Life-Cycle Environmental Impacts of the Canadian Residential Sector

Brad Kynoch, Martin Adelaar, Mary Trudeau, and John Cuddihy, Marbek Resource Consultants
Meg Ogden and Mark Holzman, Canada Mortgage and Housing Corporation
Jamie Meil, Athena Sustainable Materials Institute
Jane Thompson, Jane Thompson Architect

ABSTRACT

This study quantified and described the life-cycle environmental impacts of Canada's residential sector. The study team developed a research and analysis framework, then modeled and analyzed the results for a 2004 base case and a 2025 scenario. It was a unique attempt to cover such a wide range of analysis elements in the residential sector.

This multifaceted study included analysis of: 1) *Residential sector structures and activities by neighbourhood type*, such as: existing, renovated, and new dwellings, by dwelling type; existing and new neighbourhood infrastructure (roads and waterworks), by infrastructure type; and residential transportation, by private vehicle and urban public transit; 2) *Life-cycle stages* such as: operating (direct and indirect); and non-operating (extraction, manufacturing, transportation, on-site construction, maintenance, and replacement); 3) *Environmental impacts* such as: resource use (energy, water, land, and solids); environmental outputs (air, water, and soil emissions); and resulting environmental impacts (local, regional, and global impacts on air, water, soil/land, and biota), attributed to the residential sector, where possible; 4) *Estimated impacts in 2004 and potential additional impacts by 2025* through a business-as-usual scenario; and 5) *End-use categories* for energy and water.

The study concluded by identifying considerations for future work, including options for addressing data limitations and exclusions. It provided an initial life-cycle assessment from which to plan future research and analysis of the residential sector.

Introduction

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 tremendous environmental impacts during all life-cycle stages of development. As in many other regions of the world, Canada has become a largely urbanized society with approximately 80% of residents currently living in "urban" areas (NRCan 2006a). Looking ahead, Canada's expected population increase by 2025 would require another four million new dwelling units and incremental neighbourhood infrastructure such as roads, pipes, and wires.

As Canada's national housing agency, the Canada Mortgage and Housing Corporation (CMHC) initiated this study as a step in understanding the opportunities to reduce the environmental footprint of the residential built environment. CMHC recognized that, to consider alternate scenarios of development, it needed a robust baseline environmental profile. CMHC chose the study team for its extensive residential sector experience as well as the team's proven models and data for operating and life-cycle environmental analysis. The result is the first national-level study that quantifies and describes the life-cycle resource use, environmental outputs, and resulting environmental impacts of Canada's residential sector.

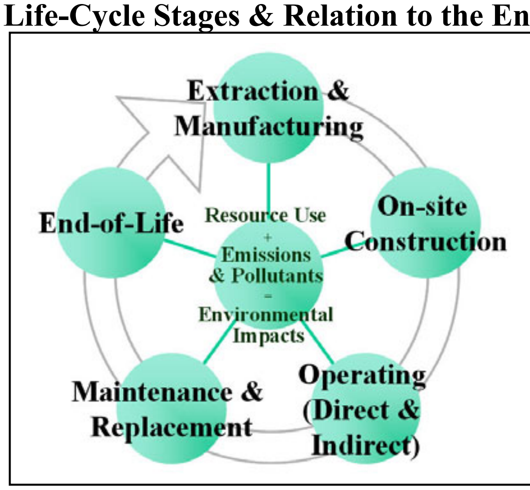
Life-Cycle Stages and their Relation to the Environment

As shown in Figure 1, residential structures and activities (e.g., dwellings, neighbourhood infrastructure, and residential transportation) go through the following life-cycle stages:

- **Extraction & Manufacturing** (Non-Operating): Resource extraction and transportation; Refining and manufacturing of materials into products; Included in embodied impacts;[1]
- **On-site Construction** (Non-Operating): Component transportation to building site; On-site construction of physical structure; Included in 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; Expressed separately to illustrate the additional impacts from every unit of operating services used;
- **Direct Operating**: Direct impacts of operating a structure, such as energy and water use and production of wastewater and solid waste;
- **Maintenance & Replacement** (Non-Operating): Manufacturing, transport and on-site construction effects of materials and activities involved in repair and replacement of a structure over its life (e.g., repainting, window and roof replacement,); and
- **End-of-Life** (Non-Operating): Deconstruction, demolition, disposal, reuse, and recycling.

As shown at the centre of "spokes" in Figure 1, each life-cycle stage: 1) **Requires resource use** — resources taken from the environment, such as primary fuels (fossil fuels, nuclear fuel, biomass, etc.), water, land, and solids (organics, minerals, metals, other); 2) **Releases environmental outputs** — emissions and pollutants released into the environment, such as air emissions (greenhouse gases, air contaminants, other), water pollutants (solids, oil & grease, chemical compounds, etc.), and soil pollutants (organic, mineral, other); and 3) **Results in environmental impacts** at local, regional, and global scales, such as smog, loss of habitat, and climate change, etc.

Figure 1. Life-Cycle Stages & Relation to the Environment



Source: Marbek Resource Consultants

[1] E.g., The *embodied* energy of a house includes primary fuels needed to: a) extract raw materials from the earth; b) refine and manufacturer materials into usable products; c) transport products to the construction site; and d) construct the house; as well as e) all energy needed to extract raw energy sources and refine the end-use fuels used in all those activities.

Study Scope & Methodology

Scope & Exclusions

In this first attempt to assess the life-cycle environmental impacts of the residential sector in Canada, the study team developed a research and analysis framework, then modeled and analyzed the results for 2004 and a 2025 scenario. This included analysis of:

- **Residential sector structures and activities by neighbourhood type**, such as: 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**, including operating (direct and indirect) and non-operating (extraction, manufacturing, transportation, construction, maintenance and replacement);
- **Environmental impacts**, including resource use, environmental outputs, and resulting environmental impacts as presented in Section 1.1, attributed to the residential sector, where possible;
- **Estimated impacts in 2004 and potential impacts by 2025** through a business-as-usual (BAU) scenario[2], utilizing national dwelling stock projections and intensification plans of three high-growth regions in Canada (more in Section 2.4); and
- **End-use categories** for energy and water.

Understandably, with an overall scope as summarized above, there were numerous exclusions, partly due to lack of reliable data. The key exclusions in the *non-operating* impact analysis were:

- Life-cycle analysis for existing dwellings and neighbourhood infrastructure because non-operating environmental impacts were already incurred when elements were constructed; Life-cycle analysis focused on newly constructed buildings and neighbourhood infrastructure, with a few exceptions;
- Maintenance and replacement impacts for existing dwellings, buildings, and infrastructure;
- Dwelling or infrastructure renovation impacts;
- End-of-life impacts; and
- Regional variations.

The key exclusions in the *operating* impact analysis were:

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

---

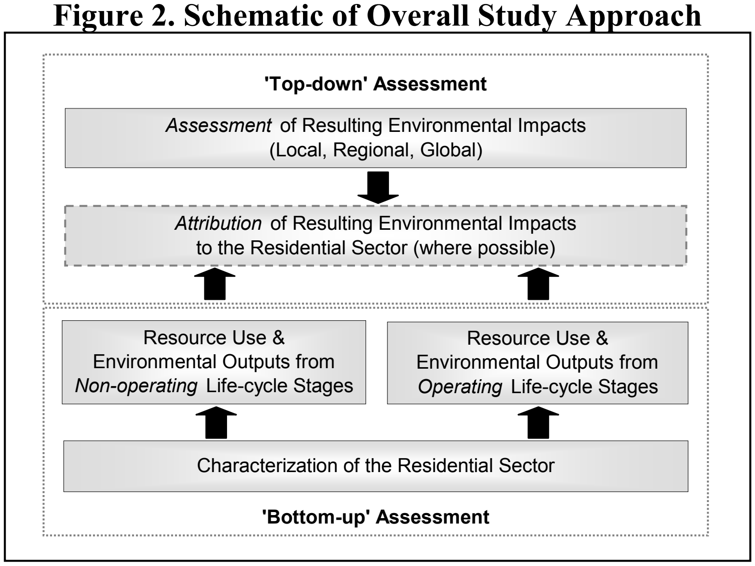
[2] A *scenario* is a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces (e.g., technology changes, energy prices). A scenario is neither a prediction nor a forecast (NRCan 2006c).

Approach

The study combined analytical and descriptive approaches, as described below and as shown in Figure 2.

- **Bottom-up assessment of resource use and environmental outputs**. An analytical approach was used to profile the physical characteristics of the residential sector during the study period, including required dwellings and neighbourhood infrastructure. Resource use and environmental outputs were then calculated for operating and non-operating life-cycle stages over the study period.
- **Top-down assessment and attribution of resulting environmental impacts**. A more qualitative approach was taken in a 'top-down' fashion to bridge the gap, descriptively, between the analytical results (i.e., resource use and environmental outputs) and the resulting environmental impacts seen locally, regionally, and globally. A recurring theme during this study was 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.

Figure 2. Schematic of Overall Study Approach



Source: Marbek Resource Consultants

Methodologies

The following is a brief description of the methodologies and models used for the areas of analysis included in this study.

- **Dwelling stock.** This analysis developed a portrait of the Canadian dwelling stock during 2004-2025.[3] Dwellings were categorized into four dwelling types: Single Detached,

[3] Key sources: a) NRCan's Energy Outlook 2006, based on their *Maple C* model with data from Informetrica — the best available source of data at the time of this study; b) Statistics Canada, 2001 Census data

Row/Town, Low-rise Multi-Unit Residential Building (MURB) units, and High-rise MURB units. The analysis employed regional data where possible.

- **Neighbourhoods**. As shown in Table 1, this analysis characterized the physical attributes of three neighbourhood types that best represented the majority of existing and new Canadian neighbourhoods.[4]

Table 1. Summary of Neighbourhood Type Definitions

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

Source: Jane Thompson Architect

- **Neighbourhood infrastructure.** Using the three neighbourhood types above, this analysis calculated the residential road and accompanying in-ground water infrastructure required during 2004–2025 to densify existing neighbourhoods and build new neighbourhoods.[5]
- **Non-operating effects from new dwellings and infrastructure.** This analysis developed resource use and environmental output indicators per dwelling and per length of infrastructure for each of the non-operating stages.[6] This required characterizing four dwelling archetypes and four infrastructure archetypes, each which included the amount and type of materials used in their construction. These per-dwelling and per-kilometre figures were then multiplied 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 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 activity levels (e.g., litres/capita/day) and market penetration levels for water-using technologies for different end uses, and the resulting water use per dwelling, by dwelling type.[7] This analysis also included changes in water use per dwelling due to renovations of the 2004 existing stock.
- **Direct operating energy for dwellings.** This analysis was completed with Marbek's *Residential Sector Energy End-use Model* in a similar fashion to the water analysis.[8]
- **Direct operating energy for municipal water systems.** This analysis used energy intensities (megajoules/litre) by fuel type to determine the energy used by municipal

[4] Key sources: a) Statistics Canada, 2001 Census data; b) Interviews with municipal planners in three high-growth regions of Canada, which, together with the Montreal region, attract the majority of new dwellings: British Columbia's lower mainland and Vancouver Island, the Calgary–Edmonton corridor, and Ontario's "Golden Horseshoe" including the Greater Toronto Area. City planners from Montreal were not interviewed due to study resources and the assumption that growth trends in Montreal are a composite of the other three high-growth regions; c) Municipal land use data from Ottawa, ON

[5] Key sources: a) CMHC's recently-developed *Sustainable Community Infrastructure Costing Tool* and background report; b) Degmar Construction (road construction consultant) from Markham, ON, who prepared material quantity take-offs and construction-related energy use by activity for various infrastructure elements

[6] Key source: Athena Sustainable Materials Institute's *Environmental Impact Estimator* and its wealth of supporting life-cycle data. http://www.athenasmi.ca/tools/impactEstimator/

[7] Key sources: a) Water use data from surveys and audits conducted in Canada and North America, compiled by NRCan and Statistics Canada; b) Marbek's in-house database of water use characteristics in the residential sector

[8] Key source: Natural Resources Canada's Comprehensive Energy Use Database

water systems to treat and distribute (pump) potable water to dwellings, and to collect (pump) and treat wastewater produced by dwellings.[9]

- **Direct operating energy for residential transportation.** This analysis estimated the vehicle-kilometres travelled per dwelling for personal vehicles and the passenger-kilometres travelled per dwelling for public transportation, all by neighbourhood type.[10] 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* life-cycle assessment model was used to develop per-gigajoule coefficients of resource use and environmental outputs to provide each fuel used to operate dwellings, municipal water systems, and residential transportation. These coefficients were then multiplied by the total (direct) operating fuel use to calculate the indirect effects of using fuels.
- **Resulting environmental impacts.** All sectors of the economy contribute to resource use and environmental outputs, including the residential sector. Given the broad nature of resulting environmental impacts, their direct and indirect causes, their linear and non-linear inter-relationships, and their local, regional, and global scales, definite attribution of impacts to a specific sector is problematic. Therefore, this analysis relied on a qualitative approach informed by the study's quantitative results and supported by data in available literature.

Building the BAU Scenario to 2025

One of the most significant challenges in this study was building a business-as-usual (BAU) scenario that reflected anticipated patterns of urban development using established projections of number and type of new dwellings and their associated land use.

Fundamentally, the method employed was to merge national dwelling projections with intensification plans of high-growth regions. The main issue that arose was that high-growth regions had a different vision of future development patterns than independently-determined dwelling stock projections. This is elaborated below.

- **Intensification plans of high-growth regions**. The study incorporated municipal planners' expectations of neighbourhood development patterns in three of Canada's highest-growth regions: British Columbia lower mainland and Vancouver Island, the Calgary–Edmonton corridor, and Ontario's 'Golden Horseshoe' (i.e., around the west end of Lake Ontario) including the Greater Toronto Area. The intensification plans for these regions had 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 assumed the

[9] Key source: Energy use statistics collected from different municipalities across Canada

[10] Key sources: a) CMHC's *Greenhouse Gas Emissions from Urban Travel Tool*; b) Toronto Transportation Tomorrow Survey 2001; c) Canadian Vehicle Survey 2004 from Transport Canada

intensification plans of these high-growth regions will be fully met. The implication 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 regions indicated expected intensification of existing urban areas through: a) Significant low-rise and high-rise multi-unit construction; b) Conversion of some existing urban green space to housing; and c) Redevelopment of some brownfields to dense housing.

- **National dwelling projections**. At the time of this study, the best available long-term housing stock projection was in Canada's Energy Outlook, 2006 (NRCan 2006a). These projections were used in our study and show a higher share of single detached houses being built during 2004–2025 than is anticipated by Canada's high-growth regions. These projections of household formation are driven by assumptions of economic growth but do not adequately reflect the likely evolution of urban intensification in Canada's high-growth regions or 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 summary, a robust and defensible method was employed to generate the BAU scenario using the best available data subject to study resources. As mentioned previously, this study explores only a BAU scenario and does <u>not</u> attempt to predict or forecast results in 2025.

Results & Implications

Based on the study scope, approach, and methodology described above, this section presents the key findings and implications of the study and discusses their sensitivity to the scenario assumptions. This section attempts to answer high-level questions such as:

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

Characterisation of the Residential Sector

Combining the national dwelling projections and densification plans of Canada's main growth regions, following are the key findings and implications for residential dwellings, neighbourhoods, and neighbourhood infrastructure over the study period of 2004–2025.

- **Four high-growth regions would attract most of the new housing**. In 2004, Canada had 12 million homes; by 2025 this is expected to increase to 16 million (NRCan 2006a). Most of the new dwellings required during 2004–2025 would be built in four high-growth regions: British Columbia's lower mainland (including Metro Vancouver/Greater Vancouver Regional District) and Vancouver Island; the Edmonton–Calgary corridor; Ontario's 'Golden Horseshoe' region (including the Greater Toronto Area); and the Montreal region. Between 1996 and 2001, population growth was roughly ten times higher in these four regions compared to the rest of Canada, resulting in more than 50%

of Canadians living in these four regions in 2001 (DSF 2003). This trend would be expected to continue, thus requiring the majority of housing growth during 2004–2025.

- Densified existing neighbourhoods, especially outer suburbs, would absorb much of the new housing. Intensification policies and initiatives would begin to have an effect on urban land use and intensity, resulting in increasingly densified neighbourhoods. The high-growth regions expect neighbourhoods within their jurisdictions to become 16% to 33% denser (i.e., accommodate more dwellings per unit area), depending on neighbourhood type. As a result, assuming intensification plans would be realized, intensified existing neighbourhoods, especially outer suburbs, would absorb about 90% of the new dwellings built in Canada during 2004–2025. These results are shown in Table 2.

Table 2. Comparison of Dwelling Stock Growth to Neighbourhood Densification during 2004–2025, by Neighbourhood Type

Indicator during 2004–2025	Neighbourhood Type		
	Inner City	Inner Suburb	Outer Suburb
% Increase in total dwelling stock[11]	33%	33%	31%
% Increase densification of existing neighbourhoods[12]	28%	16%	31%
# Existing 50-ha neighbourhoods as of 2004[13]	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		

Source: Marbek Resource Consultants & Jane Thompson Architect

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 and 95% of the total urban land area in 2004. According to the dwelling stock data used in the study and intensification trends reported by high-growth regions, existing outer suburbs would absorb 3 million (roughly 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 is realized by Canadian municipalities. Achieving the 2025 scenario's densities for large urban centres would require changes from the current preference of "single detached houses in suburban settings" to much denser forms of development.

- **Most new neighbourhood infrastructure since 2004 would be needed to densify residential areas in existing neighbourhoods**. Due to the high-growth regions' estimates for densification, over 90% of new road and water infrastructure required during 2004–2025 would be used to densify existing inner city and inner suburb neighbourhoods, while the remainder would be used to build entirely new neighbourhoods. Existing infrastructure in existing outer suburbs would be sufficient to support their densification to 2025.

[11] Based on methodology in Section 2, using dwelling stock growth from NRCan's Energy Outlook 2006
[12] Based on projections from municipal officials in high-growth regions
[13] Neighbourhood size of 50 ha arbitrarily chosen

- **Reductions in environmental impacts would be limited unless existing dwelling stock is addressed**. Of the 16 million dwellings projected for 2025, 75% had already been built by 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 2004's existing dwellings, not new dwellings.

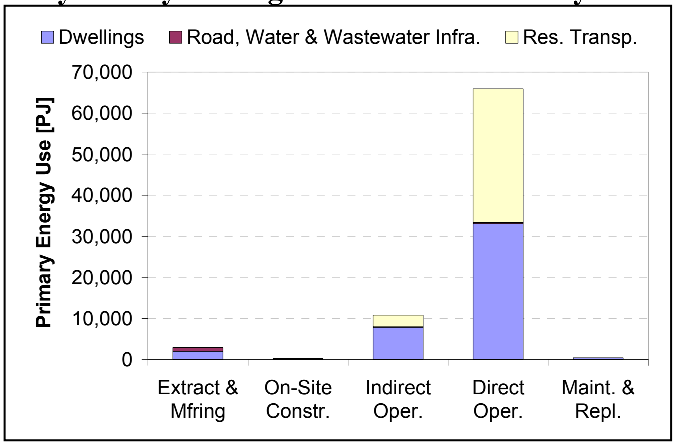
Resource Use and Environmental Outputs & Impacts

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. As mentioned in the Introduction, these residential structures and activities contribute to the overall environmental impacts of the residential sector through operating and non-operating life-cycle stages. Below are the major findings related to the residential sector's life-cycle environmental impacts over the study period of 2004–2025.

Overall Impacts

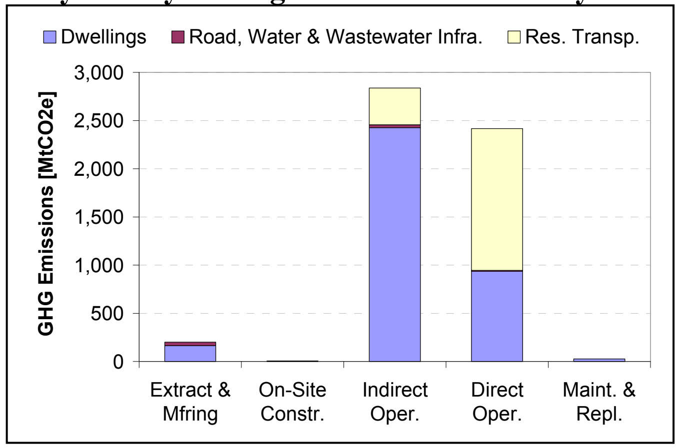
- **Operating stage would dominate overall environmental impacts**. When total resource use and environmental outputs are taken into account, the operating stage of the housing life-cycle would produce 60%–95% of the total life-cycle energy use, water use, greenhouse gases, air contaminants, water pollution, and solid waste during 2004–2025. Examples are shown in Figures 3 and 4 for primary energy and greenhouse gas emissions. The exception is life-cycle solid resource use, which would continue to be dominated by the Extraction & Manufacturing stage. The implication is that *a larger continued effort would be needed to reduce direct and indirect operating impacts than non-operating impacts.*

Figure 3. Life-Cycle Primary Energy Use by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity[14,15]



Source: Marbek /Athena/Jane Thompson

Figure 4. Life-Cycle Greenhouse Gas Emissions by the Residential Sector during 2004–2025, by Life-cycle Stage & Structure/Activity[15,16]



Source: Marbek /Athena/Jane Thompson

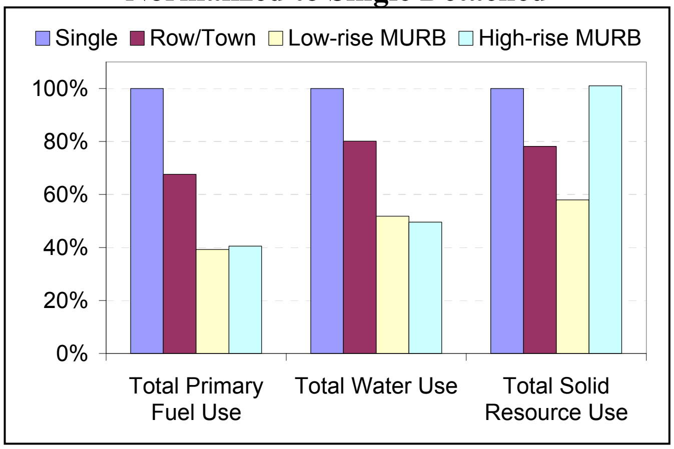
- **Operation of dwellings and residential transportation would dominate life-cycle energy use**. Dwelling operating energy (direct and indirect) would account for over 50% and residential transportation operating energy (direct and indirect) for almost 45% of the total life-cycle primary energy use of the residential sector during 2004–2025, as shown in Figure 3 above. This stresses that, in terms of energy, non-operating effects would be relatively low compared to operating effects. The implication is that *neighbourhood choice, dwelling choice, dwelling condition, and daily behaviour would continue to have a huge influence over how much life-cycle energy is used by the residential sector*.
- **Impacts of direct operating fuel and water use are exacerbated by upstream impacts**. Every unit of fuel or water consumed "inside the meter" at dwelling premises or in vehicles has also caused upstream impacts from extraction, production/refining and delivery of those commodities. Figures 3 and 4 show this labelled as the "indirect operating" stage.

Overall Impacts by Dwelling Type & Neighbourhood Type

- **Compared with other dwelling types, single detached houses would have significantly higher life-cycle environmental impacts, per dwelling.** On a per-dwelling basis over the study period, a new single detached house would require 1.3 to 2 times the life-cycle resources (with the exception of solids) and produce 1.5 to 4 times the life-cycle emissions and pollutants of other dwelling types, as shown in Figures 5 and 6. These increased environmental outputs could be assumed to result in higher environmental impacts than other dwelling types. The implication is that *there are significant environmental consequences of deciding which dwelling types to build and/or live in*.

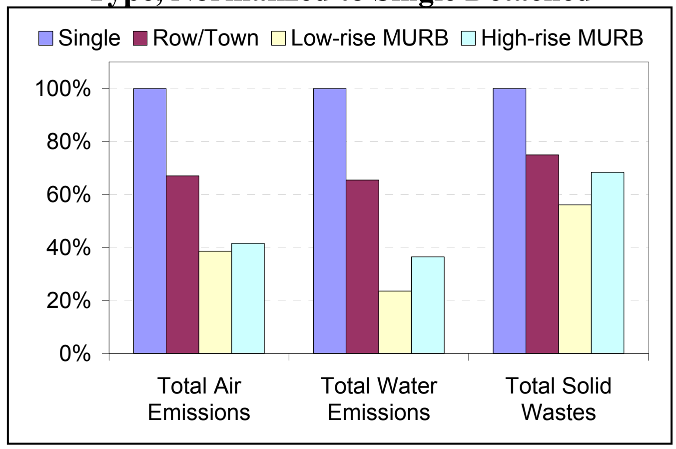
[14] *Primary energy* includes all raw energy resources (e.g., coal, crude oil, natural gas, wood, etc.) used to produce and distribute *secondary energy* purchased by consumers (e.g., electricity, heating fuels, transportation fuels, etc.)
[15] Results for some non-operating stages were almost negligible and may not be visible on chart due to scale
[16] Does not include the effects of further oil sands development on indirect operating emissions

Figure 5. Life-Cycle Resource Use per New Dwelling during 2004–2025, by Dwelling Type, Normalized to Single Detached



Source: Marbek /Athena/Jane Thompson

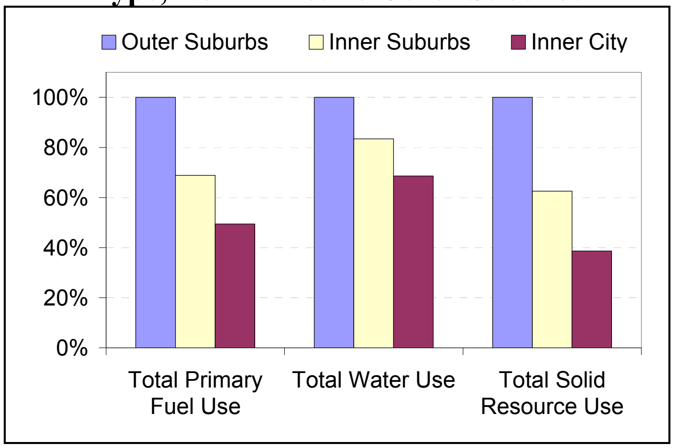
Figure 6. Life-Cycle Emissions & Pollutants per New Dwelling during 2004–2025, by Dwelling Type, Normalized to Single Detached



Source: Marbek /Athena/Jane Thompson

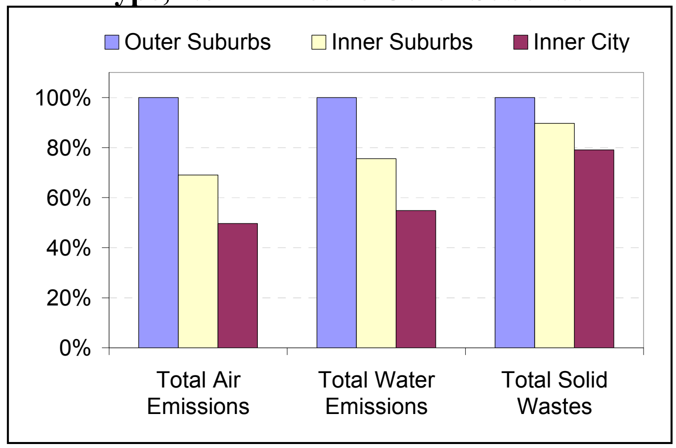
- **Compared with other neighbourhood types, outer suburb dwellings would have significantly higher life-cycle environmental impacts, per dwelling**. On a per-dwelling basis over the study period, an average new dwelling in an outer suburb would require 1.2 to 2.5 times the life-cycle resources and produce 1.1 to 2 times the life-cycle emissions and pollutants of an average new dwelling in other neighbourhood types, as shown in Figures 7 and 8. This is due to lower density dwelling types (e.g., higher share of single detached houses) and increased transportation (linked to neighbourhood type, not dwelling type) in outer suburbs. Considering the number of dwellings per neighbourhood and the number of neighbourhoods of each type in Canada, the aggregate result is that outer suburbs would require five times the life-cycle resource use and produce five times the life-cycle emissions and pollutants over the study period as inner suburbs and inner city neighbourhoods *combined*. The implication is that *there are significant environmental consequences of deciding which neighbourhood types to build and/or live in*.

Figure 7. Life-Cycle Residential Sector Resource Use per Average New Neighbourhood Dwelling during 2004–2025, by Neighbourhood Type, Normalized to Outer Suburbs



Source: Marbek /Athena/Jane Thompson

Figure 8. Life-Cycle Residential Sector Emissions & Pollutants per Average Neighbourhood Dwelling during 2004–2025, by Neighbourhood Type, Normalized to Outer Suburbs



Source: Marbek /Athena/Jane Thompson

Air Impacts

- **Dwelling and residential transportation operation would dominate life-cycle air emissions**. Residential sector life-cycle greenhouse gas (GHG) emissions would be roughly 5,500 megatonnes of carbon dioxide-equivalent ($MtCO_2e$) over the study period, as shown in Figure 4 above.[17] Over 95% of this would be generated during the operating stage of the housing life-cycle, split roughly 65% for dwelling operation and 35% for transportation operation. In contrast, transportation operation would almost entirely dominate criteria air contaminants, due to carbon monoxide emissions from mostly gasoline-powered private vehicles (EC 2007). It is important to note that neighbourhood type – not dwelling type – would continue to drive the transportation pattern of residents. For example, the average outer suburb resident uses personal vehicles for two and four times the travel distance as an inner suburb or inner city resident. The implication is that *residential sector air emissions are heavily determined by not only the home you live in and how you operate it, but also where you live and how you move*.

Water Impacts

- **Dwelling operation would continue to dominate life-cycle water use**. This study assessed water use for: material extraction, manufacturing, and transportation; fuel extraction, refining, and distribution; electricity generation; and dwelling operation. The results show a similar story to Figure 3 above — that water use from dwelling operation would account for over 80% of the total life-cycle water use of the residential sector over the study period. In 2004, Canadians consumed 335 litres of water per person per day, totalling 3.7 teralitres — equivalent to about 15 days of water flow over Niagara Falls (Niagara 2008) — and representing 60% of total annual water use in the country (CMHC

[17] To put this into perspective, the *annual* (not life-cycle) GHG emissions in 2004 for *all* Canadian sectors (not just residential), *excluding* electricity production, were 388 MtCO2e (NRCan 2006b).

2005). Canada's per-capita annual water consumption is very high, at 65% above the OECD average (UVic 2001). The implication is that *dwelling operation and the consequent demand on direct and upstream life-cycle water use would continue to result in large amounts of water-borne pollutants generated in the housing life-cycle*.

- **Annual water use in existing dwellings would decline, but total water use would still increase**. Operating water use in the existing (2004) housing stock would decrease by 20% during the study period with improved plumbing fixtures in kitchen and bathroom renovations. Unfortunately, water use in the new dwelling stock more than makes up the difference, resulting in a 13% increase in annual residential sector water use from 2004 to 2025.
- **The aquatic environment would be significantly impacted by the residential sector**. The intensity of operating water use and how it is managed would continue to deplete fresh water resources and decrease water quality. Water quality is only partially addressed by urban treatment infrastructure; while most Canadian dwellings are serviced by secondary wastewater treatment facilities, secondary treatment is a biological process and is not designed to remove all the contaminants in wastewater. At the same time, 30%–50% of storm-water and snowmelt in urban areas is converted to surface runoff and, even in rare cases where storm water treatment systems are in place, they are typically designed to address only a few pollutants.

Land & Soil Impacts

- **Extraction and manufacturing stage would dominate life-cycle solid resource use**. Excluding energy and water use and assigning all remaining assessed resources (minerals, metals, wood, etc.) equal weighting, the Extraction & Manufacturing stage of the housing life-cycle would consume the most solid resources. This is understandable, since almost all solid resources used for the residential sector are extracted from the earth during the Extraction & Manufacturing stage, when materials are prepared for construction of dwellings and neighbourhood infrastructure. About 60% of solids would be used for construction of roads and residential water and wastewater infrastructure, with the remaining 40% going to construction of dwellings.
- **Indirect operating stage would dominate life-cycle solid waste production**. With municipal solid waste from dwelling operation aside (excluded from the study scope), most of the life-cycle solid waste generated during 2004–2025 would be from indirect operating impacts, such as the solid waste from extracting, refining, and combusting coal and other fossil fuels for electricity generation.
- **Changing land use patterns would require careful targeting of activities to reduce environmental impacts**. Given expected neighbourhood development patterns, one challenge would be 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, suburban expansion and associated consumption of land

would decline significantly compared with the patterns in the past 30 years or so, and urban intensification policies and initiatives would result in existing neighbourhoods absorbing most of the new dwelling stock to 2025. The implication is that *we would need to shift environmental mitigation efforts from mostly greenfield developments in 2004 to neighbourhood intensification within existing boundaries by 2025*. 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 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", meaning it cannot absorb water. The implications are that: i) *fundamental changes to the water cycle in urban areas would occur unless management measures are taken*, for example to allow groundwater recharge; and ii) *increased impermeable area would exacerbate the "heat island" effect,* which, in turn, could produce secondary effects in local wind patterns, precipitation, smog, etc.

Integrated Impacts

Emissions, pollutants, and land alterations have local, regional and global environmental consequences, as illustrated in Table 3.

Table 3. Example 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	√	√		√	√	√	√

Source: Marbek Resource Consultants; Note: "√" means a relevant linkage exists

The magnitude of the residential sector's environmental outputs over the study period would be significant enough that they can certainly be expected to contribute to broader environmental impacts, including acid rain, smog, climate change, biodiversity decline, etc. The extent of this contribution, however, is complex and difficult to estimate.

Many regional and global scale environmental impacts are not linear outcomes of every-day choices in the residential sector, given the scale and non-linearity of the impacts, and the interdependent roles of other contributing sectors and activities. Environmental systems responses are often based on thresholds or tipping points, beyond which significant changes occur. A regional example would be land use resulting in habitat loss that leads to species extinctions; a global example would be GHG emissions resulting in climate change that leads to shifts in ocean currents. Thus, it is difficult to attribute resulting environmental impacts directly to the residential sector; any resulting insights were more indicative than definitive.

Sensitivity to Scenario Assumptions

The scenario used in this study served to explore, not forecast, the environmental impacts of Canada's residential sector to 2025. If the scenario's assumptions are not realized (e.g., fewer single detached houses or less intensification), the magnitude of the environmental impacts would change somewhat, but the implications would remain largely the same, due to:

- The dominance of the existing dwelling stock and transportation of existing residents;
- The dominance of the operating life-cycle stage; and
- The dependence of transportation use on neighbourhood type, regardless of whether the neighbourhood is densified existing or is new.

Notable exceptions are that considerably more land use and required new infrastructure would be needed if intensification is less than is planned in the high-growth regions.

Conclusions

This study was an ambitious first attempt at exploring the use of life-cycle principles to assess the environmental impacts of an entire sector.

Based on the methodology and scenario assumptions used for the study period of 2004–2025, following is a summary of the key implications presented above:

- Four high-growth regions[18] would need to accommodate most of the new housing during 2004–2025 and, according to their intensification plans, much of this would occur inside their existing urban boundaries. As a result, environmental mitigation efforts would need to shift from greenfield developments to neighbourhood intensification, especially within these regions.
- A larger continued effort would be needed to reduce direct and indirect operating impacts than non-operating impacts. This would be particularly true for dwelling and transportation operation, which dominate the operating stage. It is also important to remember that every unit of fuel or water consumed "inside the meter" at dwelling

[18] British Columbia's lower mainland and Vancouver Island; the Edmonton–Calgary corridor; Ontario's 'Golden Horseshoe' region, including the Greater Toronto Area; and the Montreal region

premises or in vehicles has also caused upstream impacts from extraction, production/refining and delivery of those commodities.

- Reductions in environmental impacts would be limited unless existing dwellings are addressed.
- There are significant and sustained environmental consequences of deciding: i) which dwelling types to build and/or live in; and ii) which neighbourhood types to build and/or live in. Single detached houses and outer suburb neighbourhoods are noticeably higher impact than other options.
- Neighbourhood choice, dwelling choice, dwelling condition, and daily behaviour all influence the life-cycle environmental impacts of the residential sector. Home builders are not the sole culprit, nor are consumers, regulators, or others. We all play a part in creating these impacts and we are all responsible for reducing them.

Since this study was only a first attempt at this scope and depth of life-cycle assessment, it does not provide the definitive answer, but will help Canadian and foreign stakeholders plan further research and explore appropriate solutions to address the residential sector's increasing environmental impact.

References

(CMHC 2005) Canada Mortgage and Housing Corporation, CMHC Newsroom. May 24, 2005. *Toronto Workshop: First Step for Canada in Residential Water Re-Use*.

(DSF 2003) David Suzuki Foundation. 2003. *Understanding Sprawl: A Citizen's Guide*. http://www.davidsuzuki.org/Climate_Change/Sprawl.asp

(EC 2007) Environment Canada. Last updated April 2007. "2005 CAC Emissions for Canada." http://www.ec.gc.ca/pdb/cac/Emissions1990-2015/EmissionsSummaries/2005_canada_e.cfm

(Niagara 2008) Niagara Parks. Accessed February 25, 2008. "Niagara Falls Facts & Figures." http://www.niagaraparks.com/nfgg/geology.php

(NRCan 2006a) Natural Resources Canada. 2006. *Canada's Energy Outlook: The Reference Case 2006*. http://www.nrcan.gc.ca/com/resoress/publications/peo/peo-eng.php

(NRCan 2006b) Natural Resources Canada. September 2006. *Energy Efficiency Trends Analysis Tables (Canada) — Total End-Use Sector — GHG Emissions*. http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablesanalysis2/aaa_00_1_e_4.cfm?attr=0

(NRCan 2006c) 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

(UVic 2001) University of Victoria. 2001. *Canada vs. the OECD* [Organisation for Economic Co-operation & Development]*: An Environmental Comparison*. http://www.environmentalindicators.com/htdocs/index.html