hectares of lost wetlands from 1989-1999. The study found that wetland loss has been the cumulative result of many decisions to convert seemingly insignificant wetland areas.

Exhibit 7.7: Calgary Wetlands: Loss & Conservation Plan[82,83]

Although an estimated 90% of its pre-settlement wetlands have been lost, the City of Calgary has recognized the importance of remaining wetlands within city limits, and the threat posed to these wetlands by urban development, by drafting a Wetland Conservation Plan (WCP). This policy makes Calgary the first city in Canada to define priorities and best practices for wetland conservation. The plan identifies 18 separate benefits in five categories, including; water quality, flood attenuation and erosion control, ecological value, climate amelioration, and socioeconomic value.

Calgary Parks is now working to develop an implementation plan for the policy, including developing wetland mitigation and evaluation procedures as well as research and monitoring programs to ensure wetlands remain sustainable and healthy. Existing wetlands have been mapped; the data will be used to assist city staff in convincing developers to incorporate key wetlands into the design of subdivisions. Ducks Unlimited Canada has partnered with the City to advise on storm water management and wetland conservation.

Note that there are significant wetland areas remaining in the Calgary Edmonton corridor, including within the city limits of both cities.

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[81] Moore, K. and K. Roger. Urban and Agricultural Encroachment onto Fraser Lowland Wetlands. Conference Poster. Presented at 2003 Georgia Basin/Puget Sound Research Conference

[82] City of Calgary Wetland Conservation Plan, http://www.calgary.ca/docgallery/bu/parks_operations/wetland_conservation_plan.pdf

[83] Report on Implementation Progress for Alberta's Strategy for Sustainability, 2005, http://www.waterforlife.gov.ab.ca/docs/WFL_ImplementationReport_Oct2005.pdf

Exhibit 7.8: Greater Toronto Area: Conservation of the Oak Ridges Moraine[84,85,86]

The Oak Ridges Moraine (ORM) is a ridge of sandy hills covering an area of 190 000 hectares located in Southern Ontario. It contains the headwaters of 65 waterways, 35 of which are in the in the GTA. Sixty five percent of the area of the moraine is located within the Greater Toronto Area.

Although the role of the moraine in recharging streams and rivers in the system is well known, uncertainties remain with respect to knowledge of the moraine's hydrology, and the potential impact of development on the moraine. Researchers have theorized that development could lead to increased flooding due to diversion of stormwater from aquifers to storm sewers, higher aquifer salinity as a result of increased use of road salt, and unknown effects of large scale groundwater consumption, increased septic system construction, and agrochemical use.

In 1999 plans to build subdivisions in Richmond Hill to house 100 000 people brought the issue of the development of the ORM to the attention of the general public. The result has been legislation from the Ontario Government, the *Oak Ridges Moraine Conservation Act, 2001*, which sets aside a small portion of the moraine area (8%) for development, while placing varying degrees of development restrictions on the remainder.

The quality of water runoff from residential areas is problematic due to use of pesticides, herbicides and other products outdoors as well as poor stormwater quality runoff from roads (see discussion above on water quality impairment).

Land Ecosystems Fragmentation

This discussion addresses two dimensions of land systems fragmentation: habitat fragmentation and ecosystem fragmentation. Habitat fragmentation disrupts natural movements of animals (and their genes), seeds, spores and pollen, as well as nutrient and energy flows." Habitat fragmentation results in genetic and reproductive isolation. Ecosystem fragmentation ultimately causes the diminishment of ecosystem services such as nutrient cycling and water purification within these areas, as well as loss of aquatic and other habitat.

Land ecosystem fragmentation is caused by residential development, largely from greenfield development where the outer suburb development expands the urban boundary. As previously noted, the expected total land area to be consumed by housing development between 2004 and 2025 is 165 square kilometres.

Canada's land area can be divided into ecozones, areas with similar characteristics throughout, including climate, vegetation, and fauna. These can be further subdivided into ecoregions. The four CMAs identified as areas likely to be responsible for the

[84] City of Toronto, http://www.toronto.ca/moraine/index.htm

[85] Oak Ridges Moraine Conservation Plan, http://www.mah.gov.on.ca/userfiles/HTML/nts_1_6846_1.html

[86] International Association for Great Lakes Research, http://www.iaglr.org/scipolicy/nps/oakridges.php

majority of Canada's future population growth are located in three different ecozones and, therefore, represent a relevant point of reference for the discussion of land ecosystem fragmentation. Two of these ecozones are the most highly human modified ecozones in Canada.

- The Vancouver/ Lower Mainland area is located in the pacific maritime ecozone, an area characterized by a warm, wet climate. The Lower mainland ecoregion is dominated by productive farmland, forestry operations in upper elevations, and coastal salt marshes on the Fraser river delta.[87] Urban growth into wetlands and along coastlines can be especially problematic.

- Both Calgary and Edmonton are located in the Northern part of the prairies ecozone. This ecozone has a continental climate, often characterized by water deficit. The dominant land use is agricultural. As an illustration of the extent of human activity in the prairies, if the area were divided into 1 km^2 plots, 97% of the plots within the prairie ecozone would be classified as "human modified", as opposed to "natural".[88] Despite human modification, the cropland and rangeland of the prairie ecozone continues to provide services such as flood mitigation and groundwater replenishment.

- The cities of Toronto and Montreal are located in the mixed wood plains ecozone, in the Lake Erie lowland and St Lawrence lowland ecoregions respectively. The dominant land uses are agricultural (approximately 60% in both regions) and urban. The mixed-wood plains are Canada's second most highly modified ecozone (after the prairies ecozone), with 88% human modified area at 1 km resolution. The most common natural land cover is mixed deciduous forests.

Most of Canada's settlements are in areas of productive farmland, meaning that as cities expand much of the land subsumed is farmland rather than natural areas. For example, of the approximately 6386 km^2 that make up four Regional Municipalities in the GTA, excluding Toronto, (i.e. Halton, Peel, Durham and York), 2861 km^2 or 44.8% was classified as farmland by Statistics Canada in 2001, down from 51.8% in 1986.[89] Most of the farmland in the GTA is prime farmland. Studies have identified land conversion for agriculture as the main driver of reductions in ecosystem services and biodiversity through habitat loss and fragmentation. There is evidence, however, that urbanization is directly responsible for species endangerment and that urbanisation degrades ecosystem services to a greater degree than conversion to agriculture.[90]

From the impervious figures, ecozones within urban areas can be expected to be fragmented unless aggressive measures are taken as part of urban development to

[87] Environment Canada. Last updated April 2005. *Narrative Descriptions of Terrestrial Ecozones and Ecoregions of Canada*. http://www.ec.gc.ca/soer-ree/English/Framework/Nardesc/TOC.cfm?EcozoneID=14

[88] Kerr and Deguise, 2004. *Habitat loss and the limits to endangered species recovery*. Ecology Letters (2004) 7: 1163-1169

[89] Tomalty, Ray and Don Alexander for CMHC. 2005. *Smart Growth in Canada: Implementation of a Planning Concept*.

[90] Gagne, Sara A. and Lenore. 2007. *Effect of landscape context on anuran communities in breeding ponds in the NCR* [National Capital Region]. *Landscape Ecology,* 22:205-215

preserve wildlife movement corridors, riparian tree cover, urban forested areas, and other land ecosystem features that protect and connect animals and their habitat.

Summary

The residential sector contributes to loss of aquatic ecosystems and alteration of aquatic and terrestrial habitats through physical and chemical changes in land use, air and water quality changes and factors that determine the viability of biota. The significance of the area of land subsumed by urban development (estimated at 165 square kilometres over the study period) is difficult to assess in the absence of local and regional information on the ecosystems displaced by this development. This additional area is also difficult to assess in isolation of the urban areas already allocated to the residential sector and their historic and on-going impacts on ecosystems. Nevertheless, the integrated impact of the residential sector on ecosystem deterioration in Canada can be expected to increase under a business-as-usual approach to residential development.

7.2.4 Impacts on Wildlife

Species become endangered, extirpated or threatened due to many factors, some of which are attributable to the residential sector while others are a result of activities in other sectors such as forestry, agriculture and mining. Habitat destruction is a major factor leading to reduction of numbers of species and the viability of populations. In Canada, it is estimated that 79% of endangered species are threatened by habitat loss.[91] Environmental contamination, climate change and the presence of introduced invasive species are other factors that can, in part, be linked to residential development and use. Exhibit 7.9 identifies the percentage of endangered species in Canada threatened by urbanization.

[91] Venter, Oscar, Belland, Brenna, Nemiroff, Leah, Brodeur, Nathalie N., Dolinsek, Ivan J., Grant, James W.A. *Threats to Endangered Species in Canada. Bioscience* 2006. Vol. 56, Issue 11

Exhibit 7.9: Endangered Species in Canada Threatened by Habitat Loss Due to Urbanization[92]

Species Type	Number in Sample Studied	% Threatened by Urbanization
All Species	488	27.9
Vascular Plants	151	37.7
Freshwater Fish	77	15.6
Birds	61	21.3
Terrestrial Mammals	36	36.1
Reptiles	34	50.0
Marine Mammals	32	6.3
Molluscs	21	33.3
Amphibians	19	31.6
Lepidopterans	19	15.8
Marine Fish	18	5.6
Mosses	13	30.8
Lichens	7	14.3

92 Venter, Oscar, Belland, Brenna, Nemiroff, Leah, Brodeur, Nathalie N., Dolinsek, Ivan J., Grant, James W.A. *Threats to Endangered Species in Canada. Bioscience* 2006. Vol. 56, Issue 11

A study done in the National Capital Region of Canada found a lower abundance and richness of individual amphibian species in urban areas (and especially in urban breeding ponds) compared to those in forested and agricultural areas.[93] This study found "amphibian communities in urban breeding ponds…experience a higher probability of local extinction due to higher mortality from road traffic and lower movement in landscapes characterized by a high proportion of roads and other impervious surfaces".

A case study on bird abundance in eastern North America found that birds are also threatened by urban environments and fragmented ecosystems.[94] The study found that bird species habitats in open, edge, and wetland areas have been affected by human disturbances and land cover changes, particularly urban low-density development in east North America. Statistics for the period 1966–2004 show a 21% decrease in the number of US and Canadian resident bird species and a 30% decrease in bird migrants within the US and Canada (especially among bird species that preferred open habits).

Summary

Literature specifically linking impacts on native species with residential sector activities is limited, likely due, in part, to problems with data availability and statistical approaches required to draw causal linkages between land changes and species population changes. The literature available does indicate linkages between urbanization and traffic with native species decline. Note that research on increases and impacts of non-native species was not conducted.

7.3 GLOBAL IMPACTS

7.3.1 Climate Change

The issue of climate change and its impacts and consequences is covered thoroughly in other literature and so is not discussed in detail here.[95] Climate change is a critical issue and a significant challenge in terms of mitigation and adaptation measures. The residential sector contributes significant amounts of carbon dioxide to the atmosphere and under a BAU scenario would increasingly contribute to climate change, in particular as a result of operating energy used in the sector (refer to Section 6.1, Overall Emissions to Air). The residential sector can also be expected to be impacted by changes in weather patterns and the water cycle resulting from climate change, including extreme weather, heat waves, flooding and drought. For example, urban drainage infrastructure is designed based on historic weather patterns, but those patterns would not be predictable indicators for future designs. The implications for urban stormwater and combined sewage infrastructure are not yet known.

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[93] Gagne, Sara A and Lenore Fahrig *Effect of landscape context on anuran communities in breeding ponds in the NCR, Canada* 2006. *Landscape Ecology* (2007) 22:205-215

[94] Valiela, Ivan and Martinetto, Paulina. *Changes in Bird Abundance in Eastern North America: Urban Sprawl and Global Footprint?* Bioscience (2007). Vol.57m Issue 4

[95] See, for example: a) Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pub/pub.htm
b) Environment Canada. *Climate Change*. http://ec.gc.ca/default.asp?lang=En&n=6EE576BE-1

7.3.2 Biodiversity Decline & Ecosystem Services

Biodiversity decline is also discussed extensively in other literature.[96] Globally, biodiversity is being lost at an alarming rate. Extinction rates are rising by a factor of up to 1,000 above natural rates.[97] Every year, between 18,000 and 55,000 species become extinct.

A key contributing factor in the decline of biodiversity is loss of habitat. As identified in Section 7.2.3 above, the residential sector contributes to aquatic and land ecosystem loss and fragmentation. However the contribution of any one sector to biodiversity decline is difficult to assess since it is a result of many pressures on regional and larger scales. All sectors contributing to habitat loss and environmental contamination can be assumed to contribute to biodiversity decline.

Biodiversity underpins many of the ecosystem services of the planet. Ecosystem services are the benefits that people obtain from ecosystems, including food, natural fibers, clean water, regulation of pests and diseases, medicinal substances, recreation, and protection from natural hazards such as floods.[98] The Millennium Ecosystem Assessment, conducted on behalf of the United Nations, assessed the consequences of ecosystem change for human well-being. The findings, developed from 2001 to 2005, provide a scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably.[99]

The assessment concluded that, over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history and this has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.[100] Gains in human well-being and economic development have been achieved at growing costs in the form of the degradation of many ecosystem services, increased risks of nonlinear changes, and the exacerbation of poverty for some groups of people.[101]

The Millennium Assessment found that land use change is the most important driver for provisioning, supporting, and regulating ecosystem services and for biodiversity.[102] The significance of the contribution of the residential sector in Canada to changes in global ecosystem functions cannot be estimated from the results of this study however as the literature results on species diversity in urbanized areas and loss of wetland habitat

[96] See, for example: *Canadian Biodiversity website*. http://canadianbiodiversity.mcgill.ca/english/index.htm

[97] Planet Arc. 2007. *UN Urges World to Slow Extinctions: 3 Each Hour*.

[98] Hefny, Manal, Elvira Pereira, Cheryl Palm. *Linking Ecosystem Services and Human Well-being.* Chapter 3. http://www.millenniumassessment.org/documents/document.341.aspx.pdf

[99] *Millennium Ecosystem Assessment*, http://www.millenniumassessment.org/en/About.aspx#

[100] *Millennium Ecosystem Assessment*, http://www.millenniumassessment.org/en/About.aspx#

[101] ibid

[102] Bohensky, Erin, Simon Foale, Cheryl Palm. *Condition and Trends of Ecosystem Services and Biodiversity*. Chapter 8. http://www.millenniumassessment.org/documents/document.346.aspx.pdf

indicate (refer to Section 7.2 above), the sector can be assumed to contribute to changes in biodiversity and ecosystem function.

7.3.3 Systems Response to Regional Contamination

Arctic Contamination

Arctic contamination is an excellent example of the negative results of pollution that result from the global environment acting as one system. Some chemicals are accumulating in the Arctic, in particular those that are volatile and therefore can be transported through the atmosphere. Long-range atmospheric transport (LTRAP) is by far the largest source of chemical contaminants to the Arctic marine environment.[103] Contaminants are transported to the Arctic through a process known as cold condensation (or the "grasshopper effect"). This mode of transport is the result of repeated volatilization of contaminants in warmer regions that are then transported and deposited in cooler regions. Contaminants are also brought to the Arctic by marine currents and river discharges.

Concentrations of mercury have been reported to be increasing in the air, sediments and in certain biota (beluga and ringed seals) in the Arctic.[104] The major source is considered to be LTRAP. Up to 50% of various metallic atmospheric contaminants in the Arctic are thought to be from fuel burning from sources in the Northern Hemisphere. Numerous organic contaminants that are neither produced nor used in the Arctic are transported to the region through LTRAP. These contaminants include certain pesticides and PCBs.

The significance of the contribution of the residential sector to Arctic contamination cannot be estimated because of the generalized nature of the LTRAP phenomenon. However, although agricultural and industrial sources are likely the most common, the analysis of this study has illustrated that the residential sector does contribute significant air pollutants to the environment and a portion of these can be expected to be transported to the Arctic over time. Similarly, urban infrastructure discharges contaminants to surface waters and a portion of these can be expected to be transported to the Arctic region considering nearly 75% of the Canadian continental landmass drains waters toward the north either into the Arctic Ocean, or into Hudson Bay and James Bay.[105]

Great Lakes Contamination

Another example of regional contamination resulting in a systems level response can be seen in the Great Lakes region. Throughout the Great Lakes Basin, forty-two "Areas of Concern" have been identified, seventeen of which are in Canada.[106] Municipal and

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[103] Canadian Department of Fisheries and Oceans (DFO). 1998. *Chemical Contaminants in Canadian Aquatic Ecosystems*. http://publications.gc.ca/control/publicationInformation?searchAction=2&publicationId=75977

[104] ibid

[105] Environment Canada, *Drainage Basins* website. http://www.qc.ec.gc.ca/CSL/INF/inf027_e.html

[106] Canadian Department of Fisheries and Oceans (DFO). 1998. *Chemical Contaminants in Canadian Aquatic Ecosystems*. http://publications.gc.ca/control/publicationInformation?searchAction=2&publicationId=75977

industrial discharges, as well as atmospheric deposition are sources of contaminants to the Great Lakes. More than 300 anthropogenic chemicals have been identified in the waters, sediment and fish of the Great Lakes, more than one third of which are classified as toxic and can have both lethal and sub-lethal effects on plant and animal life.[107] Actions to mitigate releases of chemicals to the Great Lakes have resulted in declines in many chemicals, such as PCBs, pesticides (including DDT and mirex) and metals such as mercury.[108]

Cleaning up the water media in the Lakes has resulted in a non-linear systems level response with implications for the Arctic contamination discussed above. Sediments of the Lakes release contaminants into the cleaner water to maintain chemical equilibrium. If these contaminants are volatile, they will, in turn, be released to the atmosphere if the concentrations are lower in the air than in the water. Thus, historic depositions of contaminants to sediments become released and transported, via the grasshopper effect (see Arctic Contamination above), to more northern regions. Through this process, the Great Lakes are now suspected of being a source of some contaminants to the Arctic. For example, since the 1980s, Lake Ontario has been acting as a net source to the air of polychlorinated biphenyls (PCBs) that are degassing out of the lake at a rate that currently exceeds inputs.[109]

The current role of the urban environment in the release of contaminants to the Great Lakes continues to be an issue for investigation and management measures to improve wastewater treatment and mitigate storm water runoff. The significance of the residential sector specifically has not been identified.

7.4 SUMMARY

Environmental outputs result in environmental impacts. The outputs are direct and indirect results of resource use by the residential sector. Local, regional, and global environmental impacts, however, are not as easily attributed to environmental outputs as environmental outputs are to resource use. The environment operates as a system and therefore non-linear impacts can result. For example, air releases affect water quality through deposition, and both air and water quality can affect biota. Due to the generalized nature of many of the impacts, such as biodiversity decline and Arctic contamination, the specific contribution of any sector often cannot readily be estimated. That said, given the magnitude of the outputs from the residential sector, it can be concluded that the sector impacts the environment on local, regional and global scales, and the aggregate impacts are significant in terms of environmental health.

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[107] ibid

[108] ibid

[109] International Air Quality Advisory Board. November 1998. *Special Report on Transboundary Air Quality Issues*. http://www.ijc.org/php/publications/html/spectrans/chap3.html

8. SUMMARY & IMPLICATIONS OF KEY FINDINGS

This section presents a summary of the key environmental impacts of housing in Canada, including:

- Quantitative estimates of the residential sector's life-cycle resource use, such as land consumption and conversion, fuels, minerals, metals, water, etc.
- Quantitative estimates of the residential sector's life-cycle emissions to air (GHGs, CACs, etc.), water (solids, oils, metals, etc.), and soil (organic, mineral, and solid wastes); and
- Quantitative and qualitative estimates of the residential sector's resulting local, regional, and global impacts on the environment (air, water, soil, and biota).

The discussion attempts to answer the following high-level questions:

- How are housing and neighbourhood development patterns expected to evolve?
- Which aspects of the residential sector life-cycle have the greatest impact on the environment?
- How do choices of the type of housing Canadians live in and how they operate their dwellings affect the environment?
- How do choices of where Canadians live affect the environment?

The key findings and implications in this section are organised and presented as follows:

- The Residential Sector
- Resource Use and Environmental Outputs & Impacts
- Influence of Key Market Drivers.

8.1 THE RESIDENTIAL SECTOR

The underlying analyses upon which the study findings have been generated are predicated on key assumptions of how housing and neighbourhood development patterns would emerge in the next 20 years. The challenge of managing the environmental impacts of Canada's housing stock needs to take into account that Canada is a largely urban-based society and is expected to become more so in the future.

Following are the key findings and implications for residential sector dwellings, neighbourhoods, and infrastructure:

- **Single detached houses would continue as the dominant dwelling type in 2025 —** Single detached houses would continue to be the dominant dwelling type in Canada, as a percentage of the total (existing and new) dwelling stock. There were 12 million dwelling units in Canada in 2004, of which single detached houses account for about 57% of the total. Based on the best available data at the time of this study, this share of single detached houses is expected to continue to 2025.

- **Four Census Metropolitan Area growth clusters would attract most of the new housing during 2004–2025 —** Most of the new Canadian dwellings built during 2004–2025 would be built in four regional CMA growth clusters: 1) British Columbia's lower mainland (including the Greater Vancouver Regional District, GVRD) and Southern Vancouver Island; 2) the Edmonton–Calgary corridor; 3) Ontario's 'Golden Horseshoe' region (including the Greater Toronto Area, GTA); and 4) the Montreal region. In 2001, more than 50% of Canadians lived in these urban regions.[110] Canadian residential growth between 1996 and 2001 was 7.6% in these four regions compared to only 0.5% in the rest of the country.[111] The expectation is that this trend would continue and, therefore, absorb much of the newly built dwellings during 2004–2025.

- **Existing neighbourhoods (2004), especially existing outer suburbs, would absorb much of the new housing by 2025 —** Urban intensification policies and initiatives would begin to have an effect on urban land use and intensity, resulting in increasingly densified neighbourhoods. The CMA growth clusters expect all neighbourhoods within their jurisdictions to become considerably denser, ranging from 16% to 33% denser, depending on neighbourhood type. As a result, if urban intensification plans are realized, densified existing neighbourhoods would absorb about 90% of the new dwellings built in Canada during 2004–2025.

  Taking a closer look by neighbourhood type, the large outer suburban regions of the major metropolitan centres comprise about 77% of the total dwelling stock in 2004, of which about 57% of the dwellings were comprised of single detached houses. In the BAU scenario, much of the newly built dwellings would be absorbed in the outer suburb neighbourhood type. According to the dwelling stock data used in the study and densification trends reported by the regional growth clusters, existing outer suburbs would absorb 3 million (~75%) of the 3.8 million new homes to be built in Canada during 2004–2025.

  Note that these results may vary significantly depending on the extent to which intensification policies are actually adopted in Canada. Achieving the projected 2025 densities for our large urban centres would require changes in the current preferences for "single detached houses in suburban settings" towards denser forms of development.

- **Existing dwellings (2004) would dominate annual dwelling environmental impacts in 2025, not new dwellings —** Only 25% of the estimated 2025 dwelling stock would be built after 2004. Renovation and retrofits of the existing dwelling stock represents the major market opportunity to reduce the environmental impacts of dwellings. Therefore, the study results have smaller sensitivity to the possible variations in the distribution of new dwellings by type, since most of the impacts from dwelling operation in 2025 would be from existing dwellings (2004), not new dwellings.

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[110] David Suzuki Foundation. *Understanding Sprawl: A Citizen's Guide*. http://www.davidsuzuki.org/Climate_Change/Sprawl.asp

[111] Ibid.

- **Most new neighbourhood infrastructure (since 2004) is needed for densifying residential areas in existing inner city and inner suburb neighbourhoods —** Due to the major CMA growth cluster estimates for intensification, of all the new road and water infrastructure that would be required during 2004–2025, over 90% would be needed to densify existing neighbourhoods — particularly existing Outer Suburbs — while the remaining less than 10% would be needed to build entirely new neighbourhoods.

8.2 RESOURCE USE AND ENVIRONMENTAL OUTPUTS & IMPACTS

The residential sector includes not only dwellings and their operation, but also the infrastructure and operation of municipal water systems (to service dwellings) and residential transportation. All these residential structures and their operation contribute to the overall environmental impacts of the residential sector, through the life-cycle stages of Extraction & Manufacturing, On-site Construction, Direct & Indirect Operating, and Maintenance & Replacement.

Following are the major findings related to the residential sector's life-cycle environmental impacts on air, water, soil, and biota (life). Note that the broader regional and global scale environmental impacts are not a linear outcome from every-day choices in the residential sector. The systems response of climate, biota, the water cycle and other natural cycles, such as nutrients, includes threshold responses – or tipping points- beyond which irreversible changes occur. Land use resulting in habitat loss that leads to species extinctions provides a regional-scale example; carbon emissions resulting in climate change that leads to changes in ocean currents would be a global scale example of a tipping point. However, attribution to the activity of the residential sector is difficult and the resulting insights to the impact are more indicative than definitive.

8.2.1 Overall Impacts

Following are the key findings and implications regarding overall resource use and environmental outputs of the residential sector:

- **The operating stage dominates overall environmental outputs —** When total resource use, emissions, and resulting impacts are taken into account, the operating stage of the housing life-cycle has the largest environmental outputs, consisting of roughly 75%–95% of the total life-cycle environmental outputs during 2004–2025.

- **Dwelling and residential transportation operation dominate life-cycle energy use** — Dwelling operating energy (direct and indirect) accounts for over 50% and residential transportation operating energy (direct and indirect) accounts for almost 45% of the total life-cycle primary energy use of the residential sector during 2004–2025. This stresses that, in terms of energy, non-operating effects are relatively low compared to operating effects. This also means that neighbourhood choice, dwelling choice, dwelling condition (e.g., envelope, equipment), and daily behaviour (e.g., heating/cooling, hot water use, etc.) have a huge influence over how much life-cycle energy is needed by the residential sector.

- **The impacts of dwelling direct operating energy patterns are exacerbated by upstream environmental outputs from extraction, refining, and delivery of fuels** — The operation of the dwelling stock and the consequent demands on direct and upstream energy use greatly affects the magnitude of environmental impacts. Every unit of energy delivered and consumed "inside the meter" at dwelling premises represents a fraction of the energy use in production and delivery.

- **Among dwelling types, single detached houses have the highest environmental outputs, per dwelling** — Single detached dwellings require significantly more life-cycle resources and produce significantly more life-cycle air, water, and soil pollutants. On a per-dwelling basis, single detached houses require roughly 1.3 times the life-cycle resources of row/town houses, and roughly 2 times that of low-rise apartment/condo units. Similarly, on a per-dwelling basis, single detached houses produce roughly 1.5 times the life-cycle emissions and pollutants as row/town houses, and roughly 2 times that of low-rise and high-rise apartment/condo units. These increased environmental outputs can be assumed to result in higher environmental impacts than other dwelling types.

- **Choice of building materials affects life-cycle environmental impacts** — A wide range of materials is used in the construction of dwellings. The choice of these materials directly and indirectly affects the resources used, environmental outputs and thus, environmental impacts. As such, there are pros and cons associated with each of them. For instance, higher-density development, such as high-rise dwellings, uses a significant amount of concrete, which has high upstream impacts from cement production. On the other hand, cement also helps lower the operating energy intensity (per unit area) in high-rise units, and its solid waste is inert compared to other materials.

- **Residential transportation environmental outputs are second only to dwelling impacts and are driven mostly by choice of neighbourhood type** — Where you live and how you move results in almost as much air, water and soil emissions and pollutants as the home you live in and how you operate it. Transportation operation has similar life-cycle impacts as dwelling operation, which together, dominate residential sector life-cycle outputs. Regardless of dwelling type, the neighbourhood type contributed to the transportation pattern of the residents. For example, average outer suburb dwellings use personal vehicles for roughly twice the travel distance as inner suburb dwellings and roughly four times the travel of inner city dwellings.

8.2.2 Air Impacts

Following are the key findings and implications regarding overall environmental outputs of the residential sector to air:

- **The residential sector contributes significant GHG emissions** — *Life-cycle* GHG emissions for the *residential sector* over the study period are roughly 5,500 megatonnes of carbon dioxide-equivalent ($MtCO_2e$). If dwelling energy use trends continue, the GHG emission intensity and absolute emissions from the residential sector could increase.

- **Dwelling choice and neighbourhood development patterns both affect air quality** — Criteria air contaminant (CAC) emissions impact on air quality and human and environmental health. In aggregate terms, residential transportation generates the vast majority of the residential sector life-cycle CAC emissions due to carbon monoxide emissions from mostly gasoline-powered private vehicles.

- **Annual operating CAC emissions from the residential sector are significant compared to the industrial sector** — In comparison with select industrial sectors, annual carbon monoxide (CO) emissions from the residential sector -- including those from transportation -- are about eight times higher than the total of the industrial sectors for which data were available. Volatile organic compound emissions from the residential sector annual operating activities are about 80% of the industrial sectors' total; NOx emissions are about 60% and total particulates are about 37% of the industrial sector. Only SOx emissions from the residential sector are negligible when compared to the industrial sector totals.

8.2.3 Water Impacts

Following are the key findings and implications regarding overall water use and pollutants from the residential sector:

- **Dwelling water use dominates life-cycle water use** — This study included assessing water use for dwelling water use, water use for: 1) material extraction, manufacturing, and transportation; 2) fuel extraction, refining, and distribution; 3) electricity generation; and 4) dwelling operation. Based on these water uses, water use during dwelling operation accounts for over 80% of the total life-cycle water use of the residential sector.

- **Annual water use in existing dwellings would decline —** Operational use of water by existing (2004) housing stock is expected to decline by 20% during the study period with improved plumbing fixtures due to kitchen and bathroom renovations. Water use in new dwelling stock may more than makes up the difference.

- **Dwelling operations affect water quality from upstream lifecycle stages —** The operation of the dwelling stock and the consequent demand on direct and upstream lifecycle water use results in large amounts of water consumption and water-borne pollutants generated in the housing life-cycle. The operation of dwellings represents over 80% of the total water consumed in the housing life-cycle. The volumes of water consumed by Canadians are very high relative to other nations, at 65% above the OECD average.

- **The aquatic environment is impacted by the residential sector —** The intensity of water use identified in the operations stage of the housing life-cycle, and how it is managed, has two major dimensions: i) the depletion of the water resource and ii) the effects on water quality. Water quality is only partially addressed by urban treatment infrastructure. While most of the municipal population on sewer systems in Canada is serviced by secondary wastewater treatment facilities, secondary treatment is a biological process and is not designed to remove all of the contaminants in wastewater. At the same time, about 30% to 50% of storm-water or snowmelt in urban areas is converted to surface runoff and, if treatment systems are in place, these typically are designed to address only a few pollutants.

8.2.4 Land & Soil Impacts

Following are the key findings and implications regarding overall land use and soil pollutants from the residential sector:

- **Changing land use patterns require careful targeting of activities to mitigate land use environmental impacts** — Given expected neighbourhood development patterns, one challenge is how to mitigate the effects of housing development and use in existing neighbourhoods. Land use patterns can be characterized in terms of amount, density, mix and location of housing and these patterns directly and indirectly affect infrastructure requirements, transportation mode choice and the building stock which, in turn, impacts energy and other resource use.

  Studies have identified land conversion for human uses, resulting in habitat loss and fragmentation, as the main driver of reductions in ecosystem services (e.g., life support) and biodiversity. However, as indicated in Section 8.1, the expectation is that suburban expansion and associated consumption of land is expected to decline significantly compared with the patterns we have seen in the past 30 years or so, and urban intensification policies and initiatives are expected to result in existing neighbourhoods absorbing most of the new dwelling stock to 2025.

  The expected changes in development patterns mean environmental mitigation actions would increasingly need to address the phenomenon of urbanization within existing boundaries. Urban planning to maintain terrestrial linkages, to reduce storm water runoff and to protect aquatic ecosystems would be needed as there is evidence that urbanization degrades ecosystem services to a greater degree than conversion to agriculture.

- **Land impermeability would increase, with implications for air and water quality** — This study has assessed land consumption (in terms of quantity and type), the amount of green space and impervious surface areas, infrastructure requirements (road, piping, etc.) and storm-water runoff quality and quantity. As a result of development, roughly 45% of urban land in 2025 would be classified as impermeable (i.e. water cannot infiltrate the surfaces), meaning that fundamental changes to the water cycle in urban areas would occur unless management measures are taken, for example to allow groundwater recharge. In addition, increased impervious area would exacerbate the "heat island" effect which, in turn, can produce secondary effects on local wind patterns, the development of clouds and fog, the number of lightning strikes, rates of precipitation, and smog.

- **Extraction and manufacturing dominates life-cycle solid resource use** — Excluding energy and water use, if we give all of remaining assessed resources (minerals, metals, wood, etc.) equal weighting, then the Extraction & Manufacturing stage of the housing life-cycle consumes the most resources. This is as expected, since almost all solid resources used for the residential sector are used (extracted) during the Extraction & Manufacturing stage, when materials are prepared for construction of dwellings and neighbourhood infrastructure. About 60% of solids used are for construction of roads and residential water and wastewater infrastructure, with the remaining 40% going to construction of dwellings.

- **Indirect operating stage dominates life-cycle solid waste production** — With municipal solid waste from dwelling operation aside (was excluded from the study scope), most of the solid waste generated during 2004–2025 is from indirect operating impacts, such as the solid waste resulting from extracting, refining, and combusting coal and other fossil fuels for electricity generation.

8.2.5 Integrated Impacts

Following are the key findings and implications regarding integrated environmental impacts from the residential sector:

- **Residential sector environmental outputs have regional and global environmental consequences** — The magnitude of environmental outputs to air, water, soils and land alterations of the residential sector are significant enough that they can be expected to contribute to broader environmental impacts including acid rain, smog, climate change, biodiversity decline, and Arctic contamination. The degree of impact is difficult to assess given the scale of the impacts and role of other sectors and activities in also contributing to the environmental impacts.

8.3 INFLUENCE OF MARKET DRIVERS

This section presents three key market drivers identified in Section 2 that currently affect and are likely to continue to affect, the operating and life-cycle non-operating environmental impacts of Canadian housing, residential infrastructure, and residential transportation distances for personal and commuting trips. Each market driver is characterised by certain market trends. These market trends would influence the environmental impacts of the residential sector during one or many stages of the residential life-cycle.

8.3.1 Description of Key Market Drivers

Resource Availability & Price

Resource availability and price includes land, energy, water, and raw materials, such as metals and wood. Energy sources and availability are key resource considerations for all economic sectors in Canada and are likely to be a major driver affecting the whole of the built environment, including the residential sector, for the study period and beyond. Energy prices are the result of many market and non-market forces, in North America and internationally. While there is great uncertainty regarding the future pattern of energy prices, it is expected that, in real terms, prices will continue to rise. Canadian and US government energy price forecasts tend to be conservative and assume a slow growth rate, with demand and supply balancing over the longer-term. For example, the 2005 Annual Energy Outlook – Reference Case, published by the U.S. Energy Information Administration (EIA), forecasts energy prices to rise slowly over the 2004-2025 period.

Other sources indicate that forecasts are diverging from this conservative position and are predicting a steady increase in energy prices above historical levels due to a gap between supply and demand. For instance, an April 2005 forecast from CIBC World Markets predicted that "over the next five years, crude prices will almost double, averaging close to $77/bb; and reaching as much as $100/bbl by 2010."[112]

Similarly for electricity, indications are that the current pace of investment is insufficient to address projected demand and anticipated plant retirement. The Canadian Electricity Association (CEA) estimates that new generation required to address both load growth and plant retirement during 2000–2020 is in the range of 40–55 GW and that the investments will cost C$150 billion at current prices. In addition, investment in North American transmission facilities is lagging behind the addition of new generation capacity.

Further, current natural gas supply is not expected to keep pace with projected demand. Production from traditional U.S. and Canadian basins has plateaued and recoverable volumes from new wells drilled in mature producing basins are declining.[113]

Urban Planning & Financing

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[112] J. Rubin. April 2005. *CIBC Occasional Report #53: Crude Prices will Almost Double Over the Next Five Years*. *Note: oil prices have experienced significant volatility since this study was completed.

[113] National Petroleum Council. July 2003. *Balancing Natural Gas Policy – Fuelling the Demands of a Growing Economy*.

Urban planning plays a key role in the availability of land and location of dwelling types within urban areas, through Municipal Official Plans and other planning tools. Urban planning for availability and access to public transport and walking and cycling routes also plays a key role in use of alternate transportation modes by consumers, although consumer preference is also an important factor (as described in the sub-section following).

Financing and economic measures in urban land development can be designed to influence the *location* of land developments. For example, lower development fees in areas targeted for intensification and measures to mitigate risk and liability in development of brownfield sites may influence decision-making by developers and consumers regarding the location of new homes.

Other aspects of urban planning and financing include:

- *Integrated planning*, where land use, building design, infrastructure design, energy flows, material flows, and other aspects are planned for together, early in the design process, rather than independently;
- *Criteria and standards* developed by governments, industry groups, independent standards bodies, or other stakeholder groups;
- *Implementation plans for urban intensification or other environmental policies*, where such urban planning policies, as aggressive as they may be when conceived, do not always result in appropriate action during implementation; and
- *Life-cycle 'triple bottom line' decision-making*, where urban planning decisions are based on life-cycle assessment of financial/economic, environmental, and social benefits and impacts.

Socio-demographics, Culture & Consumer Preferences

Demographic trends would influence the size of homes (e.g., aging populations may downsize) and the locations of homes, regionally. Over the period 2004-2025, Canada's population is expected to rise from 32 million to over 39 million (approximately 22%) and the urban share of the population is expected to increase from 80% to more than 87%. The Canadian population is expected to start stabilizing around 2050 at just fewer than 49 million people.[114] In addition, a shift to an older population is expected, with the share of Canadians over 60 years of age projected to increase from roughly 18% to 28%. By 2026, citizens over the age of 65 would account for 21% of the population, compared with 13% in 2000.[115] Canadian population growth has been largely driven by immigration and this trend is expected to continue. Immigration accounted for over half of population growth in each year from 1997 to the present and CMHC predicts that, by 2026, immigrants would account for nearly all of Canadian population growth.[116] Seven

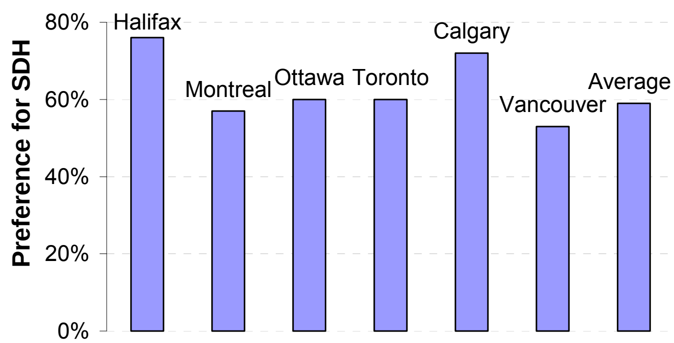
[114] United Nations. 2004. *World Population Prospects: The 2004 Revision*. Table VIII.2, p. 34. http://www.un.org/esa/population/unpop.htm

[115] Statistics Canada. March 13, 2001. *The Daily: Population Projections, 2000–2026*. http://www.statcan.ca/Daily/English/010313/d010313a.htm

out of ten immigrants settle in Toronto, Vancouver, or Montreal, with over 45 per cent in Toronto alone.

Consumer preferences regarding dwelling type, location of home relative to work, comfort, convenience, etc. are important drivers in terms of resident and neighbourhood design. In the residential sector, there is historically strong demand for ground-oriented detached dwellings. Consumer preferences for single family homes in six Canadian municipalities are summarized in Exhibit 8.1.[117]

Exhibit 8.1: Buyer Preference for Single Detached Houses (SDH)



Another important consumer expectation is that infrastructure services will continue to be both reliable and inexpensive. This expectation becomes expressed in political mandates at all levels of government and has, in part, fuelled an infrastructure deficit problem. There is little evidence so far that the public at large appreciates the increasing economic and environmental pressures and constraints that threaten the ability of governments to deliver on those expectations. Even as infrastructure problems become more obvious and acute, past experience suggests that public expectations will evolve slowly and that, over the coming decades, there will be a growing gap between expectations and capacity of municipal governments to deliver low cost services.

8.3.2 Influence of Key Market Drivers

The potential influence of the three key market drivers for the Canadian residential sector are presented in Exhibits 8.2 to 8.4, including their influence on non-operating resource use (e.g., the supply chain for housing and residential infrastructure), operating resource use (e.g., consumer preferences and lifestyle) and associated environmental outputs.

[116] Historical data from Statistics Canada. Projection from HRDC, Applied Research Branch, using demographic projection model PMEDS-D. Cited in http://www.cic.gc.ca/english/srr/pdf/res3di.pdf

[117] Canada Mortgage and Housing Corporation. 2005. *Consumer Intentions to Buy or Renovate a Home*. http://dsp-psd.pwgsc.gc.ca/Collection/CMHC/NH2/NH2-2/NH2-2-2006E.pdf

Exhibit 8.2: Example Impacts of *Resource Availability & Price* on Residential Sector

Trend	General Market Consequence	Residential Sector Impact-Non-Operating	Residential Sector Impact-Operating	Potential Residential Market Responses	Environmental Outputs
• Fossil Fuel Energy Scarcity due to global market conditions and decline in resources	• Price of materials extraction increases • Alternate energy sources become economically more attractive	• Increased cost of materials means increased cost of home supply	• Increased cost of home heating and personal transportation	• Trend to smaller, more central housing to off-set purchase price and operating price increases • Densification of neighbourhoods to off-set housing price increases in select target consumers • Trend to smaller vehicles or public transit • Energy upgrades and alternate energy sources deployed	• Decrease in GHG emissions and CAC emissions • Possible increase in impervious areas
• Land Scarcity due to urban boundary delineation	• Price of developable land increases • Pressure to develop sensitive lands within urban boundary	• Increased cost of land means increased cost of home supply	• Increased cost of home purchases	• Trend to smaller, more central housing • Densification of neighbourhoods • Increased likelihood of brownfield developments • Pressure for land development in sensitive areas and bordering sensitive areas	• Decrease in GHG emissions and CAC emissions • Possible increase in impervious area • Possible increase in development of sensitive lands • Improved soils quality in brownfields developments
• Water scarcity due to climate change	• Price of materials extraction increases as value of water is increased • Water efficient plumbing fixtures and innovative techniques in homes become economically more attractive	• Increased cost of water means increased cost of home supply • Cost of innovative water servicing approaches increases cost of housing until established in market • Innovative techniques may decrease centralized infrastructure services provided	• Increased cost of water use in homes • Increased attention to infrastructure water losses and inefficiencies by municipalities/ utilities	• Consumer demand for efficient plumbing and appliances increases • Implementation of alternate technologies for water services	• Reduced water demand

Exhibit 8.3: Example Impacts of *Urban Planning & Financing* on Residential Sector

Trend	General Market Consequence	Residential Sector Impact-Non-Operating	Residential Sector Impact-Operating	Potential Residential Market Responses	Environmental Outputs
• Municipal urban intensification plans policy and implementation	• Land scarcity (see above for resource availability)				
• Urban planning emphasis on alternative transportation modes	• Demand and awareness of alternate transportation options grows	• Long-term possibility for fewer lane kilometres of road • Use of greenspace/ parklands for paths	• Fewer single vehicle trips	• Consumers' choice of housing influenced by access to transit/ alternate modes • Value of homes in proximity to transit increases	• Fewer (or reduced rate of increase in) GHGs & CACs • Possible increase in impervious area in parklands; offset by possible reduced rate of lane kilometres installed
• Infrastructure Deficit	• Development fees increase • User fees increase • Taxes increase • Consumer satisfaction decreases	• Price of housing increases (due to development fees) • Alternate, less expensive infrastructure options proposed/ implemented	• Infrastructure conditions deteriorate • Increased cost of water use, wastewater services	• Depending on municipal policies: Possible deterioration of inner core; alternatively decreased greenfield development and increased value of core housing • Demand for water efficient fixtures • Alternate, non-conventional infrastructure options implemented	• Mixed results for air emissions and impervious surface areas depending on municipal policies; likely decrease in water use

Exhibit 8.4: Example Impacts of *Socio-demographics, Culture & Consumer Preferences* on Residential Sector

Trend	General Market Consequence	Residential Sector Impact-Non-Operating	Residential Sector Impact-Operating	Potential Residential Market Responses	Environmental Outputs
• Higher household income	• More disposable income • Higher education levels of consumer	• Increased size of homes • Demand for luxury features: larger and more windows, patios, luxury building materials (marble, specialty woods, etc.) • Trend to larger homes on standard size lots	• Increased use of resources to operate home, including energy, water, possibly chemicals (pesticides, nutrients) • Increased energy use for commute	• Higher penetration of convenience and luxury items (dishwashers, air conditioners, entertainment systems, hot tubs, pools, etc.) • Strong demand for luxury and larger vehicles	• Increased GHGs, CACs, impervious areas, releases to water •
• Population growth & increased proportion of more aged population	• Smaller households • Demand for access and services for less able-bodied population • Need for new housing for increased population base	• Decreased size of target market homes with specialized access features (e.g. few stairs) • Increased cost of housing in key areas attracting immigrant populations • Turn-over of older homes, opening up potential for renovations	• Mixed: decreased resource use by aging population downsizing homes; increased resource use in key growth areas and larger, renovated homes	• Turn-over of older homes, opening up potential for renovations • Uneven demand for housing nationally with concentration of growth in housing market in areas attracting immigrants	• Likely net increase in GHGs, CACs, impervious areas, releases to water
• Preference for single family dwellings in outer suburbs	• Markets respond to consumer demands with more product preferred and/or higher prices where demand outstrips supply	• Housing densities increase in preferred locations (including greenfields)	• Proportionately higher resource use for transportation and for home heating, water use	• Value of housing in preferred locations and styles increases	• Outer core housing results in increased outputs to air, water and soil/ land
• Preference for personal vehicle use	• Marketing and lifestyle communications assume vehicle ownership, reinforcing it as a cultural norm	• Neighbourhood design places higher emphasis on roads than on walking and alternate transportation modes	• Increased energy use, exacerbated with larger vehicle ownership	• Large variety and availability of vehicles for purchase and rental • Some alternative vehicle ownership options in larger urban centres (e.g. shared car pools)	• Increased outputs to air and water, impervious surface area increase

9. CONSIDERATIONS FOR FUTURE WORK

This section elaborates the considerations for future CMHC research and residential sector life-cycle assessments, with a particular focus on addressing the scope exclusions and data limitations noted in Section 3 and Appendix A. The section also presents a framework with which CMHC can consider building scenarios of future housing and neighbourhood development.

The base year and BAU scenario of the residential sector is the cornerstone for the analysis of environmental impacts. There are some important areas where they can be enhanced; if some of the key data limitations can be addressed it would help make the alternative scenarios more robust. We now have better insight into the overall magnitude of environmental impact and the relative contributions of the housing life-cycle stages. However, by undertaking alternative scenarios, CMHC would be able to consider the possible mitigation impacts of a range of public policy, technical and behavioural solutions.

This section is organised as follows:

- Key Data Limitations
- Key Exclusions from this Study
- Research Priorities
- Building Alternative Scenarios.

9.1 KEY DATA LIMITATIONS

The discussion of data limitations is consistent with the organisation of the overall report, using the following sub-sections:

- Dwellings & Neighbourhoods
- Operating Energy
- Operating Water
- Life-cycle Analysis
- Regional and global impacts.

9.1.1 Dwellings & Neighbourhoods

As noted, the 2004 base year estimate of the housing stock, according to type of dwelling, is a derived value in which less than optimum data sources have been used in the absence of anything better. The implication is that the environmental impact of the housing stock could be slightly under- or over-stated.

Base Year Limitations

Most significantly, the major data limitation is the reliance on a combination of the 2001 Census data and data extracted from the Informetrica Input-Output model for derivation of the dwelling stock volume and dwelling stock allocation according to type of dwelling. In all instances the 2001 data has been manipulated to bring it forward to construct the

2004 base year, using data extracted from the Informetrica Input-Output model which establishes dwelling stock as a function of household formation. The specific dimensions of these data limitations are elaborated below:

- *Derivation of the Volume of dwellings*: The 2004 base year volume of occupied dwelling units is a derived value having taken the 2001 Census data and projecting forward using the data extracted from the Informetrica Input-Output model. It is not based on actual built units, for which 2006 data is now available from the most recent census.

- *Allocation of Dwellings by Type*: The 2004 base year dwelling stock allocation is grouped into four dwelling types: i) Single Detached; ii) Row/Town houses; iii) Low-rise multi-unit residential building (MURB) units; and iv) High-rise MURB units. The allocation by dwelling types was derived using both the 2001 Census and Informetrica data. The main implication is that the division between low-rise and high-rise apartments is held constant at the 2001 provincial level (for each province as per the Census) and does not fully reflect anticipated development patterns in the key CMA growth areas.

  An additional consideration concerning the allocation of stock by dwelling type is that the quality of data available to derive a robust profile of dwelling stock in the Territories is limited. Although the Territories represent only a very small volume of the total housing stock, these limitations are significant from the standpoint of policy and programs that are region and segment specific.

- *Data to derive the base year neighbourhood archetypes*: Data used to generate the neighbourhood archetypes is based on 2001 Census tracts. Any shifts that occurred in dwelling unit mix and neighbourhood configuration during 2001–2004 have not been captured in the final depiction of the archetypes.

BAU Limitations

The BAU limitations are described below for dwellings and neighbourhoods, and for renovations and retrofits.

Dwellings & Neighbourhoods

As mentioned in Section 3.4 and Appendix A, there was no credible long-term housing stock projection available at the time of this study beyond that of the Canadian Energy Outlook (Informetrica) projections used in this study. The Informetrica model projections of household formation are driven by assumptions of economic growth but they do not adequately reflect the likely evolution of CMA growth clusters in different regions of the country and the consequent growth in construction of dwelling types consistent with the expected denser forms of development.

While this study's BAU scenario captures the high-growth CMAs' *anticipated* aggressive intensification through meeting their urban intensification commitments, there is some uncertainty of how fast and how significant intensification would *realistically* take effect over the study period. If the high-growth CMAs' intensification plans are not met in municipal implementation, actual development patterns would result in:

- Fewer new dwellings being absorbed by densified existing neighbourhoods;
- More new neighbourhoods required to house those new dwellings, many of which would be Outer Suburbs;
- More greenfield space required to build those new neighbourhoods;
- More resulting environmental impacts of land use and impermeable surfaces, such as increased stormwater run-off and ecosystem fragmentation, etc.;
- Slightly more dwelling direct and indirect operating impacts due to the relatively higher per-dwelling energy and water use of new Single Detached and Row/Town houses compared to new Low-rise and High-rise MURBs; and
- More residential transportation direct and indirect operating impacts due to the significantly higher residential transportation energy use of new Outer Suburb dwellings compared to new Inner Suburb and Inner City dwellings.

Renovations & Retrofits

The scope and pace at which renovation and retrofit of dwellings units and infrastructure take place is an important underlying dimension in understanding the evolution of the built environment under the BAU. Renovation and retrofit activities affect the demand for materials and have consequent upstream environmental implications.

However, information concerning renovation rates and the composition of typical renovations is lacking and somewhat outdated. There is a need to bring these metrics up to date and provide further elaboration of the nature of these renovation activities.

Resolution

The most immediate and productive resolution for the base year limitations is to generate a new base year using the 2006 Census data. The availability of more current housing stock data would strengthen the baseline housing profile.

The recommended resolutions for the BAU limitations include updates to:

- **Housing projections** — There is a need to consider how federal and provincial agencies can work together to ensure that the housing projections are backstopped by a robust data set that can be easily updated. The data acquisition approach needs to include a high level of dialogue with planning departments of the major CMAs to gain more insight on development patterns and trends. The housing projections should also be developed within the construct of a robust and flexible modelling platform. Given the dynamics of the housing market in Canada, influenced by several key drivers, it is very likely that ongoing projections will be needed.

- **Neighbourhood profiles** — The neighbourhood profiles developed in this study have advanced the method by which representative neighbourhood archetypes can be developed. Nevertheless, it is a relatively new and evolving field of analysis. It would be helpful to compare previous and current approaches with the view towards further refining the methods.

9.1.2 Operating Energy

The derivation of the operating energy profile for both the base year and BAU is based on three important elements: i) input data; ii) the modelling platform; and iii) the basis upon which projections are derived. Together, these three elements are designed to build a defensible energy end-use based profile of operating energy in the Canadian housing stock. The Marbek energy end-use accounting platform is robust and sufficiently "road-tested" by virtue of the ongoing utility and government studies that are underway. However, there are some important limitations with regard to data availability and quality as well as how data was used.

Limitations

There continue to be some key gaps with regard to supporting data sets for some regions of the country as well with regard to the way in which data is interpreted to arrive at defensible energy end-use profiles.

The derivation of the base year operating energy profile utilizes three categories of data sources: i) Natural Resources Canada (NRCan), both the *Energy Use Outlook* and *Comprehensive Energy Use Database* (CEUD); ii) Marbek's segment specific data inventory; and iii) other disparate sources. Fundamentally, the method used in this study is to build bottom-up, energy end-use profiles for housing that reflect important regional and dwelling stock differences. These profiles generate pictures of housing energy use patterns that are derived from an understanding of the following important data inputs, which affect both the baseline and BAU:

- Penetration of energy using equipment
- Energy performance of this equipment
- Thermal performance characteristics of the dwelling envelopes.

To effectively assemble these data inputs, the method employed uses data and learnings from province or region specific work to modify the CEUD data set which offers the platform for a national profile. The CEUD end-use data is derived from a top-down allocation of Statistics Canada data (obtained through surveys and studies).

Typically, projects undertaken at the provincial or regional levels are driven by the need for a relatively high degree of robustness because often the client is a utility company needing to prepare data and analysis for regulatory filings. Hence, the data used for these studies is often based on end-use surveys, billing based energy profiles and consultation with engineering practitioners and the design-build community who operate in specific building niches. So there is a reasonably high confidence level associated with the data and analysis from such studies.

The province and region specific study findings enabled us to adjust the CEUD data for several Canadian jurisdictions. However, it was necessary to assume that such adjustments applied to regions for which sparser empirical data was available.

Resolution

NRCan's Office of Energy Efficiency (OEE) plays a lead role in conducting energy end-use profiles of housing in Canada. To address the gaps discussed above, OEE could help to bring together federal and provincial agencies, as well as key utilities to achieve a more robust energy end-use profile of the dwelling stock in all regions of the country. The first step would be to conduct an up-to-date gap analysis with input from all three levels of government and utility.

9.1.3 Operating Water

The practice of water end-use analysis is not well advanced and lags considerably behind that of the considerable body of work focused on energy end-use profiles. With the exception of some excellent municipal studies, there are no provincial or federal profiles of water use patterns according to end-use. Having advanced the approach by which a defensible national profile can be developed, using Marbek's water end-use module, there are nevertheless some important data limitations to be addressed.

Limitations

The limitations for the operating water analysis were as follows:

- Household water usage was based on a compilation of available studies from across North America. These studies were the best available data but tended to have a bias for US jurisdictions. Where sufficient Canadian data was available on household water usage this data was used; however, in most cases this data was insufficient or unavailable.

- Regional / provincial differences in household water use, other than household type and size, were not accounted for in the model.

- The existing market penetrations of water end-use technologies (i.e., toilets, showerheads, faucets, dishwashers and cloth washers) were based on a limited Canadian dataset that likely has a significant margin of error. In some cases US market data was used to estimate penetration. Potential differences in market penetration between regions and dwelling types were also generally not accounted for in the model.

- Very limited data was available to estimate outdoor household water use, and it is likely that this parameter has a high margin of error.

- Household water use was calculated based on the number of residents in each dwelling type and was not related to the number of fixtures that are installed in each dwelling. Because the number of water end-use fixtures has been shown to have a significant impact on water use this may be a source of error.

- The future market penetration of water end-use technologies assumes that high efficiency technologies that are available today will dominate new entry into the marketplace and will replace existing equipment based on average lifetime equipment rates. However, new emerging technologies or accelerated equipment replacement programs are not considered by the model.

- The analysis assumes that the water end-use fixtures and water demand for each dwelling type will remain the same in the future. In reality, new water end-uses may emerge or their prevalence may change in the future. (e.g., people may take more showers than baths in the future, or the percentage of households with swimming pools may substantially decrease).

- The water end-use model can only estimate water use for dwelling types that are connected to municipally supplied water, and does not make estimates for dwellings that are on private well systems.

- Energy use for pumping and distribution of water and wastewater was calculated based on the energy use intensity (MJ/megalitre) of a sample municipality and may not reflect the average energy use intensity across Canada.

Resolution

Further research could be done to reduce the uncertainty regarding household water usage, from four perspectives: i) end-use intensities, ii) overall volumes, iii) addressing regional and dwelling specific variations and iv) addressing gaps with regard to outdoor use.

9.1.4 Life-cycle Analysis

Limitations

The life-cycle analysis generated key lifecycle coefficients which, in turn, formed the basis for the overall residential sector impact. The lifecycle coefficients were generated on the basis of detailed physical depictions of four residential building archetypes: single detached, row/townhouse, low-rise apartment buildings and high-rise multi-unit buildings. However, these archetype depictions are national in character, meaning that there was no provincial or regional differentiation of key physical housing construction features. Therefore, the lifecycle coefficients do not capture possibly important regional variations of construction practice and dwelling stock distributions. This is an important limitation given that, as previously noted, the BAU neighbourhood profile is driven largely by expectations of major growth in four major regional growth clusters.

The major implication of this limitation is that particular provincial/territorial intensities of resource use and resulting environmental impacts are under-represented and subsumed in the national LCA profile. For example, operating a single-family dwelling in Alberta might require more primary energy than in Quebec and would certainly generate more GHG emissions due to the fossil fuel mix of the electricity supply system in the province.

Resolution

Future analyses could include additional provincial and regional profiles of dwelling types to bring greater regional granularity to the life-cycle impacts.

9.1.5 Regional & Global Impacts

Limitations

The study outcomes provide insight to the effect of residential sector on the environment. However, there are certain data limitations that impede a full understanding of the magnitude of this impact and how it compares to the environmental effects of other sector activities such as industry and agriculture.

The data limitations start with the concept of attribution; can data support a defensible attribution of certain resource uses and pollutants to housing activities? This challenge of attribution affects virtually all aspects of environmental impact, as elaborated below:

- *Land area consumed between land and water ecosystems (in particular, wetland ecosystems)*: National level metrics tracking land use trends, such as wetland disappearance and changes in biota associated with land use, are not clearly attributed to the activities of the housing sector.

- *Waste releases to water from roads and households*: Data is available on municipal wastewater effluent quality but this is highly variable and, typically, also includes industrial and institutional sources.

- *Storm water*: Storm water is a significant contributor of pollutants to the aquatic environment, but again, the variable nature of the flows, flow quality and attribution to the residential sector are problematic.

- *Ground water*: Attribution of groundwater quality impacts to the residential sector is also problematic.

- *Local air quality*: National trends and release statistics are not necessarily indicative of local air conditions. Although the relative magnitude of releases from the residential sector can be identified on a national level, further research would be required to identify regional trends and conditions resulting from residential sector emissions.

Resolution

Even if the matter of attribution could be adequately resolved, it would be difficult to link the specific housing activities to the larger, regional and global impacts. Areas of research focus from which some better insights would emerge are:

- Fragmentation of ecosystems is not well understood in terms of "tipping points" beyond which the viability of biota in the region is lost. Ecosystem fragmentation cannot be assumed to have linear impacts.
- The portion of ecosystems required to maintain functionality and viability of biota is not known.

To address the data shortcomings relating to groundwater impact attributions, urban neighbourhoods whose drinking water is supplied by groundwater sources treat source water protection as a priority and may be a source of data for future study. These individual communities are very likely to have community-level information on ground water quality. Waterloo Ontario, for example, relies on groundwater sources for potable water and may have relevant data and studies as a case study of the effects of housing development on groundwater quality.

Research in these areas could assist municipalities in identifying protected areas and terrestrial linkages in their official plans and other land use management tools.

Further study could also be undertaken to compare the impact of the housing activity relative to the effects from other sector activities. This work would assist in prioritization for management measures by governments, similar to work done to prioritize industrial sector contributions to air pollutants and climate change.

9.2 KEY EXCLUSIONS FROM THIS STUDY

This section summarizes the key exclusions to the study scope, drawing upon observations from Section 3 and Appendix A. These exclusions to the study scope were approved by CMHC at the outset of the project.

9.2.1 Operating

This sub-section identifies key exclusions relating to the operation of the housing sector,

Exclusions

The study did not include:

- Pollutant releases to water resulting from municipal treatment and distribution of potable water, dwelling wastewater production, municipal collection and treatment of wastewater, and storm water run-off from roads; or
- Municipal solid waste from dwelling operation.

Resolution

Addressing each of the foregoing exclusions will be important to arrive at a complete picture of the residential sector environmental implications. To some degree, a resolution of these gaps starts with formulating an approach by which data at the municipal level can be effectively compiled to develop a national profile. Each of these gaps can only be addressed by ensuring a robust data set of activities and environmental impacts at the municipal level. Among these gaps it would seem that the metric of municipal solid waste production is the one that could be most easily compiled for a national inventory; at least for the major CMAs.

9.2.2 Life-cycle Analysis

This sub-section identifies key exclusions relating to the life-cycle analysis.

Exclusions

The study did not assess:

- The life-cycle effects of commercial and institutional building development and operation, as well as the infrastructure necessary to service them.
- The implications of driveways and service laneways which are an important part of the infrastructure needed to service single-detached and other low rise dwelling types.
- The maintenance and replacement of equipment and materials associated with the base year dwelling stock and stock added during the BAU period.
- End-of-life demolition, re-use, recycling, and disposal of materials used in buildings.
- The construction of centralized facilities such as wastewater treatment facilities, water purification plants and pumping stations.

Resolution

The research priorities are to address the gaps relating to: 1) the maintenance and replacement of equipment and materials associated with the base year dwelling stock; and 2) the end-of-life impacts of buildings and infrastructure. These are estimated to be significant in terms of resource use and environmental outputs (e.g., solid waste).

9.3 RESEARCH PRIORITIES

The foregoing discussion has identified many of the key data limitations and exclusions relating to the baseline and BAU profiles. The implications of these data issues, as they translate into research priorities, are presented below in section 9.3.1. In addition, we also suggest another emerging research priority that has more significant implications for consideration of future scenarios.

9.3.1 Priorities Emerging from the Study Findings

As noted, the baseline and BAU profile addresses the questions of: i) Where are we?; and ii) Where are we going? In considering the implications of data limitations and gaps, the key is to establish some sense of risk and uncertainty associated with the analysis to date. These risks and uncertainties and consequent research priorities are presented in Exhibit 9.1 using a subjective rating of high, medium and low, based simply on professional judgement.

Exhibit 9.1: Summary of Research Priorities

Category of Limitations & Gaps	Risk & Uncertainty	Research Priorities
Baseline	L-M	Update base year dwelling stock profile using the 2006 Census data.
BAU Scenario	M	Use revised dwelling stock projections based on an updated analysis of urban development patterns, particularly in high-growth CMAs.
LCA	H	Add regional variation in life-cycle analysis.
LCA	L	Add the life-cycle analysis of dwelling operating solid waste production.
LCA	L	Add the life-cycle analysis of renovation and maintenance and replacement of equipment and materials of the existing stock.
LCA	L	Add the life-cycle analysis of end-of-life activities (e.g., demolition and disposal) for the existing stock.
LCA	L	Add the life-cycle analysis of centralized infrastructure.
Environmental Impacts	M-H	Further analysis to gain better granularity on the attribution of environmental effects to the activities of the residential sector.
		Further analysis to build a national profile of stormwater emissions. A similar effort in the U.S. helped to foster key changes to the Storm Water Act.

9.3.2 Other Research Priorities

The discussion of research priorities should necessarily also consider critical gaps that affect fully capturing the value of alternative scenarios, which is the topic of the next sub-section. One critical gap concerns the data and related analysis needed to establish a proper and full valuation of the benefits of pursuing certain so-called sustainability pathways. Historically, cost-benefit analyses have focused on the savings stream associated with reduced operating costs. What has been more challenging is to capture the value of avoided costs to human health and to the environment associated with different mitigation solutions.

Certainly at the federal level there is a growing body of work and resulting database of evidence from which such valuations can be derived. Several federal agencies such as Health Canada, Environment Canada, Natural Resources Canada and the Department of National Defence (DND) have commissioned work in this area.[118]

[118] For example, see: a) Environment Canada. Sawyer, Dave. 2002. *Investigating the Co-Benefits of Greenhouse Gas Mitigation in Canada: Avoiding the Control of Criteria Air Contaminates*.
b) Marbek Resource Consultants for Natural Resources Canada Office of Energy Efficiency. 2006. *Framework for Quantifying Non-Energy Benefits of Industrial Energy Efficiency Projects*.
c) Department of National Defence. Kujawski, Woytek. *Environmental Damage Index Estimation Tool for DND Vehicle Fleet*.

9.4 BUILDING ALTERNATIVE SCENARIOS

This sub-section presents a framework with which CMHC and other decision-makers can consider building scenarios of future housing and neighbourhood development that align to sustainability pathways. To establish some context for the discussion, we start with a definition of scenario, drawn from the numerous definitions of scenario available on the web. Then we consider two main approaches to scenario building and, finally consider scenario ideas that build from the study findings.

9.4.1 Definition of 'Scenarios'

A scenario is a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g., technology changes, energy prices). *A scenario is neither a prediction nor a forecast. Scenario planning is not about predicting the future; it is about exploring the future*. Consider the distinctions among the following concepts:[119]

- **Prediction:** It will be 30 degrees tomorrow; we will go the beach.
- **Business as usual:** Normal weather patterns indicate that it will be 30 degrees tomorrow; our usual practice is to go to the beach.
- **Scenario:** If it is 30 degrees tomorrow; we may go to the beach, if transportation is available.

For the purposes of this discussion we organize scenarios into two categories:

- To explore how something will play out, be it a new public policy measure or the market entry of a new and innovative technology.
- To explore how a target of some nature can be met; that is to characterize the roadmap to get to a target, sometimes referred to as "back-casting".

Both of these two approaches to scenario-building could be considered by CMHC, as further elaborated in the following sub-section.

9.4.2 Scoping Scenario Options

In consideration of a framework for carrying out future scenarios, there are two key assumptions to consider:

- CMHC could consider exploring various alternative pathways or scenarios toward sustainability, relative to what has been profiled as the baseline and BAU situation, keeping in mind that sustainability can be defined in many different ways.
- CMHC could consider exploring the larger opportunities to reduce environmental impacts, which were highlighted by this study. These opportunities can be summarized as follows:

[119] Natural Resources Canada. 2006. *Canada's Energy Outlook: The Reference Case 2006*. http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php

- *Control* urban low-density development: The outer suburb neighbourhood type has the most significant impact, from an environmental perspective.
- *Affect choices on dwelling type*: The single detached house is the most destructive, from an environmental perspective.
- *Affect how dwellings are operated*: The operating stage (direct and indirect) of the housing life-cycle is the most destructive, from an environmental perspective.

In any event, the scenario options can be scoped within the following boundaries.

9.4.3 Exploring the Impact of Policy Instruments

CMHC could examine the most appropriate package of policy instruments as candidates for building scenarios, presumably within the purview of what the agency can either influence directly or indirectly. This can be done in one of three ways:

- Conceptualize a policy paradigm and then assess the impacts of one or more policy instruments to advance the residential sector on a course towards that paradigm;
- Conceptualize a target or desired outcome and then assess the impacts of one or more policy instruments to achieve that result; or
- Simply test the effect of implementing one or more policy instruments. We briefly discuss some options for the first two of these approaches, influenced by the findings of the study.

Below are some illustrative policy instrument options that represent the full spectrum of choices ranging from legislative regulatory-based instruments to largely market-oriented instruments:

Command & Control-Regulations

- This refers to compulsory performance or prescriptive standards designed to establish a "floor" level of performance in the marketplace. A mandatory standard is enforceable with penalties for non-compliance. Setting mandatory, enforceable urban growth boundaries would fall in this category.

Market Oriented Regulations

- This category embodies a broad range of Tools which can act as either incentives or disincentives to market participants, depending on the ultimate goals of the measure. The category includes:
  - Emissions cap and trade regimes, in which participation is compulsory but the measure allows participants to determine how they will meet the regulatory targets.
  - The design of energy and water tariffs to ensure that consumers receive the appropriate level and timing of price signals

Voluntary Standards

- This refers to performance or prescriptive standards that are promoted, supported and adopted on a voluntary basis. The idea is that market innovators will take the lead on these voluntary standards thereby fostering an eventual transition to widespread adoption.

Marginal Cost Pricing & Rate Design

- This refers to transformation from a monopoly average cost pricing regime for electricity and water to a regime that embodies marginal cost pricing. In practice, a marginal cost policy instrument could be manifested in a number of ways, including some form of time-of-use pricing measured and reported on a real time basis.

Financial Disincentives

- Charges (taxes) on emissions or water and energy use; or on certain forms of development. They do not specify a particular action; the business or consumer chooses between taking no action to reduce emissions or energy use, or reducing energy and/or emissions in order to pay less charge.

Financial Incentives

- Subsidies that are designed to reduce the cost of the “sustainability” investment and thereby, improve the “business case” for the investment.

Capacity Building

- This refers to all types of training for both the consumers and the service providers.

Market Transformation

- This is a catch-all category for a range of information type initiatives designed to build a foundation in the market for transitions to sales and purchase of high performance equipment and systems as the norm, rather than the exception. This category includes: training, broadly (e.g., advertising) and narrowly (e.g., point of sale) targeted information, voluntary performance standards (e.g., Energy Star).

Research & Development (R&D)

- R&D of Core Technologies: This refers to the full science and technology cycle to deploy key technologies necessary to meet the targets.
- R&D of Enabling Technologies and Commercialization Assistance: This refers to the tools, techniques and other support needed to accelerate the successful market adoption of the full range of solutions.

Policy Paradigms to Consider

Advanced Urban Intensification Paradigm

As noted in section 3, the BAU profile assumes some degree of penetration in Canadian municipalities of application of the urban intensification planning paradigm, with an outcome manifested in terms of less suburban low-density development and greater densification of neighbourhoods. It would be worth considering scenarios to accelerate and expand the influence of this paradigm — a much-enhanced intensification scenario.

The Canadian Urban Institute has identified six categories of actions to operationalize "Smart Growth": [120]

- Promoting cities as engines of the economy;
- Containing urban low-density development;
- Providing transportation alternatives;
- Providing housing choice;
- Protecting natural areas and cultural heritage;
- Creating community.

In this vein it is possible to consider variations on the theme that would speak to a sustainability pathway. This might include considerations of how the new urbanism movement can help advance sustainability goals.

Great Transition Paradigm

In 2002, the Stockholm Institute published a seminal document entitled *Great Transition* which looked to a future paradigm of environmental, social and economic progress transcending other less sweeping paradigms. The Great Transition paradigm offers useful insights to how collaborative dialogues could be initiated with the view of establishing either end-state goals or practical pathways with which progress can be made. The *Great Transition* approach to a sustainable civilization builds on two other paradigms: the wealth-generating features of *Market Forces* and the technological change of *Policy Reform*. However, "it transcends them by recognizing that market-led adaptations and government-led policy adjustments are not enough. *Great Transition* adds a third ingredient — a values-led shift toward an alternative global vision. Powerful additional opportunities for mending the global environment and forging more harmonious social conditions would then open."[121]

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[120] Canadian Urban Institute. March 2001. *Smart Growth in Canada*. http://www.canurb.com/media/pdf/SmartGrowthinCanada2.pdf

[121] Stockholm Environmental Institute and the Global Scenario Group. 2002. *Great Transition*. http://www.gsg.org/gsgpub.html#GT

Conceptualizing a Target or Desired Outcome

This approach lends itself to a consultative or collaborative exercise in which major stakeholders come together to characterize an end-state at a certain future milestone year that shows evidence of moving towards sustainability. We present an example to illustrate this approach:

- *American Institute of Architects (AIA) and Royal Architectural Institute of Canada (RAIC) 2030 Challenge*: This is an end-state target established to address the global issue of climate change. The AIA and RAIC have set the goal of a carbon neutral end-state for newly constructed buildings in 2030 which includes substantial carbon reductions in existing buildings. The target would be met by a combination of energy performance improvements in buildings and the supply of zero carbon energy to address any remaining demand.

9.4.4 Exploring the Impact of Technical Solutions

Underlying many of the policy solutions would be the opportunity to affect the market implementation of one or more technical solutions. Given where the major areas of focus have been identified, it is possible to identify a candidate list of technical solutions to be assessed in future scenarios:

- Air-shed and watershed management approaches
- Aggressive demand management to improve end-use efficiencies — This could explore options such as: 1) sustainable urban integrated energy solutions (BedZed[122]); 2) sustainable communities (Dockside Green[123]); 3) better end-use technologies (e.g., dual flush toilets, integration of more efficient dwellings); and 4) alternative transportation systems.
- Different materials and construction practices including re-use and recycling of materials.

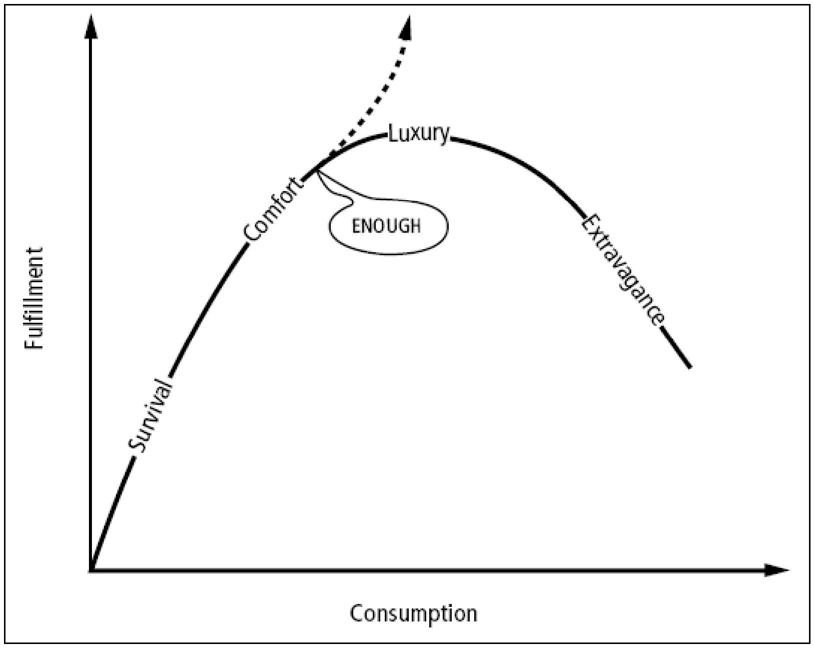
9.4.5 Exploring the Impact of Behavioural Solutions

Underlying many of the policy solutions would also be the opportunity to affect change in behaviour that, in turn, would have the effect of reducing demand for energy and water services. Exhibit 9.2 depicts the challenge in the sense that at some point the developed world needs to reconsider expectations of what is a desired quality of life.

[122] Peabody Trust. Accessed in August 2007. *Beddington Zero Energy Development (BedZED).* http://www.peabody.org.uk/pages/GetPage.aspx?id=179

[123] Windmill Development Group & Vancity. Accessed in August 2007. *Dockside Green development*. http://www.docksidegreen.com

Exhibit 9.2: Illustrative Balance of Fulfillment vs. Consumption[124]



Based on Dominguez and Robin (1992).

There is a balance point between personal fulfilment and consumption that hopefully can change so that the point on the X-axis continues to move to the left. In more contemporary terms, the use of the "Conservation Culture" by the Ontario Power Authority reflects this type of thinking.

Ultimately it is about consumer choices affecting the environmental footprint. When we consider the study findings, the scenario options to consider include investigation of change in behaviour that would result in:

- Lowering "service" expectations (e.g., the temperature in the dwelling)
- Accepting smaller living spaces
- Living closer to places of work (or working at home)
- Shopping locally and buying locally produced foods
- Choosing different materials with which to construct homes.

124 Stockholm Environmental Institute and the Global Scenario Group. 2002. *Great Transition*. http://www.gsg.org/gsgpub.html#GT

GLOSSARY OF TERMS

Apartment

A dwelling type that includes units in apartment blocks or apartment hotels; flats in duplexes or triplexes (i.e. where the division between dwelling units is horizontal); suites in structurally converted houses; living quarters located above or in the rear of stores, restaurants, garages or other business premises; janitors' quarters in schools, churches, warehouses, etc.; and private quarters for employees in hospitals or other types of institutions.

BAU (Business-As-Usual) scenario

A scenario where assumptions are made about continued trends in the way a system operates.

CAC (Criteria Air Contaminant)

Air emissions that result in the degradation of air quality. The CAC gases include carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter, and non-methane volatile organic compounds (VOCs). Impacts of CAC include smog, acid rain, and respiratory problems.

CMA (Census Metropolitan Area)

A metropolitan area of one or more adjacent municipalities centred on a large urban area (known as the urban core), where the CMA has a total population of at least 100,000, at least 50,000 of which live in the urban core.[125]

CMHC (Canada Mortgage and Housing Corporation)

A Canadian crown corporation that is Canada's national housing agency, responsible for creating innovative solutions to today's housing challenges and anticipating tomorrow's needs.[126]

CO_2e (Carbon dioxide-equivalent)

A metric measure used to compare the emissions from various greenhouse gases (see GHG) based upon their global warming potential (GWP); the GWP of a gas is a multiplier that reflects the relative impact on global warming of a tonne of the gas, relative to a tonne of carbon dioxide. Greenhouse gases are usually stated in the larger units of kilotonnes or megatonnes of CO_2e per year (ktCO_2e/yr or MtCO_2e/yr).

Condo (Condominium)

A type of joint ownership of real property, in which portions of the property are commonly owned (e.g., lobby, corridors, storage space, etc.) and other portions are individually owned (e.g., the dwellings themselves).

CWS (Canada-Wide Standard)

A set of national air emission benchmarks set by the Canadian Council of Ministers of the Environment (CCME).[127]

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[125] Statistics Canada. Last modified June 7, 2007. *Census Dictionary — Census metropolitan area (CMA) and census agglomeration (CA)*. http://www12.statcan.ca/english/census06/reference/dictionary/geo009.cfm

[126] Canada Mortgage and Housing Corporation. http://www.cmhc-schl.gc.ca/

Dwelling

A structurally separate set of living premises with a private entrance from outside the building or from a common hallway or stairway inside. A private dwelling is one in which one person, a family or other small group of individuals may reside, such as a single house, apartment, etc.

End-use

Any specific activity that requires energy or water (e.g., refrigeration, space heating, water heating, shower, toilet, etc.).

Environmental impacts of the residential sector

The resource use, environmental outputs (i.e., air, water, and soil emissions/pollutants), and resulting environmental impacts (e.g., smog, watershed impacts, biodiversity decline, climate change) that result from the construction and operation of residential structures (e.g., buildings, road and water infrastructure) and activities (e.g., residential transportation, energy conversion and distribution).

EUI (End-Use Intensity)

The amount of a commodity (e.g., energy, water) used for an end use (e.g., water heating, appliances, lighting, toilets, etc.) per unit of a defined parameter, such as building area. In the context of buildings, energy EUI is usually expressed as gigajoules per square metre of building (GJ/m^2) or kilowatt-hours per square metre of building (kWh/m^2) and water EUI is expressed as cubic metres of water use per square metre of building (m^3/m^2).

GHG (Greenhouse Gas)

A greenhouse gas absorbs and radiates heat in the lower atmosphere that otherwise would be lost in space. The greenhouse effect is essential for life on this planet, since it keeps average global temperatures high enough to support plant and animal growth. The main GHGs are carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), and nitrous oxide (N_20), but also water vapour (H_2O) is also a GHG. By far, the most abundant GHG is CO_2.

GJ (Gigajoule)

1×10^9 joules; a unit of measure for energy

GWh (Gigawatt-hour)

1×10^9 watt-hours; a unit of measure for energy

Regional growth cluster (CMA growth cluster)

A regional collection of census metropolitan areas (see CMA) that have high population growth compared to the rest of a country. Canada's four regional growth clusters are: 1) British Columbia's lower mainland (including the Greater Vancouver Regional District, GVRD) and Southern Vancouver Island; 2) the Edmonton–Calgary corridor; 3) Southern Ontario's 'Golden Horseshoe' of densely populated cities near the west end of Lake Ontario, including the Greater Toronto Area; and 4) the Montreal region. These four

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[127] Canadian Council of Ministers of the Environment (CCME). *Canada-Wide Standards*. http://www.ccme.ca/ourwork/environment.html?category_id=108

growth clusters grew by 7.6% in population between 1996 and 2001, compared to only 0.5% in the rest of the country a trend that is expected to continue.[128]

Heat island
A dome of warm and polluted air that covers an urban area and in which the temperature is higher than in surrounding areas.

ha (Hectare)
10,000 m^2; 1 km^2 = 100 ha

Household size
The number of people per household.

Housing stock
The physical number of dwellings.

Incandescent light bulb
A glass globe containing electrodes within a vacuum, which produces electric light. More commonly called an ordinary light bulb.

Kilowatt-hour (kWh)
1,000 watt-hours; a unit of measure for (electrical) energy. A kilowatt-hour can best be visualized as the amount of electricity consumed by ten 100-watt bulbs burning for an hour. Also, 1 kWh = 3.6 MJ (million joules).

m^2 (Square metre)
A unit of measure for area

m^3 (Cubic metre)
A unit of measure for volume

MJ (Megajoule)
1 x 10^6 joules or 1,000,000 joules; a unit of measure for energy

Mt (Megatonne)
1 x 10^6 (metric) tonnes; a unit of measure for weight

MURB (Multi-Unit Residential Building)
A low-rise or high-rise apartment or condominium building (see definitions) where dwellings share some common spaces, such as a lobbies, hallways, elevators, parking, etc.

Neighbourhood (residential)
An area of urban development consisting of mostly dwellings and residential infrastructure along with limited commercial and institutional buildings and properties

[128] David Suzuki Foundation. *Understanding Sprawl: A Citizen's Guide*. http://www.davidsuzuki.org/files/Climate/Ontario/Understanding_Sprawl.pdf

(e.g., offices, retail, schools, hospitals, etc.). Usually defined by area, this study arbitrarily defines a neighbourhood as covering 50 hectares.

Neighbourhood infrastructure (residential)

The roads, underground waterworks (i.e., water supply, wastewater, and stormwater), and energy distribution systems (e.g., natural gas pipes, power lines) built in a neighbourhood to service dwellings and any commercial and institutional buildings and activities.

Non-CMA

A metropolitan area that is not large enough to be considered a census metropolitan area (CMA); see CMA.

NRCan (Natural Resources Canada)

A Canadian government department responsible for protecting Canada's natural resources, such as mineral, metal, forest, and energy resources.

PJ (Petajoule)

1×10^{15} joules. A joule is the international unit of measure for energy the energy produced by the power of one watt flowing for a second. There are 3.6 million joules in one kilowatt-hour (see Kilowatt-hour).

Primary energy use

Represents the total requirement for all uses of energy, including energy used by the final consumer (see Secondary energy use), non-energy uses, intermediate uses of energy, energy in transforming one energy form to another (e.g. coal to electricity), and energy used by suppliers in providing energy to the market (e.g. pipeline fuel).

Projection

An expectation of something in the future (e.g., 100 people are expected to attend the event)

Scenario

A set of assumptions that allow exploring results, behaviours, etc. (e.g., if 100 people to attend the event, …)

Single detached house/dwelling

A house containing one dwelling unit and completely separated on all sides from any other building or structure, aside from a private garage. This type of dwelling is commonly called a single house.

Tl (Teralitre)

1×10^{12} litres or 1×10^{9} m^3 or 1 km^3; a unit of measure for volume

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APPENDIX A

DETAILED METHODOLOGY

APPENDIX A: DETAILED METHODOLOGY

Section 3.3 of this report provided the scope of this study and summarised the data sources, models, and methodologies used to assess the Canadian residential sector's environmental impacts during the study period of 2004–2025. This appendix provides a much more detailed description of the data sources, models, and methodologies used.

This appendix is organized as follows:

A.1 METHODOLOGY FOR DWELLING STOCK PROFILE

The dwelling stock profile considers the Canadian distribution of dwellings by number and type. The profile captures the 2004 baseline and a business-as-usual (BAU) scenario to 2025. The key aspects of the method and data sources are discussed below.

A.1.1 Methodology, Assumptions & Data Sources

Dwelling Type Selection

For this study, the Canadian housing stock has been grouped into four dwelling types:

- *Single Detached*, consisting of single detached houses and mobile homes
- *Row/Town*, consisting of row houses, townhouses, semi-detached houses, and duplexes
- *Low-rise MURB*, consisting of apartments and condominium units in multi-unit residential buildings (MURBs) with less then 5 storeys
- *High-rise MURB*, consisting of apartments and condominium units in multi-unit residential buildings (MURBs) with 5 storeys or more

Mobile homes were grouped with single detached houses because of their small number and because their operating energy end-uses are more similar to single detached houses than to the other dwelling types in this study.

Geographic Boundaries

The dwelling stock profile was generated at the national level by aggregating data for the following regions of Canada: the Territories (YK, NT, and NU), British Columbia (BC), Alberta (AB), Saskatchewan (SK), Manitoba (MB), Ontario (ON), Quebec (QC), and the Atlantic provinces (NB, NS, PE, and NL).

There was no dwelling stock projection by dwelling type for the Territories – only aggregate data on the total number of dwellings. Therefore, the allocation by dwelling type was taken from the 2001 Census: 68.5% Single Detached, 17% Row/Town, 13% Low-rise MURB, and 1.5% High-rise MURB. Again, due to lack of further reliable data over the study period, this allocation was frozen over the full study period.

Data Sources

Since the 2006 Canadian Census results had not yet been released as of this study, the following two main data sources were used to profile the Canadian dwelling stock:

- **Statistics Canada (StatCan) 2001 Census data**, both direct from StatCan and processed data from CMHC. This data is used for the base year (2004) allocation of dwelling stock by dwelling type.

- **Natural Resource Canada (NRCan) Canadian Energy Outlook (CEO) 2006 database**.[129] The database is housed in the NRCan's *Maple C* energy model, which is, in turn, derived from modelling undertaken by **Informetrica**, using their *Input-Output* model.[130] The NRCan Maple C database contains dwelling stock values modelled for 1980–2020. The Informetrica-derived dwelling stock profile for 1980 to 2004 has been calibrated to historical data from Statistics Canada. Although there were known limitations with this data (discussed in the following sub-section), this was the best available source for dwelling stock projections. The 2006 Canadian Census results had not yet been released and other pending dwelling stock projections had not yet been released.

Allocation & Projection by Dwelling Type

Most significantly, the major data limitation is the reliance on a combination of the 2001 Census data and data extracted from the Informetrica Input-Output model for derivation of the dwelling stock volume and dwelling stock allocation according to type of dwelling. In all instances the 2001 data has been manipulated to bring it forward to construct the 2004 base year, using data extracted from the Informetrica Input-Output model which establishes dwelling stock as a function of household formation.

The dwelling stock projections used did not have sufficient resolution by the dwelling types used in this study. Hence, the data needed to be appropriately broken down into

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[129] Natural Resources Canada. 2006. *Canada's Energy Outlook: The Reference Case 2006*. http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php

[130] Informetrica. http://www.informetrica.com/

Single Detached, Row/Town, Low-rise MURB, and High-rise MURB. This derivation included the following:

- The dwelling stock data reveals that there are, in fact, five categories of dwelling type, including mobile homes. However, we chose to roll mobile homes into the single detached segment as they account for less than 2% of the occupied stock and their energy use profile (but not resource use) is more similar to singles than multiples.

- Distributed the NRCan CEO 2001 "multiples" occupied dwelling type into three housing segments (Row/Town, Low-rise MURB, and High-rise MURB) according to the percentage allocation of these dwelling types as profiled by CMHC from census data.[131]

- For each subsequent year, the total for each dwelling type was calculated using the following formula:

$$MultStock_{i,j} = MultStock_{i,j-1} + MultCompletions_j \times \frac{MultStarts_{i,j}}{\sum_i MultStarts_{i,j}} - MultDemolitions_j \times \frac{MultStock_{i,j-1}}{\sum_i MultStock_{i,j-1}}$$

  where *i* is the dwelling type and *j* is the year.

- The NRCan CEO data provided only a breakdown between 'Row' and 'Apartment', so further derivation of Low-rise MURB and High-rise MURB was necessary. Without further reliable, published data, the relative share of Low-rise MURB versus High-rise MURB was drawn from the 2001 Canadian Census, per province, and held constant throughout the study period. This value enters into the above calculation in determining the percentage of multiple starts by dwelling type. These shares of Low-rise and High-rise MURBs by province are summarised in Exhibit A.1.

Exhibit A.1: Share of Low-rise & High-rise Apartment/Condo Units per Province, from 2001 Census

Dwelling Type	BC	AB	SK	MB	ON	QC	NB	NS	PE	NL
Low-rise MURB	75%	75%	81%	60%	37%	87%	91%	79%	99%	92%
High-rise MURB	25%	25%	19%	40%	63%	13%	9%	21%	1%	8%

A.1.2 Data Limitations

Allocation & Projection by Dwelling Type

As noted, the 2004 base year estimate of the housing stock, according to type of dwelling, is a derived value in which less than optimum data sources have been used in the absence of anything better. At the present time, there are simply no credible long-term housing stock projection sources beyond that of the Canadian Energy Outlook (CEO) projections used in this study. The Informetrica model projections of household formation are driven

[131] CMHC. 2005. Canadian Housing Observer 2005, Table 13: *Occupied Housing Stock by Structure Type and Tenure, 1991–2001* (dwelling units). http://www.cmhc-schl.gc.ca/en/corp/about/cahoob/data/data_007.cfm

by assumptions of economic growth but they do not adequately reflect the likely evolution of Census Metropolitan Area (CMA) growth clusters in different regions of the country and the consequent growth in construction of dwelling types consistent with the expected denser forms of development. The implication is that the environmental impact of the housing stock could be slightly under- or over-stated.

In particular, the CEO data has known limitations in its projection of the single detached house dwelling stock versus MURBs. As mentioned further under Methodology for Neighbourhoods, discussions with officials from the four regional growth clusters in Canada (i.e., where the majority of all new housing during the study period would be built) revealed that low-rise and high-rise MURBs are expected to grow at a faster rate than single detached houses, to accommodate the densification of existing neighbourhoods over the study period. The CEO data appears to over-estimate the number of projected single detached houses relative to other dwelling types by basing the projections on historical trends rather than emerging trends in the regional growth clusters. This data limitation is recognized and noted, but could not be rectified during this study. Therefore, the dwelling stock projections used in this study are based on the best available data at the time of the study — the CEO projection. The implications are that the housing market is likely skewed in the direction of single detached dwellings (the most operationally energy intense dwelling unit) and skewed away from low-rise and high-rise MURBs.

Projection past 2020

The CEO provides dwelling stock growth only to 2020. To generate the BAU scenario to 2025, the average growth rate by dwelling type was derived for 2004–2020 and applied for the additional five-year period during 2020–2025. Again, this was done because of lack of reliable published data at the time of this study.

Regional Limitations

The quality of data available to derive a robust profile of dwelling stock in the Territories is limited. Although the Territories represent only a very small volume of the total housing stock, these limitations are significant from the standpoint of policy and programs that are region- and segment-specific.

A.2 METHODOLOGY FOR NEIGHBOURHOODS

This sub-section describes how neighbourhoods are profiled in this study such that neighbourhoods across Canada can be depicted and assessed for impacts.

While the construction and operation of dwellings are key determinants of residential sector environmental effects, it is only at the neighbourhood level that one can begin to see the broader environmental impacts of residential development. Within the scope of this study, the impacts of neighbourhoods are considered from two perspectives:

- *Insight on the implications of large-scale development on regional ecosystem health, including consideration of habitat reduction and ecosystem fragmentation.* The neighbourhood profile generates values for land consumption (in terms of quantity and type); the amount of green space and impervious surface areas; infrastructure requirements (road, piping, etc.) and storm-water runoff quality and quantity. These measures are important inputs to the discussion of the broader, cumulative impacts perspective elaborated in Section 7 of this report.

- *The type and extent of infrastructure upon which residents depend for essential services.* The neighbourhood profile generates values for average road lengths and widths and number of connections for water distribution infrastructure from which the life-cycle analysis is undertaken. The profile also generates values for personal vehicle or transit use which are intermediate outputs for the operating energy and life-cycle assessments.

Exhibit A.2 summarises how neighbourhood archetypes are used in the study to characterize different aspects of Canadian neighbourhoods and how they are used in the operating and life-cycle analyses and the discussion of resulting environmental impacts.

This sub-section first describes the general concept of an *archetype*, and the environmental effects to be considered at a neighbourhood level. It then details how neighbourhood archetypes were selected, and how Census data was collected to numerically define each archetype.

The subsequent sub-section A.3, describes the methodology for determining the required neighbourhood infrastructure, by neighbourhood type.

Exhibit A.2: Summary of How Neighbourhood Characteristics are Used in this Study

Category	**Measure**	**Analysis**		
		Bottom-up Analysis of Operating	**Bottom-up Analysis of Non-operating**	**Top-down Analysis of Resulting Environmental Impacts**
General	Dwelling stock by dwelling type and neighbourhood type	Used		
	Mix of residential and non-residential			Used
	Population & dwelling densities		Used	
Land Use	Road pattern		Used	
	% development occurring on greenfield sites (vs. grey/brownfield)		Used	
	Land area converted for greenfield development			Used
	% converted land types per neighbourhood (derivative of previous two)		Used	
	Green space per neighbourhood		Used	
Infrastructure	Road surface area (& sidewalk where appropriate)		Used	
	Water supply piping		Used	
	Sewer system piping		Used	
Storm-water	Permeability or % imperviousness per neighbourhood (Hard surfacing including roads, sidewalks, surface parking, and roofs)			Used
Transportation	Proximity to core			Used
	Vehicle kilometres travelled (VKT)	Used		

A.2.1 Methodology, Assumptions & Data Sources

Neighbourhood Types

Three neighbourhood types were used to characterize existing and new neighbourhoods in Canada:

- **Inner City** — This neighbourhood type is representative of the downtown area of major Canadian cities, containing high density development, mixed commercial and residential use, a majority of dwelling units in low or high rise apartment buildings, and a rectangular grid of small blocks with limited green space.
- **Inner Suburb** — This neighbourhood type is representative of the ring of older suburban development surrounding the downtown core of major cities, the central area of smaller centres, and newer suburban development based on "neo-traditional" or "new urbanist" planning principles. The inner suburb is characterized by medium density development with a commercial main street providing neighbourhood services, a relatively even split between detached/semi-detached/row house development and MURBs, longer rectilinear blocks and more generous parkland.
- **Outer Suburb** — This neighbourhood type is representative of suburban or rural areas with low density development, segregated commercial or institutional uses, a majority of units as detached houses, curvilinear street patterns, larger lot sizes, and generous parkland within or surrounding residential development.

Neighbourhood Archetypes for 2004

These neighbourhood types are further elaborated as "archetypes" of the Canadian dwelling stock. *Neighbourhood archetypes* are physical depictions that are assumed to be representative of the predominant neighbourhood types in Canada. In this study, neighbourhood archetype characterizations were developed for both the study base year (2004) and the end of the study period (2025).

The method for deriving the neighbourhood archetypes takes into account the following requirements:

- Represents current neighbourhood characteristics and patterns where most people live;
- Provides a defensible allocation of dwellings types among neighbourhood types; and
- Characterizes the physical aspects of neighbourhoods that affect the environment.

This sub-section elaborates how the first two of these requirements are addressed and the supporting data used to build the archetypes. The subsequent sub-section, Section A.3, describes the methodology used in addressing the third requirement above.

Representing Neighbourhood Characteristics & Patterns Where Most People Live

A *Census Metropolitan Area (CMA)* is defined by Statistics Canada as a metropolitan area of one or more adjacent municipalities centred on a large urban area (known as the urban core), where the CMA has a total population of at least

100,000, at least 50,000 of which live in the urban core.[132] Statistically there is a wide division among the current and anticipated future land use patterns of large CMAs and smaller centres or non-CMAs, as well as among the different regions of the country. We know that the majority of Canadians live in urban areas, in a small number of heavily populated metropolitan areas and in other urban centres.

Urbanized area in Canada has increased proportionally higher than population growth, a 96% increase over a 30-year interval, compared with a 42% increase in population.[133] It has been estimated that, by 2030, nearly 90% of the population will be categorized as urban.[134] Canadian urban land use in 2001 was estimated at 30,000 square kilometres.[135]

In 2001, more than 50% of Canadians lived in four large urban regions: British Columbia's lower mainland (including the Greater Vancouver Regional District, GVRD) and Southern Vancouver Island, the Edmonton–Calgary corridor, Ontario's 'Golden Horseshoe' region (including the Greater Toronto Area, GTA), and the Montreal region.[136] Canadian residential growth between 1996 and 2001 was 7.6% in these four regions compared to only 0.5% in the rest of the country, a trend that is expected to continue. This trend is expected to continue, with the vast majority of new Canadian dwellings in 2004–2025 expected to be built in these four urban growth clusters.

To develop profiles of three neighbourhood archetypes, 2001 census data was analysed for three large CMAs and three smaller centres from different regions of the country, elaborated as follows:

- **High-Growth CMAs** — The Toronto, Vancouver and Calgary CMAs were selected to represent the three fastest growing regions of the country with the largest impact on future growth. The choice of these three urban areas provided regional variation and included a broad spectrum of urban form ranging from the very dense Vancouver to the more low-density Calgary, with Toronto as a middle ground between these two extremes. A preliminary analysis of Montreal, which represents Canada's fourth fastest growing region, showed that this CMA has urban characteristics between that of Vancouver and Toronto and was, therefore, adequately captured in the analysis of these other cities.

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132 Statistics Canada. Last modified June 7, 2007. *Census Dictionary — Census metropolitan area (CMA) and census agglomeration (CA)*. http://www12.statcan.ca/english/census06/reference/dictionary/geo009.cfm

133 Statistics Canada. *Catalogue No. 21-006 XIE — Rural and Small Town Canada Analysis Bulletin*. http://www.statcan.ca/bsolc/english/bsolc?catno=21-006-X&CHROPG=1

134 United Nations, Department of Economic and Social Affairs, Population Division. 2006. *World Population Prospects: The 2006 Revision*. http://www.un.org/esa/population/publications/wpp2006/wpp2006.htm

135 Statistics Canada. *Catalogue No. 21-006 XIE — Rural and Small Town Canada Analysis Bulletin*. http://www.statcan.ca/bsolc/english/bsolc?catno=21-006-X&CHROPG=1

136 David Suzuki Foundation. *Understanding Sprawl: A Citizen's Guide*. http://www.davidsuzuki.org/files/Climate/Ontario/Understanding_Sprawl.pdf

- **Non-CMAs** — Nanaimo, Pembroke, and Fredericton were selected to represent smaller Canadian cities and towns of different size and regions. A review of the data collected for these three centres showed very consistent densities and mix of dwelling types which indicated that regional and size variations were not significant factors for Canada's smaller cities and towns.

Providing a Defensible Allocation of Dwellings Types among Neighbourhood Types

Data from each of the cities noted above was analyzed by Census tract and then allocated to the three neighbourhood archetypes based on *density* and *form* of residential development. Urban density and form characteristics were first examined and summarized for each of the major CMAs from which weighted average characteristics were derived for each neighbourhood archetype. Then a weighted average of the CMA and non-CMA averages was derived to generate the final specification of characteristics for each neighbourhood archetype.

Further elaboration is provided below:

- *Neighbourhood densities*: The range of densities that occur in each city was reviewed and the gross density limits for each of the three neighbourhood archetypes were determined by selecting limits that resulted in the city form corresponding to the archetypes. This resulted in the following specifications:

    - Inner City: over 25 dwelling units per hectare (du/ha) gross density
    - Inner Suburb: 12.5–25 du/ha
    - Outer Suburb: less than 12.5 du/ha

- It is important to note that the indicator being used in the study is *gross density*, with the unit of measurement being dwelling units per hectare (du/ha). *Gross density* is the number of dwellings divided by total neighbourhood area, which includes strictly residential area and other non-residential areas such as parks, commercial, and institutional (e.g., school) properties. *Net density* is the number of dwellings divided by only the strictly residential area. We have chosen to measure land use as gross density to capture the total land area required for new and existing residential neighbourhoods, thus allowing more comprehensive accounting of the environmental impacts related to land use. Other studies have used net density measures that make comparisons with the measures presented here much more difficult.

- *Form of residential development*: Maps illustrating the City divisions of neighbourhood archetypes are found in Exhibit A.3. The three large city CMAs were found to comprise an inner city core containing an average of 15% of their total dwelling units, surrounding inner suburbs containing about 20% of the total units, and a large outer suburban region comprising 65% of dwelling units. The densities and housing mix of the smaller population centres all correspond to the Outer Suburb archetype. A summary of this Census-based analysis is provided in Exhibit A.4.

- The results obtained from the above analysis were then combined as weighted averages of these three high-growth CMAs. The combined results are shown in Exhibit A.8.

- The CMA and non-CMA archetypes were then combined using the 2001 Census percentages of 61.5% of dwelling units located in CMAs and 38.5% in non-CMAs. The base year dwelling stock allocations emerging from the foregoing method is pegged to the 2001 Census statistics which represent the most recent available source of complete data for these cities. The NRCan Maple-C database was used to update the allocations of dwelling stock to the study base year of 2004, using the total number of Canadian dwelling units in 2004 and assuming the percentage allocations by dwelling type derived from the 2001 Census remained constant to 2004. This approach was taken due to lack of better available data.

- The non-residential segment of each archetype included the typical portions of each neighbourhood type not occupied by housing and residential road infrastructure, such as commercial, institutional, and industrial uses and their associated road infrastructure.

- The resulting 2004 neighbourhood archetypes are shown in Exhibit A.8 and further described in Section 4.

- It is important to note that, to some extent, this analysis has broken new ground with regard to the characterization of neighbourhoods in Canada. Although there is Canadian-based research on the environmental impact of various neighbourhood configurations, none of the existing data has been developed in a way that allows empirically defensible allocations of dwelling stock into representative neighbourhood archetypes. For example, CMHC has developed tools and background data on costing sustainable planning, greenhouse gas emissions from urban travel, and residential street pattern design that allow assessment of components of the environmental impact of neighbourhood configuration. However, a methodical system had not yet been developed that would allow us to determine the percentage of Canadian households and mix of housing types located within suburban versus inner city settings in order to quantify the environmental impact attributable to neighbourhood setting variations across Canada.

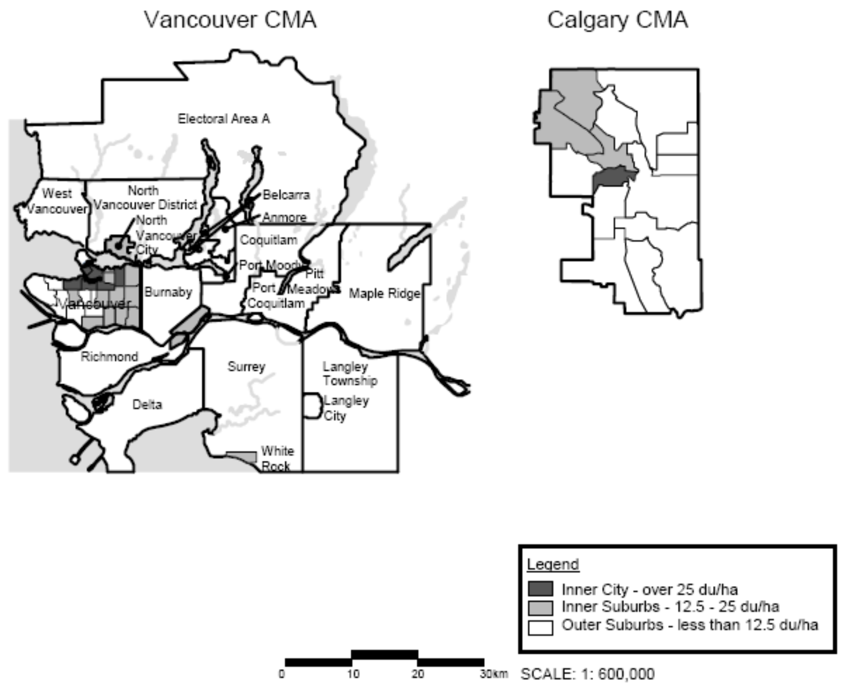
Characterizing the Physical Aspects of Neighbourhoods that Affect the Environment

Once the urban density and form was specified for each of the three neighbourhood archetypes, the next step was to specify other physical characteristics from which the broader, cumulative environmental impacts were considered. This required a more in-depth consideration of the: 1) area of developed land allocated between residential and non-residential uses; and 2) allocation of green space, built area, and paved area.

The method employed was to extract values for these measures from actual neighbourhoods that closely corresponded to the density and mix of dwelling units in the three archetypes.

City of Ottawa neighbourhoods were selected for this purpose because of their proximity to the study team, thereby enabling physical investigation to confirm the attributes. The particular neighbourhoods used as models were compared against other typical inner city, inner suburb and outer suburb neighbourhoods to ensure they were generally representative and were modified as necessary to match the calculated archetypes. Sample overhead views of the three neighbourhood types are shown in Exhibits A.5 to A.7. The results are presented in Section 4.

Exhibit A.3: Graphical View of Neighbourhood Types in High-Growth CMAs, 2001



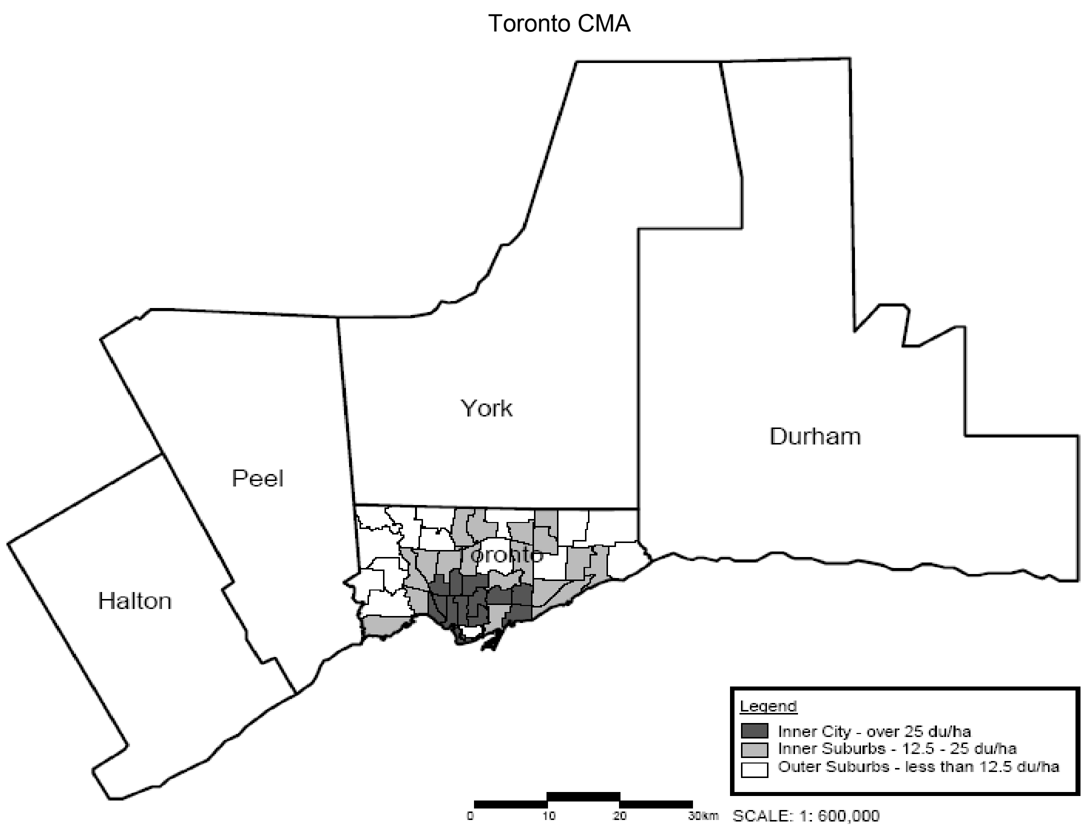
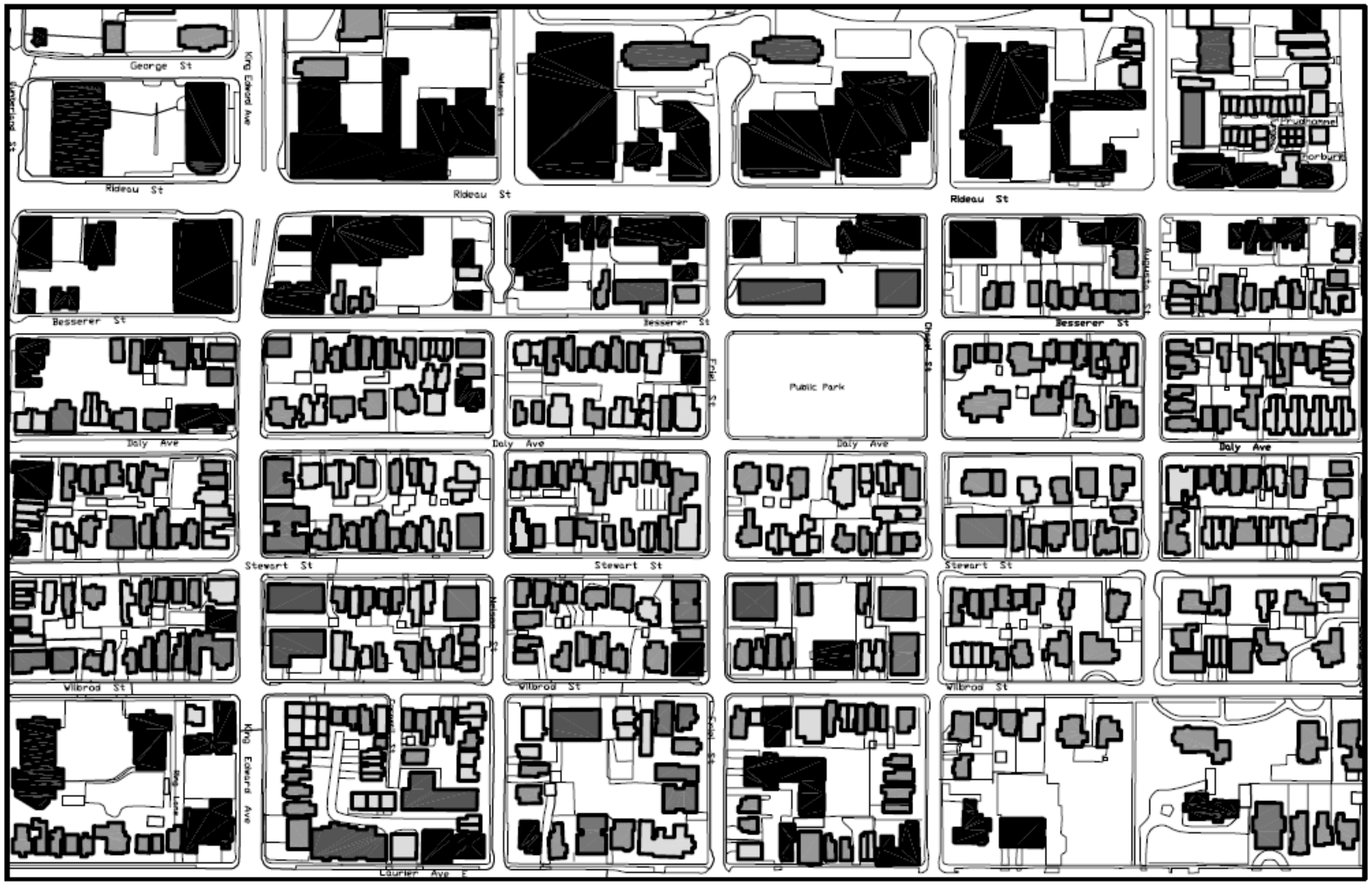


Exhibit A.4: Comparison of Neighbourhood Types in High-Growth CMAs, 2001[137]

	Total CMA Toronto	Toronto	Outer GTA	Calgary Edmonton Red Deer	Calgary	Total CMA Vancouver	Vancouver	Outer GVRD
Total du	1,792,905	937,610	855,295	759,737	345,335	648,856	240,090	408,766
Inner City								
No. of du		290,910	0		37,565		111,620	0
% of total du	16.2%	31%		10.9%	10.9%	17.2%	48.4%	
Avg. du/ha		32			27		49	
% Single Detached		19%			19%		5%	
% Semi/Row/Duplex		22%					9%	
% Apt. Under 5 Storeys		18%			81%		48%	
% Over 5 Storeys		41%					39%	
Inner Suburbs								
No. of du		382,395	0		79,980		100,890	29,785
% of total du	21.3%	41%		23.2%	23%	20.1%	42%	7.3%
Avg. du/ha		16			7		17	17
% Single Detached		35%			59%		44%	25%
% Semi/Row/Duplex		14%					27%	75%
% Apt. Under 5 Storeys		11%			41%		23%	
% Over 5 Storeys		40%					6%	
Outer Suburbs								
No. of du		264,305	855,295		227,790		27,580	376,266
% of total du	62.5%	28%	100%	65.9%	66%	62.7%	11.5%	92.7%
Avg. du/ha		9	1.5		5		9	4
% Single Detached		44%	62%		66%		65%	56%
% Semi/Row/Duplex		17%	21%				10%	44%
% Apt. Under 5 Storeys		7%	4%		34%		19%	
% Over 5 Storeys		32%	13%				6%	

137 Statistics Canada. 2001. *Community Highlights*. http://www12.statcan.ca/english/profil01/CP01/Index.cfm?Lang=E

Exhibit A.5: Overhead View of Sample *Inner City* Neighbourhood in Ottawa (Downtown), 2007

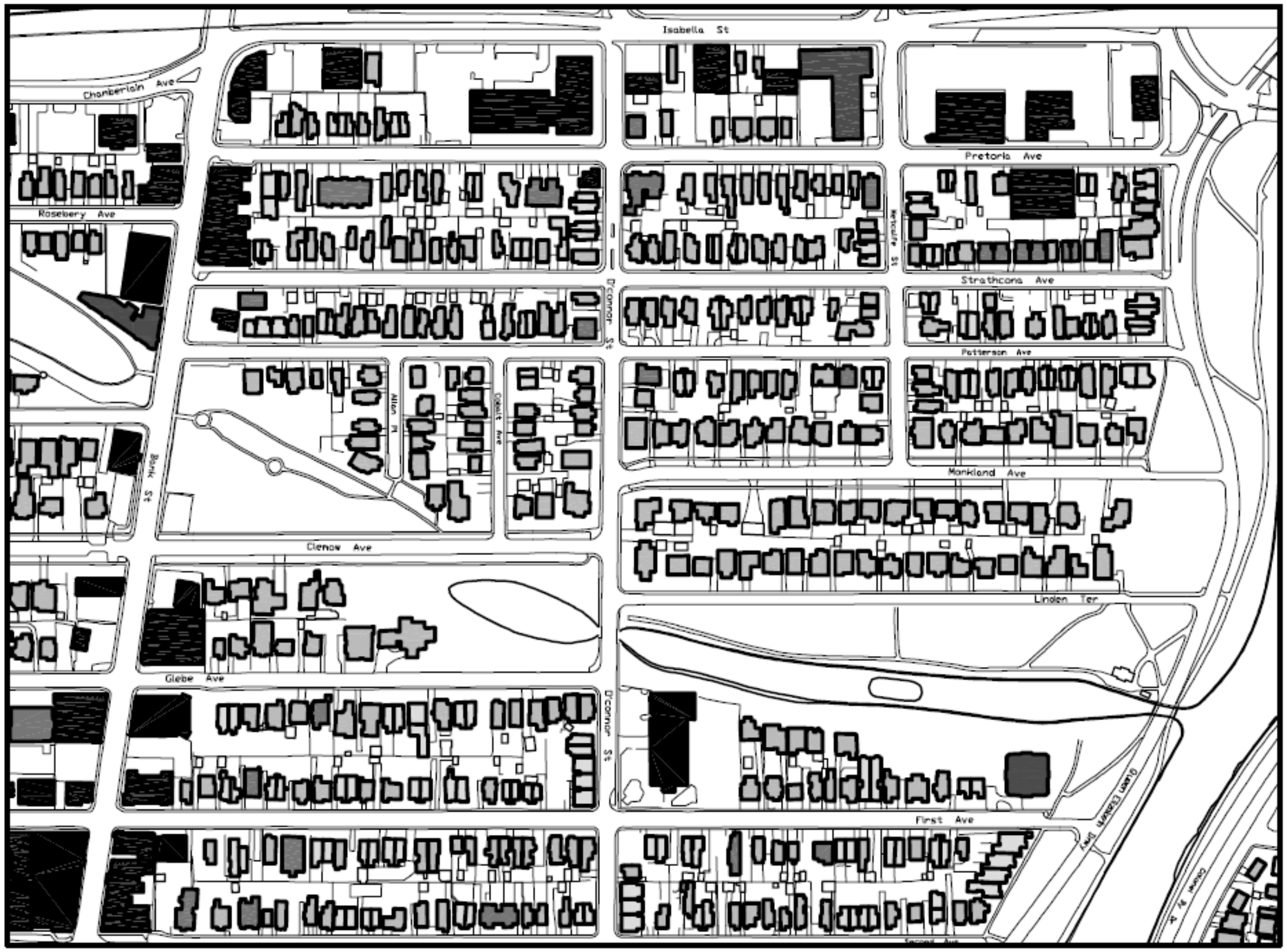


INNER CITY ARCHETYPE

Map Legend

Fill Type	Housing Type	Number of Dwelling Units		Fill Type	Housing Type	Number of Dwelling Units	
	Single Detached	270	15.0%		Over 5 Storey	720	40.0%
	Row/Duplex/Semi, etc.	360	20.0%		Non Residential		
	Under 5 Storey	450	25.0%		**Total Units**	**1800**	

Exhibit A.6: Overhead View of Sample *Inner Suburb* Neighbourhood in Ottawa (Glebe), 2007

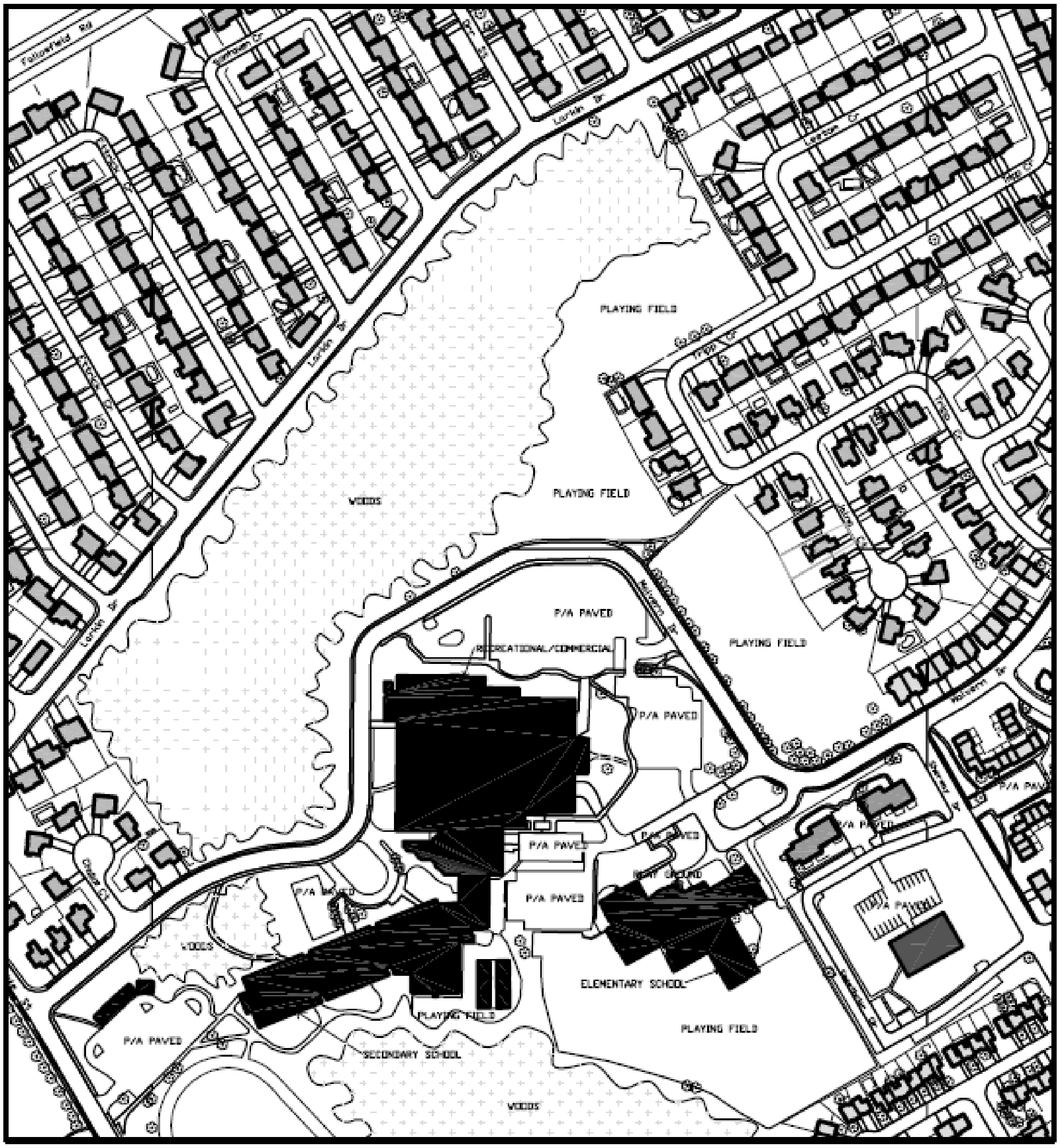


INNER SUBURB ARCHETYPE

Map Legend

Fill Type	Housing Type	Number of Dwelling Units		Fill Type	Housing Type	Number of Dwelling Units	
	Single Detached	320	40.0%		Over 5 Storey	240	30.0%
	Row/Duplex/Semi, etc.	120	15.0%		Non Residential		
	Under 5 Storey	120	15.0%		**Total Units**	**800**	

Exhibit A.7: Overhead View of Sample *Outer Suburb* Neighbourhood in Ottawa (Barrhaven), 2007



OUTER SUBURB ARCHETYPE

Map Legend

Fill Type	Housing Type	Number of Dwelling Units	
	Single Detached	146	65.0%
	Row/Duplex/Semi, etc.	32	14.0%
	Under 5 Storey	42	19.0%
	Over 5 Storey	5	2.0%
	Non Residential		
	Total Units	**225**	2.0%

Neighbourhood Archetypes for 2025

The purpose of this sub-section is to describe the methodology for profiling how the neighbourhood archetype characteristics established for the base year are likely to change during the study period and how this change would affect the distribution of dwelling types by archetype. The output is a set of three neighbourhood archetypes for the end of the study period: 2025.

The 2025 archetypes emerged from a review of growth projections and discussions with city planners from the cities of Toronto, Vancouver and Calgary. Their vision of 2025 neighbourhoods is quite different from that which would result from the NRCan projections, particularly for the cities of Toronto and Vancouver, where scarcity of available land and urban intensification policies are providing a strong impetus for intensification versus continued suburban low-density development.

The method to derive the 2025 archetypes was to merge national projections of dwelling stock with expectations of neighbourhood development patterns unique to the CMAs in Canada where highest growth is expected — Vancouver, Calgary, and Toronto. It is important to note that the 2025 archetypes are composites, taking into account the characteristics of existing neighbourhoods and the characteristics of new growth. The critical implication of this approach is that the 2025 allocation of dwelling types is different than had the projection been based solely on the NRCan forecast.

Deriving Neighbourhood Archetypes for Regional Growth Clusters

The method employed to generate the revised 2025 archetypes is presented below:

- The 2025 neighbourhood types were profiled for Vancouver, Calgary, and Toronto, based on the projections of new dwelling units, mix of dwelling unit types, development density, and their location within the urban area as intensification or greenfield development.

- A final weighted average for these cities was derived to represent 2025 neighbourhood types for these three high-growth areas. The results are shown in Exhibit A.8.

- Although most of the future growth during 2004–2025 would occur predominantly in large urban areas, the final 2025 neighbourhood archetypes are a weighted average of the CMA and non-CMA urban areas. As previously, noted, they are a composite of existing and new neighbourhood development patterns captured in the snapshot of 2025. The non-CMA neighbourhood characteristics were taken into account by assuming they had the same distribution of units as in 2004.

- The resulting 2004 and 2025 neighbourhood archetypes are shown in Exhibit 3.13 for the three high-growth CMAs, the three sample non-CMAs, and the combined result for all of Canada. As described above, the neighbourhood characteristics from 2001 were assumed to be the same for 2004. The archetypes for all of Canada are further described in the results in Section 4.

In the exhibit, note that the average neighbourhood densities (dwellings per hectare):

- Are estimated for each neighbourhood type in the high-growth CMAs;
- Are restricted to Outer Suburbs in non-CMAs because they are composed of almost exclusively Outer Suburbs, according to this analysis; and
- Result in a weighted average of the high-growth CMAs and non-CMAs.

A.2.2 Data Limitations

The data and methodological limitations for neighbourhoods are as follows:

- *Recent shifts in allocation of dwelling types* — Data used to generate the neighbourhood archetypes are based on 2001 Census tracts. Any shifts that occurred in dwelling type mix and neighbourhood configuration during 2001–2004 have not been captured in the final depiction of the archetypes.

- *Influence of stock projections from NRCan Canada's Energy Outlook 2006* — As noted previous, the NRCan Maple-C projections of dwelling stock growth were the best available to generate a Canada wide profile. If we had relied solely on the NRCan projections, the implication for the BAU neighbourhood archetypes would have been a development pattern reflecting growth we have seen over the recent past. There would have been only minor shifts in the proportions of low, medium and high density housing units constructed.

- *Achievability of urban intensification targets as set in recent years* — This study's BAU scenario assumes the major CMAs' urban intensification would be fully met. If the intensification assumptions do not play out in reality, which is highly probable, actual development patterns would result in larger greenfield areas being consumed. Since transportation energy use and related outputs are closely dependent on proximity to the urban core under a BAU scenario, the study results for the magnitude of resources used, environmental outputs and environmental impacts resulting would be larger. One key implication is that the estimated square kilometres of greenfield development area are a function of densification estimates, gleaned from discussions with municipal planning staff in the major CMAs and a review of official plans. Gaps between implementation of these targets and actual development patterns would result in a much larger total greenfield area being consumed. If more greenfield is consumed, environmental impacts would be greater.

Exhibit A.8: Weighted Average Neighbourhood Archetypes for High-Growth CMAs (2001 & 2025), Sample Non-CMAs (2001 & 2025), and All of Canada (2004 & 2025)

	Neighbourhood Type			Neighbourhood Type		
	Inner City	**Inner Suburbs**	**Outer Suburbs**	**Inner City**	**Inner Suburbs**	**Outer Suburbs**
Weighted Average for High-Growth CMAs (Vancouver, Calgary & Toronto)						
Data Year		**2001**			**2025**	
% of Total Dwellings in CMA	15%	21.5%	63.5%	14.5%	20%	65.5%
Avg Dwellings per ha	36	16	4.5	46	18.5	6
Avg Dwellings per km^2	3,600	1,600	450	4,600	1,850	600
Non-Residential % of Total Area	26%	20%	20%	35%	25%	20%
Dwelling Allocation per Nhood Type						
Single Detached	15%	40%	60%	10%	35%	58%
Row/Town	20%	15%	15%	20%	20%	18%
Low-rise MURB	25%	15%	10%	25%	15%	12%
High-rise MURB	40%	30%	15%	45%	30%	12%
Transportation						
Auto VKT/DU/yr	7,450	13,500	25,620	7,450	13,500	25,620
Transit PKT/DU/yr	6,280	5,510	6,460	6,280	5,510	6,460
Weighted Average for Sample Non-CMAs (Nanaimo, Pembroke & Fredericton)						
Data Year		**2001**			**2025**	
% of Total Dwellings in Non-CMA	0%	0%	100%	0%	0%	100%
Avg Dwellings per ha	-	-	3.1	-	-	3.1
Avg Dwellings per km^2	-	-	310	-	-	310
Dwelling Allocation per Nhood Type						
Single Detached	-	-	71.5%	-	-	71.5%
Row/Town	-	-	10%	-	-	10%
Low-rise MURB	-	-	17%	-	-	17%
High-rise MURB	-	-	1.5%	-	-	1.5%
Weighted Average for Canada (Neighbourhood Archetypes used in Study)						
Data Year		**2004**			**2025**	
% Contribution from CMAs		61.5%			72.6%	
% Contribution from non-CMAs		38.5%			27.4%	
% of Total Dwellings in Canada	9.25%	13.25%	77.5%	10.5%	14.5%	75.0%
Avg Dwellings per ha	36	16	4.0	46	18.5	5.2
Avg Dwellings per km^2 (1 km^2= 100 ha)	3,600	1,600	396	4,600	1,850	521
Non- Residential % of Total Area	26.4%	19.8%	22.4%	26.4%	19.8%	22.4%
Dwelling Allocation per Nhood Type						
Single Detached	15.0%	40.0%	64.7%	15.1%	40.2%	64.8%
Row/Town	20.0%	15.0%	14.4%	21.4%	16.0%	15.3%
Low-rise MURB	25.0%	15.0%	18.6%	24.1%	14.5%	17.8%
High-rise MURB	40.0%	30.0%	2.3%	39.3%	29.3%	2.1%
Transportation						
Auto VKT/DU/yr	7,450	13,500	25,620	7,450	13,500	25,620
Transit PKT/DU/yr	6,280	5,510	6,460	6,280	5,510	6,460

A.3 METHODOLOGY FOR NEIGHBOURHOOD INFRASTRUCTURE

As an extension of Section A.2, this sub-section described the methodology used to estimate the physical infrastructure required over the study period in each of the three neighbourhood types chosen in this study. The results from this characterization were needed to determine: 1) the resource use and environmental outputs from constructing neighbourhood infrastructure; and 2) the broader environmental impacts that result from these environmental outputs and from changes in land use, such as percentage of permeable area.

A.3.1 Methodology, Assumptions & Data Sources

The neighbourhood archetypes, which are presented in Section 4, were used as the basis to calculate the amount of residential road and accompanying in-ground water infrastructure required during 2004–2025: 1) to densify existing neighbourhoods; and 2) to build new neighbourhoods.

Key Data Sources

The study team reviewed CMHC's recently-developed Sustainable Community Infrastructure Costing Tool and background report to determine possible use for this project. This tool supports the costing of six road types with various right-of-way widths with the option for a user-defined roadway, for a total of seven possible roadway configurations. For each road type it also specifies water distribution, sewer and storm-water configurations; unfortunately these are held constant across all the specified roads, which is unlikely to be the case in reality. The tool is based on infrastructure services in the Greater Toronto Area (GTA).

Unfortunately, the tool and related background report did not have sufficient granularity on actual road width and other materials considered for each road type — instead focusing on gross right-of-way widths. However, the documentation did indicate the pipe size used for each application.

The study team utilized the services of a road construction consultant[138] to prepare material quantity take-offs and construction activity related energy use by activity for various infrastructure elements found in the three neighbourhood archetypes.

Defining & Characterizing Neighbourhood Infrastructure Types

Based on the study of sample Ottawa neighbourhoods, as described in Section A.2, and on the data sources listed above, four neighbourhood infrastructure archetypes were defined — each including roads and accompanying in-ground water supply and wastewater infrastructure.

The resulting archetypes are summarised in Exhibit A.9 with road type as the identifying designation. Each archetype is characterized by different road widths, sidewalk widths, and numbers of water works components per unit length. These same archetypes were

[138] Degmar Construction, Markham, Ontario

used for both 2004 and 2025, assuming no significant difference would occur in infrastructure planning and construction over these 21 years; this meant excluding differences in construction with more recycled content, which would likely occur, in reality.

Exhibit A.9: Neighbourhood Infrastructure Archetypes, 2004 & 2025

Neighbourhood Infrastructure Characteristics per 100-m Length of Road	Type I	Type II	Type III	Type IV
	Two-lane Local Road	Two-lane Local Road	Two-lane Collector Road	Four-lane Collector Road
Road Width (m)	8	9	11	15
Sidewalk Width (total of both sides) (m)	0	3	3	5
Number of Domestic Water and Sewer Connections	8	15	5	0
Number of Fire Hydrants	2	2	2	2
Number of Sewer Maintenance Holes	1.25	1.25	1.25	1.25
Number of Catch Basins	6	6	6	6
PVC Sanitary Sewer lines (mm)	201	201	201	201
PVC Water Mains (mm)	151	151	151	151
PVC Storm water (mm)	298	298	365	447

According to the four residential infrastructure types defined, Exhibit A.10 presents the amount of residential infrastructure required per 50-ha neighbourhood in 2004 and 2025, for both residential densification and new neighbourhoods. A typical neighbourhood area of 50 hectares was somewhat arbitrarily chosen to bound neighbourhoods into discrete areas that could be quantified in Canada and used for per-neighbourhood comparisons. Depending on the context, zero values indicate that no infrastructure of that type is required to densify an existing neighbourhood or build a new neighbourhood.

Exhibit A.10: New Road Infrastructure Required *per 50-ha Neighbourhood* for Residential Densification & New Neighbourhoods by 2025, by Neighbourhood & Infrastructure Types

Neighbourhood Type	Type I		Type II		Type III		Type IV	
	Res	Non-Res	Res	Non-Res	Res	Non-Res	Res	Non-Res
Kilometres needed to Densify an Existing 50-ha Residential Neighbourhood:								
Inner City	0	0	0	0	0	0	0	0
Inner Suburbs	0	0	0	0	0	0	0	0
Outer Suburbs	0.4	0	0	0	0.3	0	0	0
Kilometres needed to Build a New Dense 50-ha Residential Neighbourhood:								
Inner City	0	0	4.2	5.7	1.2	0.3	0	0.9
Inner Suburbs	0	0	5.0	1.2	0	0.8	0	0
Outer Suburbs	2.3	0.3	0	0	1.5	1.7	0	0

The resulting infrastructure required to service all densified existing neighbourhoods and new neighbourhoods over the study period is presented in the results in Section 4.2.

A.3.2 Data Limitations

The study resources did not allow the definition of different neighbourhood infrastructure archetypes for 2004 versus 2025, but did allow for different amounts of this infrastructure per neighbourhood type for 2004 and 2025. This limitation highlights that the study does not take into account, for example, more connections per 100 metres of road to service denser neighbourhoods in the future, relative to the base year.

A.4 METHODOLOGY FOR NON-OPERATING EFFECTS FROM NEW DWELLINGS & INFRASTRUCTURE

The non-operating stages of the residential sector, as covered by this study, include Extraction & Manufacturing, On-site Construction, and Maintenance & Replacement. This sub-section describes the methodology used to quantify the resulting resource use and environmental outputs from the residential sector for these life-cycle stages over the study period of 2004–2025. This analysis estimated the resource use (i.e., energy, water, and solids) and environmental outputs (i.e., emissions/pollutants to air, water, and soil) from extracting materials, manufacturing building products, transporting them to the construction site, constructing new buildings (i.e., dwellings) and residential infrastructure (i.e., neighbourhood roads and water systems), and providing maintenance to those same structures over the study period.

A.4.1 Modelling Platform

The modelling platform for the LCA analysis is the latest version of the Athena Institute's commercially-available *Environmental Impact Estimator* software, version 3.0.3.[139] As the only North American software for the LCA assessment of buildings, the Estimator and its internationally recognized life-cycle inventory databases are presently capable of modelling nearly all building types in North America. The Estimator and its databases cover more than 90 structural and envelope materials and handles over 1,000 different assembly combinations. To make the Estimator as transparent as possible, the Institute offers a companion compact disc (CD) containing all the ATHENA® database reports in portable document format (PDF).

For Canada, this modelling package represents average or typical manufacturing technologies and appropriate modes and distances for transportation.

This model was used to derive the LCA coefficients defined in the following sub-section.

A.4.2 Methodology, Assumptions & Data Sources

This study primarily draws on the ISO procedures for conducting an LCI, as mentioned under Life-cycle Analysis in Section 2. The LCA conducted for this study can be categorized as a 'cradle-to-gate LCI analysis', as we followed residential dwellings and related infrastructure over a period shorter than their full expected life spans.

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[139] The ultimate objective of developing this specialized software is to assist the building community in making more informed decisions regarding design and material options that will minimize a building's life cycle environmental impact. Today, over 300 members of the public, private and academic sectors use the tool for design, policy and educational purposes.

Overall Methodology

As described in Section 3.2, the methodology used for estimating the non-operating effects of new residential structures is as follows:

- For dwelling non-operating effects, per-dwelling coefficients were derived for resource use and environmental outputs for each dwelling type, and these coefficients were multiplied by the new dwelling stock from the characterization of the residential sector.
- Similarly, for neighbourhood roads and water infrastructure, per-kilometre coefficients were derived for resource use and environmental outputs for each infrastructure type, and these coefficients were multiplied by the required new infrastructure identified by the characterization of the residential sector.

Derivation of Dwelling Archetypes

As mentioned under Methodology for Dwelling Stock in Section A.1, this study categorised the Canadian dwelling stock into four dwelling types. Each of these dwelling types was characterized by size and features to form dwelling 'archetypes' that were used in further analysis of operating and non-operating impacts. The resulting dwelling archetypes are summarized in Exhibit A.11. Following the exhibit is a derivation of these dwelling archetypes.

Exhibit A.11: Summary of Dwelling Archetypes Chosen for this Study

Dwelling Type	Dwellings Included	Dwelling Features	Building Features
Single Detached	Single detached houses, Mobile homes[140]	218 m^2 (2,350 sqft), 2-storey, 3-bedroom, 2.5 bathrooms, full basement, 2-car garage	1 dwelling/building
Row/Town	Row & Townhouses, Semi-detached houses, Duplexes	139 m^2 (1,500 sqft), 2-storey, 3-bedroom, 1.5 bathrooms, full basement, 1-car garage	5 dwellings/building
Low-rise MURB	Apartments & condo units in multi-unit buildings less then 5 storeys[141]	84 m^2 (900 sqft); impacts assumed similar to 80% Row/Town (adjusted from 1,500 to 900 sqft) & 20% High-rise MURB unit	6 dwellings/building
High-rise MURB	Apartments & condo units in multi-unit buildings with 5 storeys or more	84 m^2 (900 sqft)	40 dwellings/building, 11-storey complex, 2 levels underground parking, common spaces

140 As mentioned earlier, mobile homes were grouped with single detached houses because of their operating energy end uses, not because of their construction materials and size.

141 Built according to Part 9 of the *National Building Code of Canada 2005* (National Research Council Canada), http://irc.nrc-cnrc.gc.ca/pubs/codes/nrcc47666_e.html

A dwelling archetype consists of the following key characteristics: size, footprint, construction and structure, envelope materials, and finishing. There are four main challenges to specifying of these characteristics in representative dwelling archetypes:

- For dwelling types that comprise different types of buildings (e.g., various designs and sizes of Low-rise MURBs), the challenge is to select one or a combination of those building types that best represent that dwelling type over the study period.

- For High-rise MURBs, the challenge is to select a building height and physical footprint representative of the population as a whole.

- For both Low-rise and High-rise MURBs, it was necessary to develop an empirically clear path to trace, enable, and relate the LCI data for a whole building to a single dwelling in the building. Thus the complicating factor is to relate a physical depiction of a building, which can contain more than one dwelling unit, to the unit measure of a single dwelling unit which forms the basis for the roll-up of the LCA analysis.

- There is a lack of credible information to support the characterization of typical dwelling size. No agency or trade association in Canada compiles the size of dwelling units in Canada on a statistical or time series basis.[142] This issue was addressed for all of the dwelling types assessed in the LCA through a web search[143] to review a set of dwelling types available in the Greater Toronto Area to develop representative floor plans and dwelling sizes. In general, the research indicated that all dwelling types varied considerably in size. Typical size varied with distance from the downtown core — the farther the dwelling was from the downtown core the larger it was — which, of course, affects resource use and environmental outputs.

The resulting approach used to address these challenges is described in the following depiction of the four dwelling archetypes.

Single Detached

The average dwelling size was determined to be 218 m^2 (2,350 sq ft). As modelled, the house is 2 storeys in height and has 3 bedrooms, 2.5 baths, a 2-car garage, and a full unfinished basement.

Row/Town

As previously noted, this dwelling type encompasses a number of different building types consisting of row and town housing (either two attached dwelling units or a row of dwelling units), duplexes, and semi-detached houses. The typical design characteristics of these building types are as follows:

[142] While Canadian anecdotal evidence indicates that the size of single-family houses have increased by as much as 50% since the 1970s, no easily accessible public database exists that tabulates average dwelling unit size built annually. In the US, the average square footage of a new single-family home has more than doubled from 983 sq. ft. in 1970 to 2,349 sq.ft in 2004 (Source: National Association of Home Builders (Housing Facts, Figures and Trends (March 2006).

[143] www.rentersnews.ca & www.newhomes+condos.ca

- Semi-detached (duplex) housing is typically a split bungalow or two-storey building with an above-grade floor plan larger than that of row houses.

- Row housing is typically designed as a 2 or 3-storey dwelling with a garage, entry way and mechanicals at or below grade, common rooms (kitchen, dining and living room) on the first or second floor, and bedrooms with bathrooms on the second or third floor; another bath or powder room is usually incorporated on the ground or second floor. The total living area of a row house is typically less than a semi-detached.

- In consultation with the client, the study team opted to use row housing as the representative dwelling for this dwelling type.

- The size depiction for the row/town house dwelling is 139 m^2 (1,500 sq ft) with 3 bedrooms, 1.5 baths, a 1-car garage, and a full unfinished basement.

Low-rise MURBs

Specific LCI values (resource use and environmental output factors per dwelling) could not be developed specifically for this dwelling type. However, the LCI values for the Row/Town and High-rise MURB dwelling types were used to estimate the LCI values for Low-rise MURBs.

It was decided to infer this archetype by a proportional representation of Row/Town housing (Part 9, prescriptive building code) and High-rise MURBs (5 storeys or more; Part 3 of the National Building Code) with an additional adjustment for dwelling size. The resulting LCI values for Low-rise MURBs were decided to be an 80/20 split between Row/Town and High-rise MURB, with the Row/Town dwelling size adjusted for a final dwelling area of 84 m^2 (900 sq ft), which is the same dwelling size as used in this study for High-rise MURBs. The rationale for this determination is somewhat arbitrary, but reflects the predominance of walk-up 2-10 unit apartments (as opposed to elevator-serviced units) and preference for these buildings being built according to Part 9 (as opposed to Part 3) of the National Building Code.

High-rise MURBs

The characterization of the High-rise multi-unit residential building (MURB) archetype involved two key steps: i) establish a defensible physical depiction of the high-rise building size and footprint; and ii) determine the representative size of each dwelling unit in that archetypal high-rise building.

Building Size & Footprint

There is a real lack of credible building stock data to support the physical depiction of the MURB sector. Fortunately, a credible and recent study was found which formed the basis for the MURB building characterization.[144] Notwithstanding that it was based on a small sample size, the study characterized high-rise buildings in Toronto on the basis of year built, number of units per building, storeys above grade, and parking at and below grade.

The following measures were gleaned from the raw data:

- Average of 9 storeys above grade (range of between 5 to 21)
- Average of 12 units per storey (range of between 2 to 26)
- Average of 1.3 storeys below grade. (range between 0 and 3)

The high-rise MURB building height was set at 11 storeys with 4-10 dwelling units per storey (depending on unit size – see below) with 2 storeys of underground parking (see below).

Dwelling Unit Size

The data reveals a marked difference between apartments and condominium (condo) units. Typically an apartment in the same area as a condo was found to be smaller with less common area and amenities (e.g., utility and recreational space) within the structure. We also noted a considerable difference in high-rise design between central Canada and the west coast. In Vancouver — a major condo market — condominium design has typically taken on a narrower building (floor plate) design characteristic with the primary services (elevator and stair wells) located in the central core of the building as opposed to on the end of the building to minimize the buildings foot print and maximize exterior day-lighting. So while guided by the Toronto CMHC study, the following modified size depiction was chosen to better reflect the recent changes in high-rise design:

- 84 m^2 (900 sq ft) with 2 bedrooms, 1 bathroom, and no basement, which reflects a representative average between apartments and condominium units in the inner core of cities.

Derivation of Resource Use & Environmental Outputs per Dwelling

Using Athena's Environmental Impact Estimator model, per-dwelling coefficients for resource use and environmental outputs were developed and multiplied by the number of units of each dwelling type in Canada, both in 2004 and 2025. These per-dwelling coefficients were left the same for 2025 as for 2004, due to limited study resources.

Exhibit A.12 shows these per-dwelling coefficients for each dwelling type.

[144] Canada Mortgage and Housing Corporation. 2003. *Condition Survey of High-rise Rental Stock in the City of Toronto*. Data is based on a sample of 46 high-rise buildings built in the 1990's.

Exhibit A.12: Per-Dwelling Resource Use & Environmental Output Factors, by Dwelling Type

Category		Dwellings: Single Detached			Row / Town			Low-rise MURB			High-rise MURB		
	Lifecycle Stage	Extraction & Manufacturing	On-Site Construction	Maintenance & Replacement	Extraction & Manufacturing	On-Site Construction	Maintenance & Replacement	Extraction & Manufacturing	On-Site Construction	Maintenance & Replacement	Extraction & Manufacturing	On-Site Construction	Maintenance & Replacement
	Multiplier Units	/dwelling			/dwelling			/dwelling			/dwelling		
Primary Fuel Use	Liquid Petroleum Gas, LPG [PJ]	3.60E-08	0.00E+00	3.70E-08	9.20E-09	0.00E+00	9.60E-09	5.97E-09	0.00E+00	4.61E-09	7.75E-09	0.00E+00	0.00E+00
	Diesel [PJ]	2.92E-05	4.10E-05	2.40E-06	1.94E-05	2.66E-05	1.14E-06	1.27E-05	1.81E-05	6.40E-07	1.69E-05	2.68E-05	4.68E-07
	Gasoline [PJ]	5.17E-07	0.00E+00	2.70E-08	4.52E-07	0.00E+00	6.60E-09	2.18E-07	0.00E+00	3.17E-09	3.55E-09	0.00E+00	0.00E+00
	Natural Gas [PJ]	2.51E-04	7.78E-07	3.41E-05	1.23E-04	3.28E-07	1.87E-05	7.98E-05	1.64E-07	9.65E-06	1.03E-04	3.34E-08	3.49E-06
	Wood [PJ]	2.76E-05	8.13E-10	2.87E-09	1.98E-05	3.30E-10	1.19E-09	9.51E-06	1.61E-10	7.23E-10	4.51E-08	1.13E-11	7.60E-10
	Coal [PJ]	1.32E-04	2.32E-06	2.35E-05	8.51E-05	9.41E-07	1.27E-05	6.32E-05	4.58E-07	6.81E-06	1.12E-04	3.28E-08	3.55E-06
	Heavy Fuel Oil [PJ]	4.05E-05	2.59E-07	1.01E-05	2.42E-05	1.05E-07	5.70E-06	1.77E-05	5.12E-08	2.88E-06	3.04E-05	3.61E-09	7.25E-07
	Nuclear [PJ]	6.08E-05	1.63E-06	1.13E-05	3.45E-05	6.62E-07	5.92E-06	2.44E-05	3.22E-07	3.21E-06	3.93E-05	2.27E-08	1.84E-06
	Feedstock Fuels [PJ]	1.18E-04	0.00E+00	6.20E-05	5.54E-05	0.00E+00	3.10E-05	3.98E-05	0.00E+00	1.52E-05	6.61E-05	0.00E+00	1.68E-06
	Other Oil-based Fuels [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total Primary Fuels [PJ]	6.60E-04	4.60E-05	1.44E-04	3.62E-04	2.88E-05	7.52E-05	2.47E-04	1.92E-05	3.84E-05	3.68E-04	2.69E-05	1.18E-05
Air Emissions	Carbon Dioxide, CO2 from non-biomass [kt]	3.41E-02	1.20E-03	5.24E-03	2.27E-02	9.03E-04	3.04E-03	1.67E-02	6.20E-04	1.71E-03	2.91E-02	9.34E-04	1.27E-03
	Carbon Dioxide, CO2 from biomass (biogenic/neutral) [kt]	2.76E-03	1.14E-07	4.04E-07	1.98E-03	4.65E-08	1.68E-07	9.54E-04	2.26E-08	1.02E-07	5.07E-06	1.59E-09	1.07E-07
	Carbon Monoxide, CO [kt]	1.09E-04	5.24E-06	1.28E-05	6.10E-05	4.96E-06	7.66E-06	4.41E-05	3.49E-06	4.49E-06	7.42E-05	5.55E-06	4.06E-06
	Sulphur Oxides, SOx [kt]	2.65E-04	3.97E-06	4.61E-05	1.55E-04	2.18E-06	2.59E-05	1.07E-04	1.26E-06	1.43E-05	1.62E-04	1.06E-06	9.39E-06
	Nitrogen Oxides, NOx [kt]	1.23E-04	9.99E-06	1.82E-05	8.42E-05	8.83E-06	1.13E-05	6.14E-05	6.34E-06	6.80E-06	1.05E-04	1.05E-05	6.96E-06
	Nitrous Oxide, N2O [kt]	7.95E-08	1.82E-09	1.54E-08	5.94E-08	7.40E-10	8.07E-09	4.65E-08	3.60E-10	4.38E-09	9.01E-08	2.54E-11	2.53E-09
	Total Particulate Matter, TPM [kt]	1.40E-04	1.78E-07	1.40E-05	8.27E-05	1.11E-07	1.09E-05	6.16E-05	6.79E-08	1.02E-05	1.09E-04	7.24E-08	2.48E-05
	Non-Methane Volatile Organic Compounds, NMVOC [kt]	7.94E-06	1.23E-06	5.31E-06	3.02E-06	1.07E-06	1.39E-06	2.10E-06	7.60E-07	7.02E-07	3.26E-06	1.23E-06	1.70E-07
	Methane, CH4 [kt]	6.13E-05	5.78E-07	1.29E-05	3.24E-05	2.71E-07	7.55E-06	2.06E-05	1.46E-07	4.00E-06	2.54E-05	7.92E-08	1.90E-06
	Metals [kt]	1.11E-06	1.28E-10	5.45E-09	7.92E-07	5.19E-11	3.59E-09	3.85E-07	2.53E-11	1.80E-09	2.39E-08	1.78E-12	3.94E-10
	Total Greenhouse Gases (CO2-equivalent) [ktCO2e]	5.31E-02	1.38E-03	9.25E-03	3.27E-02	9.87E-04	5.38E-03	2.31E-02	6.66E-04	2.96E-03	3.70E-02	9.58E-04	1.86E-03
Water Emissions/Pollutants	Biological Oxygen Demand, BOD [kt]	7.14E-07	1.12E-09	1.85E-07	3.32E-07	5.21E-10	1.15E-07	2.76E-07	2.77E-10	5.75E-08	5.84E-07	1.34E-10	1.28E-08
	Suspended Solids [kt]	9.16E-05	1.52E-07	5.83E-06	4.43E-05	6.21E-08	3.46E-06	3.60E-05	3.04E-08	1.75E-06	7.37E-05	2.84E-09	4.30E-07
	Dissolved Solids [kt]	2.48E-04	7.92E-08	3.59E-05	1.20E-04	4.96E-08	2.02E-05	7.73E-05	3.04E-08	1.03E-05	9.90E-05	3.28E-08	3.21E-06
	Chemical Oxygen Demand, COD [kt]	9.52E-06	1.36E-08	2.32E-06	4.62E-06	5.95E-09	1.43E-06	4.25E-06	3.05E-09	7.25E-07	1.02E-05	9.83E-10	1.81E-07
	Oil & Grease [kt]	3.46E-05	1.63E-08	1.47E-06	1.53E-05	7.03E-09	8.41E-07	1.11E-05	3.57E-09	4.25E-07	1.90E-05	9.66E-10	1.09E-07
	Sulphates [kt]	4.76E-05	9.86E-08	5.15E-06	2.18E-05	4.06E-08	2.95E-06	1.32E-05	1.99E-08	1.49E-06	1.38E-05	2.31E-09	3.77E-07
	Sulphides [kt]	3.11E-06	0.00E+00	3.98E-08	1.34E-06	0.00E+00	2.54E-08	9.58E-07	0.00E+00	1.22E-08	1.58E-06	0.00E+00	2.12E-10
	Nitrates & Nitrites [kt]	1.22E-06	5.96E-11	1.82E-08	5.40E-07	2.40E-11	1.01E-08	3.82E-07	1.16E-11	4.89E-09	6.16E-07	7.04E-13	1.16E-10
	Dissolved Organic Compounds [kt]	2.15E-06	2.41E-09	1.29E-06	1.14E-06	9.80E-10	8.23E-07	5.85E-07	4.77E-10	3.96E-07	1.98E-07	3.36E-11	2.75E-09
	Metals [kt]	1.69E-05	2.91E-08	2.84E-07	7.99E-06	1.19E-08	1.60E-07	5.69E-06	5.84E-09	9.25E-07	9.28E-06	5.98E-10	4.24E-06
Water & Solid Resource Use	Limestone [kt]	1.53E-02	5.04E-06	1.48E-03	1.35E-02	2.05E-06	4.25E-04	1.14E-02	9.96E-07	2.53E-04	2.46E-02	7.01E-08	2.44E-04
	Clay & Shale [kt]	2.28E-03	0.00E+00	5.00E-06	2.00E-03	0.00E+00	3.40E-06	1.63E-03	0.00E+00	1.85E-06	3.37E-03	0.00E+00	1.10E-06
	Iron Ore [kt]	2.06E-03	0.00E+00	3.20E-05	9.30E-04	0.00E+00	2.14E-05	6.71E-04	0.00E+00	1.03E-05	1.12E-03	0.00E+00	0.00E+00
	Sand [kt]	3.29E-03	0.00E+00	1.00E-06	1.94E-03	0.00E+00	1.00E-06	1.47E-03	0.00E+00	1.17E-04	2.67E-03	0.00E+00	5.83E-04
	Other [kt]	3.89E-03	0.00E+00	1.87E-03	1.58E-03	0.00E+00	8.94E-04	1.10E-03	0.00E+00	4.85E-04	1.69E-03	0.00E+00	2.81E-04
	Gypsum [kt]	1.04E-02	0.00E+00	0.00E+00	3.58E-03	0.00E+00	0.00E+00	1.88E-03	0.00E+00	0.00E+00	8.28E-04	0.00E+00	0.00E+00
	Aggregates [kt]	8.24E-02	0.00E+00	0.00E+00	7.44E-02	0.00E+00	0.00E+00	5.63E-02	0.00E+00	0.00E+00	1.03E-01	0.00E+00	0.00E+00
	Water [kt]	2.44E-01	0.00E+00	5.95E-02	1.19E-01	0.00E+00	3.80E-02	7.70E-02	0.00E+00	1.82E-02	9.87E-02	0.00E+00	3.91E-05
	Wood Fiber [kt]	1.35E-02	0.00E+00	0.00E+00	7.28E-03	0.00E+00	0.00E+00	3.50E-03	0.00E+00	0.00E+00	1.09E-05	0.00E+00	0.00E+00
Solid Waste	Organic Waste [kt]	5.67E-04	2.37E-03	0.00E+00	3.70E-04	1.36E-03	0.00E+00	1.78E-04	9.95E-04	0.00E+00	9.00E-07	1.72E-03	0.00E+00
	Mineral Waste [kt]	3.26E-03	2.38E-03	2.64E-04	2.56E-03	2.82E-03	1.68E-04	2.24E-03	2.18E-03	8.64E-05	5.05E-03	4.12E-03	2.78E-05
	Other Solid Waste [kt]	5.38E-03	4.28E-05	3.86E-04	2.54E-03	1.70E-05	2.06E-04	1.62E-03	8.25E-06	1.24E-04	1.99E-03	5.81E-07	1.28E-04

Derivation of Resource Use & Environmental Outputs per Length of Neighbourhood Infrastructure

Section A.3 described the methodology for neighbourhood infrastructure required. Once those infrastructure requirements were known, it was necessary to calculate the types and quantities of materials required for the construction phase of the infrastructure life-cycle. The "materials bill" required to construct the various infrastructure designs fall into the following categories:

- **Excavation Parameters**: This refers to estimates of the depth and width of the excavation required to lay pipe and road bed. The information contained under this activity stage feeds into the assumptions of the excavation equipment utilization and related operating energy of the excavation equipment, which drives the LCI analysis of energy use during this operation. It also drives some of the material usage estimates (e.g., granular backfill material).

- **Pipe & Trench Parameters**: This refers to the estimates of the pipe dimensions and thickness which drives the LCI analysis relating to the manufacture of the piping. The pipe and trench parameters drive the assumptions of concrete needed in catch basins and sidewalks, and the amount of ductile steel for manholes and storm water grates.

- **Road Bed & Sidewalk Bedding Materials:** This refers to estimates of the thickness and compaction of the gravel and other bedding material underlying the roadbeds and sidewalks.

- **Asphalt:** This refers to the assumptions of asphalt thickness and layering which drives the LCA analysis of the energy and materials required to produce and lay the asphalt.

- **Construction Equipment:** This refers to specifications of the excavation equipment used to install the infrastructure and the related operating energy per unit of pipe length and excavation depth/length. This serves the take-off for the LCI analysis of the life-cycle energy and materials required to supply and operate the equipment.

The energy use figures for on-site construction equipment are taken from a Swedish life cycle analysis study by the IVL Swedish Environmental Research Institute.[145] This study provided data for several different types of heavy machinery (e.g., excavators, dump trucks, rubber wheel loaders, compactors, asphalt pavers, etc.). Of these choices, a representative selection was made for each type of machine activity required to construct and install the infrastructure addressed in this LCI analysis. The equipment energy use data are based on the volume of material moved, or in the case of compactors and pavers, the area of ground covered.

[145] IVL Swedish Environmental Research Institute. March 2001. Life Cycle Assessment of Road, A Pilot Study for Inventory Analysis, Second Revised Edition. Håkan Stripple, B 1210 E, Gothenburg, Sweden. http://www.ivl.se/rapporter/pdf/B1210E.pdf. The Swedish values for fuel consumption by various heavy construction machinery were based on Volvo equipment which is sold internationally and hence, we believe these data to be equally applicable to Canada.

Exhibit A.13 profiles the material quantity and on-site construction requirements per 100 metres of road and accompanying in-ground water infrastructure.

Exhibit A.13: Infrastructure Material Quantity & On-Site Construction Requirements

Material or On-Site Construction Requirement	Type 1 Two-lane Local Road	Type 2 Two-lane Local Road	Type 3 Two-lane Collector Road	Type 4 Four-lane Collector Road
Excavation Parameters				
Stripping Depth (m)	0.300	0.300	0.300	0.300
Excavation Width (m)	3.35	3.35	3.42	3.50
Excavation Depth (m)	2.40	2.40	2.40	2.40
# of Compaction Layers (ea)	4	4	4	3
Maximum Straight Wall Trench Depth (m)	1.2	1.2	1.2	1.2
Maximum Depth of Compacting Layers (m)	0.5	0.5	0.5	0.5
Pipe & Trench Parameters				
PVC Storm Sewer ID (mm)	298	298	365	447
PVC Storm Sewer Thickness (mm)	10	10	12	14
PVC Storm Sewer Trench Depth (m)	2.40	2.40	2.40	2.40
PVC Storm Sewer Trench Width (m)	1.198	1.198	1.265	1.347
PVC Storm Sewer Connector Trench Width (m)	1.101	1.101	1.101	1.101
PVC Sanitary Sewer ID (mm)	201	201	201	201
PVC Sanitary Sewer Thickness (mm)	6	6	6	6
PVC Sanitary Sewer Trench Depth (m)	2.40	2.40	2.40	2.40
PVC Sanitary Sewer Trench Width (m)	1.101	1.101	1.101	1.101
PVC Water Main ID (mm)	151	151	151	151
PVC Water Main Thickness (mm)	8	8	8	8
PVC Water Main Trench Depth (m)	2.00	2.00	2.00	2.00
PVC Water Main Trench Width (m)	1.051	1.051	1.051	1.051
PVC Water Main Connector Trench Width (m)	1.051	1.051	1.051	1.051
Granular Base Below Pipes (m)	0.150	0.150	0.150	0.150
Granular Fill Above Pipes (m)	0.300	0.300	0.300	0.300
Maintenance Hole Depth (m)	2.4	2.4	2.4	2.4
Maintenance Hole I.D. (mm)	1200	1200	1200	1200
Maintenance Hole Thickness (mm)	125	125	125	125
Maintenance Hole Base Thickness (mm)	203	203	203	203
Maintenance Hole Top Opening I.D. (mm)	685	685	685	685
Maintenance Hole Top Thickness (mm)	203	203	203	203
Catch Basin Depth (m)	2.1	2.1	2.1	2.1
Catch Basin Inside Width (square) (mm)	610	610	610	610
Catch Basin Thickness (mm)	115	115	115	115
Catch Basin Base Thickness (mm)	150	150	150	150
Catch Basin PVC Connector I.D. (mm)	201	201	201	201
Catch Basin PVC Connector Thickness (mm)	6	6	6	6
Hydrant PVC Connector I.D. (mm)	151	151	151	151
Hydrant PVC Connector Thickness (mm)	8	8	8	8
San. Connection I.D. to Sidewalk (mm)	149	149	149	149
San. Connection Thickness to Sidewalk (mm)	5	5	5	5
San. Connection I.D. Sidewalk to House (mm)	101	101	101	101
San. Pipe Thickness Sidewalk to House (mm)	3	3	3	3
San. Connection Setback (from Sidewalk) (m)	5.0	5.0	5.0	5.0

Exhibit A.13 (cont'd): Infrastructure Material Quantity & On-Site Construction Requirements

Material or On-Site Construction Requirement	Type 1	Type 2	Type 3	Type 4
	Two-lane Local Road	Two-lane Local Road	Two-lane Collector Road	Four-lane Collector Road
Road Bed & Sidewalks				
Granular B Thickness (m)	0.300	0.300	0.400	0.600
# Granular B Compaction Layers (ea)	1	1	1	2
Granular A Thickness (m)	0.150	0.150	0.150	0.150
# Granular A Compaction Layers (ea)	1	1	1	1
Sidewalk Concrete Thickness (m)	0.125	0.125	0.125	0.125
Sidewalk Granular A Thickness (m)	0.100	0.100	0.100	0.100
# Sidewalk Granular A Compaction Layers (ea)	1	1	1	1
Asphalt				
Base Thickness (m)	0.050	0.050	0.100	0.120
Top Thickness (m)	0.040	0.040	0.040	0.040
# of Layers (Base & Top) (ea)	2	2	3	3
Construction Equipment				
Loader (MJ/m3)	3.00	3.00	3.00	3.00
Excavator (MJ/m3)	3.32	3.32	3.32	3.32
Dump Truck (MJ/Lm3.km)	6.77	6.77	6.77	6.77
Bulldozer (MJ/m3)	3.32	3.32	3.32	3.32
Compactor (MJ/m2)	0.6281	0.6281	0.6281	0.6281
Asphalt Paver (MJ/m2)	0.594	0.594	0.594	0.594
Asphalt Roller Compactor (MJ/m2)	0.7988	0.7988	0.7988	0.7988
Asphalt Rubber Wheel Compactor (MJ/m2)	0.7988	0.7988	0.7988	0.7988
Swelling Factor	1.3	1.3	1.3	1.3
Average Length of Construction Site (km)	0.5	0.5	0.5	0.5

Exhibit A.14 presents the resulting estimates of on-site construction direct operating energy use by various crew activities for each neighbourhood infrastructure type.

Exhibit A.14: On-site Construction Direct Operating Energy Use by Neighbourhood Infrastructure Type

On-site Equipment Diesel Energy Use [GJ]	Type 1	Type 2	Type 3	Type 4
	Two-lane Local Road	Two-lane Local Road	Two-lane Collector Road	Four-lane Collector Road
Sewer Crew	18.8	25.6	23.0	23.9
Road Crew	12.7	13.5	18.3	31.3
Paving Crew	3.5	3.9	7.2	9.9
Total	35.0	43.1	48.5	65.1

And, after taking all of the above into account by life-cycle stage, Exhibit A.15 shows the resulting per-length coefficients for each neighbourhood infrastructure type. These values were multiplied by the estimated length of required infrastructure during the study period to determine the non-operating resource use and environmental outputs from constructing new neighbourhood infrastructure.

Exhibit A.15: Per-Length Resource Use & Environmental Output Factors, by Neighbourhood Infrastructure Type

		Road, Water & Wastewater Infrastructure							
	Category	Type 1		Type 2		Type 3		Type 4	
	Lifecycle Stage	Extraction & Manufacturing	On-site Construction	Extraction & Manufacturing	On-site Construction	Extraction & Manufacturing	On-site Construction	Extraction & Manufacturing	On-site Construction
	Multiplier Units	/100m of road		/100m of road		/100m of road		/100m of road	
Primary Fuel Use	Liquid Petroleum Gas, LPG [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Diesel [PJ]	1.12E-04	1.35E-04	1.30E-04	1.51E-04	1.63E-04	1.91E-04	2.44E-04	2.86E-04
	Gasoline [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Natural Gas [PJ]	2.74E-04	2.96E-06	2.95E-04	3.60E-06	4.84E-04	4.11E-06	6.83E-04	5.60E-06
	Wood [PJ]	1.13E-08	5.72E-09	1.18E-08	7.00E-09	1.71E-08	7.92E-09	2.46E-08	1.07E-08
	Coal [PJ]	3.52E-04	3.78E-07	3.88E-04	4.63E-07	6.35E-04	5.24E-07	9.01E-04	7.08E-07
	Heavy Fuel Oil [PJ]	7.35E-04	3.57E-05	7.47E-04	4.37E-05	1.30E-03	4.94E-05	1.84E-03	6.67E-05
	Nuclear [PJ]	1.26E-04	1.34E-07	1.32E-04	1.64E-07	2.18E-04	1.85E-07	3.08E-04	2.50E-07
	Feedstock Fuels [PJ]	7.90E-04	0.00E+00	7.92E-04	0.00E+00	1.38E-03	0.00E+00	1.95E-03	0.00E+00
	Other Oil-based Fuels [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total Primary Fuels [PJ]	2.39E-03	1.74E-04	2.48E-03	1.99E-04	4.18E-03	2.45E-04	5.92E-03	3.59E-04
Air Emissions	Carbon Dioxide, CO2 from non-biomass [kt]	8.33E-02	2.99E-03	9.64E-02	3.63E-03	1.52E-01	4.14E-03	2.17E-01	5.64E-03
	Carbon Dioxide, CO2 from biomass (biogenic/neutral) [kt]	1.59E-06	6.73E-07	1.98E-06	8.24E-07	2.73E-06	9.32E-07	4.00E-06	1.26E-06
	Carbon Monoxide, CO [kt]	6.07E-05	1.36E-06	6.86E-05	1.52E-06	1.01E-04	1.93E-06	1.45E-04	2.88E-06
	Sulphur Oxides, SOx [kt]	6.77E-04	6.85E-07	7.42E-04	7.67E-07	1.22E-03	9.71E-07	1.73E-03	1.45E-06
	Nitrogen Oxides, NOx [kt]	2.61E-04	2.50E-06	3.14E-04	2.80E-06	4.53E-04	3.55E-06	6.54E-04	5.31E-06
	Nitrous Oxide, N2O [kt]	3.90E-08	3.09E-13	8.04E-08	3.78E-13	9.30E-08	4.28E-13	1.38E-07	5.78E-13
	Total Particulate Matter, TPM [kt]	6.11E-03	6.80E-07	6.64E-03	7.61E-07	8.47E-03	9.64E-07	1.27E-02	1.44E-06
	Non-Methane Volatile Organic Compounds, NMVOC [kt]	2.53E-06	5.56E-09	3.16E-06	6.80E-09	4.34E-06	7.70E-09	6.37E-06	1.04E-08
	Methane, CH4 [kt]	4.05E-05	7.12E-10	4.93E-05	8.40E-10	7.08E-05	9.52E-10	9.95E-05	1.25E-09
	Metals [kt]	3.66E-07	1.36E-12	3.76E-07	1.66E-12	6.51E-07	1.88E-12	9.20E-07	2.54E-12
	Total Greenhouse Gases (CO2-equivalent) [ktCO2e]	9.58E-02	2.99E-03	1.12E-01	3.63E-03	1.74E-01	4.14E-03	2.48E-01	5.64E-03
Water Emissions/Pollutants	Biological Oxygen Demand, BOD [kt]	7.28E-07	1.13E-09	7.62E-07	1.27E-09	1.24E-06	1.61E-09	1.74E-06	2.40E-09
	Suspended Solids [kt]	1.23E-03	7.47E-09	1.33E-03	8.36E-09	1.70E-03	1.06E-08	2.55E-03	1.59E-08
	Dissolved Solids [kt]	2.10E-04	3.29E-07	2.29E-04	3.68E-07	3.71E-04	4.66E-07	5.22E-04	6.97E-07
	Chemical Oxygen Demand, COD [kt]	5.50E-06	8.16E-09	5.89E-06	9.13E-09	9.36E-06	1.16E-08	1.31E-05	1.73E-08
	Oil & Grease [kt]	9.57E-06	7.70E-09	1.04E-05	8.61E-09	1.51E-05	1.09E-08	2.19E-05	1.63E-08
	Sulphates [kt]	1.22E-05	9.74E-09	1.78E-05	1.09E-08	2.32E-05	1.38E-08	3.27E-05	2.07E-08
	Sulphides [kt]	1.38E-10	7.61E-16	6.64E-10	9.31E-16	6.64E-10	1.05E-15	1.02E-09	1.42E-15
	Nitrates & Nitrites [kt]	1.16E-08	4.30E-18	5.24E-08	5.27E-18	5.29E-08	5.96E-18	8.06E-08	8.05E-18
	Dissolved Organic Compounds [kt]	1.39E-06	9.37E-15	1.63E-06	1.15E-14	1.84E-06	1.30E-14	2.31E-06	1.75E-14
	Metals [kt]	1.46E-06	2.04E-09	1.75E-06	2.28E-09	2.63E-06	2.89E-09	3.77E-06	4.32E-09
Water & Solid Resource Use	Limestone [kt]	4.43E-03	8.32E-07	2.10E-02	1.02E-06	2.10E-02	1.15E-06	3.21E-02	1.56E-06
	Clay & Shale [kt]	6.12E-04	0.00E+00	2.93E-03	0.00E+00	2.93E-03	0.00E+00	4.48E-03	0.00E+00
	Iron Ore [kt]	3.30E-05	0.00E+00	1.62E-04	0.00E+00	1.62E-04	0.00E+00	2.49E-04	0.00E+00
	Sand [kt]	2.99E-04	0.00E+00	1.43E-03	0.00E+00	1.43E-03	0.00E+00	2.18E-03	0.00E+00
	Other [kt]	5.39E-04	0.00E+00	5.93E-04	0.00E+00	6.75E-04	0.00E+00	8.28E-04	0.00E+00
	Gypsum [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Aggregates [kt]	2.38E+00	0.00E+00	2.64E+00	0.00E+00	3.35E+00	0.00E+00	5.02E+00	0.00E+00
	Water [kt]	6.30E-02	0.00E+00	8.13E-02	0.00E+00	9.04E-02	0.00E+00	1.16E-01	0.00E+00
	Wood Fiber [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Solid Waste	Organic Waste [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Mineral Waste [kt]	5.14E-04	0.00E+00	2.62E-03	0.00E+00	2.62E-03	0.00E+00	4.02E-03	0.00E+00
	Other Solid Waste [kt]	1.44E-03	1.47E-05	2.05E-03	1.80E-05	2.79E-03	2.03E-05	4.02E-03	2.74E-05

A.4.3 Data Limitations

The life-cycle analysis generated key lifecycle coefficients which, in turn, formed the basis for the overall residential sector impact. The lifecycle coefficients were generated on the basis of detailed physical depictions of four residential building archetypes: single detached, row/townhouse, low-rise apartment buildings and high-rise multi-unit buildings. However, these archetype depictions are national in character, meaning that there was no provincial or regional differentiation of key physical housing construction features. Therefore, the lifecycle coefficients do not capture possibly important regional variations of construction practice and dwelling stock distributions. This is an important limitation given that, as previously noted, the BAU neighbourhood profile is driven largely by expectations of major growth in three CMAs, Vancouver, Calgary and Toronto.

The major implication of this limitation is that particular provincial/territorial intensities of resource use and resulting environmental impacts are under-represented and subsumed in the national LCA profile. For example, operating a single-family dwelling in Alberta might require more primary energy than in Quebec and would generate more GHG emissions due to the fossil fuel mix of the electricity supply system in the province.

A.5 METHODOLOGY FOR MUNICIPAL WATER SYSTEM DEMAND TO SERVICE DWELLINGS

As mentioned under Scope in Section 3.1, this study includes estimating the operating water use of dwellings, the operating wastewater production from dwellings, the operating energy use for municipal water supply and wastewater systems needed to service dwellings, and the resource use and environmental outputs from providing that operating energy to municipal water systems. This sub-section provides the basis for all of these calculations by describing the methodology used to estimate the annual water use and wastewater production resulting from the daily habitation and operation of dwellings.

A.5.1 Modelling Platform

Marbek's Residential Sector Energy End-use Model (RSEEM) has been used as the platform to develop a water use accounting model. The resulting Residential Sector Water End-use Model (RSWEM) consists of two modules:

- General Parameters module that contains residential sector stock and activity data (e.g., number of dwellings, growth rates etc.); and
- Technology Module that contains data on water technology saturation levels, unit water use, etc.

RSWEM combines the data from each of the modules and calculates total water use in litres, by dwelling type and end-use, for milestone years during the study period.

A.5.2 Methodology, Assumptions & Data Sources

This sub-section is presented as follows:

- Overall Methodology for Dwelling Water Analysis
- Key Data Sources
- Derivation of Water Use per Dwelling in 2004
- Derivation of Water Use per Dwelling in 2025
- Derivation of Wastewater Production per Dwelling in 2004 & 2025

Overall Methodology for Dwelling Water Analysis

The overall approach for aggregating the water use and wastewater production of all dwellings is to take the water use per dwelling (by end use) for each dwelling type and multiply it by the total number of dwellings of each dwelling type. A similar calculation was used for wastewater production for dwellings.

The total number of dwellings by dwelling type is taken from the analysis described in Section A.1. The water analysis is based on household size (i.e., number of residents in the household), so five dwelling types were analysed based on their differing household sizes, as shown in Exhibit A.16. In particular, mobile homes were analysed separately from single detached houses, then the aggregate results for all dwellings of each dwelling type were added afterward, to produce an aggregate for the study dwelling type of Single Detached.

Exhibit A.16: Household Sizes Used for Dwelling Water Analysis[146]

Dwelling Type used within Water Analysis	Dwelling Type used to Present Results	Average Household Size [people/dwelling]	
		2004	2025
Single Detached	Single Detached	2.9	2.9
Mobile		2.3	2.3
Row & Semi-Detached	Row/Town	2.6	2.6
Low-rise MURB	Low-rise MURB	1.9	1.9
High-rise MURB	High-rise MURB	1.8	1.8

The remainder of this sub-section provides further elaboration of the data sources and methodology for deriving dwelling water use intensities per dwelling type.

Key Data Sources of Water Use Data per Dwelling

The main data sources used for the water and wastewater demand analysis are:

- American Water Works Association: 1999. Residential End Uses of Water
- CMHC: 2000. Household Guide to Water Efficiency
- Environment Canada: 2004 Municipal Water Use Report
- Marbek in-house database which, among other things, contains detailed residential water audits from a number of jurisdictions
- NRCan: Energy Consumption of Major Household Appliances Marketed in Canada
- Statistics Canada: Household Facilities and Equipment Survey
- US Environmental Protection Agency: 1998. Water Conservation Plan Guidelines
- Utility equipment saturation surveys and customer surveys

[146] Household sizes from NRCan, 2004 and StatCan, 2001. Household sizes were frozen at 2004 values due to lack of study resources and lack of available data.

The primary data sources used for the 2004 water end-use intensities were water use data from surveys and audits conducted in Canada and North America, compiled by NRCan and Statistics Canada. Market penetration of specific technologies associated with end-uses was determined from industry sales data and Statistics Canada household surveys.

Another significant source of data listed above was Marbek's in-house database of water use characteristics in the residential sector. While some of these data sets are fairly comprehensive, all of them are limited to only the jurisdictions for which the studies were commissioned, so each data set provides poor resolution of the variation of water usage between different dwelling types and regions. Therefore, the challenge for this study was to expand the Marbek data platform to represent reasonable national averages of water use for each dwelling type.

Derivation of Water Use per Dwelling in 2004

The objective of this part of the analysis was to generate defensible per-dwelling and water end-use-specific intensities for the base year. A water end-use is primarily defined as the final application or final use to which water is applied before it is discharged to the sewer collection system or outdoor environment.

For this analysis, ten water end-uses were defined — eight indoor and two outdoor uses:

Indoor

- Toilet — Water use associated with people flushing toilets
- Showerhead — Water use associated with people using showers.
- Bath — Water use associated with people using bath-tubs
- Faucets — Water use of indoor faucets typically located in kitchens, bathrooms and laundry rooms.
- Clothes Washer — Water use for automated clothes washers
- Dishwasher — Water use for automated dish washers
- Household Leaks — While not a desired end-use; household leaks contribute significantly to total residential use, primarily through leaking toilets and faucets.
- Other Domestic — Specialty fixtures (e.g., hot tubs, fountains, etc.), make-up for closed water systems (e.g., radiators, radiant floor heating, ground-source heat pumps), and other end uses not covered under other end-use categories

Outdoor

- Outdoor Residential Use — Water use primarily for irrigation, but also outdoor water use for cleaning and swimming pools.
- Distribution System Leaks — While not a desired end-use; a proportion of distribution system leaks can be attributed to the residential sector.

Water end-use intensities were derived from the analysis of two intermediate variables: i) end-use-specific activity levels (e.g., the number of daily toilet flushes); and ii) the technical performance of the water end-use activities (e.g., the volume of litres per toilet flush). This leads to the following formula:

*Water end-use intensity = water use activity level (activity/capita/day) * water use technical performance (e.g., litres per flush by type of toilet)*

The two variables used in the above calculation are derived below.

Derivation of Water End-Use Activity Levels

The review of current documentation confirmed that the preferred unit of measure for the activity levels needed to be based on household occupancy and presented on a per capita basis. The water use patterns in all dwellings are largely driven by occupant needs and behaviour. In the absence of better data, the analysis assumed that, on a per capita basis, water use in mobile homes was similar to that in row housing. In terms of absolute water consumption, this assumption has very little implication; mobile holes represent such a small share of total dwelling stock. The resulting water activity levels by end use are shown in Exhibit A.17.

Exhibit A.17: Water Activity-Level Data, by Dwelling Type, 2004[147]

Water End Use	Activity-Level Measure	Dwelling Type		
		Single Detached	Row/Town & Mobile Homes	Low-rise & High-rise MURBs
Toilet	flushes/capita/day	5.05	5.05	5.05
Standard Showerhead	showers/capita/day	4.92	4.18	3.69
Low-flow Showerhead	showers/capita/day	5.10	4.34	3.83
Bath	baths/capita/day	0.11	0.09	0.08
Faucets	minutes/capita/day	5.46	4.64	4.09
Clothes Washer	cycles/capita/day	0.35	0.35	0.26
Dishwasher	cycles/capita/day	0.16	0.14	0.12

As shown above, the research indicated that water use activity levels rarely changed according to water end-use technology, meaning that people within a certain dwelling type maintained the same activity level (e.g., flushes per capita per day or cycles per capita per day) despite having adapted to low water use technologies. The one exception was showerhead technologies, where data suggested that people take longer showers when using low-flow showerheads, as shown in the exhibit above.

Also as shown above, the research indicated that water use activity levels tend to vary among the three main dwelling types considered in the water use model. Water technologies in single detached houses have higher activity levels (per

[147] Derived from: a) Mayer, P. and DeOreo, W. et. al. American Water Works Association Research Foundation. 1999. *Residential End Uses of Water*.
b) US Environmental Protection Agency. 1998. *Water Conservation Plan Guidelines*. Appendix A.
c) POLIS Project on Ecological Governance, University of Victoria. October 2006. *Thinking Beyond Pipes and Pumps*.
d) City of Maple Ridge. June 2004. *Water Consumption in Maple Ridge*. Technical Bulletin. No. 2. June 2004

capita) than in other dwelling types, possibly due to the higher availability of bathing/showing and sinks and, therefore, more time spent for these activities.

Performance of Water End-Use Technologies

Residential water end-uses are serviced by the following technologies: toilets, showerheads, baths, faucets, clothes washers and dishwashers. The review of documentation (see Key Data Sources of Water Use Data per Dwelling, above) focused on derivation of the two main factors affecting the technical performance of the water end-use activities: i) market saturation of end-use technology according to type and ii) technical efficiency of the end-use technologies.

- **Technical Performance**: Exhibit A.18 presents the assumed performance values for the water end-use technologies modelled in this analysis.

- **Market Saturation**: Exhibit A.18 also profiles the market saturation of water end-use technologies according to dwelling type. As shown, the saturation tends to vary according to dwelling type for showerheads, dishwashers and clothes washers but, otherwise, does not appear to be driven by dwelling type. The existing market penetration rate of technologies generally did not vary between end-uses, except where detailed market data by dwelling type was available.

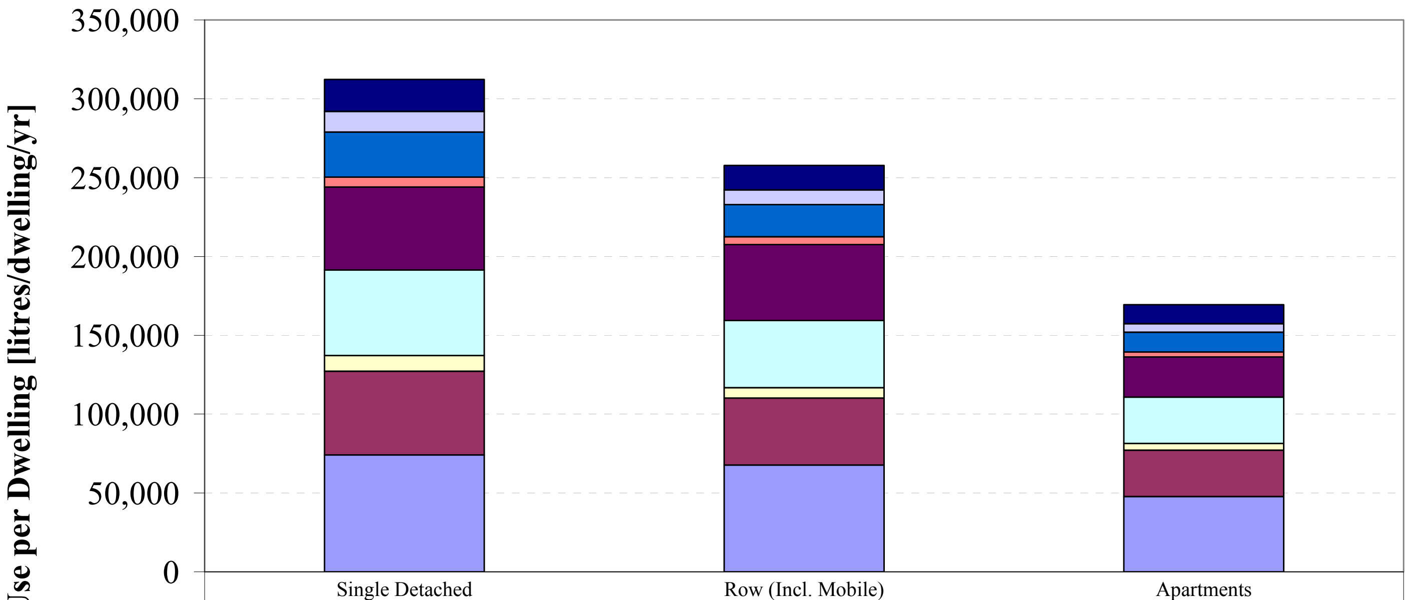
Exhibit A.18: Technical Performance & Market Saturation of Water End-Use Technologies in 2004, by Dwelling Type

Water End Use	Technology Type	Technical Performance: Water Usage		Market Saturation by Dwelling Type, 2004		
				Single Detached	Row/Town & Mobile Homes	Low-rise & High-rise MURBs
Toilet	Dual-flush	4.3	litres / flush	1.0%	1.0%	1.0%
	Low-flush	6.0		29.0%	29.0%	29.0%
	Medium	13.0		35.0%	35.0%	35.0%
	Conventional	22.0		35.0%	35.0%	35.0%
Showerhead	Low-flow	6.6	litres / minute	58.3%	54.6%	40.6%
	Standard	14.7		41.7%	45.4%	59.4%
Bath	Efficient	57.5	litres	20.0%	50.0%	50.0%
	Conventional	95.0		80.0%	50.0%	50.0%
Faucets	Low-flow	6.3	litres / minute	50.2%	48.2%	31.1%
	Standard	12.7		49.8%	51.8%	68.9%
Clothes Washer	ENERGY STAR	87.5	litres / cycle	10%	10.0%	10.0%
	Standard	150.0		90%	90.0%	90.0%
Dishwasher	ENERGY STAR	26.5	litres / cycle	20%	20.0%	20.0%
	Standard	40.0		80%	80.0%	80.0%

The resulting end-use intensities were compared to several available published sources including residential water use in Toronto, Winnipeg, Cambridge-Waterloo and national CMHC statistics.[148] The end-use intensities compared reasonably well, falling within the range of the studies and no calibration adjustments were required.

The final end-use profiles are presented in Exhibit A.19, by dwelling type.

Exhibit A.19: Annual Water End-Use Intensities by Dwelling Type, 2004



	Single Detached	Row (Incl. Mobile)	Apartments
Outdoor Use	20,194	15,549	12,116
Other Domestic	13,131	9,318	5,366
Leaks	28,545	20,425	12,589
Dishwasher	6,386	4,956	3,088
Clothes Washer	52,630	48,053	25,451
Faucets	54,160	42,586	29,523
Bath	9,987	6,754	4,209
Shower	53,145	42,463	29,370
Toilet	74,131	67,684	47,797

□

Derivation of Water Use per Dwelling in 2025

The water end-use intensities for the BAU period are calculated as a function of the natural replacement rate of the end-use technologies (e.g., 20 years for toilets), the number of new dwellings constructed and the efficiency of the predominant new technology available on the market. The derivation of 2025 water use intensities is below.

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148 Derived from: a) Mayer, P. and DeOreo, W. et. al. American Water Works Association Research Foundation. 1999. *Residential End Uses of Water*.
b) TetrES Consultants for City of Winnipeg, Waster & Waste Department. 1994. *A New Water Project Model Accounts for Water Efficiency*.
c) Pacific Institute. 2003. *Waste Not, Want Not: The Potential for Urban Water Conservation in California*.
d) City of Toronto, Works & Emergency Services. *Water Efficiency Plan*. http://www.toronto.ca/watereff/plan.htm

Market Saturation for Renovation & Retrofit Applications

The BAU analysis assumes that, in renovated or retrofitted dwellings, old and inefficient water-use fixtures (e.g., faucets, toilets, showerheads) tend to be replaced with low water-use (higher performance) technologies that have become predominantly available in the marketplace. The replacement rate of water end-use fixtures was based on typical fixture life spans reported by the U.S. Environmental Protection Agency.[149]

The BAU market penetration of water end-use technologies was primarily based on estimates of future market sales in Canada or in the United States.[150] Toilet, showerhead, clothes washer and dishwasher sales projections are all dominated by new technologies that utilise low-flow designs — many designated by the ENERGY STAR performance label.

Market Saturation for New Construction Applications

Water end-use intensities for new dwellings were considered to be identical to both renovated and retrofit end-use intensities. While this is slightly overestimates water use in new dwellings, there is no credible market data that further differentiates the technology chosen under new, renovated or retrofitted circumstances.

Using an example of a major water end use, average toilet water use per dwelling (average of all dwellings, existing and new) is estimated to decline as follows during 2004–2025:

- Single Detached: from 72,000 to 45,000 litres/dwelling
- Row/Town & Mobile: from 66,000 to 41,000 litres/dwelling
- Low-rise & High-rise MURBs: from 47,000 to 28,000 litres/dwelling

Derivation of Wastewater Production per Dwelling in 2004 & 2025

This study assumed that the annual volume of water used indoors by dwellings gets discharged back to the wastewater system, requiring pumping and treatment, while the outdoor residential water use (e.g., irrigation, cleaning, swimming pools, outdoor hot tubs, etc.) is discharged to nature. This assumption is accurate to a large degree, aside from the negligible share of human-ingested water that is not discharged to the wastewater system via toilets. The same volume of water calculated for water supply distribution system leaks was also assumed to make its way into wastewater collection systems through leaks of groundwater into underground sewers.

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149 US Environmental Protection Agency. 1998. *Water Conservation Plan Guidelines*.

150 Sources: a) Marbek Resource Consultants for Terasen Gas. 2004. *Terasen Gas Conservation Potential Review*. (Adapted data on low-flow showerheads and faucets)
b) U.S. Department of Energy. Website: *Energy Efficiency & Renewable Energy — Appliances & Commercial Standards*. http://www.eere.energy.gov/buildings/appliance_standards/

A.5.3 Data Limitations

The following BAU activity-level assumptions were also applied to the analysis, due to lack of data suggesting otherwise:

- The water end-use activity levels in the base year were held constant for the BAU period. There is no documented evidence to indicate how these activity levels might change over time.

- The base year proportion of indoor to outdoor water use was held constant due to limited study resources. It is recognized that, with rising water prices and decreasing available water resources, this proportion is likely to change in reality.

- The base year indoor and outdoor leakage factors were also frozen for the BAU period. In the case of indoor leaks, it is not anticipated that new toilet, faucet or showerhead end-use technologies would have an impact in reducing the incidence of leaks.

- It is anticipated that major infrastructure improvements (e.g., pipe replacement and lining installations) would not be carried out in a significant enough share of infrastructure to reduce the national average system distribution losses.

The supply water and wastewater analysis also includes the following limitations:

- Household water usage was based on a compilation of studies from across North America. These studies contained the best available data but tended to have a bias for U.S. jurisdictions. Where sufficient Canadian data was available on household water usage, Canadian data was used; however, in most cases this data was insufficient or unavailable.

- Regional/provincial differences in household water use, other than household type and size, were not accounted for in the model.

- The existing market penetration of water end-use technologies (i.e., toilets, showerheads, faucets, dishwashers and cloth washers) were based on a limited Canadian dataset that likely have a significant margin of error. In some cases US market data was used to estimate penetration. Potential differences in market penetration between regions and dwelling types were also generally not accounted for in the model.

- Very limited data was available to estimate outdoor household water use. Due to data limitations, there is a high degree of uncertainty associated with this metric, although outdoor water use only represents about 6% of total household water use, as shown in Exhibit A.19.

- Household water use was calculated based on the number of residents in each dwelling type and was not related to the number of fixtures that are installed in each dwelling. This may be a source of error for fixtures where the number of fixtures has an impact on water use.

- The future market penetration of water end-use technologies assumes that high efficiency technologies that are available today would dominate new entry into the marketplace and would replace existing equipment based on average lifetime equipment rates. However, new emerging technologies or accelerated equipment replacement programs are not considered by the model.

- The analysis assumes that the water end-use fixtures and water demand for each dwelling type would remain the same in the future. In reality, new water end-uses may emerge or their prevalence may change in the future. (e.g., people may take more showers than baths in the future, or the percentage of households with swimming pools may substantially decrease).

- The water end-use model can only estimate water use for dwelling types that are connected to municipally supplied water, and does not make estimates for dwellings that are on private well systems.

- Also, as mentioned above, groundwater leaks into sewers were assumed to be the same as municipal distribution system water leaks. This was due to lack of available information on the average in Canada.

A.6 METHODOLOGY FOR DIRECT OPERATING ENERGY FOR DWELLINGS

This sub-section presents the method used to derive the operating energy impacts associated with the habitation and operation of dwellings in the study base year and BAU period.

A.6.1 Modelling Platform

The Marbek Residential Sector Energy End-use Model (RSEEM) accounting model has been used as the platform to derive the aggregate energy use measures. RSEEM consists of three modules:

- A General Parameters module that contains residential sector stock and activity data (e.g., number of dwellings, growth rates etc.);
- A Thermal Archetype module, as noted above, that contains data on the heating and cooling loads in each archetype; and
- An Appliance Module that contains data on appliance and other, non-space heating and cooling saturation levels, fuel shares, unit energy use etc.

RSEEM combines the data from each of the modules and provides total energy use by dwelling type and end-use for each of the target years.

A.6.2 Overall Methodology & Data Sources

Overall Methodology

The calculation of operating energy, at the national and regional levels, is the result of a bottom-up analytical approach that utilizes the Marbek accounting model described above. The aggregate energy consumption is the result of the following relationship:

Direct operating use of all dwellings =
*Energy use per dwelling (by energy end-use) for each dwelling type **
Total # dwellings of each dwelling type

The dwelling stock profile, for both the baseline and BAU scenarios, is taken from the analysis described in Section A.1. Hence, the focus of the ensuing discussion is on the derivation of the baseline and BAU energy intensities.

Over the years Marbek has built an extensive in-house database of energy end-use characteristics in the residential sector, on the basis of several utility and government funded studies, including current work in B.C. and Newfoundland and Labrador. While some of these data sets are rich in terms of comprehensiveness and detail, they are limited to the jurisdictions and service territories for which the studies were commissioned. Therefore, the challenge for this study was to expand the Marbek data platform to the national inventory of data as obtained from NRCan, from which national levels patterns and intensities could be characterized.

An energy end use is defined as the service which is being provided through the utilization of the energy supply being provided to the dwelling premises.

The major dwelling energy end-uses analysed are as follows:

- *Space heating* — All space heating, including both central heating and supplementary heating (e.g., portable electric space heaters)
- *Space cooling* — All space cooling, including both central air conditioning (AC) and room or portable AC
- *Ventilation* — Primarily the furnace fan, but also includes the fan in heat recovery ventilators as well as kitchen and bathroom fans
- *Domestic hot water (DHW)* — Heating of water for domestic uses, excluding heating water for hydronic (radiant floor) space heating
- *Major appliances* — Includes cooking appliances, refrigerator, freezer, dishwasher, clothes washer, and clothes dryer
- *Lighting and controls* — Includes interior, exterior and holiday lighting
- *Other* — Televisions, set-top boxes (digital cable and satellite converters), entertainment systems, computers, computer peripherals, etc.

Key Data Sources

The main data sources for the operating energy analysis are as follows:

- CMHC: Canadian Housing Observer 2006 – Housing Data Tables 2005
- CMHC: 4th Quarter Housing Market Outlook, 2006
- Marbek in-house database which, among other things contains residential building archetypes for Ontario, Quebec, Manitoba and B.C.
- Marbek-Jaccard study for the Canadian Gas Association, which has a housing database.
- NRCan: Canada's Energy Outlook 2006
- NRCan: Energy Use Data Handbook (EUDH) is compiled from various residential sector surveys
- NRCan: Survey of Household Energy Use (SHEU), 2003
- Canadian Building Energy End-use Data & Analysis Centre (CBEEDAC)
- NRCan: Energy Consumption of Major Household Appliances Marketed in Canada
- NRCan: EnerGuide for Houses Database
- Statistics Canada: Household Facilities and Equipment Survey
- Utility equipment saturation surveys and customer surveys

The primary data source is the NRCan Comprehensive Energy Use Database (CEUD), which contains:

- Total provincial energy consumption by end-use, including heating and domestic hot water (DHW) by dwelling type;
- Household data used as the basis for determining per-dwelling energy end-use intensities (EUIs); these per-dwelling EUIs inherently take into consideration equipment saturations and fuel share; and
- Heating equipment stock data which provides for the calculation of space heating fuel shares by building type and region.

Marbek's in-house database was used for comparison (spot checking on a regional basis), to confirm that the national end-use values were reasonable.

A.6.3 Derivation of Energy End-Use Intensities for Base Year 2004

The derivation of the baseline EUIs using adjustments to the CEUD data involved a few important adjustments of note, elaborated below.

Step 1: Derive Low-rise & High-rise MURB EUIs for Space Heating

Data was gleaned from the CEUD to derive the space heating EUIs for 2004 for each dwelling type. Various adjustments were made based on findings from the Marbek studies and related database.

The main adjustment was taken with regard to the apartment space heating EUIs from the CEUD. They had to be further delineated according to low- and high-rise multi-unit residential buildings (MURBs). A proportion calculation was applied on the basis of the estimated suite-to-corridor space heating energy consumption:

- Low-rise MURB unit space heating energy consumption accounts for approximately 70% of the total, with building corridors accounting for the remaining 30%.
- High-rise MURB space heating energy consumption is approximately 10% higher in corridors.

Step 2: Derivation of EUIs for other end-uses

Cooling EUI adjustments take into account important regional differences to cooling load, efficiency improvements attained in cooling equipment, and increased usage patterns. Technical efficiency in cooling equipment has increased substantially, with an energy intensity reduction of 2% per square meter during 1990–2004, largely stemming from the regulation of room and central air conditioners under Canada's Energy Efficiency Regulations. Despite increases in technical efficiency, absolute energy consumption for cooling has increased substantially due to increased saturation of air conditioning load; it plays the single largest role of any residential end-use in contributing to peak power requirements in Ontario (33% of peak residential summer demand).[151] Between 1990 and 2004, both cooled residential floor space and the number of air conditioning units doubled.

Lighting accounts for approximately 5% of end-use energy consumption in the residential sector. Residential lighting energy intensity improved 2% from 1990 to 2004 on a per square meter basis. However, absolute energy consumption for lighting still increased slightly from 1990 to 2004 because of the growth in average dwelling sizes. For the BAU scenario, future regulatory interventions (e.g., for compact fluorescent lights) were not taken into account.

Values for the remaining end-use energy categories were obtained from NRCan's Energy Use Data Handbook.

The resulting energy EUIs for existing, unrenovated dwellings over the study period are presented in Exhibit A.20.

[151] Ontario Conservation Bureau. 2006. *Ontario – a new era in electricity conservation – Annual Report 2006*. p. 24. http://www.conservationbureau.on.ca/Storage/16/2123_CECOAR2006.pdf

Exhibit A.20: Energy End-use Intensities (EUIs) for Existing Unrenovated Dwellings during 2004–2025

	Per-Dwelling Energy End-use Intensities by Region & Dwelling Type [GJ/yr]							
Energy End Use & Dwelling Type	**Territories**	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**Atlantic**
Space Heating								
Single Detached	81	76	121	93	88	112	118	88
Row/Town	43	41	54	55	45	69	85	51
Low-rise MURB	21	17	38	23	22	33	37	25
High-rise MURB	22	18	39	24	23	34	39	27
Domestic Hot Water								
Single Detached	11.4	16.7	20.3	17.5	16.7	17.3	14.4	13.2
Row/Town	9.3	14.3	17.2	15.0	14.2	15.3	12.1	10.6
Low-rise MURB	6.4	7.9	9.6	8.6	8.5	8.5	8.1	7.2
High-rise MURB	6.4	7.9	9.6	8.6	8.5	8.5	8.1	7.2
Space Cooling								
Single Detached	0	0.7	1.74	0.4	1.5	2.8	0.8	0.05
Row/Town	0	0.4	0.77	0.2	0.7	1.7	0.6	0.03
Low-rise MURB	0	0.1	0.55	0.1	0.4	0.8	0.3	0.01
High-rise MURB	0	0.2	0.57	0.1	0.4	0.9	0.3	0.02
Major Appliances								
Single Detached	8.9	11.0	10.5	10.4	12.5	10.5	12.3	9.7
Row/Town	7.3	9.5	8.9	8.9	10.5	9.3	10.3	7.8
Low-rise MURB	4.9	5.2	5.0	5.1	6.3	5.2	6.9	5.3
High-rise MURB	4.9	5.2	5.0	5.1	6.3	5.2	6.9	5.3
Lighting								
Single Detached	5.6	6.8	6.8	4.9	6.3	6.5	6.1	5.3
Row/Town	4.6	6.4	5.8	4.2	5.3	5.8	5.1	4.3
Low-rise MURB	3.1	3.5	3.2	2.4	3.2	3.2	3.4	2.9
High-rise MURB	3.1	3.5	3.2	2.4	3.2	3.2	3.4	2.9
Other								
Single Detached	5.9	10.8	11.2	9.0	11.6	6.9	7.7	6.2
Row/Town	4.8	9.2	9.5	7.7	9.8	6.1	6.4	5.0
Low-rise MURB	3.3	5.1	5.3	4.4	5.9	3.4	4.3	3.4
High-rise MURB	3.3	5.1	5.3	4.4	5.9	3.4	4.3	3.4
Whole Building								
Single Detached	113	122	171	135	136	156	159	123
Row/Town	69	81	96	91	86	107	120	79
Low-rise MURB	39	39	62	44	47	54	60	44
High-rise MURB	40	40	63	45	48	56	62	45

A.6.4 Derivation of Energy End-Use Intensities for BAU 2004–2025

The method used to derive the BAU EUIs takes into account two important dynamics that affect energy intensities and aggregate energy use in residential dwellings over this time period:

- Existing dwellings are undergoing either renovations or energy retrofits. Under either circumstance, the EUIs would decline.
- New dwellings are being built and added to the dwelling stock. The whole dwelling EUIs of newly built stock would be lower than the existing stock averages.

Both of these key dimensions of the BAU derivation are elaborated below. In addition, it is important to note that the fuel shares of the 2004 existing dwelling stock are held constant at base year levels over the study period, in the absence of better data.

Derivation of Energy EUIs for New Construction during 2004–2025

For new construction, one of the challenges was to consider how recent trends would evolve going into the BAU period. A review of construction trends reveals that unit window, wall and roofing thermal efficiency levels have increased in all regions and air leakage rates have also been reduced, by as much as 30% compared to buildings constructed in the 1990s. However, there are also dwelling building trends that counteract these thermal improvements:

- The amount of window area in new houses has increased by up to 20% compared to typical existing homes.
- On average, new dwelling floor areas are 15%–20% larger than existing dwellings.
- Many non-MURB dwellings also feature an increase in exterior wall surface area of 5%–20%. This reflects both the increased floor area and a tendency for homes to include architectural features with more corners and details that diverge from the standard rectangular shapes.

Key assumptions by major end uses are summarized below.

Space Heating

For space heating, the following steps were taken:

- For each region, the space heating energy intensity of new homes is developed starting with the total 2004 heating energy consumption of dwellings built during 2001–2004.
- This total is then allocated by dwelling type according to historical space heating energy use patterns and corrected for the differences in new stock composition by dwelling type (e.g. the number of new row houses may be higher proportionately than it is historically).
- The energy consumption for each dwelling category is then divided by the total number of dwellings in the appropriate category to yield the energy intensity for each dwelling type.

- Divided the number of 2001–2004 vintage homes by the heating energy allocated in the CEUD to 2001–2004 vintage homes and then scaled by dwelling type as per the existing stock, adjusted for growth.
- Investigated how increases in architectural features (exposed surface area), window to wall ratios, and overall house sizes have affected the whole dwelling EUIs.
- Made adjustments to the average EUIs to better reflect actual new housing energy performance characteristics.

Domestic Hot Water (DHW)

Nationally, domestic hot water EUI decreased by 11% on a per household basis during 1990–2004 and 15% on a per square meter basis. For DWH, the study used the provincial rates of change to provide greater accuracy for DHW energy use, and assumed no technological changes.

Space Cooling

The saturation of air conditioners is approximately 33% greater in new homes than existing homes, yet the average efficiency of new air conditioners is about 30% higher than existing units (SEER 13 vs. SEER 10), thus these two factors essentially cancel out. For lack of better information, we assumed, for all provinces, that the average cooling efficiency increases at the average historical rate over the study period for both new and existing dwellings.

Major Appliances

We assumed that new appliance energy efficiency improves at the same rate as in the existing stock. The unit energy consumption (UEC) values of existing and new appliance stock during 1990–2004 showed that refrigerators, freezers and clothes dryers have sustained the greatest increases in efficiency over this period. While efficiency gains are steady (likely due to stock replacement rates), much of the technological innovation as exhibited by UECs for new stock occurred during the early 1990s. However, recent data indicates that refrigerators, ranges, and to a lesser extent freezers, are undergoing another round of efficiency increases.

Appliances are assumed to improve by the same percent for all regions based on a grouped appliance efficiency gain. This gain was determined from existing stock and new stock UECs, based on expected improvements from other in-house studies, UEC trends from NRCan, international market analysis (identify current international top performers), etc.

Lighting

This study did not include detailed technology profiles or modelling for lighting, since the trends did not warrant it. Currently, the penetration of compact fluorescent lights (CFLs) is quite low, which light-emitting diodes (LEDs), especially white LEDs, are currently still in the developmental stage for reliable and cost-effective residential space lighting. Light-emitting diodes are currently being used for back-lighting applications and holiday lights, and are expected to transform the market within the next 5 to 8 years, with estimated annual electricity savings of 40–45% relative to incandescent lamps, for each converted household.[152]

Reduced lighting loads also lower the cooling load if air-conditioning is provided, but increase the heating load.

The resulting energy EUIs for new dwellings over the study period are presented in Exhibit A.21.

[152] Marbek Resource Consultants for BC Hydro. 2007. *BC Hydro Demand-Side Management Potential – Update 2007*.

Exhibit A.21: Energy End-use Intensities (EUIs) for New Dwellings Built during 2004–2025

Energy End Use & Dwelling Type	Per-Dwelling Energy End-use Intensities by Region & Dwelling Type [GJ/yr]							
	Territories	BC	AB	SK	MB	ON	QC	Atlantic
Space Heating								
Single Detached	73	76	97	84	79	90	95	79
Row/Town	39	41	43	49	41	55	68	46
Low-rise MURB	21	17	31	20	21	28	32	24
High-rise MURB	21	18	32	20	22	29	33	25
Domestic Hot Water								
Single Detached	9.9	15.6	15.9	14.4	13.3	13.9	10.1	9.6
Row/Town	8.3	13.1	13.1	12.3	11.3	12.4	8.5	7.7
Low-rise MURB	5.6	6.6	7.2	7.0	6.1	6.4	5.5	5.2
High-rise MURB	5.6	6.6	7.2	7.0	6.1	6.4	5.5	5.2
Space Cooling								
Single Detached	0.00	0.67	1.74	0.39	1.45	2.80	0.82	0.05
Row/Town	0.00	0.55	1.74	0.23	0.75	1.71	0.59	0.03
Low-rise MURB	0.00	0.30	0.96	0.10	0.37	0.82	0.30	0.01
High-rise MURB	0.00	0.30	0.96	0.10	0.39	0.86	0.30	0.01
Major Appliances								
Single Detached	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Row/Town	7.4	7.8	7.7	7.8	7.7	8.0	7.6	7.3
Low-rise MURB	5.1	4.3	4.3	4.5	4.6	4.5	5.1	4.9
High-rise MURB	5.1	4.3	4.3	4.5	4.6	4.5	5.1	4.9
Lighting								
Single Detached	5.6	6.9	6.9	5.0	6.3	6.5	6.1	5.3
Row/Town	4.6	5.9	5.8	4.3	5.4	5.8	5.1	4.3
Low-rise MURB	3.1	3.2	3.3	2.5	3.2	3.2	3.4	2.9
High-rise MURB	3.1	3.2	3.3	2.5	3.2	3.2	3.4	2.9
Other								
Single Detached	6.0	10.9	11.6	6.3	8.0	6.8	8.1	6.4
Row/Town	6.0	10.9	11.6	6.3	8.0	6.8	8.1	6.4
Low-rise MURB	6.0	10.9	11.6	6.3	8.0	6.8	8.1	6.4
High-rise MURB	6.0	10.9	11.6	6.3	8.0	6.8	8.1	6.4
Whole Building								
Single Detached	103	120	142	119	117	129	129	110
Row/Town	64	78	81	79	72	89	97	70
Low-rise MURB	38	37	52	37	39	46	51	40
High-rise MURB	38	37	54	37	40	47	52	41

Derivation of Energy EUIs for Base Year Dwellings During 2004–2025

Some portion of the dwellings that exist in the 2004 base year are expected to undergo renovation and energy retrofit activities during the BAU period to 2025 which would affect the whole building and end-use specific EUIs. It is therefore important to provide a reasonable estimate of the impact of these "naturally" occurring activities on the net heating and cooling loads of the existing dwelling stock. In effect, energy retrofits are assumed to encompass two activities: i) energy performance improvements that piggyback on renovations and ii) stand-alone energy performance improvements. In theory, a large scale renovation would afford a more intensive whole dwelling performance upgrade.

It is important to note that fuel shares for the 2004 existing dwelling stock are held constant at 2004 levels over the study period due to limited study resources. In actuality, fuel shares would change over the study period due to consumer preference, resource availability and price, etc.

The analysis has drawn upon previous energy efficiency potentials studies in which the "typical" retrofit upgrade measures associated with a retrofit were profiled and then the rates at which the bundle of measures are introduced into the existing stock of buildings was defined.[153] In some cases, the energy impact of the upgrades was estimated using the HOT2000 model.[154] Exhibit A.22 presents an example of how these retrofit activity rates can be depicted according to dwelling type.

Exhibit A.22: Annual Energy Retrofit Activity by Dwelling Type[155]

Retrofit Measure	Dwelling Type & Participation Rate (%)			
	Single Detached	Row/Town	Low-rise & High-rise MURBs	Mobile/Other
Insulation Improvements	4.20	2.40	2.30	4.10
Exterior Doors	5.40	5.90	2.80	5.30
Window Replacements	6.70	7.00	4.10	6.60
Fireplace Improvements	2.90	1.60	1.20	2.70
Heating System Conversions	0.90	0.40	0.10	0.90
Energy Source Conversions	0.90	0.80	0.10	0.90
Equipment Replacements	2.90	2.10	1.00	2.90
Average	3.41	2.89	1.66	3.34

[153] As noted previously, these are primarily drawn from studies from which Marbek has developed an in-house database.

[154] HOT2000 is a free model from NRCan that simulates the impacts of design changes and/or renovations on the energy intensity of dwellings, primarily focusing on the building envelope.

[155] Sources: a) Natural Resources Canada. 2000. *Home Energy Retrofit Survey — Statistical Report*.
b) *BC EnerGuide for Houses database*, as reported in *BC Hydro Conservation Potential Review* 2002.

The investigation of trends affecting the EUIs revealed the following:

- Improvement in the space heating energy intensity of existing homes occurs through renovations that affect the building envelope and through replacement of low-efficiency heating equipment (also considered renovations for the purpose of this work). On-going in-house research examining the results of various energy use simulations undertaken on a number of dwelling types has demonstrated widely varying results for heating and cooling load reductions. Complicating the issue is the fact that many major renovations also involve dwelling expansion, which reduces the overall energy performance gain associated with the envelope improvement. An average space heating and cooling reduction of 3% was assumed for each average dwelling renovation, since this was representative of most of the renovations that were occurring.
- Window replacements are currently the most frequent activity in an envelope retrofit and they occur at roughly double the rate of new home construction (because the replacement project only includes half the windows in the house, there are about equal numbers of windows sold for new homes as for replacements). Windows probably last about 30–40 years, which amounts to an annual replacement rate of 3%.
- A window replacement saves between 5%–6% of the heating energy in an old house. Based on the results of other previous studies, it was decided to multiply this savings value by about 1.5 to account for other window performance measures that might be included.

Improvements in the space cooling energy intensity of existing dwellings are achieved through renovations affecting the building envelope and through equipment replacement. As mentioned in the first bullet above, renovations and equipment replacement are considered to reduce cooling loads by 3%. The savings discussed above are moderated by installations of cooling equipment in residences which were originally not actively cooled. In order to capture the effects of stock additions, the cooling energy intensity of existing dwellings increases at the average regional rate.

Televisions & Television Peripherals

This energy end-use is rapidly growing in intensity relative to the other dwelling end-uses and, consequently, there was careful attention placed on how this might affect EUIs in the BAU period.

The North American television industry has announced its commitment to convert all analog television to digital broadcasting within the next 5 years. These broadcast changes are occurring at a time when television technology and programming options are also rapidly changing. Some television technology changes, such as the introduction of Liquid Crystal Display (LCD) and plasma models, may also have significant impacts on household electricity consumption. It is also possible that these changes will result in an increased rate of turnover in the current stock of televisions to models that are better able to take advantage of the high definition digital signal.

LCD is expected to become the dominant television technology by 2010, capturing approximately 57% of sales in that year. Although LCD screens typically use less electricity on a per inch basis, consumers typically choose screens that are larger when purchasing an LCD screen compared to cathode ray tube screens (CRTs). The most popular television on the market today is the 27-inch CRT, but this is expected to shift within the next five years to the 32-inch LCD television. This trend has the effect of reducing the electricity advantage that would be gained from a direct switch from CRT technology to LCD technology.

In addition to the increase in screen size, high definition (HD) television models typically consume more power than equivalent standard definition televisions for all technology types. Since the trend with televisions is towards higher definition sets with greater resolution, television unit electricity use is expected to increase in the future.

The growing popularity of larger and higher resolution screens means that by 2010 national television electricity consumption is also expected to grow by up to 50%. In light of the changes noted above, the unit energy consumption (UEC) for televisions is estimated to increase from 178 to 250 kWh/yr over the study period.[156]

One implication of the above pending changes toward digital television broadcasting is that new signal adaptors, commonly referred to as set-top boxes (STBs), will need to be added to nearly two-thirds of Canadian households to receive a television signal. Industry representatives estimate that each Canadian subscriber household has, on average, 1.5 set-top boxes.[156] They also note that the trend is towards a greater number of set-top boxes per household and, by 2010, the industry estimates that the average will have increased to approximately two set-top boxes per subscriber household.

When complete, the switch to digital broadcasting is expected to increase national set-top boxes electricity consumption by up to four times its current level due to the added requirement for set-top boxes among those televisions currently operating on analog cable or over-the-air broadcast signals. Moreover, within these set-top boxes the most significant trend is towards greater functionality, which is directly associated with further increases in unit electricity consumption.

In light of the changes noted above, UECs for television peripherals are assumed to increase from 220 to 310 kWh/yr over the study period.[156]

Computers & Peripherals

Electricity consumption for personal computers is expected to increase despite the move to more energy-efficient flat screen technology. Again, this is due in part to the growing preference for larger screens but mainly due to a trend towards longer

[156] Marbek Resource Consultants for Natural Resources Canada . September 2006. *Technology and Market Profile: Consumer Electronics*.

operating hours both in full operating mode and in idle mode. There is also a move towards increasing numbers and functionality of computer peripherals (e.g., printers, digital music players, multiple monitors, web cameras, storage devices, etc.), increasing consumption further.

UECs for personal computers and their peripherals are assumed to increase from 390 kWh to 560 kWh/yr over the study period.[157]

A.6.5 Data Limitations

The derivation of the operating energy profile for both the base year and BAU is based on three important elements: i) input data, ii) the modelling platform and iii) the basis upon which projections are derived. Together, these three elements are designed to build a defensible energy end-use based profile of operating energy in the Canadian housing stock. The Marbek energy end-use accounting platform is robust and sufficiently "road-tested" by virtue of the ongoing utility and government studies that are complete or underway.[158] However, there are some important limitations with regard to data availability and quality as well as how data was used:

- The derivation of the base year operating energy profile utilizes three categories of data sources: i) Natural Resources Canada (NRCan), both the *Energy Use Outlook* and *Comprehensive Energy Use Database* (CEUD) ii) Marbek's segment specific data inventory and iii) other disparate sources. Fundamentally, the method used in this study is to build bottom-up, energy end-use profiles for housing that reflect important regional and dwelling stock differences. These profiles generate pictures of housing energy use patterns that are derived from an understanding of the following important data inputs, which affect both the baseline and BAU:

  - Penetration of energy using equipment;
  - Energy performance of this equipment; and
  - Thermal performance characteristics of the dwelling envelopes.

- To effectively assemble these data inputs the method employed uses data and learnings from province or region specific work to modify the CEUD data set which offers the platform for a national profile. The CEUD end-use data is derived from a top-down allocation of Statistics Canada data (obtained through surveys and studies).

  Typically, projects undertaken at the provincial or regional levels are driven by the need for a relatively high degree of robustness because often the client will be utilities needing to prepare data and analysis for regulatory filings. Hence, the data used for these studies is often based on end-use surveys, billing based energy profiles and consultation with engineering practitioners and the design-build community who

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[157] Marbek Resource Consultants for BC Hydro. 2007. *BC Hydro Demand-Side Management Potential – Update 2007*.

[158] Demand-Side Management Potential Reviews conducted during 2000–2007 for BC Hydro, Manitoba Hydro, Hydro Quebec, Newfoundland Hydro, Enbridge Gas, Terasen Gas, Canadian Gas Association.

operate in specific building niches. So there is a reasonably high confidence level associated with the data and analysis from such studies.

The province and region specific study findings enabled us to adjust the CEUD data for several Canadian jurisdictions. However, it was necessary to assume that such adjustments applied to regions for which sparser empirical data was available.

- The scope and pace at which renovation and retrofit of dwellings units and infrastructure take place is an important underlying dimension in understanding the evolution of the built environment under the BAU. Renovation and retrofit activities affect the demand for materials and have consequent upstream environmental implications. However, information concerning renovation rates and the composition of typical renovations and retrofits is lacking. The last comprehensive study undertaken by NRCan was published in 1995.

A.7 METHODOLOGY FOR DIRECT OPERATING ENERGY FOR MUNICIPAL WATER SYSTEMS

This sub-section presents the analysis of the energy used in municipal water treatment and pumping services that arise from dwelling water demand. The analysis considers these impacts for the study base year and the BAU period.

A.7.1 Methodology, Assumptions & Data Sources

The consumption of potable water in dwellings requires upstream municipal potable water treatment and pumping, as well as downstream municipal wastewater pumping and treatment. It was assumed that stormwater drainage was gravity-fed with passive treatment, if applicable, thus not requiring operating energy to manage stormwater.

The direct operating energy calculations used for water supply and wastewater systems were as follows:

Energy Required for Water Pumping & Treatment (for each Dwelling Type) =
Annual Potable Water Demand per Dwelling (L / dwelling / year) *
Energy Required for Treatment & Pumping (kWh / L) * Number of Dwellings

Energy Required for Wastewater Pumping & Treatment (for each Dwelling Type) =
Annual Wastewater Produced per Dwelling (L / dwelling / year) *
Energy Required for Treatment & Pumping (kWh / L) * Number of Dwellings

There are several key variables that must be assessed to apply these calculations. The study method addresses these variables as shown in Exhibit A.23.

Exhibit A.23: Utilization & Derivation of Key Variables for Calculation of Municipal Water System Operating Energy

Variable	Application	How Addressed
Dwelling stock	Needed to derive stock specific and aggregate impacts	Stock values taken from Section 4 outputs
Dwelling water demand	Needed to derive up-stream pumping and treatment demand	Values for aggregate potable water demand, by dwelling type taken from Section A.5 outputs
Water treatment demand	Needed to derive the energy consumption of treatment	Derived in this section
Water pumping demand	Needed to derive the energy consumption of pumping	Derived in this section

The remainder of this section provides further elaboration of the method and supporting data sources to address water treatment and pumping energy intensities for these services.

Energy End-Use Intensities for Water & Wastewater Pumping & Treatment

The treatment and pumping of municipal water and wastewater requires substantial energy inputs. These activities can be expressed as an energy intensity of the volume of water that is treated or pumped (kWh/ML).

The average energy intensities to treat and pump a megalitre (ML) of municipal *supply water* were based on energy use statistics for different municipalities across Canada. The most important factors that influence energy requirements are the water treatment type (e.g., conventional filtration or membrane filtration) and regional terrain that impacts the pumping requirements to deliver the water to dwellings and other buildings.

The average energy intensities to pump and treat a megalitre of municipal *wastewater* were also based on energy use statistics for different municipalities across Canada. An estimate of wastewater pumping intensity was based on data available from the City of Ottawa, which upon review of data for other Canadian jurisdictions, was deemed to be representative of an average for Canada.[159] The most important factors that influence energy requirements are the wastewater treatment type (e.g., primary, secondary), the size of the treatment facility, and regional terrain that impacts the pumping requirements for wastewater collection.

The pumping and treatment of potable water and wastewater uses different fuel sources depending on the region in Canada. The distribution of fuel types used for potable water and wastewater treatment and pumping was estimated based on the national average fuel type distribution of electricity, natural gas and diesel for industry.[160] For pumping, 85% of the fuel use was estimated to be electricity and the remaining 15% was split between natural gas and diesel, based on the national average fuel shares for the industrial sector.

159 Personal Communication. February 22, 2007. City of Ottawa. David Robertson, Wastewater Treatment Program Manager. Since Ottawa employs typical filtration methods (i.e., secondary treatment) and is relatively flat (which could be an average between areas which require a lot of pumping like Vancouver or areas like Quebec that require minimal pumping).

160 NRCan. 2004. *Energy Use Data Handbook, 1990 and 1998 to 2004 – Industrial Sector*. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_ind_ca.cfm?attr=0

Exhibit A.24 identifies the resulting energy intensities that were derived from available data and used in the study.

Exhibit A.24: Energy Intensities of Potable Water & Wastewater Treatment & Pumping[161]

Activity	Total Energy Intensity [GJ/ML]	Energy Intensity [GJ/ML] by Fuel Type		
		Electricity	Natural Gas	Diesel
Potable Water Treatment	2.52	1.05	1.27	0.20
Potable Water Pumping	0.36	0.31	0.05	0.01
Wastewater Pumping	0.22	0.18	0.03	0.00
Wastewater Treatment	2.12	0.89	1.07	0.17

A.7.2 Data Limitations

Energy use for pumping and distribution of water and wastewater was calculated based on the energy use intensity (GJ/ML) of a single representative municipality (i.e., Ottawa).

A.8 METHODOLOGY FOR DIRECT OPERATING ENERGY FOR RESIDENTIAL TRANSPORTATION

A.8.1 Methodology, Assumptions & Data Sources

Estimates of typical automobile and transit use for each of the three archetypes was derived using the “Greenhouse Gas Emissions from Urban Travel Tool” developed by CMHC, the Toronto Transportation Tomorrow Survey 2001, and the Canadian Vehicle Survey 2004 from Transport Canada.

The pertinent neighbourhood archetype characteristics, as derived earlier, were used as input to the Urban Travel Tool and the resulting numbers compared with data on automobile use from the 2001 survey results in the Toronto Census tracts corresponding to our three neighbourhood archetypes. The ratio of personal vehicle use between the three neighbourhood archetypes was generally consistent using the two methods, but the kilometres travelled were quite different, as shown in Exhibit A.25.

[161] a) Energy intensity of potable water treatment (700 kWh/Mlitre), potable water pumping (100 kWh/Ml), and wastewater pumping & treatment (650 kWh/Ml, split 10% for pumping and 90% for treatment) are Canadian averages provided by program managers at the City of Ottawa and the Regional of Peel (Toronto), who cited 2005 data from a confidential survey of 37 municipalities in Canada.
b) Fuel split of potable water treatment and wastewater treatment energy intensity is assumed to be same fuel split as Canadian industrial sector average in 2004, as per: Natural Resources Canada. August 2006. *Energy Use Data Handbook, 1990 and 1998 to 2004*: Industrial sector data table. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_ind_ca.cfm?attr=0
c) Fuel split of potable water pumping and wastewater pumping energy intensity is assumed to be 75% electricity and 25% as the same fuel split as Canadian industrial sector average in 2004, as per same reference as above.

Exhibit A.25: Comparison of Per-Dwelling Average Annual VKT & PKT, 2001[162]

Inner City Neighbourhood Archetype					**Ratios - VKT**	
Ward	**Avg. VKT**	**Avg. PKT**				
14	9.95	6.62			Raw Survey Data - VKT	
17	10.49	7.07			High Density =	1
18	7.44	6.30			Medium Density =	1.71
19	6.87	3.73			Low Density =	3.05
20	4.75	2.91				
21	8.89	5.46			Tool VKT	
22	8.47	5.15			High Density =	1
27	4.49	2.48			Medium Density =	1.81
28	5.73	3.63			Low Density =	3.44
29	9.40	5.74				
31	12.78	9.36			**Ratios – PKT**	
32	14.64	7.09	Tool VKT	28.1		
Avg.	**8.66**	**5.46**	Tool PKT	17.2	Raw Survey Data - PKT	
					High Density =	1
Inner Suburb Neighbourhood Archetype					Medium Density =	1.39
6	19.42	5.80			Low Density =	0.64
10	12.86	7.56				
11	15.83	7.50			Tool PKT	
12	14.07	8.19			High Density =	1
13	15.35	8.44			Medium Density =	0.88
15	9.77	6.68			Low Density =	1.09
16	13.43	6.01				
23	15.32	11.48				
26	12.46	6.13				
30	9.03	5.33				
33	17.92	10.47				
34	16.6	7.55				
35	14.53	11.18				
36	17.67	7.2				
38	14.24	6.33				
39	16.42	9.85				
40	14.17	5.61				
43	17.77	5.6	Tool VKT	50.9		
Avg.	**14.83**	**7.61**	Tool PKT	15.1		
Outer Suburb Neighbourhood Archetype						
City Of Toronto				CMA Excluding City of Toronto		
1	19.82	7.38		**Municipality**	**Avg. VKT**	**Avg. PKT**
2	20.38	6.39		Durham	26.23	0.45
3	17.43	7.15		York	32.65	4.51
4	20.52	6.74		Peel	29.27	2.15
5	14.30	8.23		Halton	24.30	0.23
7	17.71	5.21		**Avg.**	**28.77**	**2.13**
8	12.46	7.42				
9	15.03	6.79				
24	17.37	11.61				
25	17.61	5.23				
37	13.99	7.88				
41	19.29	8.92				
42	22.50	13.27				
44	35.28	6.39	Tool VKT	96.6		
Avg.	**18.84**	**7.76**	Tool PKT	18.8		
Combined Outer Suburb Neighbourhood Archetype						
Avg VKT: 26.4		Avg PKT: 3.47				Figure 7

Because of this difference in kilometres travelled and because the CMHC Urban Travel Tool was not designed specifically for these estimates, an average vehicle-kilometres-travelled per dwelling unit in Canada was derived using the Transport Canada figures and apportioned to each archetype using the ratios generated by the Urban Travel Tool, as shown in Exhibit A.26.

[162] Sources: a) Canada Mortgage and Housing Corporation & Natural Resources Canada. *Greenhouse Gas Emissions from Urban Travel Tool for Evaluating Neighbourhood Sustainability*.
b) 2001. Toronto Transportation Tomorrow Survey 2001. http://www.jpint.utoronto.ca/ttshome/

Exhibit A.26: Per-Dwelling Average Annual VKT, 2001[163]

High Density	.0925 x 28.1 x 365 =	949
Medium Density	.1325 x 50.9 x 365 =	2,462
Low Density	.7750 x 97.7 x 365 =	27,637
		31,048

Transport Canada

avg. distance travelled **x** total light vehicles in Canada ÷ total Canadian du
16,000 x 17,700,000 ÷ 12,548,588 = 22,568 km/du per year

	Tool Values (km/du/day)	Ratio	Reduction Factor	Adjusted Values (km/du/day)	Annual Values
Inner City	28.1	1	1.375	20.4	7,450km
Inner Suburb	50.9	1.81		37.0	13,500km
Outer Suburb	96.6	3.44		70.2	25,620km

The ratios of public transit use in each archetype varied more significantly between the Urban Travel Tool and Transport Canada Survey results. The values arrived at using the Urban Travel Tool have been included in the neighbourhood archetypes as the best available estimate of typical transit use, but the accuracy of these figures has not been verified against known Canadian totals for transit. The implications of this uncertainty are minimal, since private vehicle use dominates residential transportation impacts. Given the small focus in this study on transportation relative to dwelling impacts, this was not pursued further.

The resulting vehicle-kilometres travelled (VKT) for personal vehicle use and passenger-kilometres travelled (PKT) for public transit use are shown in Exhibit A.27, and assume the 2004 transportation values to be the same as 2001. Due to limited study resources, limited relevant data, and the complexities of transportation demand from various neighbourhood and market trends, we have also assumed constant personal vehicle and public transit use for the BAU scenario to 2025. Rates of personal vehicle use versus public transit depend on a series of difficult-to-predict trends including household disposable income, fuel prices, investment in public transportation, changes in public transit coverage and rider-ship, and the distance of new and existing housing from employment and services. Full implementation of urban intensification plans would be expected to increase the public transit share, however the trend in modal split in recent years has been relatively constant with a slight increase in the share of personal vehicle use over transit in some areas. Future assessment of alternative scenarios could attempt to more accurately reflect the complex changes in residential transportation expected from denser neighbourhoods and other trends.

[163] Sources: a) Canada Mortgage and Housing Corporation & Natural Resources Canada. *Greenhouse Gas Emissions from Urban Travel Tool for Evaluating Neighbourhood Sustainability*.
b) Transport Canada. 2004. *Passenger Transportation*. http://www.tc.gc.ca/pol/en/Report/anre2005/7D_e.htm

Exhibit A.27: Estimated Personal Vehicle & Public Transit Use by Neighbourhood Type for 2004 & 2025

Transportation Type	Units	2004			2025		
		Inner City	Inner Suburbs	Outer Suburbs	Inner City	Inner Suburbs	Outer Suburbs
Personal Vehicle	**VKT/dwelling/yr**	*7,450*	*13,500*	*25,620*	*7,450*	*13,500*	*25,620*
Public Transit	**PKT/ dwelling/yr**	*6,280*	*5,510*	*6,460*	*6,280*	*5,510*	*6,460*

The VKT and PKT figures were then multiplied by the number of dwellings in each of the three neighbourhood types to give total VKT and PKT for all dwellings in Canada. The NRCan Energy Outlook 2006 was then used to identify the total annual operating energy in Canada *by fuel type* for "Light Duty Vehicles" and "Public Transit". These values are shown in Exhibit A.28. For personal vehicles, this total annual operating energy was divided by the total VKT estimated in our study, to determine the average operating energy per VKT. A similar method was used for public transit, also drawing from the NRCan Energy Outlook 2006. These results are also shown in Exhibit A.28. In effect, this calibrates our residential transportation energy use numbers with the NRCan Energy Outlook 2006.

Exhibit A.28: Personal Vehicle & Public Transit Energy Use by Fuel

Transportation Type	Transportation Mode	Fuel Type	% of total	Annual Energy Use **[PJ]** as per NRCan Energy Outlook 2006		Calculated Annual Energy Use [MJ] per VKT or PKT	
				2004	2025	2004	2025
Personal Vehicle	Light-Duty Vehicles	Gasoline*	~99%				
	Light-Duty Vehicles	Diesel	~1%				
		Total	**100%**	**1,263 PJ**	**1,708 PJ**	**4.70 MJ/vkt**	**4.83 MJ/vkt**
Public Transit	Transit Buses	Gasoline	5.2%				
	Transit Buses	Diesel	82.8%				
	Commuter Rail	Diesel	4.9%				
	Transit Rail	Electricity	7.1%				
		Total	**100%**	**56 PJ**	**62 PJ**	**0.74 MJ/pkt**	**0.62 MJ/pkt**

* includes ethanol

A.8.2 Data Limitations

Estimates of typical vehicle use in each of the three archetypes were compiled from three sources: i) the Greenhouse Gas Emissions from Urban Travel Tool developed by CMHC and NRCan; ii) the Toronto Transportation Tomorrow Survey 2001; and iii) the Canadian Vehicle Survey 2004 from Transport Canada. Based on the accuracy and comparability of these sources we believe the numbers we have used are a, accurate reflection of personal vehicle use.

The ratios of public transit use in each archetype varied more significantly between the Urban Travel Tool and Survey results but could not be verified against known Canadian totals for transit use. The values arrived at using the Urban Travel Tool have been included in our archetypes as the best available estimate of typical transit use, but the accuracy of these figures has not been verified.

Due to limited study resources, limited relevant data, and the complexities of transportation demand from various neighbourhood and market trends, we have assumed constant personal vehicle and public transit use for the BAU scenario. Future assessment of alternative scenarios could attempt to more accurately reflect the complex changes in residential transportation expected from denser neighbourhoods and other trends.

A.9 METHODOLOGY FOR INDIRECT EFFECTS OF OPERATING ENERGY USE

This sub-section describes the methodology in estimating the indirect/upstream resource use and environmental outputs (e.g., emissions/pollutants to air, water, and soil) from extracting, refining, and delivering the operating energy (e.g., refined petroleum products, electricity) used during the operating stage of the life-cycle. As discussed in Section 2, these indirect effects of direct energy use are shown separately to clearly illustrate the additional impacts that occur for every unit of operating energy used.

A.9.1 Methodology, Assumptions & Data Sources

Similar to the methodology presented in Section A.4, the Athena *Environmental Impact Estimator* LCA model was used to develop per-gigajoule coefficients of resource use and environmental outputs for each fuel type used to operate dwellings and residential transportation. Exhibit A.29 shows the per-gigajoule coefficients by fuel type, which are used to multiply by each gigajoules of operating energy used over the study period.

A.9.2 Data Limitations

As per the Scope of this study, the indirect effects of operating energy use do not include the life-cycle impacts of constructing the actual fuel refining plants and electricity generation plants.

Exhibit A.29: Direct & Indirect Resource Use & Environmental Output Factors per Gigajoule of Operating Energy, by Fuel Type

	Category	Operating Energy Use											
		Electricity		Natural Gas		Fuel Oil		Diesel		Gasoline		Wood	
	Lifecycle Stage	Direct	Indirect (Upstream)	Direct (Combustion)	Indirect (Upstream)	Direct (Combustion)	Indirect (Upstream)	Direct (Combustion)	Indirect (Upstream)	Direct (Combustion)	Indirect (Upstream)	Direct (Combustion)	Indirect (Upstream)
	Multiplier Units	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ	/PJ
Primary Fuel Use	Liquid Petroleum Gas, LPG [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Diesel [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Gasoline [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00
	Natural Gas [PJ]	1.56E-01	6.33E-02	1.00E+00	1.32E-01	0.00E+00	7.75E-02	0.00E+00	7.67E-02	0.00E+00	7.29E-02	0.00E+00	0.00E+00
	Wood [PJ]	1.73E-04	7.05E-05	0.00E+00	9.11E-05	0.00E+00	1.62E-04	0.00E+00	1.60E-04	0.00E+00	1.52E-04	1.00E+00	0.00E+00
	Coal [PJ]	4.91E-01	2.00E-01	0.00E+00	5.95E-03	0.00E+00	1.07E-02	0.00E+00	1.06E-02	0.00E+00	9.98E-03	0.00E+00	0.00E+00
	Heavy Fuel Oil [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Nuclear [PJ]	2.98E-01	1.21E-01	0.00E+00	2.10E-06	0.00E+00	3.74E-03	0.00E+00	3.75E-03	0.00E+00	3.54E-03	0.00E+00	0.00E+00
	Feedstock Fuels [PJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Other Oil-based Fuels [PJ]	5.52E-02	2.25E-02	0.00E+00	1.23E-02	1.00E+00	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Total Primary Fuels [PJ]	1.00E+00	4.07E-01	1.00E+00	1.50E-01	1.00E+00	9.21E-02	1.00E+00	9.12E-02	1.00E+00	8.65E-02	1.00E+00	0.00E+00
Air Emissions	Carbon Dioxide, CO2 from non-biomass [kt]	0.00E+00	7.22E+01	4.92E+01	6.55E+00	7.45E+01	8.20E+00	6.92E+01	8.13E+00	4.42E+01	7.69E+00	0.00E+00	0.00E+00
	Carbon Dioxide, CO2 from biomass (biogenic/neutral) [kt]	0.00E+00	3.43E-02	0.00E+00	1.17E-02	0.00E+00	1.90E-02	0.00E+00	1.89E-02	0.00E+00	1.79E-02	1.12E+02	0.00E+00
	Carbon Monoxide, CO [kt]	0.00E+00	3.56E-02	2.50E-02	9.60E-02	1.43E-02	1.98E-02	1.55E-02	1.97E-02	1.35E+01	2.00E-02	0.00E+00	0.00E+00
	Sulphur Oxides, SOx [kt]	0.00E+00	5.70E-01	3.13E-02	8.22E-01	6.85E-01	8.05E-02	8.96E-02	7.98E-02	1.83E-02	7.56E-02	1.50E-02	0.00E+00
	Nitrogen Oxides, NOx [kt]	0.00E+00	2.73E-02	1.29E-01	5.01E-02	1.58E-01	2.65E-02	7.42E-02	2.62E-02	3.51E-01	2.48E-02	1.05E-01	0.00E+00
	Nitrous Oxide, N2O [kt]	0.00E+00	5.46E-04	0.00E+00	5.01E-06	0.00E+00	8.88E-06	0.00E+00	8.66E-06	0.00E+00	8.25E-06	1.20E-02	0.00E+00
	Total Particulate Matter, TPM [kt]	0.00E+00	1.63E-02	3.92E-03	1.59E-03	4.01E-02	5.19E-03	4.64E-03	5.13E-03	2.22E-02	4.88E-03	2.29E+00	0.00E+00
	Non-Methane Volatile Organic Compounds, NMVOC [kt]	0.00E+00	5.47E-02	3.96E-03	2.21E-01	8.02E-04	1.81E+00	6.18E-04	1.55E-01	4.54E-01	1.63E-01	1.99E+00	0.00E+00
	Methane, CH4 [kt]	0.00E+00	1.53E-01	1.46E-03	1.59E-01	2.86E-03	1.26E-02	1.61E-04	1.25E-02	0.00E+00	1.19E-02	1.12E+00	0.00E+00
	Metals [kt]	0.00E+00	3.83E-05	0.00E+00	6.88E-06	4.57E-04	1.50E-05	2.58E-05	1.22E-05	0.00E+00	1.36E-05	0.00E+00	0.00E+00
	Total Greenhouse Gases (CO2-equivalent) [ktCO2e]	0.00E+00	1.20E+02	4.97E+01	5.57E+01	7.54E+01	1.21E+01	6.93E+01	1.20E+01	4.42E+01	1.14E+01	3.49E+02	0.00E+00
Water Emissions/Pollutants	Biological Oxygen Demand, BOD [kt]	0.00E+00	2.63E-04	0.00E+00	1.24E-03	0.00E+00	4.01E-04	0.00E+00	4.02E-04	0.00E+00	3.78E-04	0.00E+00	0.00E+00
	Suspended Solids [kt]	0.00E+00	4.48E-02	0.00E+00	2.31E-02	0.00E+00	7.62E-03	0.00E+00	2.44E-03	0.00E+00	2.34E-03	0.00E+00	0.00E+00
	Dissolved Solids [kt]	0.00E+00	3.59E-03	0.00E+00	1.29E+00	0.00E+00	1.09E-01	0.00E+00	1.08E-01	0.00E+00	1.02E-01	0.00E+00	0.00E+00
	Chemical Oxygen Demand, COD [kt]	0.00E+00	3.57E-03	0.00E+00	1.79E-02	0.00E+00	2.72E-03	0.00E+00	2.69E-03	0.00E+00	2.54E-03	0.00E+00	0.00E+00
	Oil & Grease [kt]	0.00E+00	4.42E-03	0.00E+00	2.25E-02	0.00E+00	2.55E-03	0.00E+00	2.50E-03	0.00E+00	2.37E-03	0.00E+00	0.00E+00
	Sulphates [kt]	0.00E+00	2.89E-02	0.00E+00	4.59E-02	0.00E+00	3.24E-03	0.00E+00	3.18E-03	0.00E+00	3.03E-03	0.00E+00	0.00E+00
	Sulphides [kt]	0.00E+00	0.00E+00	0.00E+00	8.76E-06	0.00E+00	8.81E-04	0.00E+00	2.13E-05	0.00E+00	2.03E-05	0.00E+00	0.00E+00
	Nitrates & Nitrites [kt]	0.00E+00	1.52E-05	0.00E+00	7.51E-08	0.00E+00	1.23E-07	0.00E+00	1.21E-07	0.00E+00	1.13E-07	0.00E+00	0.00E+00
	Dissolved Organic Compounds [kt]	0.00E+00	7.23E-04	0.00E+00	3.67E-03	0.00E+00	9.54E-04	0.00E+00	2.63E-04	0.00E+00	2.48E-04	0.00E+00	0.00E+00
	Metals [kt]	0.00E+00	8.47E-03	0.00E+00	1.91E-04	0.00E+00	9.89E-05	0.00E+00	6.50E-04	0.00E+00	6.03E-04	0.00E+00	0.00E+00
Water & Solid Resource Use	Limestone [kt]	0.00E+00	1.51E+00	0.00E+00	1.29E-02	0.00E+00	2.34E-02	0.00E+00	2.33E-02	0.00E+00	2.19E-02	0.00E+00	0.00E+00
	Clay & Shale [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Iron Ore [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Sand [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Other [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Gypsum [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Aggregates [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Water [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wood Fiber [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Solid Waste	Organic Waste [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Mineral Waste [kt]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Other Solid Waste [kt]	0.00E+00	1.25E+01	0.00E+00	2.42E+00	0.00E+00	5.07E-01	0.00E+00	4.11E-01	0.00E+00	3.88E-01	0.00E+00	0.00E+00

A.10 METHODOLOGY FOR RESULTING ENVIRONMENTAL IMPACTS

Environmental impacts result from many factors, including the environmental outputs quantified in this study, such as pollutants and land use change, as well as systems level responses, such as changes in biota supported regionally and melting ice due to warmer air temperatures. All sectors of the economy contribute to environmental outputs, including the residential sector, and thus, given the broad nature of environmental impacts, attribution of impacts to a specific sector is problematic. For this reason, the methodology for assessing resulting environmental impacts relies on a qualitative approach that is informed by quantitative data generated by this study and supported by data available in literature.

A.10.1 Methodology, Assumptions & Data Sources

Scale

As outlined in Exhibit 2.1 *Relationship of Residential Sector to Environmental Impacts*, and Section 2.4, environmental impacts are analyzed according to the scale at which they occur: local; regional (including national) and global. Environmental impacts are not bound by property (dwelling) or political borders (municipal, provincial and national). Environmental impacts are also not necessarily well bounded in terms of clear start and finish of impacts. For this reason, the environmental impacts are not described in the same terms as the other aspects of this study.

At all scales, impacts of environmental outputs are observed for each media and for biota. The larger the scale, the more the impacts reflect the integration of local impacts and additional systems-wide effects of environmental outputs. At the global scale, impacts have wide-reaching implications for multiple media and biota. The approach at this scale is therefore to discuss the impacts without categorization by media type. The approach at local and regional scales, as described following, is a hybrid of media-based and integrated impacts analysis.

Local Impacts

Most local scale impacts can be considered in terms of the media they most directly impact (i.e., air, water, land/soil) and impacts on biota. Analysis at this scale on the basis of media is a simplifying approach that allows discussion of the most immediate and well-understood impacts. Given the inclusions and exclusions outlined under Study Scope in Section 3.1, the local scale environmental impacts analyzed include impacts on air and water media. The ‘heat island effect’ is also discussed; however this effect is not readily categorized in terms of media-specific impacts.

For each of the local scale impacts analyzed, relevant quantitative results from the study are identified. Additional quantitative results from literature are provided for context and, where applicable, comparison with study results. A qualitative analysis of impacts is provided with reference to the quantitative results. Data sources for quantitative literature information include federal government reports, Canadian Council of Ministers of the Environment reports and other scientific literature and web-based information.

Regional Impacts

Regional impacts are considered as a combination of media-specific and integrated impacts. Impacts analyzed in this study include smog, acid rain, ecosystems (e.g., watersheds) and wildlife impacts, such as species extirpation or threatened status. Similar to the local scale approach, quantitative study results are provided where applicable and the analysis builds on impacts identified at the local scale. Specific regional issues in Canada are identified where literature data allows, such as areas prone to impacts of acid rain for example. Where insufficient data was located in the literature, a case study approach is taken to inform the discussion. Specifically, case study research was undertaken to inform the discussion on ecosystem fragmentation and research focused on the four areas in Canada projected to experience the most intense growth within the study period. Data sources for quantitative literature references and case study information include federal and municipal government sources, scientific literature and web-based sources.

Global Impacts

Global impacts are discussed relatively briefly in this study for two reasons. Firstly, direct attribution of these impacts to the residential sector is not possible due to the differences in scale, the broad nature of the systemic responses and the multiple factors contributing to the impacts. Secondly, global impacts are addressed in depth in other literature whose primary purpose is to analyze the impacts. It is nonetheless important to identify global scale impacts since activities of the residential sector do ultimately contribute to these impacts. Global impacts discussed in this report include climate change, biodiversity decline and ecosystem services, and global implications of regional contamination. These three impacts are discussed because the activities of the residential sector result in environmental outputs that have been demonstrated to cause these impacts (carbon emissions and land use change resulting in habitat loss for example). Data sources for the quantitative literature references include the United Nations Millennium Ecosystem Assessment, federal government sources and scientific literature and web-based literature.

A.10.2 Data Limitations

The study provides estimates of the impacts of the residential sector on the environment. However, the data limitations impede a full understanding of the magnitude of this impact and how it compares to the environmental effects of other sector activities such as industry and agriculture. Limitations result from two basic factors: 1) a lack of data and research on linkages of environmental outputs to impacts; and 2) differences in scale between the environmental outputs of a sector and many environmental impacts that preclude attribution of impacts to a sector.

Some data and research is available on municipal and/or urban impacts. For example, data is available in Canada for some pollutants released through municipal wastewater systems. Similarly, research is available on impacts of urbanization on species abundance. Where this information is discussed, it should be kept in mind that the residential sector comprises only part of the municipal and/or urbanized area contributions to the impacts identified.

The data limitations start with the concept of attribution: Can data support a defensible attribution of certain resource uses and pollutants to housing activities? This challenge of attribution affects virtually all aspects of environmental impact:

- Allocation of the land area consumed between land and water ecosystems (in particular, wetland ecosystems). National level metrics tracking land use trends, such as wetland disappearance, cannot be defensibly attributed to housing. Similarly, documented changes in biota associated with land use cannot be attributed to housing activities.

- Waste releases to water from roads and households cannot be appropriately attributed to the residential sector. Data is available on municipal wastewater effluent quality but this is highly variable and, typically, also includes industrial and institutional sources.

- Stormwater is a significant contributor of pollutants to the aquatic environment, but again, the variable nature of the flows, flow quality and attribution to the residential sector are problematic, aside from gross estimates of stormwater production from increases in impervious area.

- Attribution of groundwater quality impacts to the residential sector is also problematic due to very limited data across the country on groundwater quality and quantity.

- National trends and release statistics are not necessarily indicative of local air conditions. Although the relative magnitude of releases from the residential sector can be identified on a national level, further research would be required to identify regional trends and conditions resulting from residential sector emissions.

In addition, environmental outputs in this study are calculated for the full life-cycle of new housing stock and operating outputs of existing housing stock. Environmental impacts analyzed are a result of environmental outputs of the full life-cycle of existing housing stock with discussion of trends expected based on business as usual lifecycle outputs of additional stock. Although this may appear to create a mismatch between the outputs and impacts, an analysis excluding the non-operating outputs of existing stock is not possible because our current environment already reflects the integrated results of historical outputs, including any resulting incremental and non-linear impacts. An analysis of impacts that excluded existing stock outputs would be hypothetical and irrelevant.

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Creation Date: 8/12/2009 3:02:00 PM
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Last Saved On: 8/12/2009 3:02:00 PM
Last Saved By: mogden
Total Editing Time: 7 Minutes
Last Printed On: 9/4/2009 2:43:00 PM
As of Last Complete Printing
Number of Pages: 213
Number of Words: 67,644 (approx.)
Number of Characters: 385,577 (approx.)