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Autonomous Vehicles, Parking & the Real Estate Sector

IN ALBERTA & CANADA

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The Transition Accelerator
L'Accélérateur de transition

ALBERTA REAL ESTATE FOUNDATION
CESAR | CANADIAN ENERGY SYSTEMS ANALYSIS RESEARCH
UNIVERSITY OF CALGARY

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ABOUT THE TRANSITION ACCELERATOR

The Transition Accelerator (The Accelerator) exists to support Canada's transition to a net zero future while solving societal challenges. Using our four-step methodology, The Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.

Our four-step approach is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

1 UNDERSTAND the system that is being transformed, including its strengths and weaknesses, and the technology, business model, and social innovations that are poised to disrupt the existing system by addressing one or more of its shortcomings.

2 CODEVELOP transformative visions and pathways in concert with key stakeholders and innovators drawn from industry, government, indigenous communities, academia, and other groups. This engagement process is informed by the insights gained in Stage 1.

3 ANALYZE and model the candidate pathways from Stage 2 to assess costs, benefits, trade-offs, public acceptability, barriers and bottlenecks. With these insights, the process then re-engages key players to revise the vision and pathway(s), so they are more credible, compelling and capable of achieving societal objectives that include major GHG emission reductions.

4 ADVANCE the most credible, compelling and capable transition pathways by informing innovation strategies, engaging partners and helping to launch consortia to take tangible steps along defined transition pathways.

ABOUT THE AUTHORS

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David B. Layzell, PhD, FRSC is an Energy Systems Architect with the Transition Accelerator, a Faculty Professor at the University of Calgary and Director of the Canadian Energy Systems Analysis Research CESAR initiative. Between 2008 and 2012, he was Executive Director of the Institute for Sustainable Energy, Environment and Economy (ISEEE), a cross-faculty, graduate research and training institute at the University of Calgary. Before moving to Calgary, Dr. Layzell was a Professor of Biology at Queen's University, Kingston (cross appointments in Environmental Studies and the School of Public Policy), and Executive Director of BIOCAP Canada, a research foundation focused on biological solutions to climate change. While at Queen's, he founded a scientific instrumentation company called Qubit Systems Inc. and was elected 'Fellow of the Royal Society of Canada' (FRSC) for his research contributions.

Mark Stout MES, P.Eng

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Mark Stout, MES, P.Eng has more than 10 years' experience in urban mobility and urban development research, planning, and design. He has operated in government and consulting environments and understands the planning and design process of multimodal streets/mobility infrastructure for cities. His past work includes infrastructure planning, including but not limited to statutory land use policy planning, multimodal corridor planning studies, transportation impact assessments, and cycling facility design for all ages and abilities, etc. At CESAR, Mark explored the future of urban mobility, including how the convergence of autonomous mobility on demand (AMOD) could be directed to put Canada on a pathway to a low-carbon economy while addressing other challenges in the personal mobility sector. Mark has a Masters of Environmental Studies in Urban Planning from York University and a Bachelor of Science in Civil Engineering from Queen's University. He is a Registered Professional Planner (RPP) and Professional Engineer in Alberta.

Jonathan Leary

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Jonathan Leary joined CESAR as a summer student in 2020 through the NSERC CREATE-IISC (Integrated Infrastructure for Sustainable Cities) program. At CESAR, Jonathan worked on two projects, one focused on the future of autonomous vehicles in Alberta and the other on efforts to establish a hydrogen economy in Alberta. Driven by a desire to solve real-world issues, Jonathan recently transferred from the Faculty of Science (Honours in Chemistry) to the Schulich School of Engineering, where he plans to obtain a Bachelor of Science in Engineering.

Chris Stone BSc.

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Chris Stone graduated from Queen's University in Kingston, Ontario, with a Bachelor of Science in Geological Engineering. Since graduating Chris has been working as a consultant on various data science and software development projects. He brings a diverse range of interests and skills to CESAR; his background in geological engineering and experience with computers and technology afford him a skillset that is well suited to the inter-disciplinary approach of understanding Canada's energy systems.

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LIST OF ABBREVIATIONS

ACES	Autonomous, Connected, Electric, Shared
AMoD	Autonomous Mobility-on-Demand
AREF	Alberta Real Estate Foundation
AV	Autonomous Vehicle
CanESS	Canadian Energy Systems Simulator
EV	Electric Vehicle
GM	General Motors
HH	Household
LDV	Light Duty Vehicle
MaaS	Mobility-as-a-Service
PUDO	Pick Up and Drop Off
SAE	Society of Automotive Engineers
TaaS	Transportation-as-a-Service
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2W	Vehicle to Web

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EXECUTIVE SUMMARY

For the past 100 years, the automobile, especially personally owned vehicles, have greatly impacted the design of our cities and how we live in them. However, Canada's personal mobility systems are poised to be radically transformed by the convergence of four disruptive technology and business model innovations: vehicle automation, connectivity, electrification and car sharing. Together, these innovations enable **Autonomous Mobility-on-Demand (AMoD)**, whereby fleets of autonomous, connected and driverless vehicles will pick up and drop off passengers, effectively replacing the need for personal vehicle ownership, while providing a more convenient, safer and lower cost service.

To better understand the forces driving the transition to AMoD and the implications for the real estate sector in Alberta and across Canada, this study quantifies the household cost of personal vehicle ownership in Alberta and Canada, with a particular focus on the embedded cost of parking in the residential, commercial and institutional sectors. The study then explores the ways in which a transition to AMoD is likely to impact urban design and the real estate sector.

> "This study quantifies the household cost of personal vehicle ownership in Alberta and Canada, with a particular focus on the embedded cost of parking in the residential, commercial and institutional sectors."

THE COST OF PERSONAL VEHICLE OWNERSHIP

Expressed per capita, Statistics Canada[1] reports that annual household expenditures in 2017 were 6% higher in Alberta ($26,056/person-yr) than in Canada ($24,509/person-yr) with shelter being the dominant expense at 29% of the total in both jurisdictions. Expenditures on personal mobility were the second largest and at $5,573/person-yr are 14% higher in Alberta than in Canada ($4,887/person-yr). In both jurisdictions, personal vehicle ownership accounts for 90% of the household expenses for personal transport.

These Statistics Canada data assign parking cost as only about 2% of personal vehicle ownership ($118 and $94/person-yr, for Alberta and Canada, respectively). However, these number reflect only the out-of-pocket costs for household parking, not the embedded cost for residential parking, or the cost of commercial and institutional parking that is provided 'free' but that adds to the cost of goods and services. This study works to fill this knowledge gap.

[1] Statistics Canada, Table 11-10-0222-01. www150.statscan.gc.ca

THE SCALE AND COST OF LIGHT DUTY VEHICLE PARKING

The analysis presented here is, to our knowledge, the first detailed assessment of the number and cost of light duty vehicle (LDV) parking in Canada. Compared to all Canada, Alberta has more persons per household (2.8 vs. 2.6), more light duty vehicles (LDV) per capita (0.73 vs 0.62) and therefore more LDVs per household (2.07 vs. 1.61).

To quantify the embedded cost of parking in household expenses, estimates were made for the number of parking spots and their associated land, construction and maintenance cost in the residential and commercial/institutional sectors. On-street parking spaces were also estimated. Insights included:

For Alberta	For Canada
Alberta has between 13 and 18 million parking spaces for the 3.1 million registered light duty vehicles in the province, or 4.3 to 5.8 parking spaces per vehicle. About 32% of these spaces are associated with the residential sector, 23% with commercial and institutional sectors and the balance are on-road spaces,	Canada has between 71 and 97 million parking spaces for the 23 million registered light duty vehicles in the province, or 3.2 to 4.4 parking spaces per vehicle. About 40% of these spaces are associated with the residential sector, 26% with commercial and institutional sectors and the balance are on-road spaces.
The annualized cost of the residential and commercial/institutional (C&I) parking in Alberta is between \$8.1 and \$22B/year. That is equivalent to \$1,932 to \$5,134/person-year, 44% of which is linked to residential and 56% is commercial/institutional. These costs are embedded in the cost of residences and or in the products and services from commercial and institutional sectors.	The annualized cost of the residential and commercial/institutional (C&I) parking in Canada is between \$52 and \$143B/year. That is equivalent to \$1,452 to \$3,967/person-year, 46% of which is linked to residential and 54% is commercial/institutional. These costs are embedded in the cost of residences and or in the costs of products and services from commercial and institutional sectors.

When the household expenses associated with personal vehicle ownership were adjusted to include the embedded costs for parking in the cost of shelter (residences) or in the cost of goods and services from commercial and institutional sectors, there was a 31% (Canada) or 36% (Alberta) increase in the estimated household cost of personal mobility in Canada (**Figure I**). Clearly, the full costs of parking must be included when considering the AMoD transformation of personal mobility in Canada.

"The full cost of parking must be included when considering the AMoD transformation of personal mobility in Canada."

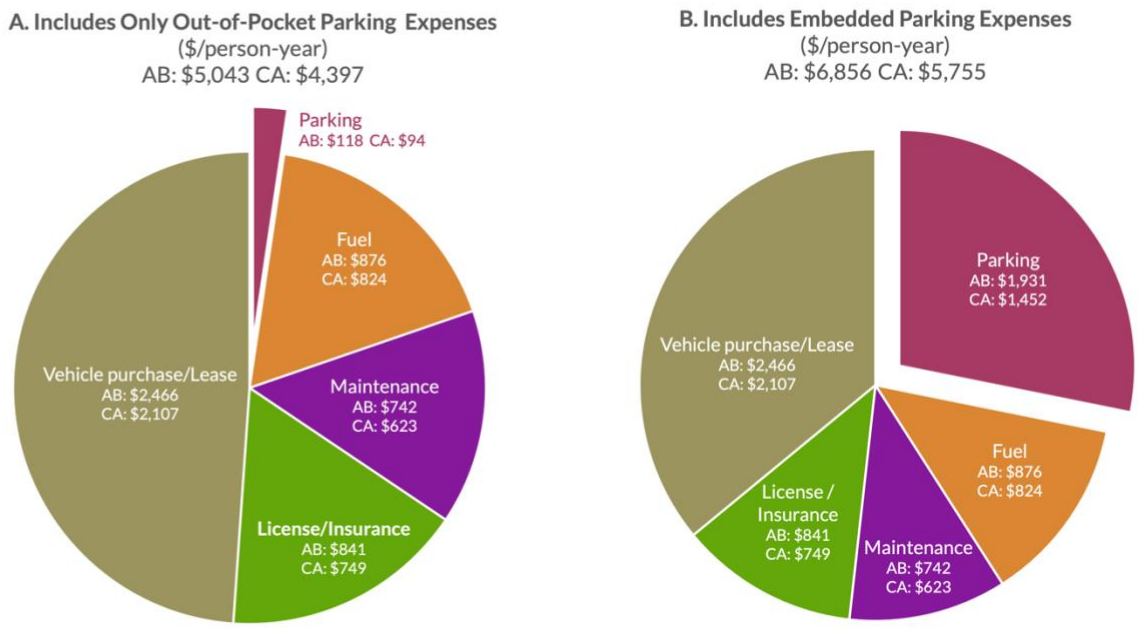


Figure I Household Expenditures Associated with Personal Vehicle Ownership (2017)

Values are expressed as CA$ per person-year based on 2.8 and 2.6 persons per HH in Alberta and Canada, respectively. **A.** Summary of Statistics Canada data (Table: 11-10-0222-01) which only considers out–of-pocket expenses for parking. **B.** Similar to Panel A,but incorporates the low estimate from this study on the embedded expenses for parking that are associated with providing shelter and in goods and services from commercial and institutional sectors. AB, Alberta; CA, Canada.

AMoD AND THE REAL ESTATE SECTOR

The transition of the business model for personal mobility from personal vehicle ownership to AMoD, could reduce household expenses, and increase disposable income. Given that one AMoD vehicle should be able to deliver the service now provided by eight personally owned vehicles, a transition to AMoD could decrease personal mobility costs for by 50% or more. Implications of AMoD for the real estate sector include:

- The transition to fully autonomous vehicles is likely to begin with luxury, personally owned vehicles that will be able to drop off their owners and drive themselves to lower cost parking lots. Strategically located, higher cost parking lots will lose customers and value.
- Urban public transit is likely to be an early adopter of AMoD vehicles, especially in providing first mile/ last mile services to connect to commuter trains and express buses. This could reduce demand for second vehicles in households, and parking at transit stations.
- Widespread deployment of AMoD has the potential to dramatically reduce the use of, and demand for personally owned vehicles. In the residential sector, this may result in:
  - Removal of driveways, and conversion of garages to secondary suites, laneway housing, etc
  - A movement against personal vehicle parking on streets, in favour of pick up and drop off (PUDO) locations, bicycle lanes and wider sidewalks,
  - Unused parking lots/ parkades associated with condominiums and apartments,
  - Elimination of minimum parking requirements for new residential construction, but new demands for safe and convenient pick up and drop off (PUDO) locations.

- In the commercial and Institutional sectors, AMoD deployment may result in:
  - Demolition or refurbishment of above ground parking facilities so they can be repurposed,
  - Surface parking converted to other uses, including increases in densification or greenspace,
  - More attention being paid to PUDO locations and designs.
  - Underground parking facilities will either be taken over by companies providing AMoD fleets or be allocated to other uses.
  - Reducing or eliminating street parking to allow more 'people-friendly' places.
  - Phasing out of car dealerships, fueling stations, vehicle service facilities etc.
  - A need to rethink how strip malls, box stores, shopping malls and specialty shops will need to adapt to a new business model for personal mobility.

While much uncertainty exists regarding the timing of the transition to AMoD, there is widespread understanding that this is the direction society is headed, driven by economics and convenience. The real estate sector can benefit from understanding, advancing and adapting to the transition.

1 INTRODUCTION

Personal Mobility represents a substantial financial burden on households in Canada, accounting for about 20% of annual expenditures. Only the annualized cost for providing shelter is higher at 29% (**Figure 1.1A**). Of the costs for personal mobility, 90% are associated with owning (43%), licensing/insuring (15%), maintaining (13%), fueling (17%) and parking (2%) personally owned vehicles. Public Transport, including surface and air travel accounts for the remaining 10% (**Figure 1.1B**).

However, we live in a time of transformative and disruptive change driven by technology, business model and social innovations. Such disruptive forces could dramatically alter household expenditures and the industry sectors that are dependent upon them.

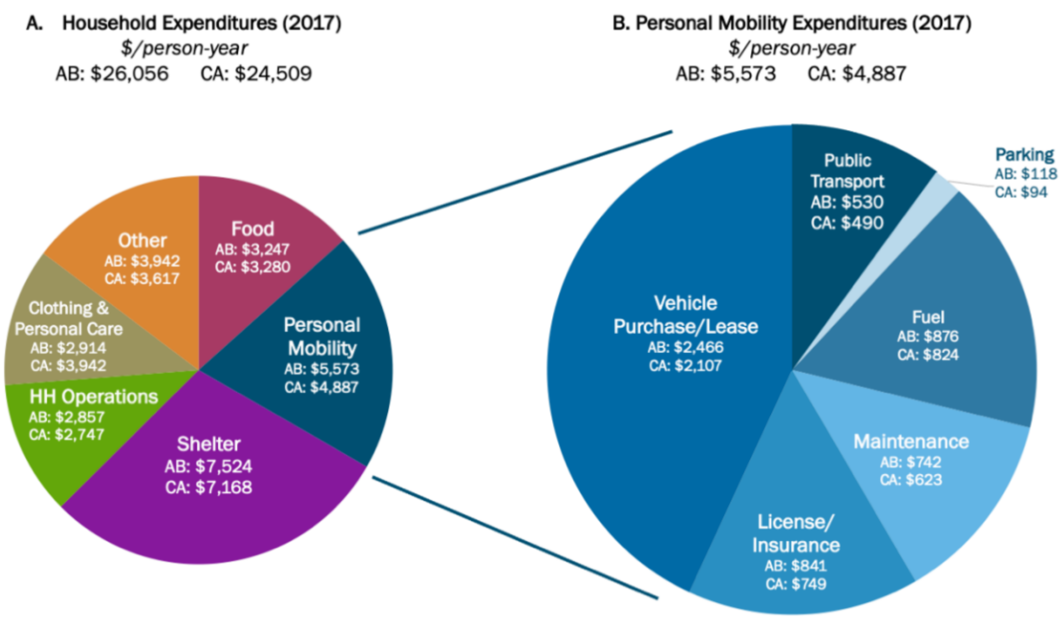


Figure 1.1 Household Expenditures associated with personal vehicle ownership in Alberta and Canada

Household (HH) Expenditures associated with personal vehicle ownership in Alberta and Canada in 2017, expressed as CA$ per person-year based on 2.8 and 2.6 persons per HH in Alberta and Canada, respectively. **A.** Summary of Statistics Canada data [1] which only considers out–of-pocket expenses for parking. **B.** Like Panel A but incorporates 82% (proportion of light duty vehicles personally owned) of the low estimate from this study on the embedded expenses for parking that are associated with providing shelter and in goods and services from commercial and institutional sectors. AB, Alberta; CA, Canada.

For example, the personal mobility sector in Canada and around the world is poised to be radically transformed by the convergence of four disruptive innovations. [2] The first, and perhaps most important is automation made possible by advances in sensor technologies, powerful computers, and artificial intelligence. Closely associated with automation is high-speed wireless connectivity to other vehicles, as well as traffic infrastructure, the internet, passengers, and pedestrians. Vehicle electrification made possible by improvements in the cost and performance of batteries and motors, as well as the proliferation of recharging infrastructure. Finally, new vehicle sharing technologies and behaviours are becoming more popular thanks to the efforts of companies like Car2go, Uber and Lyft, to mention but a few (**see Table 1.1**).

On their own, each of these technological innovations promise to change the way Canadians move around, but together they have the potential to transform the business models used to support personal mobility, the structure of our cities and the energy systems on which our economy is built.

Autonomous Mobility-on-Demand (AMoD) describes a shift away from personally owned modes of transportation towards mobility solutions that are consumed as a service, an evolution of ridesharing platforms such as Uber and Lyft. Autonomous, connected, driverless vehicles will pick up and drop off passengers, effectively replacing the need for personal vehicle ownership, while providing a more convenient, less expensive service.

> "Autonomous Mobility on Demand (AMoD) describes a shift away from personally-owned modes of transportation towards mobility solutions that are consumed as a service."

A single shared AMoD vehicle may be able to provide mobility services for up to ten personally owned vehicles, with each AMoD vehicle driving 150,000 to 200,000 km/year, instead of the 15,000 to 20,000 km/year typical of personally owned vehicles. AMoD vehicles are expected to log over 1 million km in their 5 to 8-year lifetime, over 4 times the vehicle-km-travelled (VKT) achieved by today's vehicles over their 15-year lifetime. This change favours more expensive vehicles that have lower maintenance and fuel costs, supporting the shift to less polluting, electric vehicles over those with internal combustion engines. This will allow AMoD to deliver mobility at a fraction the cost of our current modes of transportation. RethinkX [2] predicts that over the next 10 years, a fleet of autonomous electric vehicles in North America will contribute to a 40% increase in personal mobility demand while providing mobility service at a quarter the current cost. Others, including the Victoria Transport Policy Institute [3] are not so bullish, suggesting the transformation will not be fully realized until the 2050's or 2060's. However, there is widespread agreement on the forces driving transformative change in the sector.

Table 1.1 Types of 'Mobility-as-a-Service'

Human Operated	Autonomously Operated
Public Transport (buses, trains, etc.)	Autonomous Public Transport
Mobility-on-demand (Ride-hail, ride-share, and car-share)	Autonomous Mobility-on-demand
Electric Scooters	—
Bike-share (Electric)	—

The AMoD disruption promises to deliver a major boost in household disposable income. For example, in Canada, transportation accounts for 20% of the average household budget, or $12,707 per household-year, with 90% of that linked to personal vehicle ownership. [3] If AMoD were to reduce that by 50%, the increase in disposable household income per year could become one of the largest economic stimuli in the next two decades.

AMoD will not only completely transform our existing transportation system but promises to redefine urban land use and the design of our cities. Our cities have been shaped by personal vehicle use. Personally-owned vehicles are only used about 4-5% of the time; 95% of the time they are parked [4], taking up valuable land and making our cities more car-friendly than people-friendly. More AMoD vehicles and many fewer personally owned vehicles will result in less parking demand and have many other impacts on our urban landscape.

This study strives to better understand the magnitude and annualized cost of parking for personally owned vehicles in Alberta so the potential implications of a transition to AMoD vehicle could be put into perspective. For comparative purposes, values for Canada are also generated to assess whether Alberta's numbers are similar to or greater than that in other provinces.

To our knowledge, this is the first detailed assessment of the parking inventory and annualized cost for Alberta and Canada. The Statistics Canada data presented in **Figure 1.1** shows parking as only 2% of annual household expenditures for personal mobility ($94 and $118/person-year for Canada and Alberta, respectively). However, these values represent only direct, out-of-pocket expenses for parking. They do not include the embedded costs for residential parking (i.e., in the cost of shelter), or in the commercial and institutional sectors that provide 'free parking' and add that cost to their markup for the products and services they sell.

This study attempts to quantify the actual societal cost for light duty vehicle parking in Alberta and Canada. The functional units for the study are population and household numbers so the report begins there (**Section 2**). The estimates for off-street residential (**Section 3**) and commercial (**Section 4**) parking, as well as on street (**Section 5**) parking draw heavily on data from a variety of government and industry sources. **Section 6** provides a summary overview of the findings and draws on a literature review (**APPENDIX A**) to explore the implications of AMoD on future for parking in Alberta and Canada.

The primary audience for this report is the real estate sector because the Alberta Real Estate Foundation (AREF) not only contributed to the study, but their sector is likely to be impacted by the transformational changes that our cities will experience in the transition to AMoD in the future.

2 ROAD VEHICLE REGISTRATIONS AND POPULATION

Data from Statistics Canada showed that, in 2018, there were 3.5 million registered motorized road vehicles in Alberta, up from 2.1 million in 2000; an average annual growth rate of 2.7% per year (**Figure 2.1A**). In comparison, registration of road vehicles in all of Canada grew 1.9% annually over the same period (**Figure 2.1B**). [5] Of these vehicles, 87% to 94% were Light Duty Vehicles (LDV).

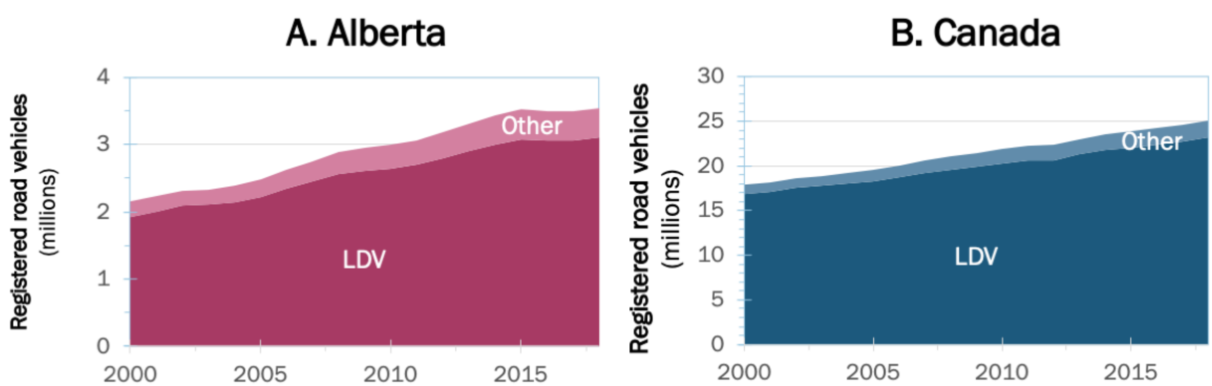


Figure 2.1 Road vehicle registrations in Alberta and Canada

Road vehicle registrations in Alberta (A) and Canada (B). Light Duty Vehicles (LDV); and Other (Motorcycles, Mopeds, Medium Duty and Heavy Duty Vehicles). [5]

The faster growth in vehicles registered in Alberta is largely explained by the 2.3% average annual growth of Alberta's population in comparison to a rate of only 1% per year on average in the rest of Canada over the same period (**Figure 2.2A**). [6]

The number of registered LDV's was divided by the populations of Alberta and Canada to determine the number of LDV's per capita in each region (**Figure 2.2B**). While there were 0.62 LDVs per capita in Canada in 2018, per capita LDVs in Alberta were 16% higher at 0.73.

Of the 25.1 million motorized road vehicles registered in Canada, about 92% were LDVs (**Figure 2.1B)** and the Canadian Energy Systems Simulator (CanESS) [7] model estimates that 82% of those vehicles are personally owned (**Figure 2.2C)**

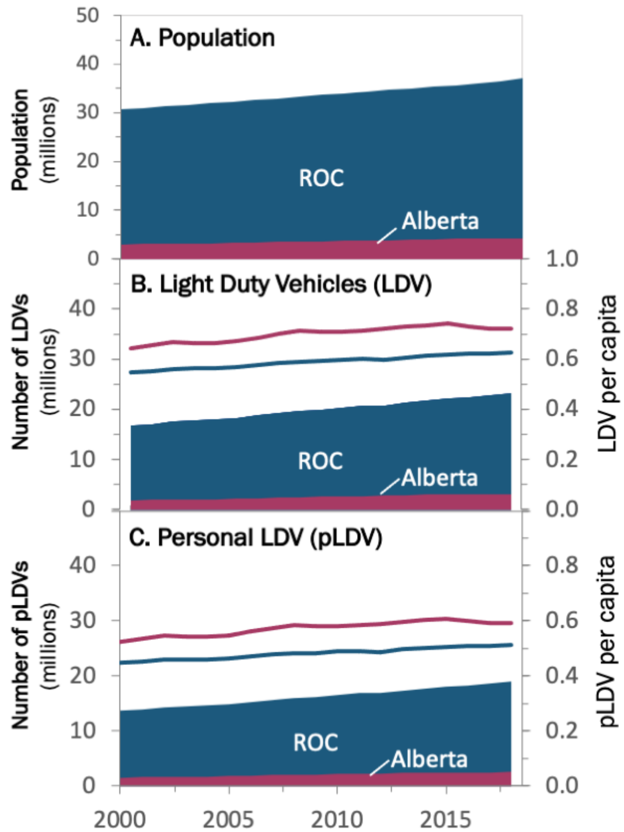


Figure 2.2 Population, total and personal number of light duty vehicles in Alberta and Canada

The population (A), total (B) and personal (C) number of light duty vehicle for Alberta, and the rest of Canada [5], [6]. The trendlines in panels B and C represent number of vehicles per capita (right-hand axis). ROC, rest of Canada

3 ROAD VEHICLE RESIDENTIAL PARKING INVENTORY AND COSTS

3.1 Household Numbers

To estimate the residential parking inventory in Alberta and Canada, data were first collected from Statistics Canada [8] on the number of households by type in each region as summarized in **Figure 3.1.** Of the 1.48 million households in Alberta 81% were considered single residential, and they included single detached (64%), semi-detached (6%), row houses (8%) and apartments in duplexes (3%). The remaining 19% were considered multi-residential.

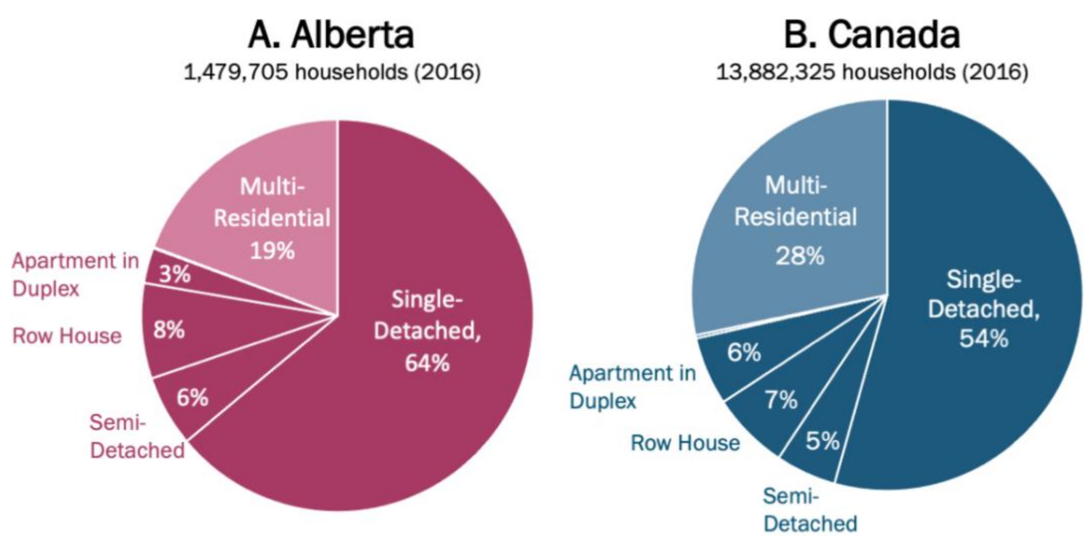


Figure 3.1 Household numbers in Alberta and Canada

Household numbers in Alberta (A) and Canada (B) in 2016 grouped by single residential (darker colour) or multi–residential land uses (lighter colour) [8].

Compared to Alberta, there is a larger proportion of multi-residential households in Canada (28% vs. 19%) and a smaller proportion of single-residential households (**Figure 3.1**).

The household data in **Figure 3.1** were combined with population and vehicle data (**Figure 2.1**) to show that, compared to the rest of Canada, Alberta households have about 8% more persons (2.8 vs. 2.6) and 29%

more light duty vehicles (2.1 vs. 1.6). (**Table 3.1**) This can partially be attributed to relatively more young families with children in Alberta, a greater proportion of Albertans living in single-detached households where vehicles are needed, and more vehicles per capita. (**Figure 2.2**)

Table 3.1 Comparison of persons per household vehicles per capita and per household

	A	B	C	D
Item	Metric	Alberta	Canada	Percentage Difference (Alberta/Canada)
1	Persons per household	2.8	2.6	+ 7.69%
2	LDVs per capita	0.73	0.62	+17.7%
3	LDVs per household	2.07	1.61	+28.6%

Comparison of Alberta and Canada in persons per household (**Item 1**), and registered light duty vehicles per capita (**Item 2**) and per household (**Item 3**). Data from **Figure 2.2** and **Figure 3.1**.

3.2 Residential Parking Inventory

SINGLE RESIDENTIAL PARKING

To estimate the number of parking spaces associated with single-residential households, the 2015 Natural Resources Canada Survey of Household Energy Use [9] was first used to estimate the proportion of households that have zero, one, two or three + garage spaces **(Table 3.2B)**. Note that Alberta single-residential households have a much higher proportion of two-car garages (64%), when compared to the rest of Canada (37%).

Combining that information with household numbers **(Figure 3.1)** and making assumptions about the number of garage and driveway spaces associated with each household type **(Table 3.2C)**, made it possible to calculate low and high estimates for the number of spaces associated with single residential households in Alberta and Canada **(Table 3.2D)**. In Alberta, off-street parking spaces were estimated to range from 4.0 to 5.2 million spaces, compared to 24 to 34 million spaces for all Canada **(Table 3.2D)**.

It is important to note that many households do not use their garage spaces for vehicles, but rather for storage, workshops etc. Therefore, it is fair to say that the estimates in **Table 3.2** may include some parking spaces that are never used for parking.

Table 3.2 Inventory of parking spaces for single residential households in Alberta and Canada

A	B				C			D			
Garage Type	Garage Inventory[a] (millions of garages)				Off-Street Spaces per HH			Total Single Residential Spaces[e] (millions of spaces)			
	Alberta		Canada		Garage[b]	Driveway		Alberta		Canada	
	Count	%	Count	%		Low[c]	High[d]	Low	High	Low	High
No garage	0.14	12%	2.70	29%	0	1	2	0.14	0.29	2.70	5.41
1 car	0.19	17%	2.93	31%	1	1	2	0.39	0.58	5.87	8.80
2 car	0.75	64%	3.45	37%	2	2	3	3.02	3.77	13.8	17.2
3 car	0.08	7%	0.31	3%	3	3	4	0.48	0.56	1.84	2.14
Total	1.17	100%	9.39	100%				4.03	5.20	24.2	33.6

Notes on data sources and assumptions used:

a) The national population growth rate of approximately 1% annually [6] was applied to garage inventory for 2015 [9] to estimate 2016 inventory.
b) Assumes a household with no garage has 1 off-street parking space in the driveway.
c) Assumes each garage parking space has equivalent driveway parking capacity.
d) Assumes one more driveway space than number of garage spaces.
e) $D = B \times C_{Garage} + B \times C_{Driveway}$

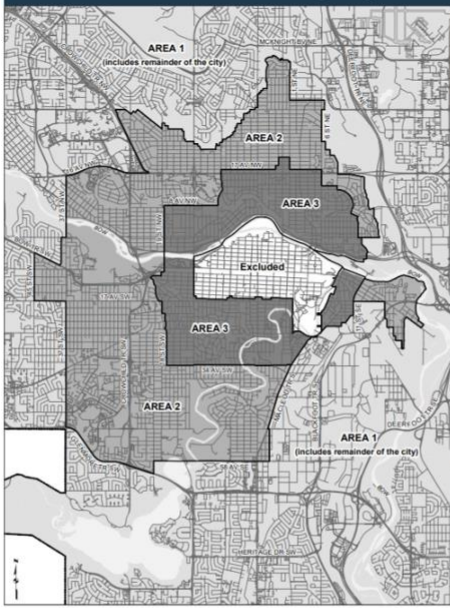
MULTI-RESIDENTIAL PARKING

Multi-residential households such as apartments in low- and high-rise buildings provide parking in either surface, aboveground, or underground complexes. The minimum number of parking spaces required for each unit of multi-residential housing is typically regulated. These regulations stipulate the minimum number of parking spaces that dwellings of various sizes and characteristics must provide. To approximate the number of parking spaces provided by multi-residential households in Alberta, the minimum required parking spaces per household (or living unit) was obtained from Calgary Land Use Bylaw 1P2007 [10] and Edmonton Zoning Bylaw 12800. [11]

The Calgary bylaw separates the city into zones that have different parking requirements. Multi-residential complexes in the city centre have lower parking requirements (0.75 to 1 space per household) than in the suburbs (0.9 to 1.25 spaces per household) (**Figure 3.2**). On the other hand, in Edmonton, the parking requirements are uniform across the city and range from 1 to 1.75 spaces per household depending on the size of the multi-residential unit (Error! Reference source not found.).

According to a US report from the Research Institute for Housing America, surface parking accounts for about 70% of multi-residential households, while aboveground and underground parking each account for about 15% of multi-residential households (**Table 3.3A**) [12]. In the absence of Canadian data, these fractions were used in this study. Note that the type of parking was not assumed to be related to the number of spaces provided; parking types are used later in the report to calculate the cost of building and maintaining parking spaces.

Calgary Multi-Residential Parking Requirements



Building Characteristics	Area 1	Area 2	Area 3	Excluded
	minimum spaces per unit			
3 or more unit building with shared entrance unit floor area > 60 m^2	1.25	1.0	0.9	0.75
3 or more unit building with shared entrance unit floor area <= 60 m^2	1.0	1.0	0.9	0.75
3 or more unit building with no shared entrance	1.25	1.0	1.0	1.0
Single residential building within a multi-residential development	1.25	1.0	1.0	1.0

Figure 3.2 Multi-Residential off-street parking requirements per household/unit specified in Calgary Land Use Bylaw 1P2007. [10]

The number of households (**Table 3.3**) were then multiplied by one space per household for a low estimate; 1.5 spaces for a high estimate (**Table 3.3C**) to calculate a range for the total number of parking spaces associated with multi-residential households in Alberta and Canada (**Table 3.3D**). Values range from 0.29 to 0.43 million spaces for Alberta, and from 3.9 to 5.9 million spaces for Canada.

Edmonton Multi-Residential Parking Requirements

Dwelling Size	Minimum Parking Requirement
Studio	1
1 Bedroom	1
2 Bedroom	1.5
3 or more Bedroom	1.7

Figure 3.3
Multi-Residential off-street parking requirements per household/unit specified in Edmonton Zoning Bylaw 12800. [11]

Table 3.3 Inventory of parking spaces for multi-residential households in Alberta and Canada

A		B			C			D				
Parking Type	Dist.	Multi-residential households (millions)		Notes	Off-Street spaces per household		Notes	Total multi-residential parking spaces (millions)				Notes
								Alberta		Canada		
		Alberta	Canada		Low	High		Low	High	Low	High	
Surface parking	70%	0.20	2.75		1	1.5		0.20	0.30	2.75	4.13	
Aboveground structured parking	15%	0.04	0.59		1	1.5		0.04	0.06	0.59	0.88	
Underground structured parking	15%	0.04	0.59		1	1.5		0.04	0.06	0.59	0.88	
Total	**100%**	**0.29**	**3.93**	a	-	-	b,c	**0.29**	**0.43**	**3.93**	**5.90**	d

Notes:

a) Estimated based on data in the Scharnhorst (Research Institute for Housing America) report [12]

b) Assumes 1 space per Multi-Residential Household, typical in many areas of cities e.g. Calgary Multi-Residential Districts range from 0.9 to 1.25 depending on household size and area of city [10]

c) Assumes 1.5 spaces per multi-residential household, typical in many cities e.g. Edmonton Multi-Unit Housing ranges from 1 to 1.7 depending on household size [11]

d) C = A x B

SOURCE: STATISTICS CANADA 2016 CENSUS [8]

SUMMARY OF RESIDENTIAL PARKING INVENTORY

The number of spaces estimated for single- and multi-residential households in the previous sections (**Table 3.2** and **Table 3.3**) were summed to approximate the total number of off-street parking spaces provided for the residential sector (**Figure 3.1**). Alberta was estimated to have 4.3 to 5.6 million off-street parking spaces, compared to 28 to 40 million spaces in all of Canada.

This equates to Alberta having 14 to 15% of all residential parking in Canada, despite the province containing only 11% of the national population. This difference can be attributed to the higher number of vehicles per household (**Table 3.1**) and the larger proportion of single-residential households in the province (**Figure 3.1**).

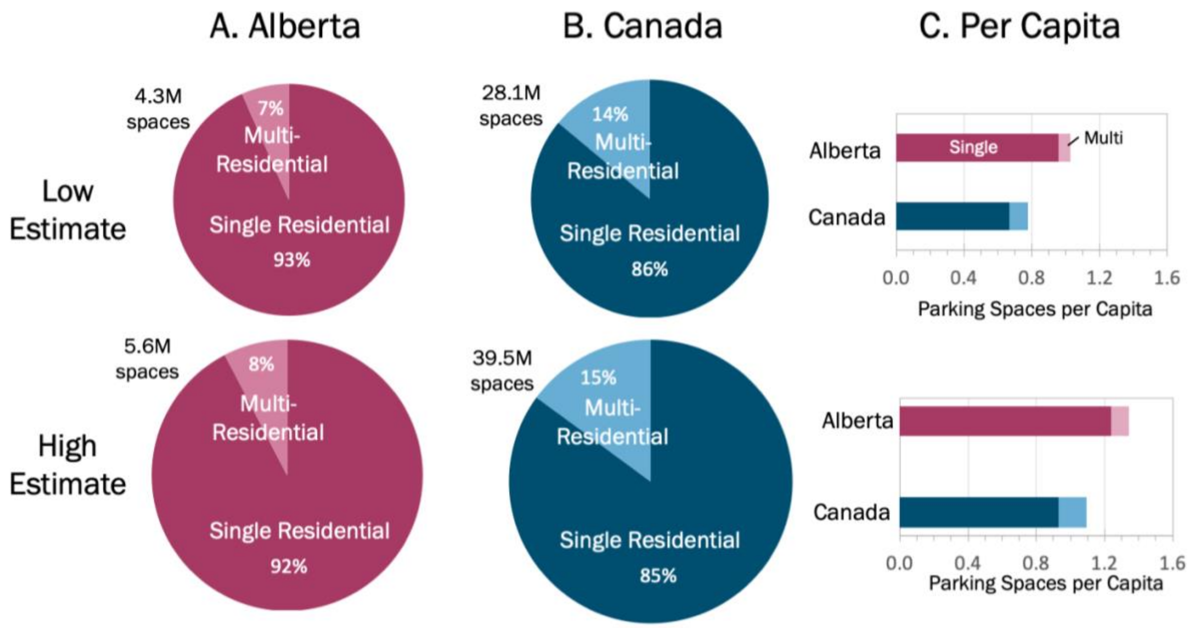


Figure 3.4 Summary of residential parking composition inventory Alberta (A), Canada (B), and per capita (C).
SOURCE: FOR PANELS A AND B, DATA FROM **TABLE 3.2** AND **TABLE 3.3**.

3.3 Residential Parking Cost Estimates

To determine a total cost of residential parking in Alberta and Canada, land, construction and operations/maintenance costs were obtained from a variety of sources [13], [4], [14], and assigned to the parking types assessed in this study. As summarized in **Table 3.4**, the land acquisition cost per square foot was taken from Altus Group's 2019 Canadian Cost Guide in which they estimate a price of $25/ft2 for single-residential land, $50/ft2 of land for multi-residential surface parking, and $100/ft2 of land for multi-residential aboveground parking [13]. For underground parking, land acquisition was assigned no additional cost, since that cost was attributed to the purpose for the above ground building. The costs per square foot were multiplied by the average size of a parking space, 330 ft2 [4], to establish a cost per space for each type of parking (**Table 3.4**).

Table 3.4 Land, construction, and operations and maintenance cost per square foot of parking by residence and parking types

A	B	C		D		E
Residence Type	**Parking Type**	**Land**		**Construction**		**O & M**
		$/ft² [a]	$/space[b]	$/ft² [a]	$/space[b]	$/space[d]
Single Residential	Garage	25	8,250	75	24,750	100
	Driveway	25	8,250	10	3,300	25
Multi-Residential / Commercial Institutional	Surface	50	16,500	-	7,500 [c]	200
	Aboveground	100	33,000	90	29,700	800
	Underground	-	-	140	46,200	800

Notes:
a) Land and construction costs per square foot from Altus Group [13].
b) Cost per square foot multiplied by average parking space size of 330 ft² [4].
c) Cost of surface parking construction per space [14].
d) Operations and maintenance cost of garages and driveways of single-residential households was estimated to be the annual cost of minor maintenance, roof repair, snow-removal, etc.
e) Operations and maintenance costs for multi-residential, commercial, and institutional parking facilities from Victoria Transport Policy Institute [14].

Construction costs for garages and driveways of single-residential households were assigned values of $75/ft² and $10/ft², respectively [13]. Multi-residential household parking was assigned a cost of $90/ft² for aboveground parking, and $140/ft² for underground parking [13]. As with the land acquisition cost, these costs were multiplied by the average size of a parking space (330 ft²) to obtain the construction cost per parking space (**Table 3.4D**). Therefore, construction of residential parking was estimated to range from $3300 per space for a driveway to $46,200 per space for a underground parking in a multi-residential building.

Operations and maintenance costs for driveway and garage parking spaces were assigned values of $25 and $100, respectively, per year. This was estimated to include the cost of minor maintenance, roof repair, snow removal, etc. Annual operations and maintenance costs for surface, aboveground, and underground parking facilities were adopted from the Victoria Transport Policy Institute (**Table 3.4E**) [14]. These costs include "cleaning, lighting, maintenance, repairs, security, landscaping, snow removal, access control (e.g., entrance gates), fee collection (for priced parking), enforcement, insurance, labor, and administration." [14]. Additionally, the VTPI estimates that parking facilities require repaving every 5-10 years, and major reconstruction after 20-40 years, especially in harsh climates and areas that use road salts in the winter [14].

The land acquisition and construction costs for each category of parking were multiplied by the number of spaces of each to estimate the total cost for Alberta and Canada (**Table 3.5**). Because these totals consist of the up-front capital expenses of land acquisition and construction, they were distributed over an amortization period to calculate an annualized value. An amortization period of 50 years (roughly the lifespan of the infrastructure) at 2% interest (approximately the rate of inflation) was chosen for the low estimate; 20 years at 5% for the high estimate.

Table 3.5 Calculation of the annualized cost of residential parking in Alberta and Canada

Parameter				Single Residential				Multi Residential						Total Residential	
				Garage		Driveway		Surface		Above Ground		Underground			
	#	Name	Units	Alberta	Canada	Alberta	Canada	Alberta	Canada	Alberta	Canada	Alberta	Canada	Alberta	Canada
A. Unit Costs	1	Land Acquisition	$/space	8,250	8,250	8,250	8,250	16,500	16,500	33,000	33,000	-	-	**-**	**-**
	2	Construction	$/space	24,750	24,750	3,300	3,300	7,500	7,500	29,700	29,700	46,200	46,200	**-**	**-**
	3	Operations and Maintenance	$/space/year	100	100	25	25	200	200	800	800	800	800	**-**	**-**
B. Low Estimate	4	Number of spaces	millions	1.94	10.8	2.09	13.5	0.20	2.75	0.04	0.59	0.04	0.59	**4.31**	**28.1**
	5	Total land cost	billions 2018$CA	16.0	88.7	17.2	111	3.30	45.4	1.41	19.5	-	-	**37.9**	**265**
	6	Total construction cost	billions 2018$CA	48.1	266	6.88	44.4	1.50	20.6	1.27	17.5	1.98	27.2	**59.7**	**376**
	7	Amortization period	years	50											
	8	Interest rate	percent/year	2.0%											
	9	Annual land cost	billions 2018$CA/year	0.51	2.82	0.55	3.53	0.11	1.44	0.05	0.62	-	-	**1.21**	**8.42**
	10	Annual construction cost	billions 2018$CA/year	1.53	8.47	0.22	1.41	0.05	0.66	0.04	0.56	0.06	0.87	**1.90**	**12.0**
	11	Annual O&M cost	billions 2018$CA/year	0.19	1.08	0.05	0.34	0.04	0.55	0.03	0.47	0.03	0.47	**0.35**	**2.91**
	12	**Annual total cost**	**billions 2018$CA/year**	2.23	12.4	0.82	5.28	0.19	2.65	0.12	1.65	0.10	1.34	**3.46**	**23.3**
C. High Estimate	13	Number of spaces	millions	1.94	10.7	3.26	22.8	0.30	4.13	0.06	0.88	0.06	0.88	**5.63**	**39.5**
	14	Total land cost	billions 2018$CA	16.0	88.7	26.9	189	4.95	68.1	2.12	29.2	-	-	**50.0**	**374**
	15	Total construction cost	billions 2018$CA	48.1	266	10.8	75.4	2.25	31.0	1.91	26.2	2.97	40.9	**65.9**	**440**
	16	Amortization period	years	20											
	17	Interest rate	percent/year	5.0%											
	18	Annual land cost	billions 2018$CA/year	1.29	7.12	2.16	15.13	0.40	5.46	0.17	2.34	-	-	**4.01**	**30.1**
	19	Annual construction cost	billions 2018$CA/year	3.86	21.4	0.86	6.05	0.18	2.48	0.15	2.11	0.24	3.28	**5.29**	**35.3**
	20	Annual O&M cost	billions 2018$CA/year	0.19	1.08	0.08	0.57	0.06	0.83	0.05	0.71	0.05	0.71	**0.44**	**3.89**
	21	**Annual total cost**	**billions 2018$CA/year**	5.34	29.5	3.10	21.7	0.64	8.77	0.37	5.16	0.29	3.99	**9.74**	**69.2**

Notes:

a) Number of spaces from **Table 4.2.1**
b) Total land acquisition cost calculated as **Item 1 x Item 4** for low estimate or **Item 1 x Item 13** for high estimate.
c) Total construction cost calculated as **Item 2 x Item 4** for low estimate or **Item 2 x Item 13** for high estimate.
d) Annual land cost (**Items 9 and 18**) is the annual payment calculated based on amortization period of 50 years at 2% for the low estimate, and 20 years at 5 % for the high estimate.
e) Annual construction cost (**Items 10 and 19**) is the annual payment calculated based on amortization period of 50 years at 2% for the low estimate, and 20 years at 5 % for the high estimate.
f) **Item 12** is calculated as the sum of **Items 9, 10 and 11**.
g) **Item 21** is calculated as the sum of **Items 18, 19 and 20.**

These result in annualized total costs of land acquisition and construction, shown in **Table 3.5**, **Rows 9** and **10** for the low estimate, and **Rows 18** and **19** for the high estimate. Annual operations and maintenance costs were taken as the yearly cost per parking unit (**Table 3.5, Row 3**) multiplied by the total number of parking spaces for the low and high estimates (**Table 3.5, Rows 4** and **13,** respectively).

Combining the annualized cost of land acquisition, construction, and operations and maintenance yields a total annual cost of parking ranging from 3.5 to 9.7 billion dollars in Alberta, and 23 to 69 billion dollars in all of Canada. These are shown in **Table 3.5, Rows 12** and **21** under the rightmost column, labeled "Total Residential". The results are visualized in **Figure 3.5**.

The total annualized costs of residential parking from **Table 3.5**, visualized in **Figure 3.5** were then combined with population data (to determine the cost of residential parking per capita in Alberta and Canada (**Figure 3.C**). The results show that Albertans pay between 21-28% more per person per year for residential parking than the average Canadian.

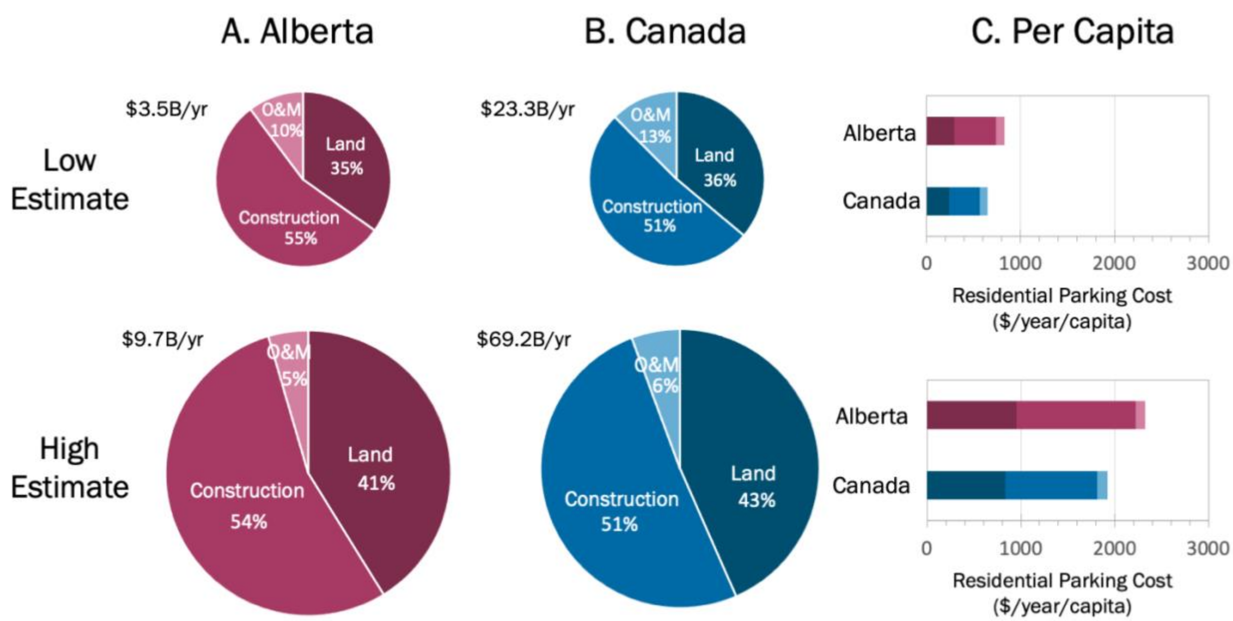


Figure 3.5 Components of annualized residential cost of parking and costs per capita

Components of annualized residential cost of parking (2018 Canadian dollars) for Alberta (A), Canada (B), and costs per capita (C) for each region. For panels A and B, the area of the high estimate chart is proportional to the area of the lowest estimate.

SOURCE: DATA FROM FIGURE 2.2 AND TABLE 3.5.

4 COMMERCIAL AND INSTITUTIONAL INVENTORY AND COSTS

4.1 Floor Area by Land Use

The commercial and institutional inventory include non-residential buildings such as offices, hospitals, elementary and secondary schools, nursing and residential care facilities, warehouses, hotels, food and beverage retail, non-food retail, vacant buildings, and other spaces [15]. Statistics Canada defines the "Other" category of commercial and institutional buildings as "buildings with more than 50 percent of its floor space used for commercial activities or for activities focusing on not-for-profit services in the public's interest, that were not included in [the categories previously listed]. Examples include entertainment, leisure and recreation buildings (arenas), shopping centres, colleges and universities." [15]

Commercial and Institutional buildings are subject to a different set of parking requirements than residential buildings, requiring a separate analysis to quantify the parking they provide. The total floor area occupied by commercial and institutional buildings for Alberta and Canada was obtained from Statistics Canada's Survey of Commercial and Institutional Energy Use (**Figure 4.1**) [16], [15]. The data show that, proportionally, Alberta dedicates 7% more floor space to retail than Canada on average and 10% more of its floor area for other uses, while having 15% less office floor space. Floor space dedicated to education, health, hospitality, and storage were similar in the two regions (**Figure 4.1**).

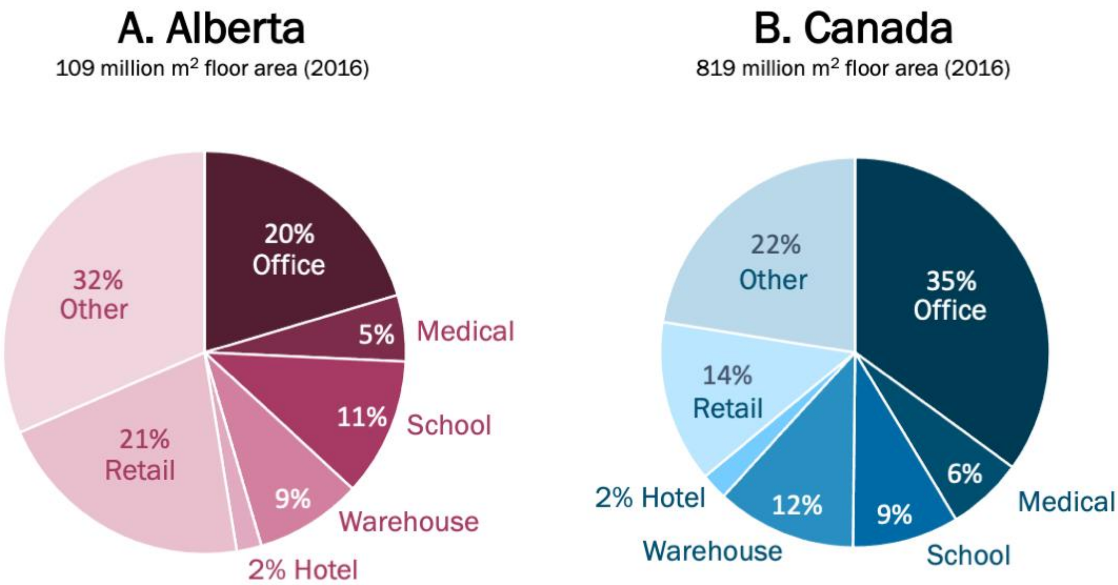


Figure 4.1 Commercial and institutional floor area by land use in Alberta (A) and Canada (B).

SOURCE: DATA FROM STATISTICS CANADA. [16], [15]

4.2 Commercial and Institutional Parking Inventory

As with residential parking, parking requirements for commercial and institutional facilities are regulated. Calgary and Edmonton have bylaws stipulating the minimum parking requirements of various building types as a proportion of their floor area (**Table 4.1**) [10], [11]. As these bylaws specify the minimum requirements for parking area per 100 m2 of floor area and some builders may put in additional parking, the minimum requirement was multiplied by 1.2 to provide a high estimate of parking provided. The parking requirements in the Calgary and Edmonton bylaws were averaged to provide minimal estimates for all Alberta (**Table 4.1C**).

The floor areas from **Figure 4.1** were divided by the average size of a parking space (330 ft2) [3] to determine the total number of parking spaces provided by each category of building.

Reviewing the bylaws of other major Canadian cities was outside the scope of this report; a cursory review indicated that parking requirements were lower in other areas of Canada than in Alberta, and an estimate of 10% lower off-street parking requirements was assumed. However, because of the lack of a comprehensive review of land use bylaws in other major Canadian cities, it is possible that parking requirements for the rest of Canada have been overestimated. The floor areas for each sector in square metres **(Table 4.1B)** were multiplied by the parking spaces required per hundred square metres of floor area **(Table 4.1C)** to determine low and high estimates of parking spaces for both Alberta and Canada **(Table 4.1D)**. The estimates ranged from 3.2 to 3.9 million parking spaces in Alberta, and 20.3 to 24.3 million in the rest of Canada **(Table 4.1D)**.

Table 4.1 Inventory of parking spaces for commercial and institutional land uses in Alberta and Canada

	A	B			C					D			
		Floor Area (2016) millions of m² floor			Min. Off-Street Parking Required spaces per 100 m² floor area					TTL Commer'l & Institut'l Parking '000's of spaces			
	Commercial / Institutional Land Uses									Alberta		Canada	
		Alberta[a]	Canada[b]	Notes	Edm'ton[c]	Notes	Calgary[d]	Notes	Average	Low	High[k]	Low[l]	High[k]
1	Office buildings	22	287		3.4		2.0		2.7	602	722	6,972	8,367
2	Medical uses												
	Office buildings (medical)	3	16		4.5		6.0		5.3	136	163	752	903
	Assisted daily/residential care facilities	2	20		2.7		2.7		2.7	60	72	492	590
	Hospitals	1	16		1.1		1.1		1.1	11	13	156	187
3	Elementary and secondary schools	12	72		1.4	g	1.4	j	1.4	170	204	910	1,092
4	Warehouses	9	95		1.0		1.0		1.0	94	113	857	1,029
5	Hotels, motels or lodges	2	18	f	2.7	h	2.7	h	2.7	59	70	440	528
6	Retail												
	Food and beverage stores	4	23		3.3		4.0		3.7	132	158	757	909
	Non-food retail stores	19	88		3.3		4.0		3.7	711	854	2,892	3,470
7	Other activity or function (see note)[e]	34	184		3.3	i	4.0	i	3.7	1,262	1,514	6,076	7,291
8	**Total**	**109**	**819**							**3,236**	**3,884**	**20,304**	**24,365**
	Distribution of parking type												
9	Surface, 70% of total									2,265	2,718	14,213	17,056
10	Aboveground, 15% of total									485	583	3046	3655
11	Underground, 15% of total									485	583	3046	3655

Notes:

a) Floor areas obtained from 2009 Survey of Commercial and Institutional Energy Use. [16] Alberta was separated out from prairies using the proportion of Alberta population to that of all prairies and applying 11.6% growth over 5 years (determined annual growth then did annual for 5 years also from 2009-2014). Floor area was then assumed to increase at 1% per year from 2014 to 2016, matching population growth [6].
b) Floor area inventory for 2014 was obtained from Natural Resources Canada Survey of Commercial and Institutional Energy Use [15]. A 1% annual growth rate [6] was applied to estimate 2016 floor area inventory.
c) Edmonton Zoning Bylaw No. 12800 [11]
d) Calgary Land Use Bylaw 1P2007 [10]
e) Includes such buildings as recreational buildings, pools, theatres, shopping centers, colleges and universities [15].
f) Hotel floor area data for Alberta were questionable [16] so Alberta data were estimated as a proportion of Alberta to Canadian population (12% in 2016 [6]).
g) Assumes 100 m2 per classroom [17].
h) Assumes 400 ft2 per hotel room
i) Assumes same as retail parking requirement.
j) Assumes same as Edmonton ratio, Calgary ratio is student numbers based.
k) Assumes 20% higher than the 'Low', since parking is regulated as a minimum requirement, and more can be provided.
l) A review of parking requirements in other major cities of Canada (data not shown) indicated that parking requirements were approximately 10% lower than that in Edmonton and Calgary. Therefore, the low estimate for Canada was obtained assuming parking requirements were 10% than Alberta.

The number of parking spaces estimated in **Table 4.1D** were combined with population data to determine the number of commercial and institutional parking spaces per person in each region. In Alberta, there are 0.77 to 0.93 commercial/institutional parking spaces per person, compared to 0.56 to 0.67 in all of Canada (**Figure 4.2**). Therefore, Alberta is estimated to have about 38% more spaces per person than in the Canadian average. However, it is important to note that several assumptions were made in generating these estimates, especially for the Canadian numbers, so these projections must be treated with caution.

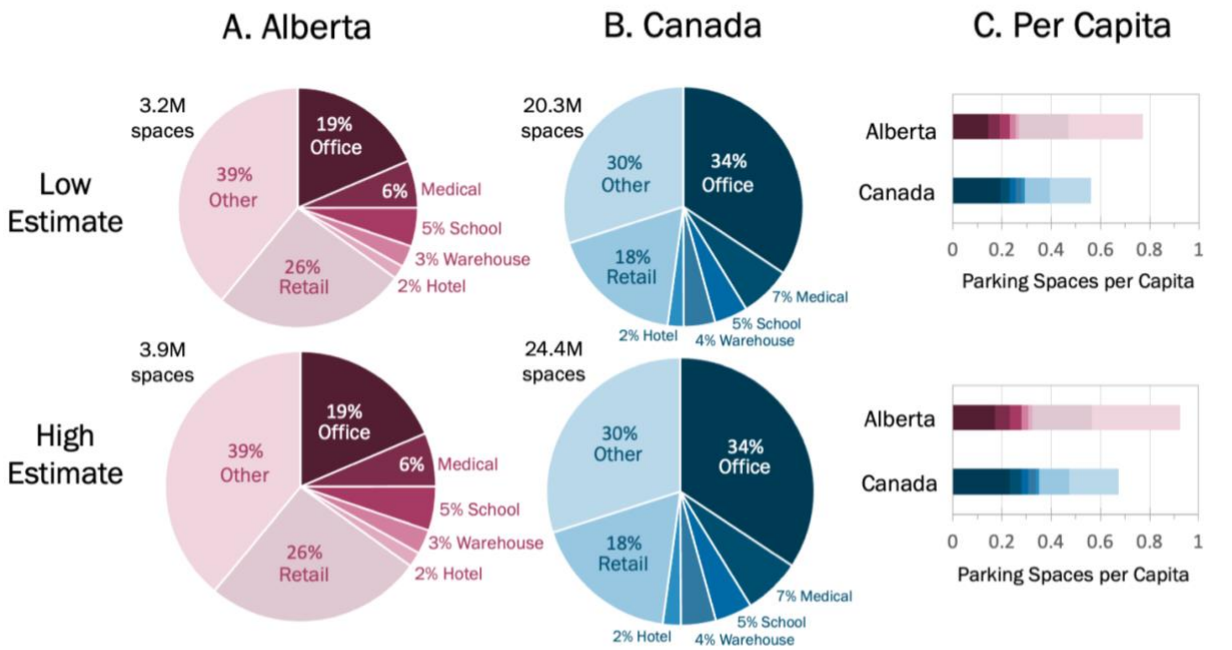


Figure 4.2 Inventory of parking spaces for commercial and institutional land uses in Alberta and Canada.
SOURCE: DATA FROM NATURAL RESOURCES CANADA [16], [15] AND **FIGURE 2.2**

4.3 Commercial and Institutional Parking Cost Estimates

The number of commercial and institutional parking spaces in **Figure 4.2** were then used to calculate the annual cost of those parking spaces in Alberta and Canada. As with the analyses of multi-residential parking in **Table 3.2** and **Table 3.3**, parking spaces were assumed to have an area of 330 ft2 per unit [4]. The cost of land acquisition and construction for surface, above ground, and underground parking were assumed to be the same as in the multi-residential analysis **(Table 3.4)** where land costs ranged from $50-$100 per ft2, and construction costs were $90/ft2 for above ground parking garages, $140/ft2 or underground parking garages and $7,500 per unit [18] for surface parking.

When the cost data are combined with the number of spaces, the cost of commercial and institutional parking in Alberta ranged from $4.6B/year to $11.8B/year **(Figure 4.2, Figure 4.3)**. Expressed per capita, commercial and institution parking cost Albertans $1106 to $2813/capita, about 37% more than the cost for the average Canadian of $807 to $2050/capita **(Figure 4.3)**.

Table 4.2 Calculation of the annualized cost of commercial and institutional parking in Alberta and Canada.

A				B						C	
Parameter				Commercial / Institutional						Total Commercial / Institutional	
				Surface		Above Ground		Underground			
	#	Name	Units	Alberta	Canada	Alberta	Canada	Alberta	Canada	Alberta	Canada
Unit Costs	1	Land Acquisition	$/space	16,500	16,500	33,000	33,000	-	-	-	-
	2	Construction	$/space	7,500	7,500	29,700	29,700	46,200	46,200	-	-
	3	Operations and Maintenance	$/space/year	200	200	800	800	800	800	-	-
Low Estimate	4	Number of spaces	Millions	2.27	14.2	0.49	3.05	0.49	3	**3.24**	**20.3**
	5	Total land cost	Billions 2018$CA	37.4	235	16.0	101	0.00	0.00	**53.4**	**335**
	6	Total construction cost	Billions 2018$CA	17.0	107	14.4	90.5	22.4	141	**53.8**	**338**
	7	Amortization period	Years	50							
	8	Interest rate	Percent/year	2.0%							
	9	Annual land cost	Billions 2018$CA/year	1.19	7.46	0.51	3.20	-	-	**1.70**	**10.7**
	10	Annual construction cost	Billions 2018$CA/year	0.54	3.39	0.46	2.88	0.71	4.48	**1.71**	**10.7**
	11	Annual O&M cost	Billions 2018$CA/year	0.45	2.84	0.39	2.44	0.39	2.44	**1.23**	**7.72**
	12	**Total annual cost**	**Billions 2018$CA/year**	2.18	13.7	1.36	8.51	1.10	6.91	**4.64**	**29.1**
High Estimate	13	Number of spaces	Millions	2.72	17.1	0.58	3.65	0.58	3.65	**3.88**	**24.4**
	14	Total land cost	Billions 2018$CA	44.9	281	19.2	121	0.00	0.00	**64.1**	**402**
	15	Total construction cost	Billions 2018$CA	20.4	128	17.3	109	26.9	169	**64.6**	**405**
	16	Amortization period	Years	20							
	17	Interest rate	Percent/year	5.0%							
	18	Annual land cost	Billions 2018$CA/year	3.60	22.6	1.54	9.68	-	-	**5.14**	**32.3**
	19	Annual construction cost	Billions 2018$CA/year	1.64	10.3	1.39	8.71	2.16	13.5	**5.18**	**32.5**
	20	Annual O&M cost	Billions 2018$CA/year	0.54	3.41	0.47	2.92	0.47	2.92	**1.48**	**9.26**
	21	**Total annual cost**	**Billions 2018$CA/year**	5.78	36.3	3.40	21.3	2.63	16.5	**11.8**	**74.0**

Notes:

a) Number of spaces from **Table 4.1**
b) Total land acquisition cost calculated as **Item 1 x Item 4** for low estimate or **Item 1 x Item 13** for high estimate.
c) Total construction cost calculated as **Item 2 x Item 4** for low estimate or **Item 2 x Item 13** for high estimate.
d) Annual land cost (**Items 9 and 18**) is the annual payment calculated based on amortization period of 50 years at 2% for the low estimate, and 20 years at 5 % for the high estimate.
e) Annual construction cost (**Items 10 and 19**) is the annual payment calculated based on amortization period of 50 years at 2% for the low estimate, and 20 years at 5 % for the high estimate.
f) **Item 12** is calculated as the sum of **Items 9, 10 and 11**.
g) **Item 21** is calculated as the sum of **Items 18, 19 and 20**.

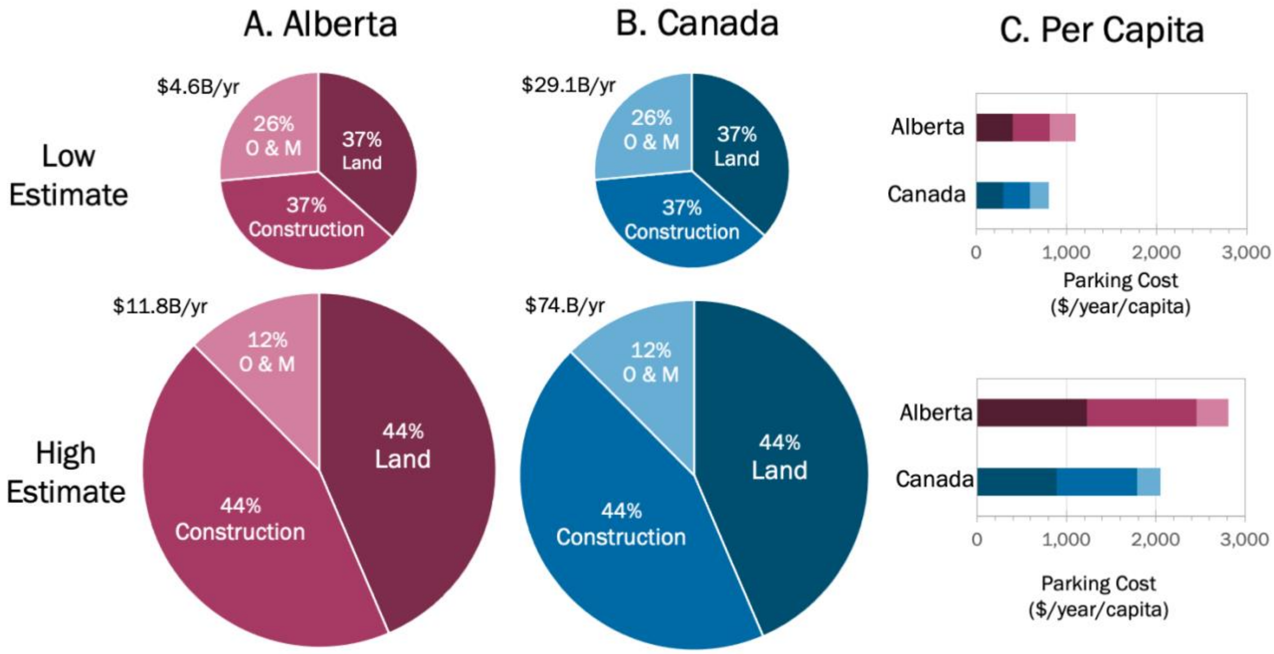


Figure 4.3 Components of annualized commercial/institutional cost of parking

Components of annualized commercial / institutional cost of parking ($2018 Canadian Dollars) for Alberta (A), Canada (B), and costs per capita (C).

SOURCE: DATA FROM TABLE 4.2 AND FIGURE 2.2.

5 ON-STREET PARKING INVENTORY

Streets also serve as parking spots for residential and commercial/ institutional sectors. In the study, we have only attempted to estimate the number of spaces, not the cost of the land, construction and maintenance of these spaces. While the costs may be substantial, we assumed that they are part of the road network and not dedicated for parking use. Of course, if street parking were to no longer be needed, the space could be used for pick up and drop off sites, wider sidewalks, green space, bicycle lanes, etc. So certainly, this space has value.

Statistics Canada categorizes roads as either highway, arterial, collector, or local (**Figure 5.1**). They also collect and provide data on the lengths of these road types in all provinces and territories (**Table 5.1A** and **B**) [17]. Highway and arterial roads were assumed to have no on-street parking. Collector roads were further separated in to four-lane and two-lane roads. The number of lanes was considered in determining the total length of parkable streets; a four-lane street does not have parking in all four lanes, only the outer two, so the length of four-lane roads was divided by two to obtain the true length of parkable space (**Table 5.1B**).

Highway	Highways are defined as roads that move high volumes of traffic and have controlled entrance and exit, a dividing strip between the traffic in opposite directions, and typically two or more lanes in each direction. Highways do not provide access to property, and generally do not accommodate cyclists or pedestrians.
Arterial	Arterial roads are defined as roads that move moderate to high traffic volumes over moderate distances between principal areas of traffic generation and gather traffic from collector roads and local roads and move it to the highway system. Arterial roads are generally designed for medium speed, have capacity for 2 to 6 lanes, and may be divided, with limited or controlled direct access from adjacent developments and with on-street parking discouraged
Collector	Collector roads are defined as roads that move low to moderate traffic volumes within specific areas of a municipality and collect local traffic for distribution to the arterial or highway system. Collector roads are generally designed for medium speed, have capacity for 2 to 4 lanes, are usually undivided, with direct access from adjacent development permitted but usually controlled, and with controlled on-street parking usually permitted
Local	Local roads are defined as roads that provide for low volumes of traffic and access to private properties; local roads are designed for low speeds, have capacity for 2 undivided lanes of traffic; through traffic is discouraged and parking is usually permitted though often controlled."

Figure 5.1 Categories of roadways used in on-street parking inventory analysis.

SOURCE: STATISTICS CANADA. [20]

Table 5.1 Calculation of on-street parking inventory in Alberta and Canada.

	A	B		C		D		E		F				G			
	Road Type	Street Length (thousand km of 2-lane) [a]		Street Length (thousand km of 1-lane equiv.) [b]		Parkable Street (thousand km) [c]		Percentage of Parkable Street		Total Length of Parking Zones (thousand km) [e]				Parking Spaces (millions) [f]			
										Alberta		Canada		Alberta		Canada	
#		Alberta	Canada	Alberta	Canada	Alberta	Canada	Low	High	Low	High	Low	High	Low	High	Low	High
1	Highway	32.2	113														
2	Arterial	9.56	88.3														
3	Collector	25.5	110														
4	4 Lane Collector (50% of Collectors)	12.7	55.2	6	28	3.18	13.8										
5	Single-Sided Parking					1.59	6.90	40%	60%	0.64	0.96	2.76	4.14	0.09	0.14	0.39	0.59
6	Double-Sided Parking					1.59	6.90	80%	120%	1.27	1.91	5.52	8.28	0.18	0.27	0.79	1.18
7	2 Lane Collector (50% of Collectors)	12.7	55.2	13	55	6.37	27.6										
8	Single-Sided Parking					3.18	13.8	40%	60%	1.27	1.91	5.52	8.28	0.18	0.27	0.79	1.18
9	Double-Sided Parking					3.18	13.8	80%	120%	2.55	3.82	11.0	16.6	0.36	0.55	1.58	2.37
10	Local [i]	109	440	109	440	54.6	220										
11	Single-Sided Parking					27.3	110	40%	60%	10.9	16.4	44.0	66.1	1.56	2.34	6.29	9.44
12	Double-Sided Parking					27.3	110	80%	120%	21.8	32.7	88.1	132	3.12	4.68	12.6	18.9
13	**Total**	176	752							38.5	57.7	157	235	**5.50**	**8.25**	**22.4**	**33.6**

Notes:

a) Data from Statistics Canada [20]
b) Assumed 50% of all streets have designated on-street parking [19].
c) Factored street length to accommodate single- or double-sided parking, For the estimate, only 60% of the street was assumed to be available for parking due to driveways, fire hydrants, loading zones, bus stops, etc.
d) Total distance available for on-street parking.
e) Product of parking distance divided by parallel parking space length of 7 metres. [11]
f) Assumed 50% of collector roads are four-lane and 50% are two-lane.
g) Assumed 50% of parkable streets with designated on-street parking have single-sided parking, and 50% have double-sided parking. [19]

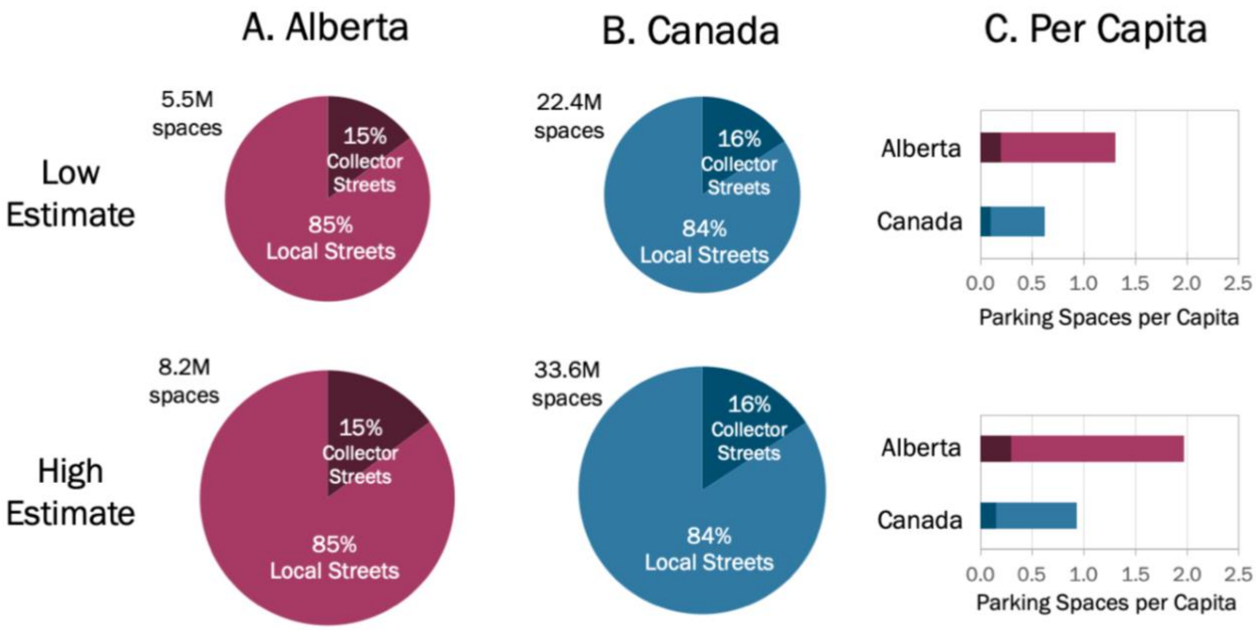


Figure 5.2 Components of on-street parking inventory in Alberta (A), Canada (B), and per capita (C).

SOURCE: DATA FROM TABLE **5.1**.

Prior research showed that approximately 50% of all roads have designated on-street parking [19], so the road lengths in **Table 5.1B** were halved to estimate the length of designated parking (**Table 5.1C**). Designated parking zones were assumed to have 40% to 120% of usable parking due to the presence of fire hydrants, loading zones, fire hydrants, bus stops, etc. (**Table 5.1E**). Finally, the length of parkable space was divided by an average parallel parking space length of 7 metres [19] to obtain the total number of parking spaces (**Table 5.1F**). The results, summarized in **Figure 5.2**, show that on-street parking ranged from 5.5 to 8.2 million spaces in Alberta, and from 22.4 to 32.6 million in all of Canada.

The number of parking spaces in **Figure 5.2** were divided by population [6] to yield the number of parking spaces per capita in each region (**Figure 5.2C**). For Alberta, it was estimated that the number of spaces per person in Alberta ranged from 1.3 to 2.0, and from 0.62 to 0.93 in all of Canada.

6 SUMMARY AND CONCLUSION

6.1 The Shift to Autonomous Mobility on Demand (AMoD)

Four new vehicle technologies – autonomy, connectedness, electrification and sharing – are slowly converging to create a new business model for personal mobility across Canada and around the world. Referred to as Autonomous Mobility on Demand (AMoD)[2], this business model could replace personal vehicle demand with a fleet of driverless vehicles that pick up and drop off customers where requested. Since one AMoD vehicle has the potential to displace six to ten personally owned vehicles, this new business model promises lower costs, more convenience, fewer accidents, less air pollution, and the potential to transform urban ecosystems.

The timeline for this transformation is uncertain. Some argue that it is imminent, [21],[22] others that it will be a few years away, [23] while still others suggest it will be decades into the future. [24] Few, if any, suggest that the transition is not happening.

Parking is one feature of the urban ecosystem that will be impacted greatly by AMoD. Assuming each AMoD vehicle replaces eight personally owned light duty vehicles (LDVs), the number of LDVs on the road in Alberta could drop from 3.1 million to less than 0.5 million. Each day, most of these vehicles would be on the road for 16+ hours after logging hundreds of km of service. They would return to the parking lots of fleet operators to be refueled, cleaned, and serviced.

To understand the potential impact of AMoD on parking, this study first quantifies the current scale and cost of parking in Alberta and Canada, then draws on literature in this rapidly emerging field (**see APPENDIX A**) to explore how parking and the real estate sector are likely to be impacted in cities of the future.

6.2 The Scale and Annualized Cost of Parking in Alberta and Canada

To park Alberta's 3.1 million LDVs (Canada has 23 million), there are 13 to 18 million parking spaces (71 to 97 million spaces in Canada) (**Table 6.1, Item 4**), or 4.3 to 5.8 parking spaces for every vehicle in Alberta (3.2 to 4.4 spaces per vehicle in Canada) (**Table 6.1, Item 5**) About one third of these spaces are off-street residential, while another 25% are off-street spaces provided by the commercial and institutional sectors.

[2] Also known as ACES (Autonomous, Connected, electric Shared), Robo-taxis, Transportation-as-a-Service (TaaS), Mobility-as-a-Service (MaaS)

The remaining spaces are on-street parking and so serve both residential and commercial/institutional needs (**Figure 6.1**).

Table 6.1 Summary of estimated parking inventory and cost for Alberta and Canada.

		Inventory (MILLIONS OF SPACES)				Annual Cost (BILLIONS 2018 $CA)			
		Alberta		Canada		Alberta		Canada	
#	Parking Sector	Low	High	Low	High	Low	High	Low	High
1	Residential	4.31	5.6	28.1	39.5	3.46	9.74	23.3	69.2
2	Commercial	3.24	3.9	20.3	24.4	4.64	11.8	29.1	74.0
3	On-street	5.50	8.25	22.4	33.6	-	-	-	-
4	Total	13.0	17.8	70.9	97.5	8.10	21.5	52.4	143

Totals		Inventory (MILLIONS OF SPACES)				Annual Cost (BILLIONS 2018 $CA)			
5	Total per vehicle	4.26	5.80	3.16	4.35	2,646	7,032	2,339	6,392
6	Total per capita	3.11	4.23	1.96	2.70	1,932	5,134	1,452	3,967

The annualized cost for off-street parking in Alberta ranges from $8.1B to $21.5B/year ($52B to $143B/year in Canada) (**Table 6.1, Item 4**), with commercial and Institutional parking accounting for 52% to 57%, and residential parking making up the balance (**Figure 6.2**). Construction costs tend to dominate the annualized costs, accounting for 37% to 55%, compared to 35% to 44% for land and 5% to 26% for operations and maintenance (**Figure 3.5, Figure 4.3**).

Expressed per capita, off-street parking costs the average Albertan $1,931 to $5,134 per year, about 32% more than the cost for the average Canadian ($1,452 to $3,967/year) (**Table 6.1, Item 6** and **Figure 6.2**). These cost estimates are 15 to 43 times larger than those provided by Statistics Canada for the direct, out-of-pocket cost of parking for households in Canada (**Figure 1.1B**). This is because most of the parking costs calculated here are embedded in the price that is paid for housing, or for production and retail of virtually all goods and services, especially if 'free parking' is provided.

Taking the full cost of LDV parking into account, it is possible to estimate the cost to households of today's personal mobility system that is focus on personally owned light duty vehicles (**Table 6.2**). Since the majority (82%, **Figure 2.2**) of LDVs are personally owned, the estimates for LDV parking costs were multiplied by 0.82 to generate an estimate of parking's impact on the annual per capita household expenses (**Table 6.2, Item 4**). To this number, was added the annualized per capita costs to purchase, license/insure, maintain, and fuel the vehicles (**Figure 1.1B** and **Figure 2.2, Items 5-8**).

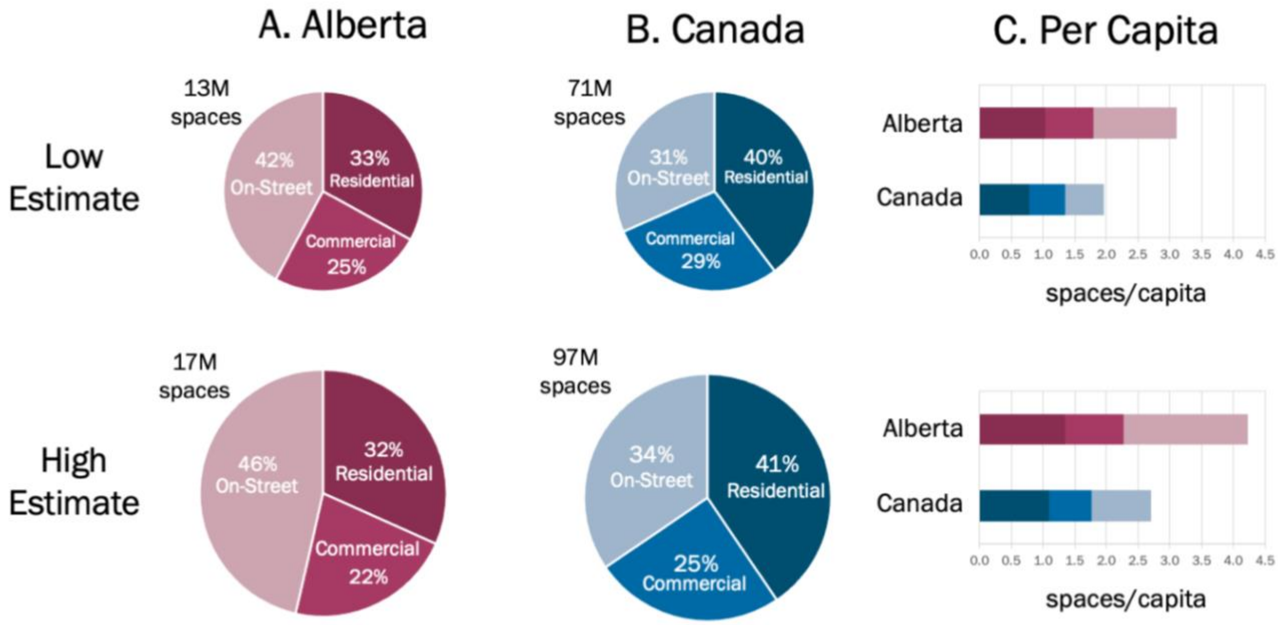


Figure 6.1 Summary of parking inventory in Alberta (A), Canada (B), and per capita (C).

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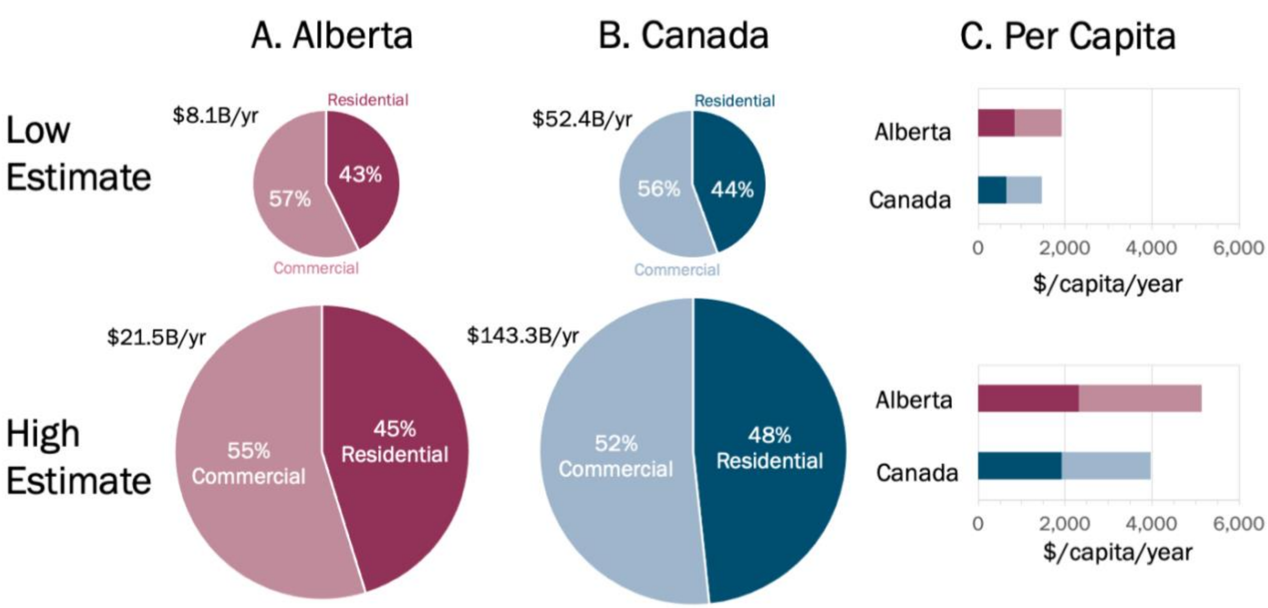

Figure 6.2 Summary of parking costs in Alberta (A), Canada (B), and per capita (C).

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Table 6.2 Estimate of the cost to households of today's personal mobility system focused on personally owned light duty vehicles.

	Item	NOTES	Alberta	Canada
1	Household expenses ($/HH-year)	{1}	$72,958	$63,724
2	Average household size (persons/HH)	{2}	2.8	2.6
3	Household expenses ($/pers-year)	{3}	$26,056	$24,509
Personally owned LDV costs			$/person-year	
4	Parking	{4}	$2,897	$2,222
5	Vehicle purchase/lease	{5}	$2,466	$2,107
6	Insurance & licensing	{5}	$841	$749
7	Maintenance/repairs	{5}	$742	$623
8	Fuel	{5}	$876	$824
9	Total		$7,822	$6,525
10	% of household expenses	{6}	30%	27%

Notes:

{1} From Statistics Canada
{2} From Table 3.1
{3} Item 1 x Item 2; see also Figure I
{4} Average of low and high-cost estimates from this study (Figure 6.2) x proportion of LDV that are personally owned (82%, Figure 2.2)
{5} From Figure I-B
{6} Item 9 ÷ Item 3

Note that the annualized household costs for parking were estimated to range from $6,508 to $9,135/person-year for Alberta, and from $5,494 to $7,556/person-year for all Canada (**Table 6.2, Item 9**). In total, the personal vehicle ownership model that dominates the personal mobility system in Canada today accounts for 22% and 35% of household expenses in Alberta and Canada, respectively (**Table 6.2, Item 10**).

Given the average household cost for shelter in Canada ranges from $7.2K to $7.5K/person-year (**Figure 1.1A**), the lower end of the range of estimates for embedded parking cost seem more reasonable.

When the household expenses associated with personal vehicle ownership were adjusted to include the lower estimate for the embedded cost for parking, there was a 31% (Canada) or 36% (Alberta) increase in the estimated household cost of personal mobility in Canada (**Figure 6.3**). Clearly, the full costs of parking must be included when considering the AMoD transformation of personal mobility in Canada.

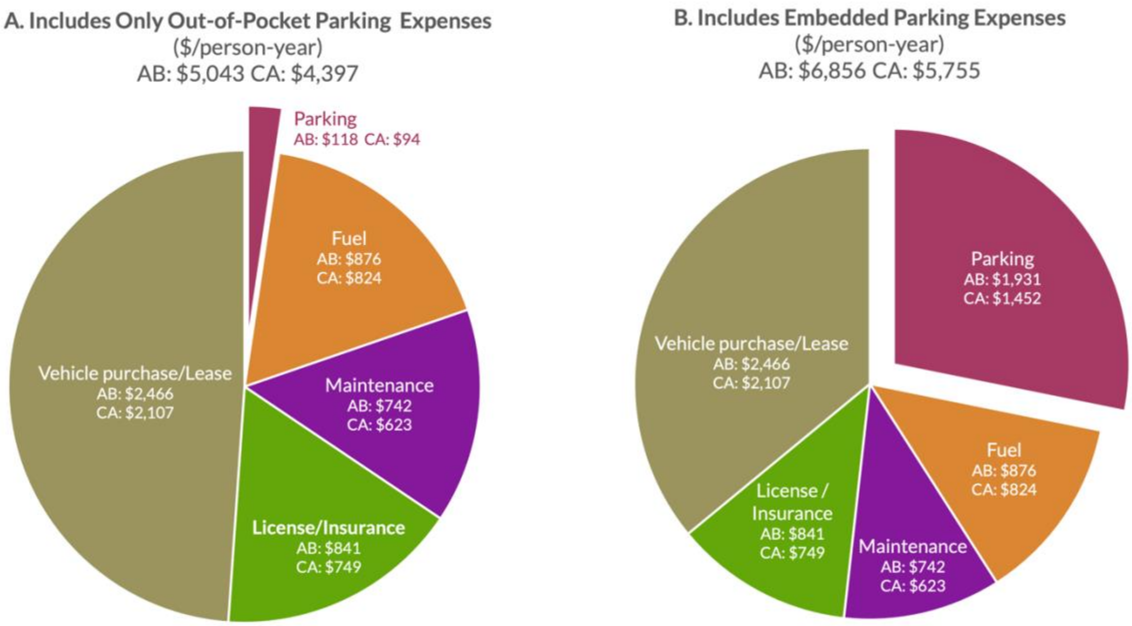

Figure 6.3 Household Expenditures associated with personal vehicle ownership in Alberta and Canada

Household (HH) Expenditures associated with personal vehicle ownership in Alberta and Canada in 2017, expressed as CA$ per person-year based on 2.8 and 2.6 persons per HH in Alberta and Canada, respectively. A. Summary of Statistics Canada data (Table: 11-10-0222-01) which only considers out–of-pocket expenses for parking. B. Similar to Panel A, but incorporates the low estimate from this study on the embedded expenses for parking that are associated with providing shelter and in goods and services from commercial and institutional sectors. AB, Alberta; CA, Canada.

A transition to AMoD promises to substantially reduce the cost of personal mobility for households by eliminating the expenses associate with personal vehicle ownership, insurance, parking, maintenance, and fuel. Certainly, there will be costs associated with accessing personal mobility from AMoD service providers, but the more efficient use of the vehicle, the avoidance of parking costs, and the lower maintenance, insurance and fuel cost should reduce overall costs to households by 50% or more [2].

At 50% of the current cost of personally owned LDVs in Alberta today, the savings ($3428/ person-yr, $9,598/HH-yr) for the 1.5 million households (**Figure 3.1A**) would be $14.4B/yr. In Canada, the savings ($2,878 person-yr, $7,482/HH-yr) for the 13.9 million households (**Figure 3.1B**) would be $104B/yr.

6.3 Implications for AMoD for Parking and Real Estate in Canada

If there is a large-scale shift from personally owned LDVs to AMoD, parking requirements for these AMoD vehicles is likely to be minimal and associated primarily with fleet operations where the vehicles are refueled and serviced. Assuming a need for 2 to 3 spaces per AMoD vehicle, the required 1 to 1.5 million spaces would represent a 90% reduction in the number of parking spaces in the province, and across Canada.

Appendix A of this report reviews some of the recent literature on the implications of autonomous vehicles and AMoD for parking and for the evolution of urban ecosystems.

Key insights from this work include:

- The transition to fully autonomous vehicles is likely to begin with luxury, personally owned vehicles. Unless regulated appropriately, these vehicles have the potential to exacerbate many of the problems that cities face concerning congestion, urban sprawl, climate change, air pollution and street parking.
- Urban public transit organizations will need to adapt to fully autonomous vehicles or risk losing ridership. Transit agencies could incorporate AMoD vehicles in their fleets to address the first mile/last mile challenge that riders face, and thereby increase ridership on trains and express bus routes.
- Deployed more fully, AMoD has the potential to dramatically reduce the use of, and demand for personally owned vehicles. In the residential sector, this may result in:
    - Driveways being replaced with lawns, gardens or patios, and attached garages being converted into living spaces, or secondary suites,
    - Laneway garages being converted into laneway houses,
    - A movement against personal vehicle parking on streets, in favour of pick up and drop off (PUDO) locations, bicycle lanes and wider sidewalks,
    - The need to find alternative uses for parkades associated with condominiums and apartments,
    - No minimum parking requirements associated with new residential construction, but there will be a need to bring forward innovative approaches to provide safe and convenient PUDO locations.
- In the commercial and Institutional sectors, AMoD deployment may result in:
    - Demolition or refurbishment of above ground parking facilities so they can be repurposed,
    - Potential to convert existing surface parking to other uses, including increases in densification or greenspace,
    - More attention being paid to PUDO locations and designs. Minimal standards for PUDOs may be written into municipal bylaws,
    - Underground parking facilities will either be taken over by companies providing AMoD fleets or be allocated to other uses.
    - Reducing or eliminating street parking to allow more ‘people-friendly’ places.

- Phasing out of car dealerships, fueling stations, vehicle service facilities etc.
- A need to rethink how strip malls, box stores, shopping malls and specialty shops will adapt to a new business model for personal mobility.

While much uncertainty exists regarding the timing of the transition to AMoD, there is widespread understanding that this is the direction society is headed, driven by economics and convenience. The real estate sector can benefit from understanding, advancing and adapting to the transition.

APPENDIX A
Literature review on the Implications for the Real Estate Sector of Autonomous Mobility on Demand

A.1 Introduction

Since the advent of the automobile, speculation surrounding self-driving cars has been rampant. [25] While considered the work of dreamers in the past, self-driving, or autonomous vehicles (AV) are no longer a dream but a reality that is expected by many in the coming decade.

In light of the rapid development currently taking place, the Society of Automotive Engineers (SAE) has established a classification system (**Figure A.1**) to better understand and categorize existing and future AV's. [26], [27] Most modern cars fall somewhere in line with SAE levels 0-2, with no mass produced vehicles currently offering level 4 or 5 automation. [28] To place into context, any Tesla Vehicle equipped with the optional Autopilot feature is regarded as a level 2 AV, [28] but not level 3, as the vehicle requires that the driver continuously monitor conditions even while autopilot is engaged. [29] While no mass produced fully autonomous vehicles are currently available for purchase, companies such as Waymo (formerly the Google self-driving project), Uber, Lyft, and others have been running tests of autonomous vehicles on public roads in complex situations such as the Las Vegas Strip. [28] Closer to home, Canadian company Pacific Western Transportation recently concluded a trial run of their driverless shuttle, called the ELA, on lane-separated roads in Beaumont [30] and Calgary [31] Alberta. (**Figure A.2**)

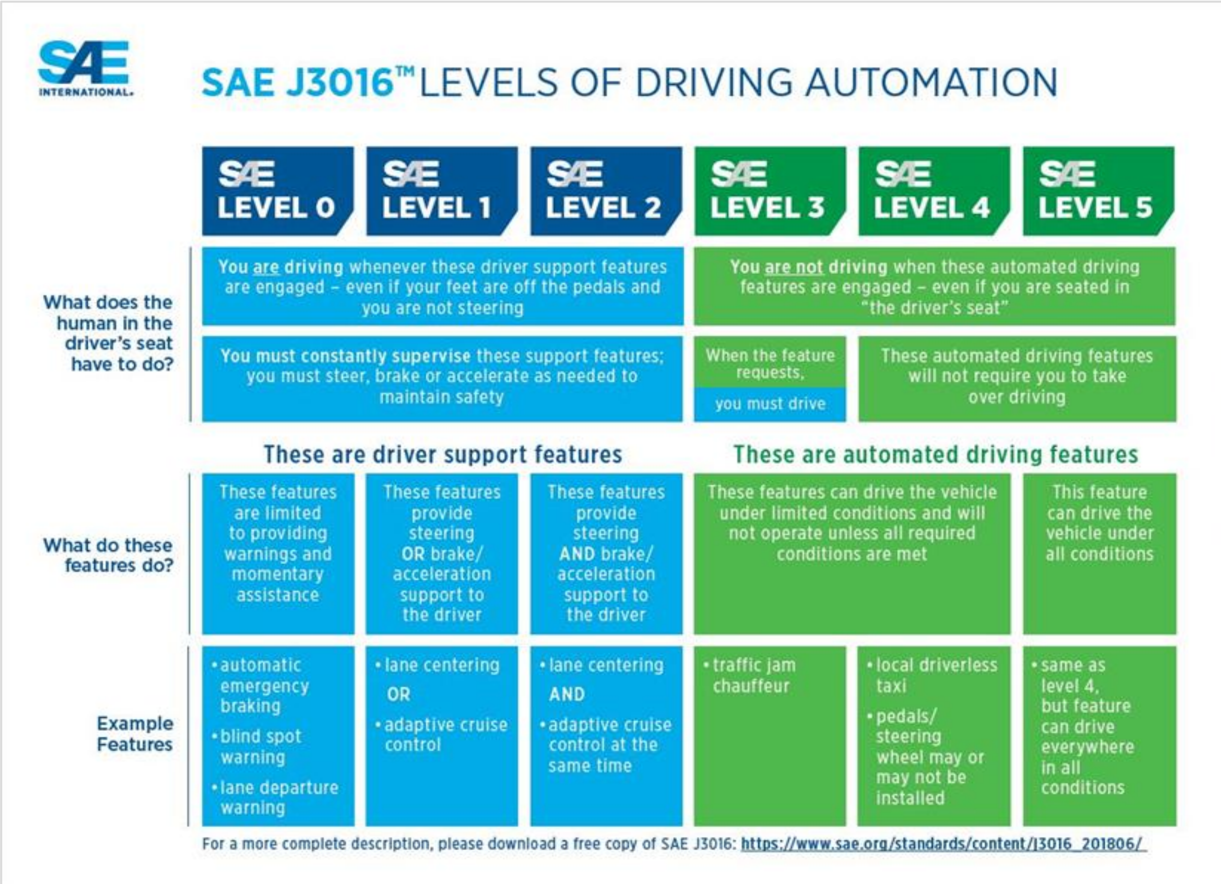

Figure A.1 The six levels of automation described by the Society of Automotive Engineers (SAE) [26].

AV development is not restricted to technology companies, traditional auto manufacturers such as Ford, Tesla, Renault, and Daimler are reportedly planning to roll out level 4 & 5 vehicles in the next decade. [28] Additionally Tesla's current production cars, including the model X and 3 are manufactured with the appropriate hardware so that they can one day be converted to a level 4 or 5 AV with only a software update. [29]

While exact timelines of AV introductions are to be determined by individual manufacturers, it is not unreasonable to expect that by 2030, level 5 AV's will be deployed and may even dominate in target markets. AV technologies threaten to not only transform personal mobility but will impact other aspects of our cities and the behaviour of their citizens.

This analysis provides an overview into some of the changes that are likely to occur with vehicle automation (as well as vehicle connectedness, electrification and sharing), with a particular focus on the real estate sector. We also offer regulatory and policy suggestions that could be used to direct these disruptive forces to ensure that they help to address rather than exacerbate societal challenges. The following three sections of this review describe deployment scenarios in the order that we (and others) see as most probable.

Figure A.2 Pictured is an ELA driverless shuttle boarding zone in Beaumont, AB. These vehicles operated on the streets of Beaumont and in Calgary on lane separated from regular traffic. [30]

A.2 Personally Owned Autonomous Vehicles

Many vehicle manufacturers are now testing autonomous vehicles [33] and are working toward mass production of level 4 & 5 AV's in the next five years or so. The first-generation AV's are expected to come with a hefty price tag that keeps them out of reach of the average consumer. [28] Wealthy consumers will be the quickest to adopt vehicle autonomy as optional extra, [32], [34] along with vehicle electrification. [35]

The emergence of personally owned electric AVs will be correlated with an increased demand for electric vehicle chargers in high-end homes. Current EV technology requires 1 to 12 hours charging per day, making the home one of the most convenient and secure places to charge. [36] Vehicle owners may also want heated garages to protect expensive batteries from Canada's harsh winters.

As AV technology becomes more reliable and acceptable, governments may allow these vehicles to drive empty. Assuming no legislative barriers, a family member could take the AV to work, then have it return to their home to pick up another family member to go to school, work or other appointments, saving not only the cost of parking, but the need for a second car in the household.

In the future, those who use a car may not be required to hold a valid driver's license since they do not need to operate the vehicle. This has the potential to extend personal mobility to previously under-served sectors including seniors, children, and the handicapped. Combined with the movement of empty vehicles, the extension of personal mobility to previously unserved individuals supports the projection that there is likely to be more kilometers travelled per capita per year a future AV world. [37]

In these early stages of AV deployment, overnight residential parking demand will be maintained, although perhaps for fewer vehicles per household. Parking when outside of the house is more complex. Academic literature identified three parking strategies for AVs, [38] especially in city centres where parking costs tend to be high. The vehicle could **(a)** drive itself empty to a nearby low cost or free parking spot outside the city centre, **(b)** return home to park for free and be on call to return to pick up the passenger when needed, or, **(c)** if the stop is short, it could continuously drive empty in the near vicinity until the passenger was ready to be retrieved.

All of these scenarios promise to exacerbate the congestion problems of our cities, while increasing, not decreasing the energy demands of personal mobility. Clearly, municipal leaders will need to consider policies and regulations to direct these disruptive technologies in ways that address, not exacerbate societal challenges. Per km road taxes, that could be higher for empty vehicles, may offer one solution. Indeed, such taxes are likely for the future, especially since electric vehicles avoid the gas taxes that currently pay for much of the road infrastructure across Canada. Targeted parking regulations could also be used to ban AV's from parking in time-limited free parking spaces or on certain streets.

It is important to note that parking for AV's may be different from parking for traditional vehicles as discussed in a recent publication. [38] Vehicles in AV only lots, should be able to park much closer together as shown in **Figure A.3** since they do not face challenges associated with opening doors. They can also use car-to car connectivity to unpark themselves. There are also benefits to these parking lots from the perspective of municipalities. Centralized AV lots have to the potential to free up on-street and close-proximity spaces for traditional vehicles. As such, it is in the interest of municipalities to promote use of these lots to better control the disruption.

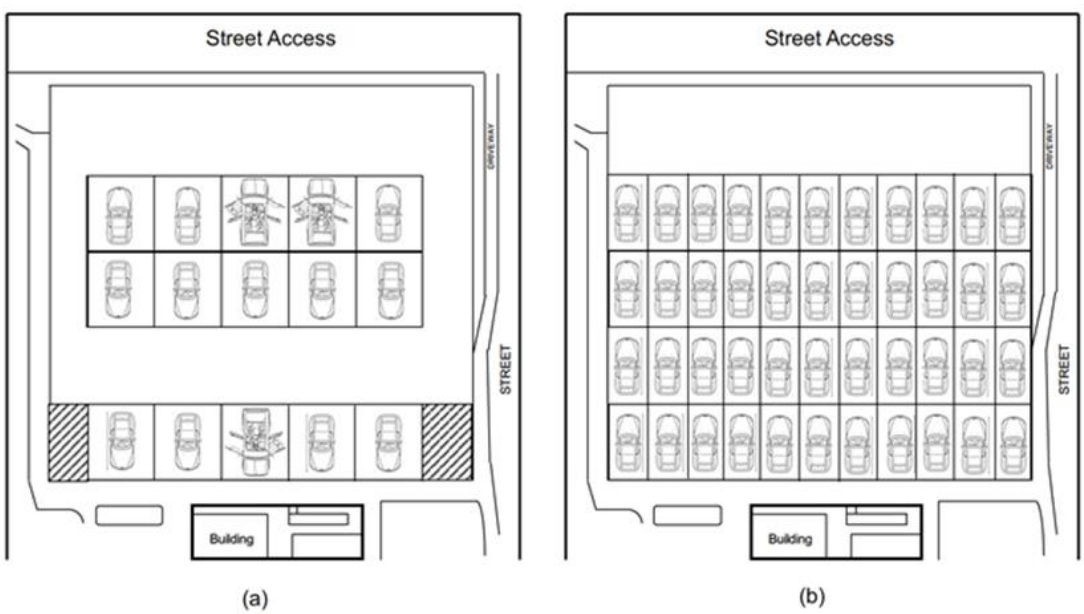

Figure A.3 Comparison of conventional parking design and AV parking design

Adapted from Roorda et al. shows the difference between conventional parking design and AV parking design. AV parking design uses driverless technology to park vehicles closer together (up to 6 inches apart) and allow for more vehicles to be parked per unit of land. [39]

AV-only parking lots may provide an interim solution for parking structures previously dedicated to traditional vehicles. As the AV rollout continues and parking demand declines, [38] parking lot owners will be challenged to find alternatives uses, particularly for those owning parkades with slopped floors since they are difficult to convert to other functions. [38] A parking facility dedicated to AVs could offer one solution.

Another change that can be expected with the early adoption of personally owned AV's is building design. With vehicle owners not having to park the cars themselves, there may be increased pressure on building owners/operators to provide pickup and drop-off (PUDO) locations, especially for office and condominium buildings in high density regions of the city. AV only sections of these parking lots could hold more vehicles thereby reducing the cost while increasing convenience.

With the growth and sophistication of AV technologies, there is a significant reduction in the 'opportunity cost' of long-distant commuting. Even in stop and go traffic, the car is doing the driving so that time could be used by the passenger for working, relaxing, or entertaining oneself. There is growing concern that personally owned AVs will encourage urban sprawl, [40] depopulate city centres, increase vehicle-kilometers travelled, take over valuable farmland and adversely impact biodiversity. The global trend to urbanization is known to reduce human impacts on the environment, [41] and personally owned AVs could slow or reverse that trend. There are many policy instruments that could be used to direct how this disruptive technology is deployed to ensure optimal societal benefits, especially in an era where every vehicle is equipped with their global positioning system (GPS) coordinates, and the potential exists to allocate taxes to vehicle km travelled, class of road being used or even time of day.

A.3 Autonomous Vehicles and Public Transit

Public transit has long been a major expense for municipalities, but it provides an essential service, especially in cities. Public transit is not only less expensive than personal vehicle ownership and us, but it helps to reduce congestion and lower parking demand in city centres.

The introduction of AV technologies will be a challenge for public transit, [37] especially in a post COVID world concerned about community transmission of disease. As noted in the previous section, the ability for AV owners to avoid the high cost of downtown parking, and the potential to shift from a two car to a one car family may divert riders from public transit in a post pandemic world.

However, strategically deployed, shared AVs could also be used by municipalities to encourage and expand demand for public transit. Currently, transit systems run on fixed routes and buses are often empty or near empty during off peak hours. Moreover, transit systems are not always convenient. Users must walk to the bus stop, wait for the bus, possibly transfer to a train on another bus and then walk to their destination.

With a fleet of shared AVs, transit systems could address the 'first mile – last mile' barrier to public transit use. Transit owned AVs responding to cell phone directions could pick up commuters at their homes and deliver them to trains or express buses that would efficiently and conveniently bring them to the city centre. These AVs could also bring them back home from the train/ bus station at the end of the day. In Calgary, a human driven, on-demand van is (**Figure A.4)** and has been successfully demonstrated since 2019.

Figure A.4 The City of Calgary's Transit On Demand Van [42]

Such autonomous mobility on demand (AMoD) or 'robo-taxi' service should be more affordable than the existing human-driven taxi, or ride sharing services like Uber or Lyft and may claim considerable share of the transportation market. [43] Major manufacturers such as General Motors (GM) are already planning for these eventualities by designing AV's suited to ride share services and developing AV sharing business models. [44] The exact timing of the roll out is unknown but is expected to come after personal AV's since full level 5 automation is needed and the public needs to gain confidence in the technology. Modelling has shown that AMoD should be able to operate at a cost that is comparable to existing transit. [38]

A.4 Widespread Deployment of AMoD

As AV technologies become more widespread and accepted, and 5G networks are established across Canada, companies with fleets of connected, level 5 AVs are expected to offer AMoD, initially in the densely populated cities and eventually expanding to all regions of Canada. The 5G networks will allow vehicles to communicate with one another (V2V), to infrastructure such as stop lights etc. (V2I) and with the Web (V2W) for information on congestion, accidents, road repairs, etc.

While some AMoD companies may charge per trip, most are expected to offer a personal mobility service to deliver a preset number of kilometers of travel per month for a subscription fee. When a trip is needed, a cell phone application will bring a vehicle to your location within a few minutes, drive you to your destination and then drop you off. Another car can be called when you wish to take the return trip.

Compared to owning, operating, and maintaining a personal vehicle in Canada (~$12-14K for about 16,000 km/yr), AMoD service should be about half the cost, and more convenient since the company takes care of parking, refueling, maintenance, cleaning etc. AMoD is expected to dramatically reduce personal vehicle ownership, and have major impacts on cities including:

Figure A.5 An example of laneway housing in Vancouver, British Columbia. Image courtesy of City of Vancouver. [45]

OFF STREET RESIDENTIAL PARKING

Off street residential parking will no longer be needed. This means:

- **Homeowners with driveways and attached garages** will want driveways replaced with lawns, gardens or patios, and the garages converted into living spaces, or secondary suites.
- **For communities with garages on laneways**, there could be a major interest in laneway housing (**Figure A.5**), and municipalities may be encouraged to allow properties in these communities to sever the laneway house from the main property. There will be a movement for the city to pave and maintain laneways (e.g. snow removal).
- **Condominiums and apartments** will struggle with what to do underground parking space (more storage, rent for commercial use?) Surface parking lots will be converted to PUDOs and other uses.
- **Communities relying on street parking** will find homeowners wanting the street in front of their house to be available as a PUDO, so will demand that street parking be banned. Bicycle paths, gardens and wider sidewalks will be more highly valued than street parking (**Figure A.6**). There will be fewer concerns about secondary suites.
- New housing developments will not require parking but will have a priority for PUDO design that is safe, convenient, and ideally sheltered from the elements. The cost per residential unit should be lower, and land developers should have more flexibility in the kind of building they can put on land.

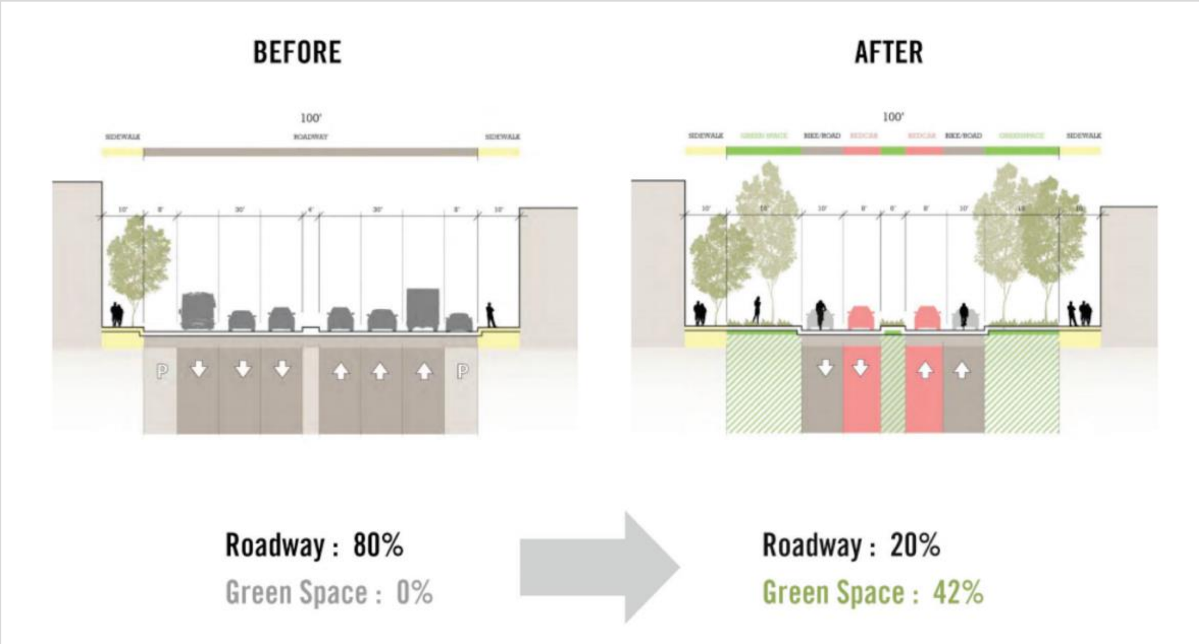

Figure A.6 An example of how much roadway can be reclaimed in an AMoD world. [42]

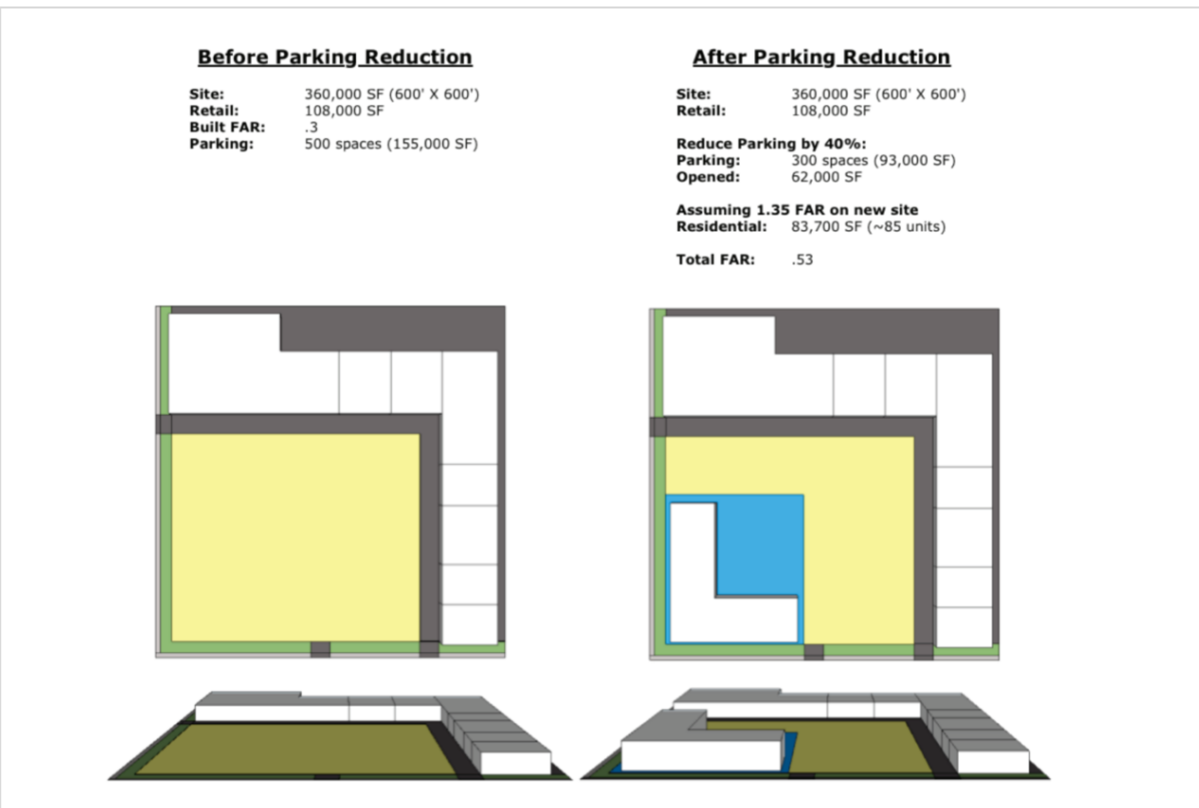

Figure A.7 Example of how a strip mall location could add additional units in a reduced parking demand scenario. [46]

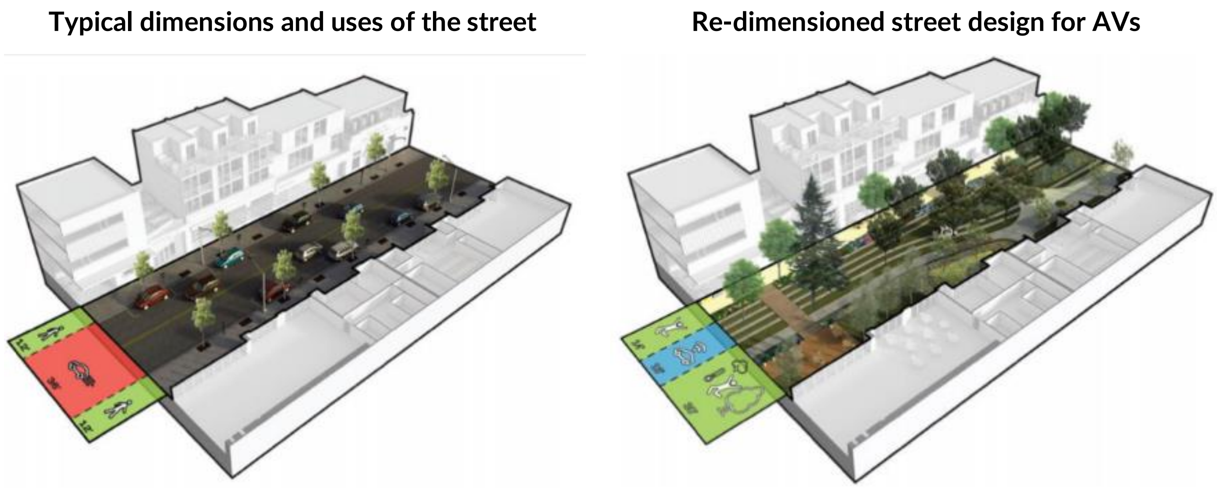

Figure A.8 How Autonomous Mobility on Demand (AMoD) could impact road and streetscape design. [48]

COMMERCIAL AND INSTITUTIONAL PARKING

Commercial and Institutional parking demands will be much lower. This means:

- **Above Ground Parking lots** are currently being designed with level floors spaced for a future retrofit into another building type. One example is the recently constructed parkade at the Foothills Hospital. [47] In the future, replacement, or retrofits of above ground parkades will become more common place.
- **Shopping Centre /strip mall parking** will be replaced with PUDOs, parklands, or new residential or commercial buildings such as that shown in **Figure A.7.**
- **Underground parking** in city centres could be taken over by AMoD fleet operators to refuel, clean and service their vehicles. Alternatively, the space could be made available for commercial applications such as indoor agricultural production etc.
- **City streetscape.** With a reduction in the demand for parking in commercial and institutional regions of our cities, there is an opportunity to create more people-friendly spaces **(Figure A.8).**
- **Pick up and Drop off (PUDO) Designs.** The decrease in the importance of parking in building design will be matched by the increase in the importance of safe, efficient, and convenient PUDO that are also capable of managing a large number of people at peak hours. While few designs have been released, an AMoD PUDO is currently being constructed in Las Vegas by The Boring Company for their Las Vegas Convention Center Loop Project (**Figure A.9**). They envisage having autonomous Tesla's moving people though tunnels bored under the city.

Figure A.9 Artwork released by The Boring Company showing their plans for a PUDO in their Las Vegas Loop Project. [49]

PARKING AND SERVICING AMOD FLEETS.

To serve the personal mobility needs for a city of 1 million people would require 100,000 to 200,000 shared autonomous vehicles. Some of the largest lots for these vehicles would likely be located at the outer edges of the city core, [38] if not in underutilized parking facilities located within the centre of the city. Others would be distributed around the city where there is access to either large amounts of electricity or the hydrogen to fuel the vehicles. While plug in electric vehicles should have a lower fuel cost, the cost of the recharging infrastructure becomes formidable when considering the logistics of refueling 1000+ vehicles in a single location per day. Fleets of hydrogen fuel cell electric vehicles can be refueled more quickly than electric vehicles so the infrastructure investments can serve more vehicles. This reality can make hydrogen fuel vehicles a more attractive alternative when considering large fleets of working vehicles. Also, in Alberta the high carbon intensity of the Alberta grid means that the life cycle greenhouse gas emissions for a fleet of hydrogen fuel cell electric vehicles would be lower than that for plug in electric vehicles.

OTHER REAL ESTATE RELEVANT IMPACTS

The shift from personally owned gasoline fueled LDVs to electric AMoD vehicles will be associated with the phasing out of car dealerships, fueling stations and vehicle service shops. The owners of the AMoD fleets may be the companies building the vehicles, allowing them to maintain the vehicles themselves. Moreover, electric vehicles have many fewer moving parts than gasoline vehicles and so maintenance costs would be less. It remains to be seen how AMoD will impact strip malls, shopping centres, large box stores, coffee shops and other retail sectors. How they respond to these disruptive innovations may ultimately determine their fate.

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