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THE FUTURE OF FREIGHT

PART A: TRENDS AND DISRUPTIVE FORCES IMPACTING GOODS MOVEMENT IN ALBERTA AND CANADA

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UNIVERSITY OF CALGARY

CESAR

A project associated with

The Transition Accelerator

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The authors would like to thank the many Canadian freight transportation organizations that provided valuable insights and guidance in the preparation and interpretation of the findings presented here.

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VERSION 2

About CESAR and The Transition Accelerator

CESAR (Canadian Energy Systems Analysis Research) is an initiative started at the University of Calgary in 2013 to understand energy systems in Canada, and develop new analytical, modeling and visualization tools to support the transition to a low-carbon economy.

In 2017, CESAR launched its **Pathways Project** to define and characterize **credible** and **compelling** transition pathways for various sectors of the Canadian economy that would help the nation meet its 2030 and 2050 climate change commitments made in Paris in 2015 (**Figure 1.1**).

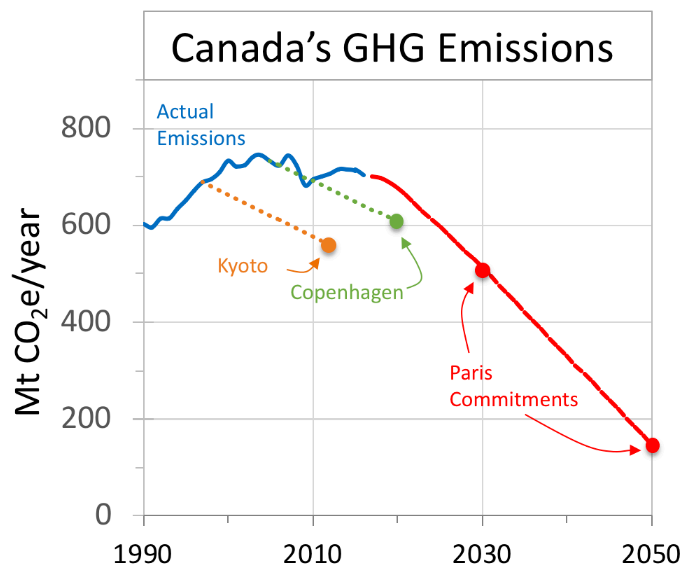

Figure 1.1. Canada's greenhouse gas emissions (solid blue line), showing the future trajectory needed to meet Paris commitments (red line). Past failed commitments are also shown. Data from the 2018 National Inventory Report for Canada for 1990-2016 (http://www.publications.gc.ca/site/eng/9.506002/publication.html)

A CESAR Scenarios publication in early 2018[1], and the support and encouragement from a number of charitable foundations led to discussions among CESAR's Director, **David Layzell,** Carleton University professor **James Meadowcroft** (Canada Research Chair in Governance for Sustainable Development, School of Public Policy and Administration) and Université de Montréal professor **Normand Mousseau** (Dept of Physics and Academic Director, Trottier Energy Institute) regarding the need for a pan-Canadian initiative to accelerate the development and deployment of Transition Pathways.

1 D. B. Layzell and L. Beaumier, "Change Ahead: A Case for Independent Expert Analysis and Advice in Support of Climate Policy Making in Canada," CESAR Scenarios, vol. 3, no. 1, Feb. 2018 [Online]. Available: https://www.cesarnet.ca/publications/cesar-scenarios/change-ahead-case-independent-expert-analysis-and-advice-support

With guidance and financial support from a number of private Canadian foundations, a charitable non-profit was launched in 2019 and called the **Transition Accelerator**. Associated with the launch, a report was published[2] to articulate a philosophy and methodology that is now used by both CESAR and the Accelerator.

In defining and advancing transition pathways, **CESAR** and the **Accelerator** recognize that transformative systems change is needed to achieve climate change targets (see **Figure 1.1**). However, for many, perhaps most Canadians, climate change is not a sufficiently compelling reason for large-scale systems change, especially if it has substantive costs. Nevertheless, we live in a time of disruptive systems change driven by innovations that both promise and deliver highly compelling benefits, such as enhanced convenience, comfort, status, value for money and quality of life. What if it were possible to harness these disruptive forces to also deliver societal objectives for climate change mitigation?

The **Accelerator**'s mandate is to work with key stakeholders and innovators to speed the development and deployment of credible and compelling pathways that are capable of meeting climate change targets using a four-stage methodology:

1. **Understand** the system that is in need of transformative change, 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, the academy, environmental organizations and other societal groups. This engagement process will be 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 researchers then re-engage the stakeholders to revise the vision and pathway(s) so they are more credible, compelling and capable of achieving societal objectives that include GHG mitigation (see **Figure 1.2**)
4. **Advance** the most credible, compelling and capable transition pathways by informing innovation strategies, engaging

2 J. Meadowcroft, D. B. Layzell, and N. Mousseau, "The Transition Accelerator: Building Pathways to a Sustainable Future," vol. 1, no. 1, p. 65, Aug. 2019. [Online]. Available: https://www.transitionaccelerator.ca/blueprint-for-change

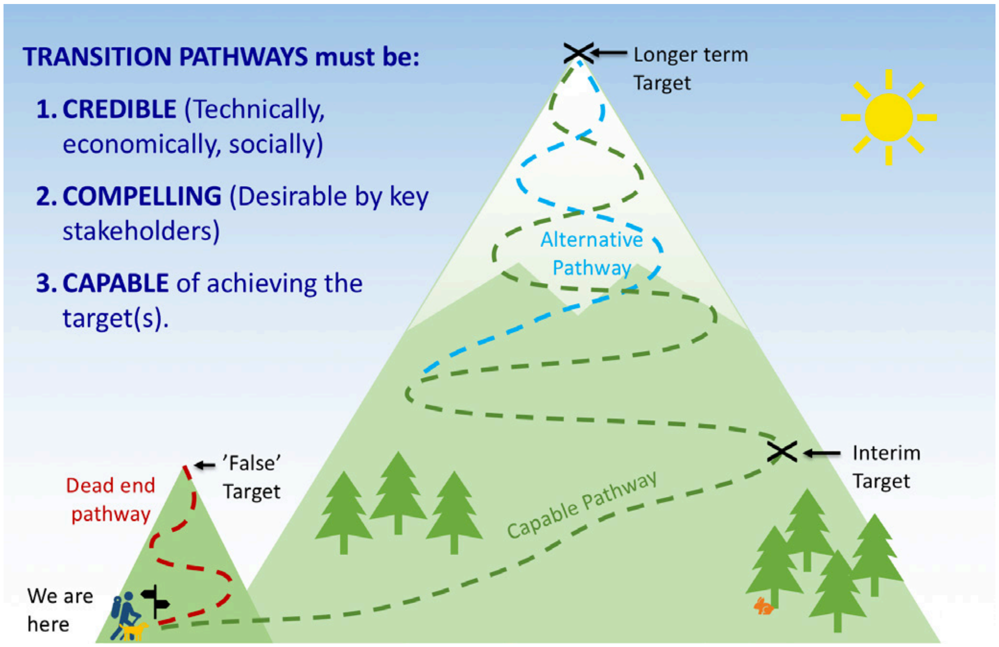

Figure 1.2. Criteria for a useful transition pathway. The two-mountain image is provided to stress the importance of pathways being capable of achieving longer term targets. Some climate change policies encourage dead end pathways to 'false' targets based only on incremental GHG reductions, but which are clearly are not on a pathway to a longer-term target.

decision makers in government and industry, participating in public forums, and consolidating coalitions of parties enthusiastic about transition pathway implementation.

This study reports Stage 1 results for the freight transportation sector in Canada.

About the Authors

Jessica Lof, B Comm, MSc (SEDV)

Jessica Lof is a Research Lead for the Canadian Energy Systems Analysis Research (CESAR) Initiative at the University of Calgary with a special interest in low-carbon transition pathways for Canada's transportation systems. Jessica is also actively exploring hydrogen economy ecosystems and evaluating system-level opportunities and trade-offs while connecting with stakeholders.

Jessica joined CESAR with more than a decade of business experience in the railway and trucking sectors. Throughout her career, she has designed transportation and logistics solutions that enable economic potential and drive operational efficiency in a vast array of industries, including wind energy, oil and gas, automotive and global trade.

Jessica has a Master of Science degree in Sustainable Energy Development, a Bachelor of Commerce degree and a professional designation with the Canadian Institute of Traffic and Transportation.

David B. Layzell, PhD, FRSC

David Layzell is a professor at the University of Calgary and Director of the Canadian Energy Systems Analysis Research (CESAR) Initiative, as well as co-founder of the Transition Accelerator. 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.

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CAGR	Compound Annual Growth Rate
CanESS	Canadian Energy Systems Simulator
GHG	Greenhouse gas
GVWR	Gross Vehicle Weight Rating: weight of the truck plus the weight of its maximum carrying capacity
H_2	Hydrogen
HDV	Heavy duty vehicle: vehicles with a GVWR of >= 15 tonnes
HFO	Heavy Fuel Oil
ICE	Internal combustion engine
LCV	Long Combination Vehicle: HDV hauling more than one trailer at a time
Other Road Freight	Vehicles with a GVWR >= 3.9 < 15 tonnes with a primary purpose of moving freight
NO_x	Nitrogen Oxides
Road Freight	Vehicles with a GVWR >= 3.9 tonnes with a primary purpose of moving freight
SO_x	Sulphur Oxides
TKM	Tonne-kilometre of freight being transported
$PM_{2.5}$	Particulate Matter 2.5 µ in diameter
V2V	Vehicle to Vehicle - connected vehicle application
V2I	Vehicle to Infrastructure - connected vehicle application
V2D	Vehicle to Device - connected vehicle application C4G Canadian Climate Change and Clean Growth Institute
V2P	Vehicle to Pedestrian - connected vehicle application

Executive Summary

Road freight transportation is **essential to the prosperity of Alberta and Canada,** and a major source of greenhouse gas (GHG) emissions. Between 1990 and 2016, road freight demand in Alberta increased by 165%, reflecting the importance and strong ties this sector has to the growing economy of the province. Diesel is the dominant fuel for freight transportation.

"The freight sector is stressed and poised for transformative change."

For the freight sector to achieve the climate change targets that have been set by the Pan-Canadian Framework,[1] transformative, system-level changes are needed. Given the narrow economic margins for success in this sector, it is difficult to see how climate change concerns alone will be successful in driving and achieving the magnitude of systems change required.

However, the freight sector also faces health and environmental concerns such as air pollution, accidents and congestion, as well as business model issues including high operating costs, low margins, driver shortages, limited asset utilization and low load factors.

Disruption is clearly on its way with autonomous trucks, vehicle electrification, connected vehicles, collaborative transportation management and the physical internet. The freight sector is stressed and poised for transformative change.

Connected autonomous vehicles and big-data are perhaps the most substantive forces for systems change and they are likely to bring along other innovations such as vehicle electrification. Certainly, the movement to vehicle electrification would have the largest impact on Alberta's economy, which depends heavily on an ongoing demand for diesel fuel. A crucial question for Alberta involves the implications for the province of battery-electric versus hydrogen fuel cell electric heavy duty vehicles (HDV). What impact would each have on the transportation sector and on the economy of the province and Canada?

1 https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework.html

This report summarizes the trends and disruptive forces impacting goods movement in Alberta and Canada, with a particular focus on road freight. Freight transport is widely considered to be on the cusp of transformative change, driven by technology, business model and social innovations emerging from the digital revolution which has already disrupted the music, retail, book, movie, news media and telecommunication sectors.

The authors hope that a better understanding of the challenges and opportunities facing the freight sector will inform policy and investment decisions on how best to direct disruptive forces in this sector to achieve societal goals that include, but are not limited to, GHG management.

Below is a summary of the highlights from the findings and insights of this report, many of which need to be considered in developing a vision and strategy for transformative systems change.

"A crucial question for Alberta involves the implications for the province of battery electric versus hydrogen fuel cell electric vehicles."

Greenhouse gas emissions from freight transport

The freight transportation sector is a significant emitter of GHG emissions in Canada and Alberta, contributing:

- 70 million tonnes of CO_2e in Canada; 18 million tonnes in Alberta
- 10% of Canada's and 7% of Alberta's total GHG emissions in 2016

Road freight accounts for up to 88% of the freight transportation sector's GHG emissions while moving only one-third of Canada's freight and just under one-half of Alberta's freight. Diesel fuel is the dominant fuel for freight transportation.

Canada's prosperity and livelihood depends on the strength of its freight systems

Demand for freight transportation is closely tied to economic growth. In Canada, every dollar of GDP is associated with 0.52 tonne kilometers (TKM) of freight transportation; in Alberta, 0.65 TKMs are moved per $GDP.

Demand for freight transportation has been growing more rapidly in Alberta than the national average. Between 1990 and 2016, Alberta demand has grown by 107%, while Canada has grown by 51%. This is despite a large decline in freight movement in Alberta between 2014 and 2016.

Road freight has been outpacing growth in other modes, such as rail, that have lower GHG intensities. This has caused a multiplicative effect to GHG emissions in the freight sector. Between 1990 and 2016, Alberta's road freight demand has grown by 165%, while Canada has grown by 97%.

The shift to road freight can be explained by the freight system responding to changing dynamics of the economy such as short delivery times, just-in-time delivery and e-commerce.

There is global and national evidence that Canada's freight systems are currently stressed in their ability to support the economy.

The Scale and Dynamics of the Road Freight Sector

It is estimated that there are about 300,000 heavy duty vehicles (HDV) used in freight service with about 36,000 new HDVs added to the fleet per year (2016). The fast turnover rate provides an opportunity to introduce new technology.

While policies have led to improvements in HDV fuel efficiency, this has not translated into improved energy intensity (the energy used to move a tonne of freight one kilometer). This could be explained by supply chains prioritizing short, flexible delivery times over load optimization.

The profit margins for trucking are small and likely contribute to a competitive, mistrustful culture that has been reported to characterize the sector. Furthermore, the sector is dispersed across more than 40,000 carriers, most of which are very small, creating a fragmented industry that lacks a unified voice.

Labour is a large cost component for an industry that is a significant employer for Canada and Alberta. However, the industry is facing a severe labour shortage in the years to come that will need to be addressed for the sector to remain competitive.

Although productivity has been improving, overall performance continues to impact the industry's ability to (1) support economic growth, (2) optimize its asset utilization, (3) overcome driver shortage and (4) contribute to the societal costs of road congestion for all road users.

System Impact on Health and the Environment

Motor vehicle safety has improved in recent decades but remains a serious concern for the road freight industry.

Road freight accidents have been linked to inadequate training and driver fatigue.

Air pollution is a growing concern for road freight transportation and many municipalities around the world have taken steps to ban the use of diesel combustion engines within their city limits. Others have announced bans that will be implemented between 2030 and 2040.

GHG Mitigation Strategies

Factors contributing to the increase in transportation-related GHG emissions include demand (activity), mode share, energy intensity and fuel carbon content, with activity growth being the dominant factor.

Scenario analysis shows that mode change and energy efficiency strategies are important, but incapable of reducing GHG emissions much below 2005 levels.

To overcome the upward pressure caused by demand growth, a transition to very low- or zero-emission fuels is urgently needed.

Forces for Systems Change

While GHG emissions are a major concern with the sector, it is not the only concern. Addressing some of the other important issues would attract support from the industry and the general public to achieve transformative change in freight transportation systems.

There are many innovations emerging to potentially disrupt the road freight sector, and several of these show promise to be both credible and compelling, especially when strategically combined and directed.

- Electrification options for HDVs are quickly being advanced, generating excitement in the road freight sector for their environmental and operational benefits. Two of the most promising electrification options in North America include the battery electric and the hydrogen fuel cell electric HDV.
- Autonomous technology, in its various forms, has benefits including improved safety, fuel efficiency and labour productivity, and at a fully driverless level, operating costs can be substantially reduced.

- Connected vehicles able to communicate with their surroundings and vehicles that use telematics and the Internet of Things to communicate performance, have safety, efficiency,and productivity benefits.
- Collaborative Transportation Management is an example of a social and business model innovation that encourages an open exchange of information, along with joint transportation and logistics planning, between organizations with common needs.
- The physical Internet concept integrates many of the above innovations to create a grand vision for freight transport whereby goods are transported in the same way that data moves over the internet. The physical internet includes utilizing standardized interlocking containers moving across multiple modes and carriers, and interchange locations based on algorithms and predetermined criteria – all to lower costs and enhance operational efficiency.

Directing Systems Change

Some incremental improvement has been seen in recent years, indicating that the sector may be receptive to change.

The wide range of economic, environmental and health issues facing the sector suggests that this industry is poised for larger transformative systems change, through adopting disruptive technological, social, and business model innovations emerging to address those issues.

The challenge will be to strategically direct, guide and otherwise nudge the disruption to attain a balance of economic and environmental objectives, including meeting Canada's climate change commitments.

The electrification of road freight provides the opportunity to eliminate tailpipe emissions and, when combined with other innovations like the autonomous truck and digital connectivity, it is easy to envision its role in the future of freight.

A crucial question for Alberta involves the implications for the province of battery electric versus hydrogen fuel cell electric HDVs. Which transformative technology is better for the key industry sectors (freight transport, oil and gas, electricity generation) and the economy of the province and Canada?

1. Introduction

Freight transportation is vital to Canada and Canadians. By moving goods and commodities between links in the supply chain, freight transportation acts as a conduit to support both the economy and Canadians' wellbeing.

Freight transportation is also a large consumer of fossil fuels and therefore a major contributor of GHG emissions. This makes the sector an obvious target for climate change initiatives that can help Canada reach its 2030 GHG reduction commitments (30% reduction below 2005 level of emissions) [1] and do its share to constrain global warming to <2°C by 2050.

To date, technology and policy measures to reduce GHG emissions have focused on improving the efficiency of diesel engines [2], reducing wind and road resistance [3] and incorporating biofuels (e.g. biodiesel) into the fuel mix [4]. Despite these measures, GHG emissions from heavy duty diesel vehicles in Canada has risen from 13 Mt CO_2e/year in 1990 to 37 Mt in 2005 and 46 Mt CO_2e/yr in 2016 [5]. Clearly, a new approach is needed to incentivize transformative, rather than incremental, changes in this sector.

In recent decades, transformative changes have been seen in many other economically-important sectors, including music, movies, books, photography, media and telecommunications. However, the technological, business model and social innovations driving changes in those sectors promised and delivered improved efficiency, comfort, service, convenience, return-on-investment and quality of life, not environmental benefits. It seems likely that the attributes they offered are more compelling to 'key stakeholders' than the promise of lower GHG emissions and a more stable climate for future generations.

In the freight transportation sector, the key stakeholders are clearly the companies that provide the transportation service to either move their own goods, or to provide a freight service for others. If there are mounting forces for transformative systems change in the freight transportation sector, there may be opportunities to harness or otherwise direct these forces to achieve multiple societal benefits, including climate change mitigation.

This report aims to understand the freight sector in Canada and in Alberta, including the:

- Scale and role of the sector in the economy;

- Recent trends in the sector, and what is driving (or not driving) those trends;
- Strengths and weaknesses of the sector;
- The disruptive technology, business models and social innovations that have the potential to drive systems change.

The authors hope the insights gained from this report will inform a deeper analysis of possible visions and pathways for transforming this important sector in the Canadian economy, to not only enhance its environmental performance, but to make the sector more competitive and enhance the contribution it makes to the quality of life of Canadians.

Where data is available, the report also focuses on the situation in Alberta, a province with per capital diesel use in heavy duty trucking that is 2.3 times greater than the national average [6].

2. An Overview of the Freight Transportation Sector

The freight transportation sector in Canada contributed 70 million tonnes of carbon dioxide equivalents (Mt CO_2e) in 2016 [5], representing 10% of Canada's total GHG emissions (**Figure 2.1A**). Of this amount, the road freight sector contributed 59 $MtCO_2e$ or 84% of the total freight transportation emissions.

However, the road freight sector (see **Box 2.1** for definitions) moves only about one-third of the 854 billion TKM transported in Canada (**Figure 2.1**). In contrast, rail transportation contributes less than 10% of the sector's GHG emissions, but handles about 44% of Canada's freight transportation demand.

This is because road freight consumes on average 3 MJ of fuel energy for every TKM travelled, while rail consumes only 0.23 MJ/TKM, (**Figure 2.2**). Therefore, road transport consumes 13 times more energy than rail per unit of freight moved.

Certainly, shifting more freight from trucks to trains would reduce GHG emissions. However, the demand for just-in-time delivery, the movement to e-tailing (i.e. electronic retailing) and the trend in recent decades to divest from less active railway track infrastructure suggests that road freight will continue to play a vital role in supporting Canada's supply chains.

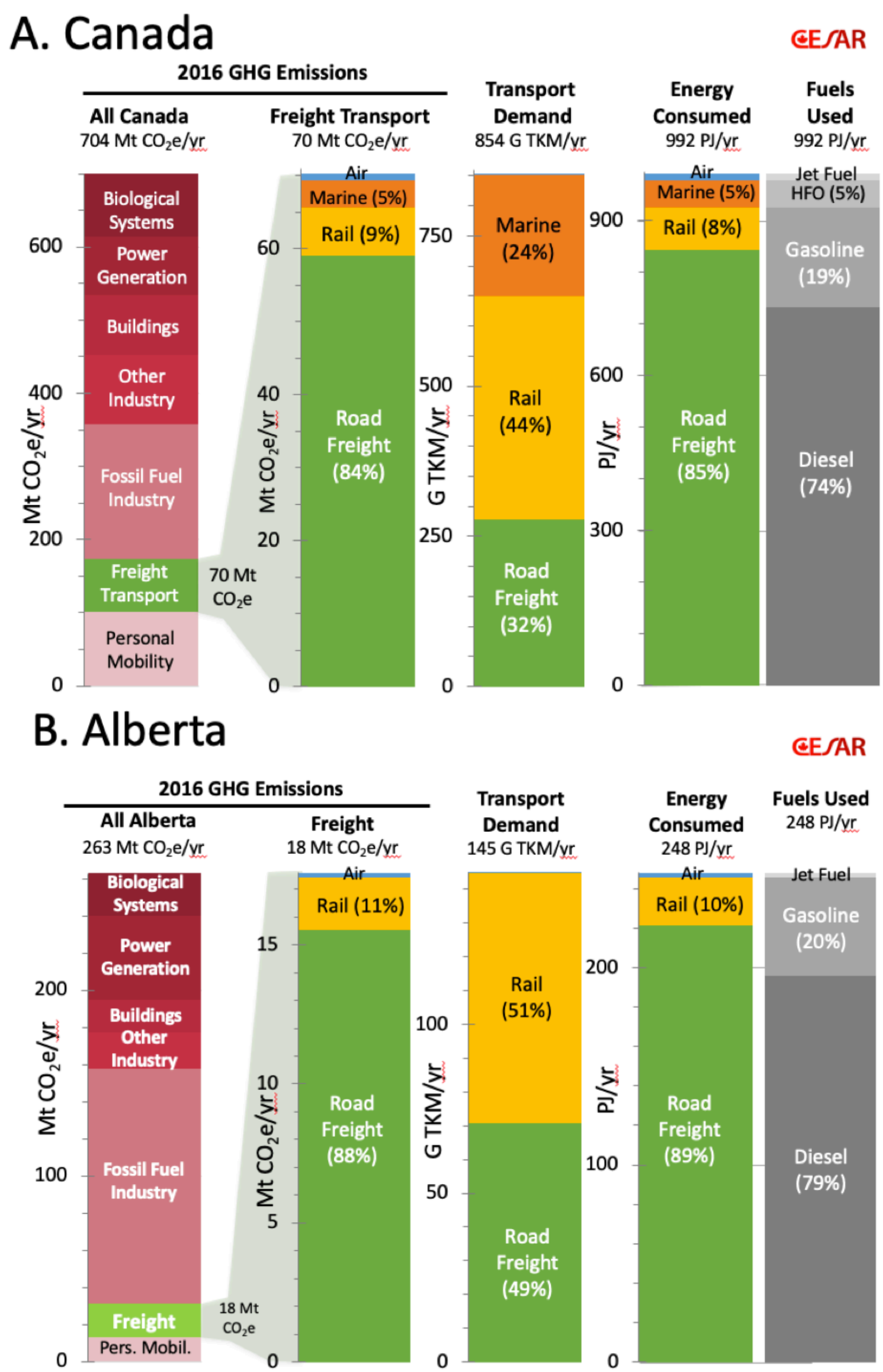

Figure 2.1. An overview of Canada's (A) and Alberta's (B) Freight Transportation Sector in 2016, including (left to right) their contribution to total GHG emissions (Mt CO2e/yr), modes contributing to GHG emissions, freight moved (t-km travelled), energy used (PJHHV/yr) and fuels consumed (PJHHV/yr). Road freight represents vehicles with a Gross Vehicle Weight Rating (GVWR) of 3.9 tonnes or greater. Data compiled from the National Inventory Report [5] for GHG emissions/ energy consumed/fuels used, Statistics Canada [7], [8], and Natural Resources Canada [9]-[10] for transportation demand.

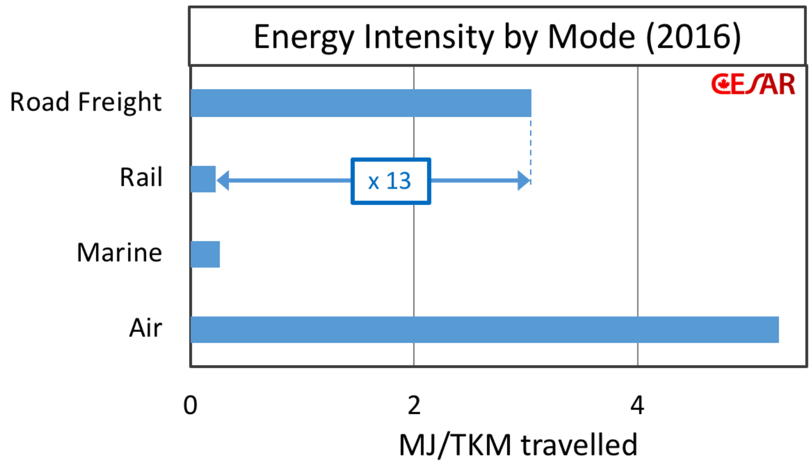

Figure 2.2. Energy intensity for freight transport (MJHHV per tonne-km [TKM] travelled) by mode. Underlying data is from the National Inventory Report [5], Natural Resources Canada [9]-[10], and Statistics Canada [7],[8].

"...the demand for just-in-time delivery [and] the movement to e-tailing... highlight[s] the need to find strategies to reduce or eliminate tailpipe emissions from freight transportation in Canada."

These trends highlight the need to find strategies to reduce or eliminate tailpipe emissions from freight transportation in Canada.

Diesel is currently the dominant fuel (~74%) supporting freight transport (Figure 2.1), providing dense, accessible and affordable energy suitable for the performance needs of heavy-duty vehicles (HDV) and railway locomotives. Diesel is also increasingly being used in marine transport since the sector is shifting away from heavy fuel oil (HFO) for environmental reasons associated with the high sulphur content in HFO [11].

Gasoline is used for a portion of Canada's road freight, mostly in vehicles with a gross vehicle weight rating (GVWR) between 3.9 and 15 tonnes (**Box 2.1**). These vehicles are more likely to travel shorter distances and haul smaller payloads, so the advantages of diesel are less apparent [12].

In Alberta, freight transport contributed 18 Mt CO2e/yr, a per capita rate 2.1 times higher than the Canadian average (i.e. 4.2 t CO2e/cap in AB vs 1.9 t CO2e/cap in Canada) (**Figure 2.1B**). Despite having only 12% of the Canadian population, Alberta moves about one-quarter of Canada's total transportation demand in units of TKM traveled. Given the lack of marine transport in Alberta, road transport accounted for 88% of the emissions and 39% of all freight moved in the province (**Figure 2.1B**).

Box 2.1. Road Freight Classification

Transportation equipment varies depending on the goods being hauled, the regions travelled and the markets served. Freight vehicles are classified according to their GVWR, which includes the weight of the truck and the weight of its maximum carrying capacity.

In this study, the following two groupings are used to represent road freight transport with HDV being the primary focus.

Road Freight	GVWR	Examples
HDV	> 15 tonnes	Combination Tractor Trailers, Dump Trucks
Other Road Freight	3.9 < 15 tonnes Urban	Delivery Trucks, Cargo Vans, Large Pick-up Trucks, Vocational vehicles

3. Freight Transportation Demand (Activity) and the Economy

Canada's prosperity and livelihood depend on the strength of the freight systems that support the economy by moving goods for Canada's industries and delivering products to consumers.

Supply chains drive freight transportation demand and these forces have been evolving over the past decades and will continue to evolve in the decades ahead. Deregulation, free trade and containerization have opened the doors to the global market, allowed international production-sharing arrangements and enabled the just-in-time qualities of the modern supply chain [13]. Combined, these are key drivers behind the 51% increase in freight transportation demand between 1990 and 2016 and the 97% growth in road freight (**Figure 3.1A**).

The mode share for freight has shifted more towards road freight, growing from one-quarter of Canada's freight moves in 1990 to close to one-third in 2016. Rail freight has maintained close to its 45% share over the decades, while domestic marine freight has lost market share (**Figure 3.1A**).

In Alberta over the same period (1990-2016), the TKM demand for Alberta has grown by 107%, with road freight growing by 165% and rail growing by 82% (**Figure 3.1B**). Even though the road freight sector experienced considerable growth in recent years, rail remains the primary mode of freight transportation in both Alberta and Canada.

For reasons discussed previously (**Figure 2.2**), when growth in truck transportation outpaces growth in modes with low energy intensities like rail and marine, there is a multiplier effect on energy use and GHG emission growth for the freight sector.

It should be noted that transportation activity data for road freight in Canada are currently very limited. Statistics Canada and Transport Canada data are based on survey data completed only by for-hire carriers that have annual revenues greater than $1.3 million [8], thereby not including own-account trucking or small commercial carriers. This data gap may be filled in the future with the introduction of Transport Canada's new Canadian Centre on Transportation Data [15].

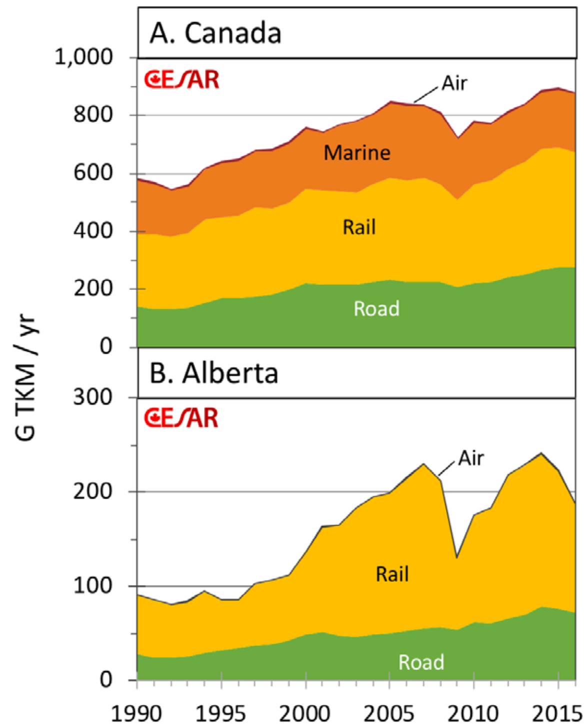

Figure 3.1. Freight Transportation Activity in billion tonne-km (GTKM) travelled per year by mode for Canada (A) and Alberta (B). Canada data from Statistics Canada [8] and Natural Resources Canada [9] with truck demand back-castfor years prior to 2004 using the CESAR baed on GHG data from the National Inventory Report [5].

Freight transportation activity growth is closely tied to economic growth. Every dollar of Canada's gross domestic product (GDP) in 2016 required 0.52 TKM of freight transportation. Likewise, every dollar of Alberta's 2016 GDP required 0.65 TKM of freight movement (**Figure 3.2**).

In general, goods movement in Canada has been declining in importance as a proportion of the national GDP. Such decoupling is expected in developed countries as their economies shift to more service industries [17]. Alberta seems to be resisting this decoupling trend as its economy has a greater dependence on freight transport and it has not noticeably declined over the past 20 years (**Figure 3.2**).

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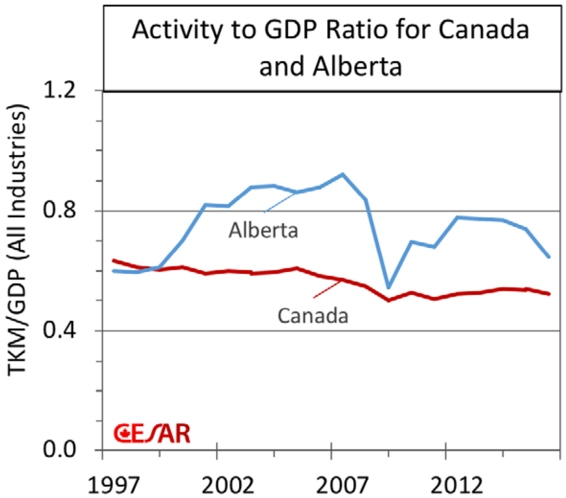

Figure 3.2. Freight Transportation Activity (TKM/yr) to gross domestic product (GDP [2007$]/yr) ratio for Canada and Alberta. Represents the freight transportation activity associated with producing $1 of GDP for all industries in Canada and Alberta in 2007 chained Canadian dollars. Data is sourced from Statistics Canada [8], [16]

of Transport Canada's new Canadian Centre on Transportation Data [15].

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Freight transportation shifts with the changing dynamic of the economy. For instance, the continued rise of e-commerce accounted in 2016 for 2.4% of Canada's total retail sales, up from 1.6% just four years earlier [18], and global online giants Alibaba and Amazon traded 700 billion $US in goods with compound annual growth rate (CAGR) of 33% since 2012 [19]. As a result, home delivery segments are emerging using other road freight vehicles that have a GVWR <15 tonnes, thereby changing the structure of the conventional retail freight model with increased importance being added to the 'last mile' (final delivery) segment of the shipment [20].

Freight transportation also has an integral role in supporting Canada's presence in the global marketplace. However, according to the World Economic Forum's Enabling Trade Index [21], Canada's global ranking has deteriorated in recent years compared to its international peers, in areas that include timeliness of shipments and ease and affordability of shipments (**Figure 3.3**).

*"By identifying shortcomings, the stage can be set for **holistic and transformational changes** in our freight systems."*

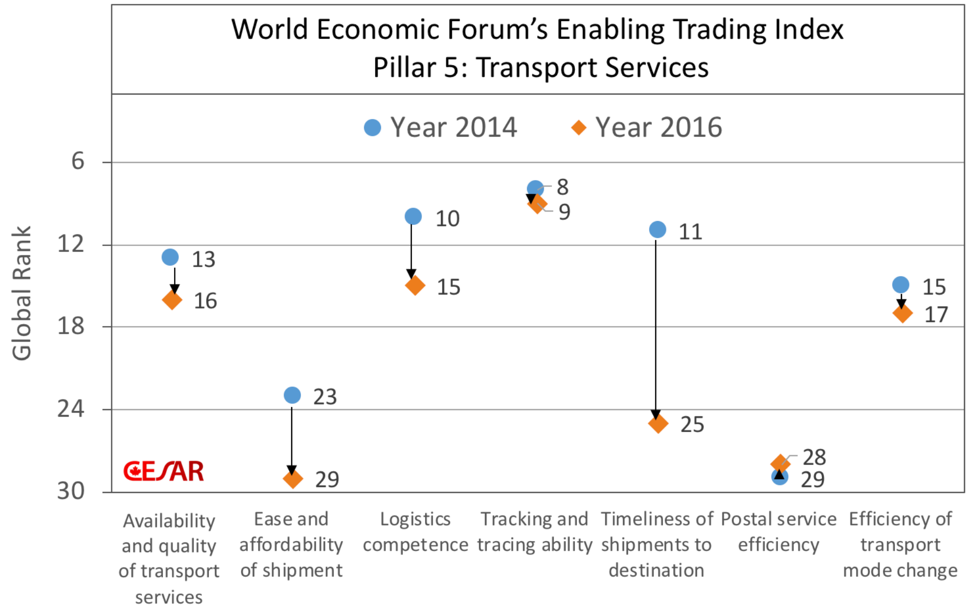

Figure 3.3. Trends in the World Economic Forum's Transportation Services (Pillar 5) ranking [21] for Canada between 2014 and 2016.

Whether this rank is used as a gauge of global competitiveness or used as a benchmark for the overall system performance, it signals that the efficacy of Canada's freight sector could be improved.

Canada has been criticized for lacking a comprehensive transportation framework, including failing to integrate transportation into industry, trade and infrastructure policy development [22]. By identifying shortcomings, the stage can be set for holistic and transformational changes in our freight systems.

4. Road Freight Industry Dynamics

Before systems change can be directed to address issues including GHG emissions and other environmental factors, it is important to deeply understand the dynamic of the industry. The road freight sector can differ depending on the goods being hauled and the region being travelled, but there are some common traits and trends seen by the industry as a whole.

4.1. Fleet Profile

To support Canada's demand for truck transportation, a fleet of vehicles is required that is proportionate to the demand and mix of services. It is estimated that there are currently about 300,000 HDVs in Canada with a GVWR greater than 15 tonnes used for freight transportation (**Figure 4.1**)

Between 1990 and 2015, Canada's HDV fleet has grown by a net 119% when considering new vehicles purchased and vehicles retired. This represents an average 3% CAGR. The Canadian Energy Systems Simulator (CanESS) stock and flow model [14] estimated that the annual number of new freight HDVs acquired has also grown at a CAGR of 3% per year, from 15,000 new vehicles in 1990 to 31,000 new vehicles in 2016. Periods of recession, such as in 2008/9, have an impact on the number of trucks purchased (**Figure 4.1**).

Meanwhile, the annual HDV retirement was projected to have increased from about 11,000 HDVs in 1990 to 18,000 HDVs in 2016, at an annual growth rate of about 2% per year. On average, the CanESS model projects that new HDVs account for 9% of the total annual fleet and about 6% of the fleet is retired each year.

The CanESS model [14] calibration projected that the average HDV on the road in Canada is less than 10 years old, but it is possible that trucks are registered and not actively used in service (**Figure 4.2A**).

"...the number of new HDVs acquired has grown [at a rate of] 3% per year... to ***31,000 new vehicles [purchased] in 2016****."*

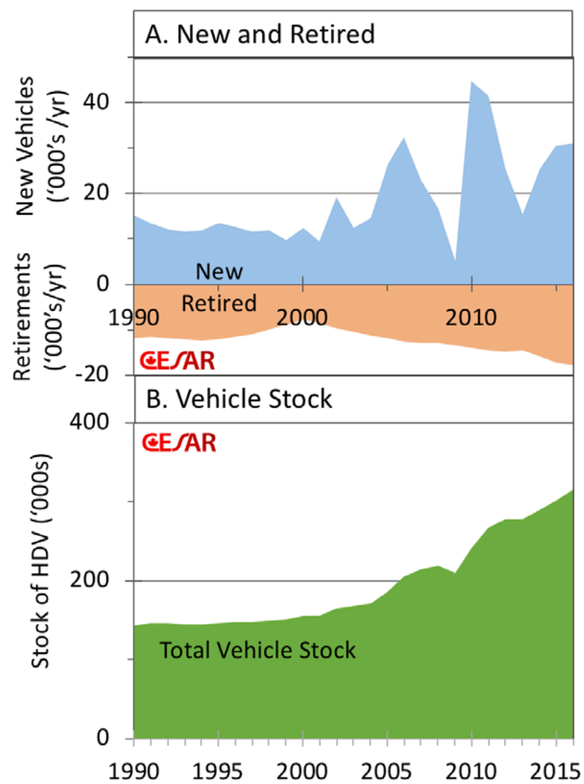

Figure 4.1. Estimates of new and retired HDVs (A) and HDV stocks for Canada (B). Stock values estimated using the Can ESS model [14] that was last calibrated with Statistics Canada data for registered vehicle stock in 2013 [23].

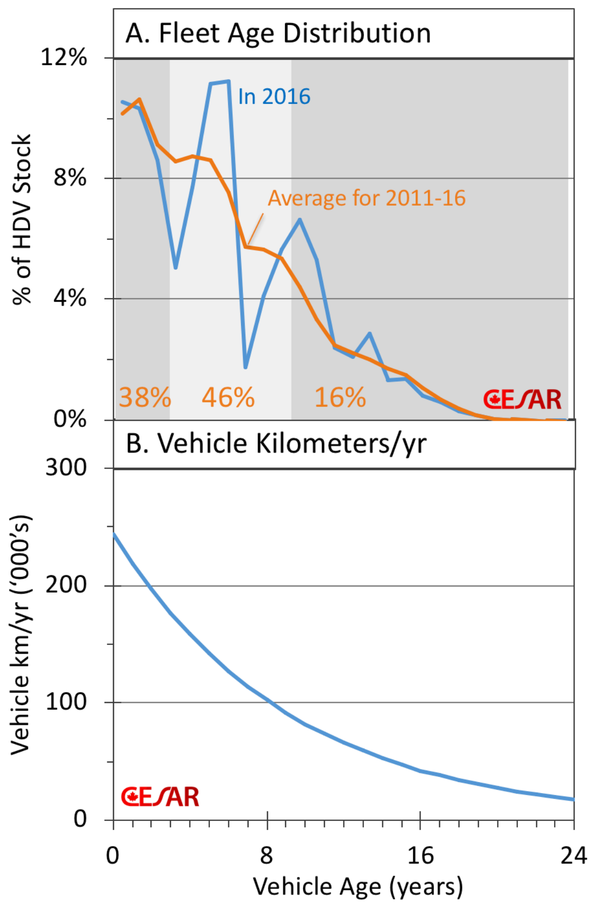

Figure 4.2. Fleet age distribution (A) for HDV kilometers travelled (VKT) per year by vehicle age (B). Estimates obtained from the CanESS model [14] [23].

Based on industry discussions, CESAR assigned new HDV trucks 240,000 km per year, with annual vehicle distance travelled decreasing by about 10% every subsequent year (**Figure 4.2B**).

In practice, the annual distance travelled per year can vary depending on a company's operating model. For example, one company interviewed by CESAR put as much as 300,000 km per vehicle during the first years of operation, while other companies said new trucks average around 150,000 kms per year.

The lifespan of a truck will vary depending on the trucking company and the industry segment they are serving. For example, a trucking company interviewed by CESAR said they typically turn over their truck stock within three years, while another trucking company reported holding on to their trucks for over 10 years.

The relatively fast turnover of the trucking sector's operating assets compared to other industries provides an opportunity for new technology to be introduced and adopted.

4.2. Fuel Efficiency of Heavy Duty Vehicles

HDV fuel efficiency has improved, dropping from around 43 litres per 100km in 1990 to just over 31 litres per 100 km in 2016 (**Figure 4.3A**).

This downward trend may be attributed to a combination of factors including engine improvements, vehicle enhancements such as aerodynamics, and modified driving habits, and are contrary to reports by the International Council for Clean Transportation (ICCT) and the North American Council for Fuel Efficiency (NACFE) [24] that the industry has an inherent reluctance to adopt new technologies.

It is also worth noting that these improvements were made despite air pollution regulations which came into effect in 2004 [25] that negatively impacted fuel efficiency.

Fuel efficiency improvements are supported by government initiatives and policy tools including the Canadian Environmental Protection Act's HDV GHG emission regulations [2] and NRCAN's Smartway program [26].

While HDV fuel efficiency has improved, this has not translated into improved energy intensity, the energy used to move a tonne of freight one kilometer (**Figure 4.3B**). The lack of complete TKM data is likely skewing the results in the 1990s, but with Statistics Canada TKM data reporting available post-2004, the data is more indicative of the intensity trends. Energy intensity has trended upwards in the trucking sector over the last 10 years. This could be explained by supply chains prioritizing short, flexible delivery times over load optimization.

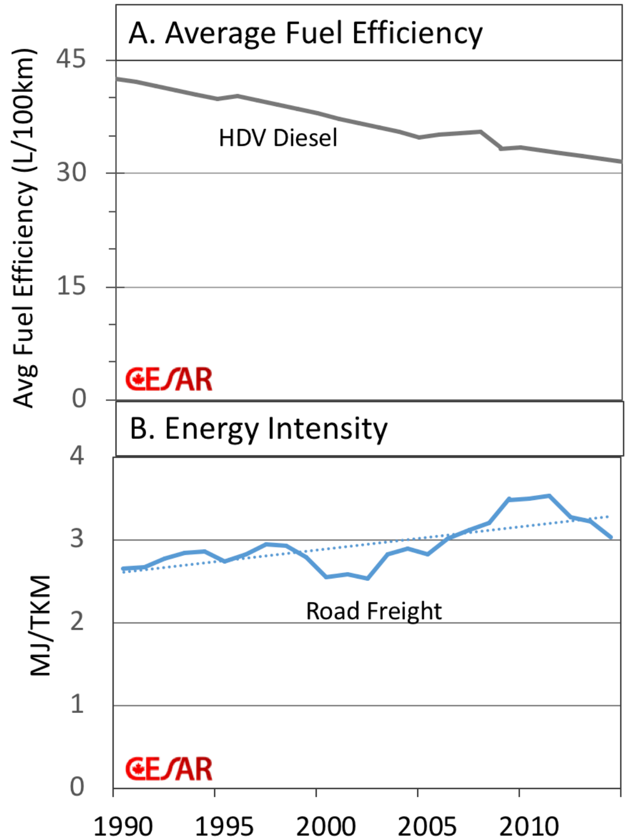

Figure 4.3. Average fuel efficiency (A,L/100 km) of heavy duty road vehicles and trends in energy intensity (B, MJ/TKM) for road freight, marine and rail movement. Fuel efficiency and energy consumption are from Natural Resources Canada [9] and TKM from Statistics Canada [8] with back-casting using CanESS model [14].

"While HDV fuel efficiency has improved, this has not translated into improved energy intensity, the energy used to move a tonne of freight one kilometer."

4.3. Economics of the Trucking Business

Operating ratios, calculated by dividing operating expenses by operating revenues, are an indicator of profitability in the trucking sector.

Long-distance shipments have ratios around 94% for generalized freight (**Figure 4.4A**). In other words, for every dollar of revenue earned, the company's profit is six cents. Specialized freight, which includes dry and liquid bulk trucking companies, forest product trucking companies, and other specialized trucking companies, are slightly more profitable, as are local truck operators. However, local shipments generate less revenue per shipment (**Figure 4.4B**).

"...the profit margins for trucking are small, and likely contribute to a competitive, mistrustful culture that has been reported to characterize the sector."

Regardless of the operating segment, the profit margins for trucking are small and likely contribute to a competitive, mistrustful culture that has been reported to characterize the sector [28].

Labour is the largest component in the cost of a typical shipment in Canada, estimated at 33% of the total operating costs to transport 17 tonnes of freight over a distance of 750 km (**Figure 4.4C**). Fuel costs are the next largest cost component, accounting for 23%. Fuel

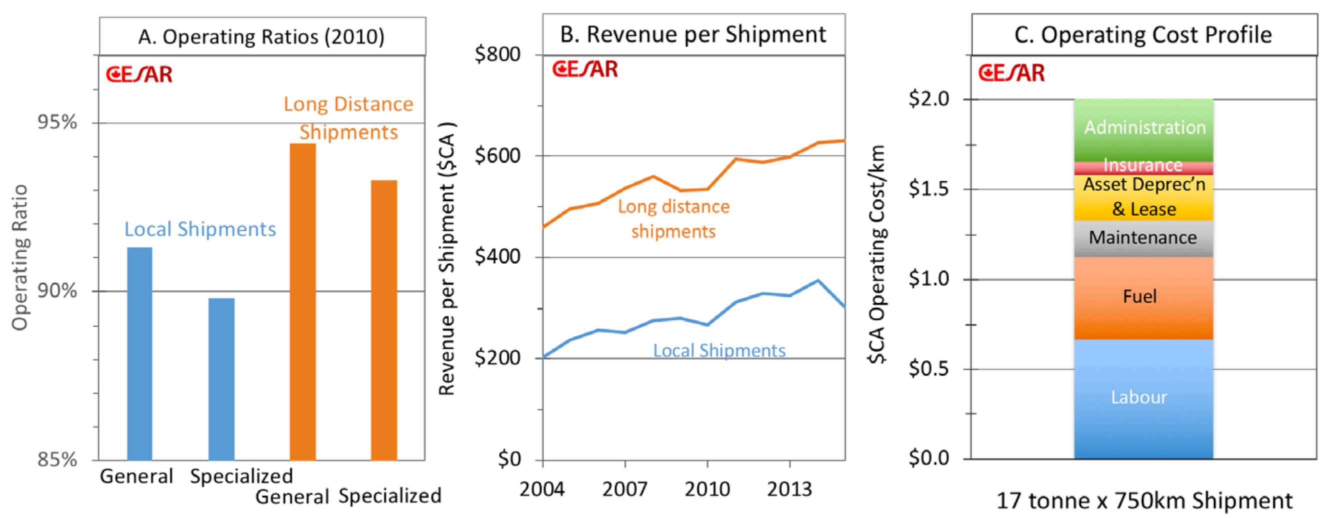

Figure 4.4. Trucking Sector Operating Ratios (A), Average Revenue per Shipment (B), and Operating Cost Profile (C). Local shipments are shipments that are transported less than 25km. Operating ratio is a profitability measure often used by the freight transportation sector of operating costs divided by operating revenues. Data from Statistics Canada [8], [27].

efficiency measures can help reduce fuel costs; however, in the for-hire trucking segment where fuel surcharges pass through fuel costs to the shippers, there may be less incentive to reduce fuel costs [24].

Maintenance is another significant operating cost (**Figure 2.9C**). In addition to the costs for repair and upkeep represented in this analysis, trucks undergoing unplanned maintenance are taken off the road and therefore unable to make money during the time they are in the garage.

4.4. Shipment Characterisitics

Road freight shipments in Canada have been getting longer and heavier (**Figure 4.5A**), due to a variety of possible causes including improved capacity utilization when not running empty and fuel efficiency.

The increase in weight could also be a result of the increased use of long combination vehicle (LCV) configurations such as B-train and turnpike double trailer configurations [29]. These configurations have lower energy intensities than single trailer loads by hauling more freight per power unit. However, the utilization of LCVs requires compatible road infrastructure and operating regulation.

There has also been a tendency for longer trips over the past decade (**Figure 4.5B**). This could reflect some shift from marine and rail to truck for longer distance moves.

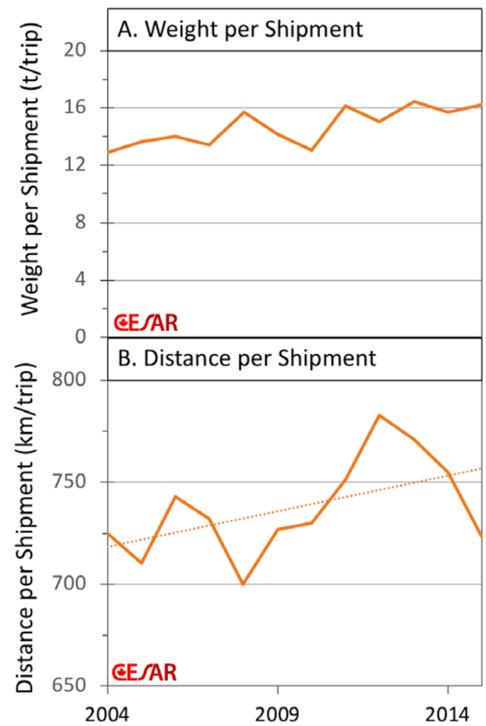

Figure 4.5. Average weight per heavy duty freight trip (A) and average distance travelled (B) per shipment in Canada. Includes ony greater than 25 km. Sourced from Statistics Canada [8].

4.5. Load Factor

Load factor is a proportion of the total vehicle payload capacity that is utilized when in operation. Low load factors are a reflection of the trades-offs that the freight sector makes between (a) shipment ease and timeliness values shown previously in Figure 3.3, and (b) energy intensity as shown in Figure 4.3B.

Despite the increase in shipment weights, energy consumption per TKM has still been increasing for the trucking sector, suggesting that overall load factors are likely poor, and getting worse, reflecting considerable empty space in trailers of HDVs moving on Canadian roads.

Even though many trucking companies measure their own load factor performance, consolidated data are currently lacking.

NRCan's SmartWay members [26] are reporting significantly higher load factors (**Figure 4.6A**) than is determined based on energy use (**Figure 4.6B**). However, SmartWay is a voluntary program, so it is likely that the data only reflect the performance of top performers rather than a broader-based sample.

Some trucking segments are more prone to incur empty kilometers or load their trailers with excess capacity, based on equipment, commodity being hauled, and regional constraints. For example, based on a survey performed by the Private Motor Truck Council of Canada, only 44% of their respondents pursue supplemental freight to fill their empty backhauls [30].

"...overall ***load factors are likely to be poor and getting worse****, reflecting considerable empty space in trailers of HDVs moving on Canadian roads."*

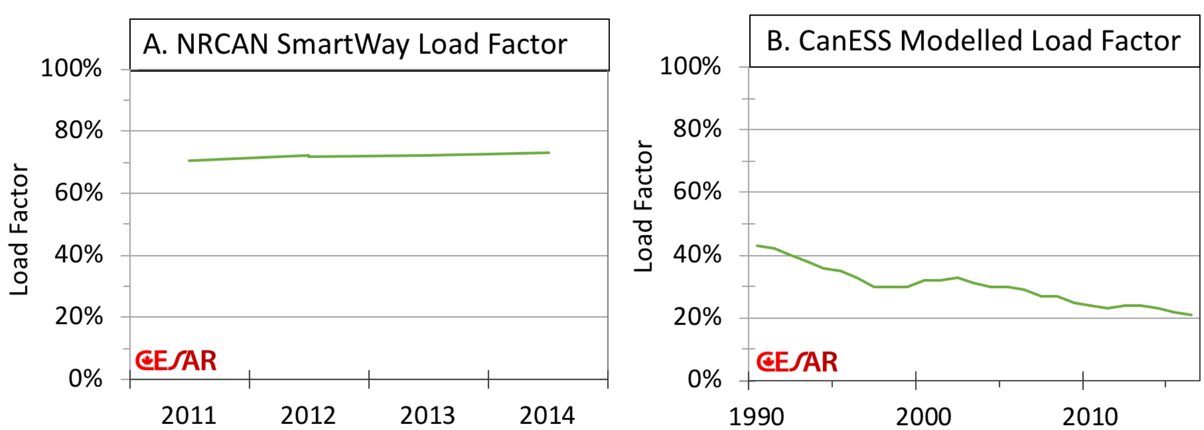

Figure 4.6. Load Factor, SmartWay Reported (A) and Modelled (B). Load Factor as a Product of Capacity Utilization and Loaded Kilometres Travelled. NRCAN SmartWay collects capacity utilization and empty kilometres from its members [26], and CanESS load factor is determied based on a combination on Statistics Canada data sources for transportation, energy use and stock data [14].

4.6. Trucking Companies

There are more than 40,000 general and specialized freight trucking companies in Canada, most of which are companies with only one to four employees (**Figure 4.7A**). In Alberta, there are almost 6,000 trucking companies with a similar proportion of one to four employees as the national average (**Figure 4.7B**).

Many companies with fewer than 10 drivers are owner-operators who provide vehicles with drivers to larger freight companies that market and manage the service. The truck carriers interviewed by CESAR used mixed strategies regarding the use of owner-operators. With some companies, owner-operators play an integral role in their operating model, while other companies give preference to in-house equipment and drivers.

Trucking companies with more than 50 employees have increased in Canada between 2014 and 2017. However, in Alberta, companies with over 50 employees have fluctuated between 60 and 66 companies (**Figure 4.7B**) during this period.

Not seen in the data of Figure 4.7 is the fact that some companies are consolidating. Companies like Mullen Group [32] and TFI

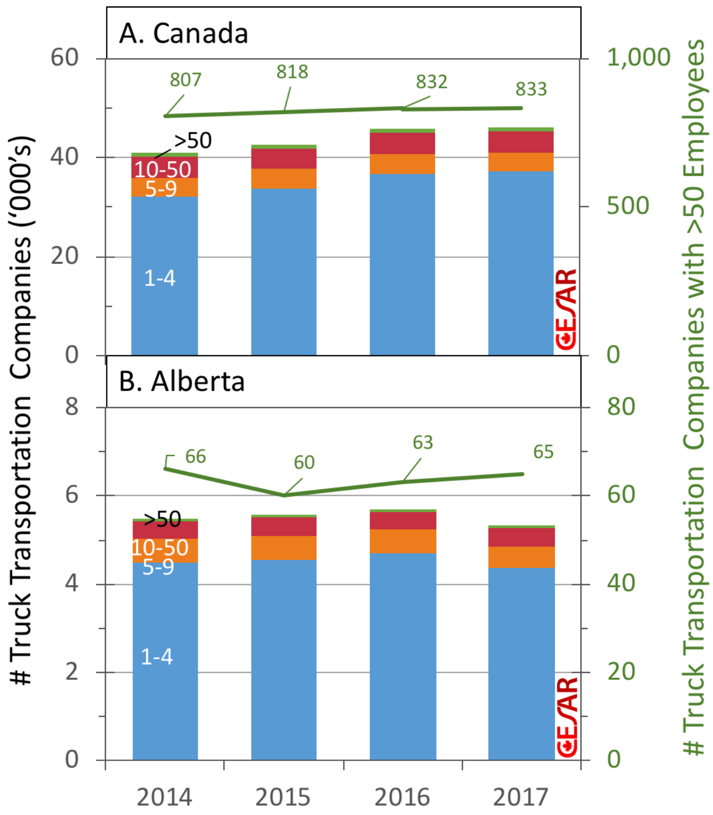

Figure 4.7. Number of trucking companies in Canada (A) and Alberta (B). Bar charts show total number of companies classified into company size (number of employees/company).The line and right axis shows number of companies with over 50 employees. Data from Statistics Canada [31].

"...the quantity and diversity of companies... creates a fragmented industry [that] lacks a unified industry."

International [33] have been acquiring trucking companies across Canada and operating them as independent companies.

The quantity and diversity of companies represented in the trucking sector creates a fragmented industry. The lack of a unified voice for the industry is further aggravated by inconsistent regulatory regimes across all provinces [22].

4.7. Workforce

The trucking sector is an important employer in Canada, employing more than 200,000 Canadians, including about 35,000 Albertans in 2017. Truck transportation employment has grown by 21% in Canada (**Figure 4.8A**) and 35% in Alberta between the years 2000 and 2017 (**Figure 4.8B**).

Labour shortage is a critical issue currently facing the trucking sector in Canada, impacting both the for-hire and private truck sectors alike. A report prepared for the Canadian Truck Alliance estimated that by 2024, Canada's demand for truck drivers will exceed the supply by almost 35,000 drivers (**Figure 4.8C**).

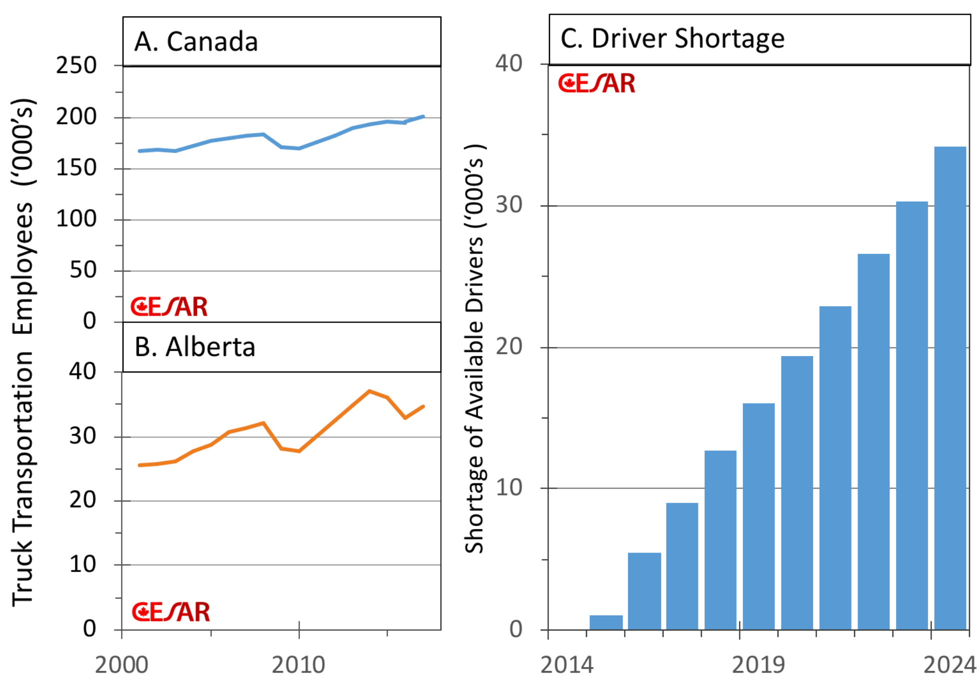

Figure 4.8. Number of truck transportation employees in Canada (A) and Alberta (B), and the existing and projected shortage of drivers to 2024 (C). Data compiled from Statistics Canada [35] and CPCS [34].

Reasons for the shortage include an aging labour pool with more than 55% of the workforce over the age of 44 years [34]; also, the work is perceived to have undesirable working conditions, impeding the industry's ability to attract and retain a younger workforce.

"Labour shortage is a critical issue... by 2024, Canada's demand for truck drivers will exceed supply by 35,000 drivers."

For the road freight sector to remain productive and competitive, the industry will need to find ways to manage the shortage.

4.8. Productivity and Congestion

On average, every employee in the trucking sector directly contributes 133,000 CAN$ towards the Canadian economy (**Figure 4.9**). This has improved since 2001 when the trucking sector noticeably underperformed Statistics Canada's "All Industries Average" with single factor productivity levels of just over 100,000 CAN$ per employee.

Productivity in the trucking sector can be linked to external factors including: regulations on hours of service; trailer length and weight; speed limits; waiting at loading docks, weigh stations, and interchange terminals; and

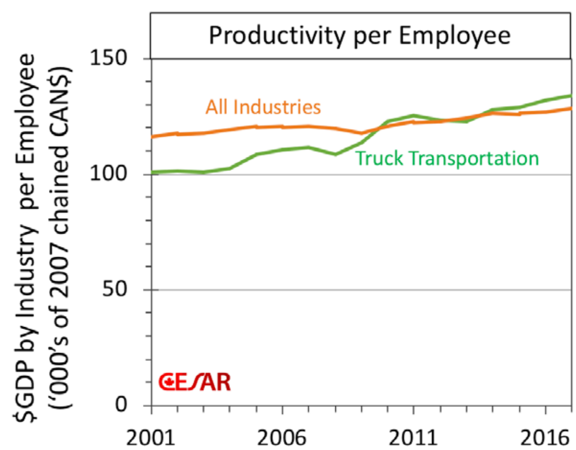

Figure 4.9. Productivity of the freight trucking sector per employee. This single factor analysis was completed using GDP by industry and employment data sourced from Statistics Canada [16, 34].

"Although productivity has been improving, performance overall continues to impact the industry's ability to: a) support economic growth, b) optimize asset utilization, c) overcome driver shortage and d) reduce congestion."

time spent in traffic, along with operational factors such as load factor and route planning.

Although productivity has been improving, performance overall continues to impact the industry's ability to (a) support economic growth, (b) optimize asset utilization, (c) overcome driver shortage, and (d) reduce road congestion that impacts all road users.

A 2006 study by Transport Canada estimated that the overall cost of urban road congestion, including the economic costs of lost time, wasted fuel, and GHG emissions, range from 3.1 to 4.6 billion (2006) CAN$ in Canada, with 80% of the total cost assigned to the Greater Toronto Area, Montreal, and Vancouver [36].

Furthermore, congestion can be associated with stress, affecting the wellness and safety of drivers and impacting the perceived attractiveness of trucking jobs.

5. Environmental and Health Impacts

5.1. Accidents

Motor vehicle safety has improved over the past decades but still remains a serious concern for the road freight industry.

In 2015, just over 400 deaths occurred as a result of collisions involving road freight vehicles, a substantial reduction of 48% from the more than 600 fatalities in 1997, (**Figure 5.1A**) and a decline from 3.5 fatalities per billion TKM in 1997 to 1.5 fatalities per billion TKM in 2015 (**Figure 5.1B**).

In comparison, however, fatalities associated with personal vehicles has declined by 70% for that same period. Moreover, crashes involving HDVs more frequently cause severe injuries and fatalities than those involving passenger vehicles [38].

Given the nature of the work with monotonous long hours, driver fatigue is recognized as a critical risk factor linked to collisions in the road freight sector [38].

Canada works to manage this risk with its hours of service regulations under the Canada's Motor Vehicle Transport Act, restricting drivers to 13 hours of drive time or 14 hours of on-duty time per day [39] with an impending amendment that mandates the use of electronic logging devices (ELD) to track and verify duty hours [38].

Across the country, inadequate and inconsistent driver training is also linked to accidents in the trucking sector. This issue received national attention in April 2018 in the wake of the devastating accident involving a commercial tractor-trailer and a bus carrying the Humboldt Broncos junior hockey team, resulting in the deaths of 16 people [40] (**Box 5.1**).

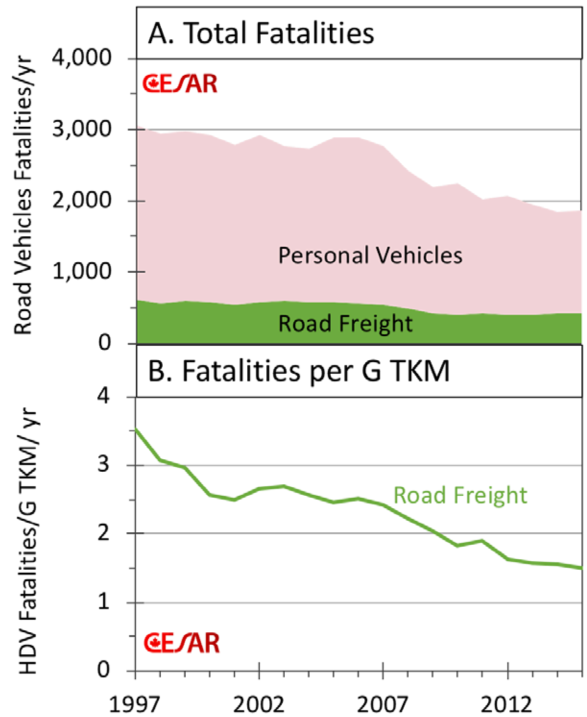

Figure 5.1 Trends in fatalities resulting from motor vehicles in 2015 (A) and Road Freight-Related Fatalities per GTKM Moved (B). Based on data from Transport Canada [37].

Following the Humboldt Broncos tragedy, Alberta and Saskatchewan introduced standardized mandatory entry-level training (MELT) for new commercial drivers, along with enhanced safety standards to be implemented in March 2019 [41]. Ontario is the only other province with MELT regulations and the federal government has agreed to develop a national training standard [41].

"In 2015, just over 400 deaths occurred as a result of collisions involving road freight vehicles... driver fatigue is a critical risk factor... [and] inadequate and inconsistent driver training is also linked to accidents in the trucking sector."

Regulations like MELT, hours of service limits and ELD mandates are needed to improve safety, but they will likely have an impact on the industry's productivity and asset utilization and provinces are finding themselves challenged to balance compulsory training while managing severe driver shortages [40].

Box 5.1. The Humboldt Broncos Tragedy

On April 6, 2018, a tractor trailer collided with a bus carrying the Humboldt Broncos hockey team on a rural Saskatchewan intersection, tragically killing a total of 16 people including 10 hockey players between the ages of 18 and 21, the head coach, the assistant coach, an athletic therapist, two media personnel and the bus driver.

The truck driver was charged with 16 counts of dangerous operation of a motor vehicle causing death and 13 counts of dangerous operation of a vehicle causing bodily injury, and was sentenced to 10 years in prison.

The driver was employed by a two-truck, Alberta-based trucking company and according to CBC News, the driver of the tractor trailer unti was on his first trip as a professional driver and had only received 12 hours of behind-the-wheel training prior to this devastating trip [40].

The heartbreaking incident brought to light serious safety concerns arising from inconsistent and inadequate training standards across the fragmented trucking sector.

Accidents also have financial implications to the individual and to the taxpayer. According to a 2010 study prepared for the Edmonton Capital Region Intersection Safety Partnership, every fatal collision is estimated to incur direct costs around 180,000 CAN$ associated with property damage, emergency response, health services, legal services, travel delay and lost productivity. When costs associated with future income losses and cost associated with pain, suffering and grief are considered, the cost per fatal collision increases by another 1.7 million CAN$, not including the statistical valuation of life [42].

5.2. Air Pollution

Air pollution is a growing concern associated with freight transportation, particularly for road freight running on diesel internal combustion engines. In fact, many municipalities around the world have taken steps to ban the use of diesel combustion engines within their city limits.

As of September 2018, 18 countries and over 16 major international cities (**Box 5.2**) have introduced plans to phase out internal combustion engine vehicles and/or introduce incentives for the adoption of electric vehicles between 2020 and 2040. Recently, British Columbia also mandated a zero-emission vehicle standard by 2040 [43].

Box 5.2. Nations and Cities with Actions to Phase-out Internal Combustion Engines

From Centre for Climate Protection [43]

Nations

Austria	India	Scotland
Britain	Ireland	South Korea
China	Israel	Spain
Costa Rica	Japan	Taiwan
Denmark	Netherlands	Germany
France	Norway	Portugal

Cities

Athens	London	Quito
Auckland	Los Angeles	Rome
Barcelona	Madrid	Seattle
Cape Town	Milan	Vancouver
Copenhagen	Mexico City	
Heidelberg	Paris	

Moreover, with the adoption of the Clean Air Action Plan (CAAP), the Port of Los Angeles and Long Beach have plans to give preference to near-zero and zero-emission HDVs, rather than diesel engines, entering their terminals [44].

Diesel HDVs are a large contributor of air pollutants in Canada. Nationally, Canada has been able to reduce air pollutants (**Figure 5.2A**) despite growth in transportation activity. However, according to data retrieved from Environment Canada, Alberta has not been able to achieve the same level of reductions in HDVs as the national average (**Figure 5.2B**). For example, in Alberta from 1990 to 2016, NO_x, which is linked to acid rain, smog, human health hazards and other environmental effects, has increased by 24%. Nationally, NO_x emissions have decreased by 23%.

Improvements in reducing air pollution associated with road freight can be attributed to on-road vehicle and engine emission regulations [46] that took effect in 2004 in efforts to control NO_x and particulate matter emissions; particulate matter

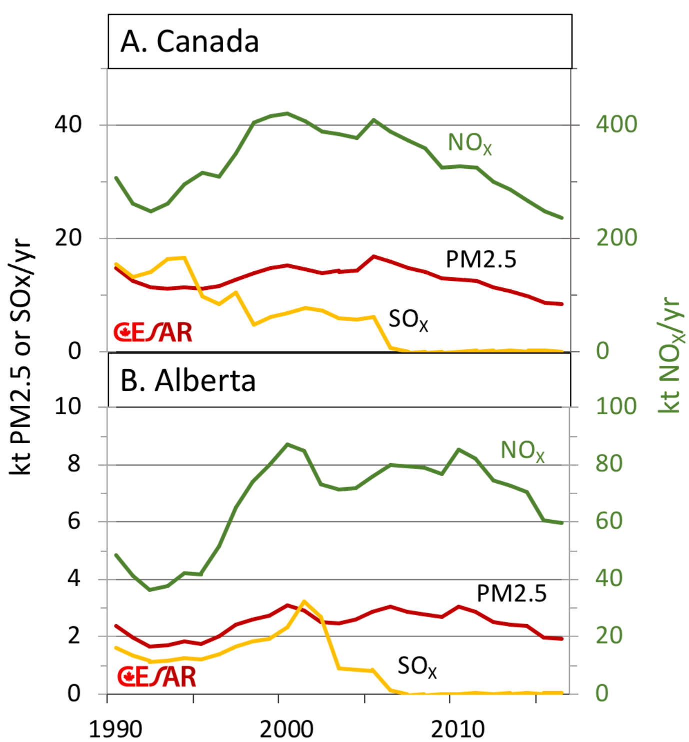

Figure 5.2. Trends in air pollution from diesel-fueled road freight transportation in Canada (A) and Alberta (B), including nitrogen oxides (NO_x, right axis), sulphur oxides (SO_x), and particulate matter with a diameter of 2.5 microns or less ($PM_{2.5}$). Data from the Government of Canada [45].

is linked to cardiac and respiratory diseases and impacts visual air quality.

Sulphur oxides in Canada and Alberta have nearly been abated for diesel road freight with the introduction of the Sulphur in Diesel Fuel Regulation [47] in 2002. This pollutant is linked to respiratory health effects, acid rain and other environmental effects.

5.3. GHG Emissions

In 2016, Canada's GHG emissions from freight transport totaled 70 Mt CO_2e/yr (**Figure 5.3A**), but this number does not include the up-stream emissions associated with crude oil recovery, refining and transport. From Alberta oil, these processes add additional GHG emissions ranging from 25% for light sweet crude to 55% for oil sands bitumen produced through steam assisted gravity drainage [48]. Neither do the emissions estimates include the GHG footprint associated with manufacturing the trucks or building the road infrastructure.

Between 1990 and 2016, freight transportation (all modes) GHG emissions have grown at a CAGR of 3% in Canada (**Figure 5.3A**) and 4% in Alberta (**Figure 5.3B**). This translates to 203% emissions growth in Alberta compared to the 113% national average growth of freight transportation GHG emissions over the same period.

In 2016, HDVs accounted for about 50% of all the GHG emissions from freight movement in Canada and Alberta. Much of the growth was from Alberta, especially between 1995 and 2014 when emissions in the

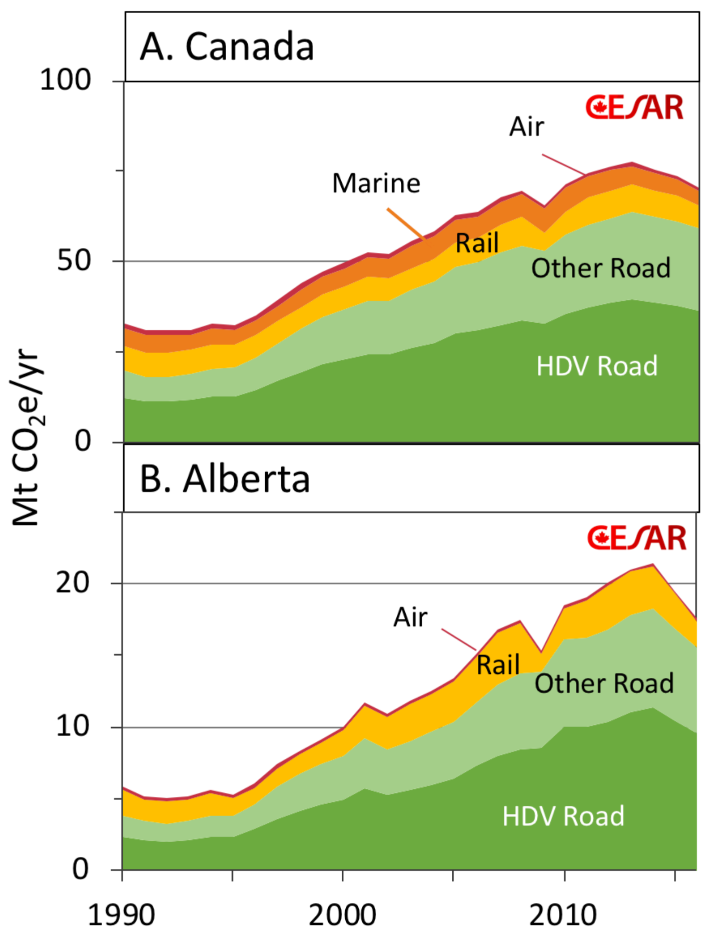

Figure 5.3. Trends in GHG emissions from freight transport in Canada (A) and Alberta (B). Based on data from the National Inventory Report [5], assuming that the split between HDV and Other Road Frieght is 62%/38% [9].

HDV sector grew by over five-fold from 2.4 to 11 Mt CO_2e/yr (**Figure 5.3B**). The decline in world oil price and therefore the investment in Alberta accounts for the subsequent decline in energy use and emissions between 2014 and 2016.

Even with this recent decline, the growth in Alberta's HDV freight emissions between 1990 and 2016 was over 300%. Contributing factors to this increase include demand ('activity'), mode share, energy intensity, and fuel carbon content, with activity growth being the dominant factor [17].

"...from a climate change perspective, the attention needs to be focused on developing and implementing extremely low... or zero-emission transportation fuel."

Assuming fossil diesel remains the dominant fuel for freight transport into the future, the most promising strategies to reduce GHG emissions include (a) shifting more freight to rail, (b) increasing the load factor, and (c) enhancing fuel efficiency though engine technology and/or modified driving practices. A recent scenario analysis (**Figure 5.4**) projecting

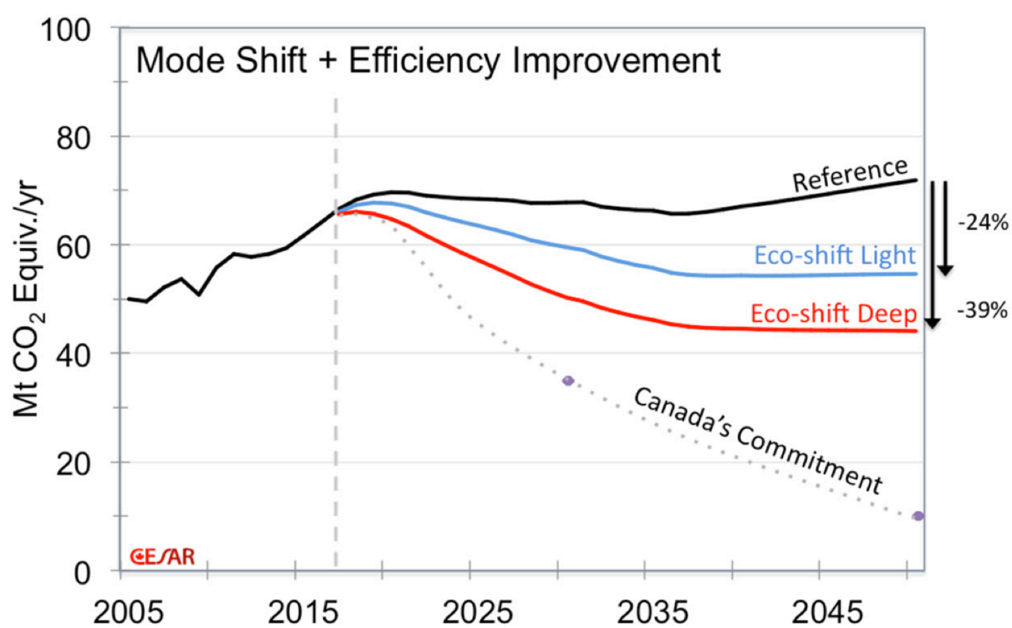

Figure 5.4. Scenario analysis for GHG emission reductions from mode shift and energy efficiency. Eco-shift light [and deep] represents a 3% [5%] load factor improvement, 12% [19%] fuel efficiency gain, and 66% [77%] of surface freight moving by rail. Refernce case accounts for all existing and impending policy. Analysis completed previously by author [49].

implementation of these levers at various degrees, showed that while reducing emissions relative to a reference (i.e. business as usual) scenario, they are unable to achieve climate change targets.

Clearly, from a climate change perspective, the attention needs to be focused on developing and implementing extremely low (i.e. <20% of existing) or zero-emission transportation fuel.

6. Forces for Systems Change

As noted in the previous sections of this report, Canada's freight transportation sector faces many challenges needing solutions, including the role of the sector in creating unintended consequences. **Figure 6.1** provides a summary of these challenges and issues.

While GHG emissions are a major concern, it is not the only challenge the sector faces. Indeed, one could argue that addressing some of the other issues would attract more support than GHG management

Economic	**Poor Load Factor.** Trucks driving empty or with excess trailer capacity reduces system efficiency;
	High Operating Costs. Labour, maintenance, and fuel costs impact profitability;
	Labour Shortages. A driver shortage of 34,000 drivers is projected within the next 7 years across Canada resulting from undesirable working conditions;
	Limited Asset Utilization. For safety reasons, Canadian regulations restrict drivers to 13 hours of drive time or 14 hours of on-duty time per day. The truck asset is often unused for at least 10-11 hr /day;
	Productivity Concerns. Waits at loading docks, intermodal terminals, border crossings and weigh stations further reduce efficiency and profitability and the industry's ability to support the economic growth;
	Congestion. Links to societal costs ranging between 3.1 and 4.6 billion CAN$;
Health & Environmental	**Accidents.** In 2015, the trucking sector was linked to 417 fatalities in Canada;
	Air Pollution. With 240,000 tonnes of nitrogen oxide emissions, trucking in Canada contributes to acid rain and smog. It also generates high levels of particulate matter that is linked to cardiac and respiratory diseases;
	GHG Emissions. Canada's road freight sector currently accounts for 59 million tonnes of CO_2 emissions per year, 8% of national GHG emissions.

Figure 6.1. Summary of the challenges and unintended consequences of Canada's road freight transportation sector.

from the industry (e.g. load factors, productivity, labour shortages, operating costs) or from the general public (accidents, congestion, air pollution), for transformative change in our freight transportation systems.

Addressing some of these other issues could significantly reduce the sectoral or societal costs of freight transportation and create an opportunity to dramatically reduce the environmental footprint of the sector, even if the short-term costs to achieve the environmental benefits were slightly higher than that of the current system.

In fact, there are many technology, business model and social innovations that have been emerging in recent years with the intent to transform or disrupt freight transportation across North America and around the world. Some of these will be described in the following sections.

6.1. Vehicle Electrification

Once thought impossible, electrification options for HDVs are quickly taking form and generating excitement in the road freight sector, not only for the environmental benefits associated with a zero-emission vehicle but also for the potential operational benefits such as improved fuel efficiency, reduced noise, lower maintenance requirements and high torque and pulling power.

Two of the most promising electrification options in North America include the battery electric and the hydrogen fuel cell electric options as summarized in **Figure 6.2**. The battery electric HDV technologies, like those currently being developed by Tesla [50], Daimler [51], and

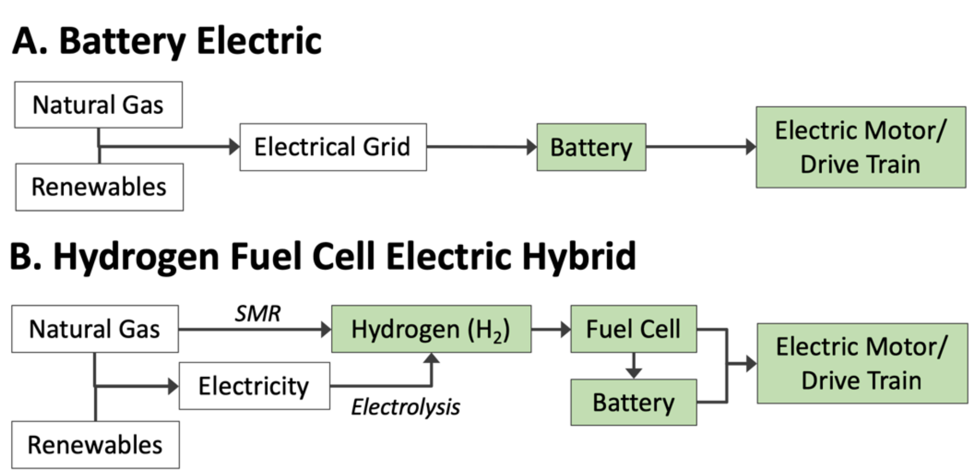

Figure 6.2. Zero-emissions electric truck options. The shaded boxes represent technologies that are aboard the vehicles; steam methane reforming [SMR].

Thor Trucks [52], use a large on-board battery pack to store the electrical energy that will be used to move the HDV.

The battery must be charged from the electricity grid, presumably while the vehicle is stationary (**Figure 6.2A**). However, a number of technologies for vehicle charging while in motion are currently being tested [53], [54] or being proposed for future deployment [55].

The hydrogen fuel cell electric technologies for HDV, like those being developed by Nikola Motors [56], Toyota [57], and Kenworth [58], are powered by electricity generated from hydrogen onboard the vehicle using a fuel cell (**Figure 6.2B**). These vehicles are typically hybrids, so they also have a battery bank (smaller size than that found in an equivalent battery electric vehicle) which can be charged by the fuel cell and by regenerative braking. The battery power provides additional energy to the motor on hills or when accelerating [59].

Even with the range of benefits these electric vehicle alternatives may offer, a compelling case needs to be made to the key stakeholders for them to replace the incumbent diesel HDV alternatives, especially in terms of performance and total cost of ownership. Ultimately, electric HDVs will need to be fit for the service they are providing, and meet the range, pulling power, weights, and refuelling/charging demands of today and the future of freight transportation.

Perhaps by combining th is technology with other emerging innovations like digital connectivity and autonomous trucks, the case for the electric HDV can be strengthened.

6.2. Autonomous Trucking and Platooning

Autonomous technology in its various forms has much appeal for the road freight sector. At lower levels of automation, features like adaptive cruise control and collision avoidance can help enhance the driver experience and improve fuel efficiency and safety. Many HDVs in Canada already adopt this technology.

Truck platooning technology made possible by vehicle to vehicle (V2V) communication and autonomous technology allows two or more trucks to travel very close to one another at high speeds, accelerating and decelerating in unison. This reduces aerodynamic drag and the fuel cost for all but the first vehicle [60].

Although there are some that are not convinced of the actual fuel savings in real world applications where it is possible for platoons to be broken-up [61], a recent McKinsey report [62] has proposed that the deployment of autonomous trucking will roll out in the following four 'Waves' on US highways over the next 10 years:

- **Wave 1:** (2018-20). Constrained platooning of two trucks, with two drivers on interstate highways, but they drive independently on other roads. Through fuel savings, this would reduce the total cost of ownership (TCO) by 1%.
- **Wave2:** (2022-25). Constrained platooning of two trucks, with one driver in lead vehicle on interstate highways. A second driver is recruited to drive the second vehicle on other highways. Through fuel and salary savings, TCO would be reduced by 11%.
- **Wave 3:** (2025-27). Constrained autonomy with platooning involving multiple trucks, with only one driver in lead vehicle on interstate highways. The trucks would be dropped off at dedicated truck stops for other drivers to take to their final destination. Through fuel and salary savings, TCO would be reduced by 20%.
- **Wave 4:** (2027+). Full Autonomy with autonomous and platooning trucks driving individually on all highways and in platoons of 2 or more trucks. Through fuel and salary savings, TCO would be reduced by 45%.

"A recent McKinsey report has proposed ...full autonomy [for HDV would] reduce the total cost of ownership (TCO) by 45%."

Because of these cost savings, more freight movement could be diverted from energy efficient railways to much less energy efficient trucks (**Figure 2.2**), leading to unintended environmental consequences, especially if the trucks are diesel fueled. Ideally, the shift to vehicle autonomy should coincide with a shift to vehicle electrification, and policies should be in place to encourage ongoing or expanded use of rail for freight movement.

CESAR's independent assessment of the TCO for fully autonomous and electric HDV vehicles place savings at about 24% below the current business model (**Figure 6.3**). While our underlying assumptions are different from those in the McKinsey study, they do illustrate the concept that it may be possible to harness a strong economic driver to achieve environmental objectives.

While driverless technology should be able to address labour shortage concerns in the freight sector, there are also concerns about the many thousands of truck drivers that may lose their driving jobs [63]. Other reports [64] challenge this assertion and a recent book makes a case that global depopulation and worker shortages in aging populations are the much bigger challenge in the decades leading to the mid-21st century.

History has shown that disruptions of this nature are difficult to avoid [65], but adapting to them should be part of any transition strategy in a rapidly changing world.

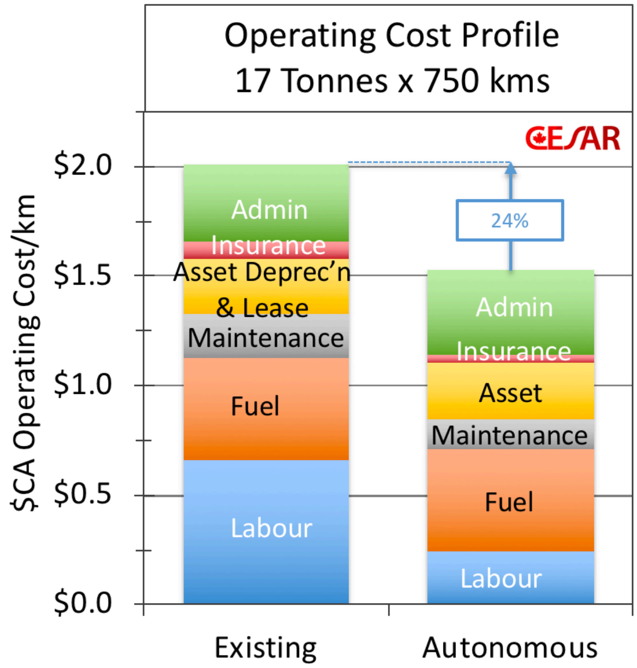

Figure 6.3. Estimated operating cost profile for autonomous electric HDV. Calculated from **Figure 4.4C** data assuming (a) drivers represent 70% of salary, wage and benefit costs and this portion of the cost is reduced by 90%; (b) asset cost increases are fully offset by increased use rate; (c) 30% lower maintenance cost; (d) no change to fuel and G&A costs.

6.3. Connected Vehicles

A vehicle that is capable of communicating and sharing information with its surroundings using short-range wireless devices is known as a connected vehicle [66]. This differs from automated or autonomous vehicles which refers more to the vehicle functions that are controlled without driver input. The technologies are independent but together are complimentary [66] (see Box 6.1 for definitions).

There is almost an endless combination of communication patterns that can involve the connected vehicle. For instance, applications can include V2V, vehicle to pedestrian (V2P), vehicle to infrastructure (V2I), vehicle to device (V2D), and more [67] that can help avoid collisions, traffic congestion, and improve fuel efficiency [68].

At a systems level, connected vehicles can be part of an Intelligent Transportation System (ITS) and Smart Corridors, like those being developed by Transport Canada [69]. These systems facilitate information sharing through the creation of interconnected transportation networks. An ITS uses wireless V2V, V2I, and V2D interactions

Box 6.1. Connected Vehicle Definitions

Connected Vehicle: Technologies that ensure communications between a vehicle and its surroundings with short-range wireless devices [66]

Automated/Autonomous Vehicle: Vehicles with functions controlled by the vehicle without driver input. The Society of Automotive Engineers International (SAE) defines six automation according to degree of driver involvement [66].

V2x: Describes the vehicle communication interaction type, which can include vehicle to: vehicle (V), infrastructure (I), pedestrian (P), device (D), and others [68].

Intelligent Transportation Systems: Technology that enables the collection and disbursement of information required for effective road transport decision making. This can include current/predictive travel conditions, electronic filing of commercial vehicle crdentials/reporting, and automated means of inspection/authentication [69].

Telematics: The technology of sending remote object information using a telecommunication device; commonly includes Global Position (GPS) vehicle tracking devices [71].

Internet of Things (IoT): A network of physical objects with embedded sensors that transmit information [72].

Block Chain: A distributed, yet secure community-shared digital database or "ledger" that requires data standardization and data validation performed by data chain paricipants [73].

to achieve benefits such as safety, security, traffic monitoring, and route planning [70].

At a company level, connected technology is also rapidly advancing as a fleet and shipment management tool. Telematics technology [71], paired with Internet of Things (IoT) networks [72], commonly use global positioning systems (GPS) and other sensors, to collect and send remote information about the vehicle location and operations. The data retrieved can be compiled, analyzed and managed to promote operational efficiencies, enhance productivity, and implement preventative maintenance programs.

In addition, this technology can be used to encourage positive driving behaviors including enforcing eco-driving and safe-driving habits by restricting idling and speed control, and control driver hours of service with electronic logging devices (ELD).

When the information gained from digital technology is communicated in real-time, further efficiencies can be attained through route optimization and scheduling software [72].

While the benefits of telematics and IOT can be achieved by individual links in the supply chain, Block Chain holds the promise to be the platform that can transparently integrate data for the entire supply chain, including buyers, sellers, carriers, third-party logistics providers, customs agents and other stakeholders – thereby improving trust and expediting feedback loops [73].

The smooth exchange of data achieved through digital technology will foster the collaboration to inspire operational efficiency within a strengthened integrated supply chain. Furthermore, the standardization required for the technology's success will reinforce the notion of holistic systems thinking when it comes to our freight transportation systems.

6.4. Collaborative Transportation Management (CTM)

As society moves towards a culture that values shared interest over individual gains, collaborative business models are evolving. CTM or collaborative logistics is an example of this social and business model innovation that encourages an open exchange of information, joint transportation and logistics planning, and/or asset sharing between organizations with common needs yet are possibly competitors [74].

Combined with digital information, freight exchanges and third-party logistics (3PL) providers have an important role in facilitating the shift towards CTM by providing the platform for participants to objectively share resources and expand capabilities. This role will only become more critical with the expansion of e-commerce and customized manufacturing [75].

CTM has been reported to reduce transportation costs, shorten delivery times and optimize load capacity by as much as 10% to 42% [76]. CTM is also thought to be a predecessor to the Physical Internet transformation [77] discussed below.

6.5. Physical Internet

The physical Internet concept brings together many of the above innovations to create a grand vision for freight transport whereby goods are transported in the same way that data moves on the internet. The key objectives for the physical internet, as envisioned by Montreuil, 2012 [78], is to improve "by an order of magnitude the economic, environmental, and societal efficiency and sustainability of the way goods are moved, stored, realized, supplied and used across the world" (**Figure 6.4**).

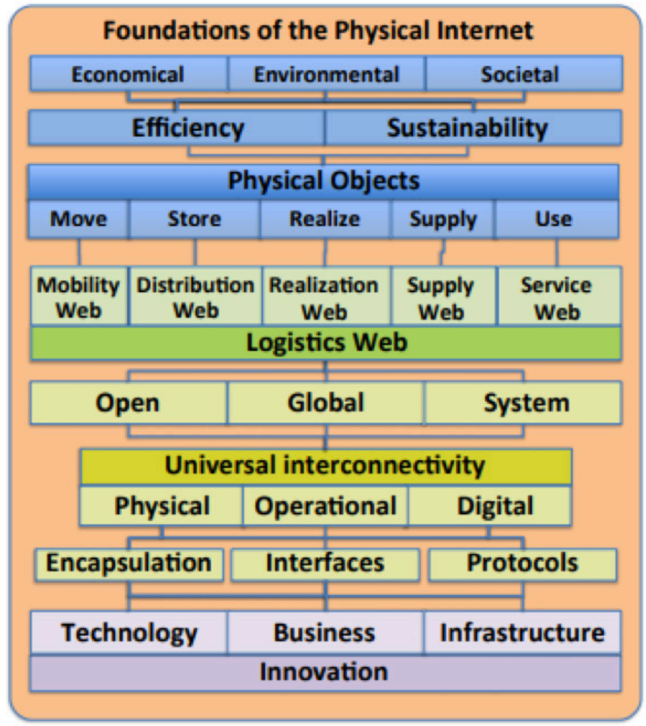

Figure 6.4. Foundations Framework for the Physical Internet. Original figure, taken from Montréuil, 2012 [78].

This business model, technology, and infrastructure innovation has all freight of varying sizes and forms packaged in standardized, modular, interlocking units embedded with smart technology, moving from origin to destination through a network path based on capacity and delivery requirements [79].

The system would utilize multiple modes, carriers and interchange points with routing and prioritization decisions made by optimization algorithms using predetermined criteria. It is expected that this system would include large amounts of automation, particularly at interchange and sorting points.

The system benefits include improved load factor with a reduction in empty-haul kilometers, better capacity utilization and the creation of a more predictable working environment for drivers [79].

This concept may seem like a long-term reach now, but it is something that would evolve in layers over time with the ramping up of many social, business model, and technology innovations. Considering the emerging business model of the distribution giant Amazon that employs highly automated distribution centers and innovative logistics to meet short transit schedules [80], the reality of a physical internet may not be that far in the future.

6.6. From Drones to Hyperloops

Modern supply chains are continually searching for the next disruptive technology that can be implemented to enhance business models. For example, drones are being tested for driverless home deliveries; robotics are becoming more common for freight handling and warehouse efficiency; delivery lockers are being introduced to facilitate last mile logistics [20]; and 3D printing is being explored as means for dematerialization that would reduce the demand for transportation [81].

Other innovations like hyperloops, which transport pods through a network of low-pressure tubes travelling at speeds as fast as 1,000 kms per hour, are able to take advantage of the energy savings achieved with rail transport while possibly outperforming the delivery times of trucking, but are currently infrastructure- and capital-intensive [82].

These and other nascent technologies may prove to serve only niche markets, or they may be part of a disruptive force that completely transforms freight transportation systems. Whichever the case, it is important that innovation is guided to align with the economic and environmental goals for the sector.

7. Conclusion

Freight transportation is an essential part of both the Canadian and Albertan economies. However, the road freight transportation sector, which emits large amounts of GHG emissions and air pollutants and is linked to road accidents and congestion, faces significant environmental and health issues that worsen with economic growth. As a system, road freight transportation in Canada has also struggled to efficiently and cohesively perform the services needed to competitively support the modern supply chain. The sector is burdened with issues such as labour shortage, poor load factor, constrained productivity and high operating costs.

There has been some incremental improvement in recent years, indicating the sector may be receptive to change. This suggests, given the wide range of economic, environmental and health issues confronting road freight transportation, the sector is really poised for larger transformative systems change by adopting disruptive technological, social, and business model innovations emerging to address these issues.

The challenge will be to strategically direct, guide, and otherwise nudge the disruption to attain a balance of economic and environmental objectives, including meeting Canada's climate change commitments. The electrification of road freight provides the opportunity to eliminate tailpipe emissions and when combined with other innovations like the autonomous-connected HDV, it is easy to envision it in the future of freight.

A disruption that includes the electrification of freight will have consequences beyond the transportation sector. Freight transportation is currently a large consumer of diesel fuels and an important market for the end-products of Alberta's crude oil production which makes up a significant portion of Canada's economy. Alberta is clearly in the transportation fuels business, and it is critical to identify strategies that will ensure Alberta can still be a major player in the new and improved transportation systems of the future.

A crucial question for Alberta involves the implications to the province of battery electric versus hydrogen fuel cell electric HDVs. Which transformative technology is better for the key industry sectors (freight transport, oil and gas, electricity generation) and the economy of the province and Canada?

A crucial question for Alberta involves the implications to the province of battery electric versus hydrogen fuel cell electric HDVs. ***Which transformative technology is better for the key industry sectors (freight transport, oil and gas, electricity generation) and the economy of the province?"***

Part 2 of this report addresses this question by carrying out a systems-level techno-economic and environmental assessment (TEEA) of three energy systems for vehicle electrification (battery electric, hydrogen fuel cell electric with the hydrogen from fossil fuels, and hydrogen from renewables), and compares these with a similar analysis of 'reference' energy systems supporting freight transportation through diesel or biodiesel fuels. In addition, Part 2 evaluates the fit for freight transportation service of the battery electric HDV versus a hydrogen fuel cell electric HDV, compared to the incumbent diesel internal combustion option.

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