University of Victoria | Graduate Studies

Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

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"An Examination of Heavy-duty Trucks Drivetrain Options to Reduce GHG Emissions in British Columbia"

Department of Mechanical Engineering

Wednesday December 11, 2019
10:00 A.M
Clearihue Building
Room B017

Supervisory Committee:
Dr. Curran Crawford, Department of Mechanical Engineering, University of Victoria (Co-Supervisor)
Dr. John Axsen, Department of Mechanical Engineering, UVic (Co-Supervisor)
Dr. Andrew Rowe, Department of Mechanical Engineering, UVic (Member)
Dr. Katia Rhodes, School of Public Administration, UVic (Outside Member)

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Dr. Heather MacLean, Department of Civil & Mineral Engineering, University of Toronto

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Dr. Wendell Clanton, School of Music, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

Heavy-duty trucks (HDTs) emit more than 5% of global greenhouse gas (GHG) emissions. Furthermore, GHG emissions from this sector are expected to steadily grow due to economic growth, globalization, industrialization, online shopping, and fast delivery expectations. This study was focused on the Canadian province of British Columbia (BC) as a case study where HDTs are responsible for more than 4% of total provincial GHGs. BC, along with many regions around the world, has been committed to reduce its GHG emissions by 80% below 2007 levels by 2050. The goal of this study was to evaluate the potential of meeting this objective for BC HDTs using alternative drivetrain technologies. First, a component-level model was developed in Matlab to compute on-road energy consumption and CO2 emissions of compressed natural gas and diesel HDTs based on their physical parameters (e.g. mass) over several selected drive cycles. Results of the first contribution indicated a CNG drivetrain emits 13-15% fewer GHG than a comparable diesel. Road grades of several main BC routes were included in the drive cycle simulations, which is an important factor that can increase the fuel consumption and CO_2 emission by as much as 24% relative to a flat route assumption.

In the second contribution, the physical energy consumption model was extended to compare 16 diverse drivetrain technologies, including a pure battery electric. The comparison metrics were also extended to well-to-wheel GHG emissions, total ownership costs (TOC) (including infrastructure), and abatement costs (based on incremental TOC cost over GHG emissions reduction), and cargo capacity impacts. The 16 considered drivetrains were distinguished by their fuel types, combustion technology, drivetrain architecture, and connection to the electricity grid (e.g. catenary vs fast charging stations). Next, the activity data of 1,616 HDTs operating in BC with sparse recording intervals was used to select 6 representative freight routes with different ranges of 120-950 km split into short and long haul routes. A combination of filtering and interpolation techniques was used to develop 1-Hz drive cycles compatible with the characteristic of HDTs categorized by the U.S. National Renewable Energy Laboratory. Results indicated a battery electric and battery electric catenary using hydroelectricity emits 95–99% lower GHGs than a baseline diesel. Furthermore, the parallel hybrid diesel was found to have both the lowest TOC and abatement costs for both short and long haul routes. Moreover, plug-in parallel hybrid fuel cell and conventional diesel drivetrains

were found to have the highest cargo capacity on short and long haul routes respectively. Finally, a Monte Carlo analysis using 5000 simulations was performed for the longest freight routes to observe sensitivities to input parameters. Comparing median magnitudes, the uncertainty analysis indicated that the battery electric drivetrain has the lowest WTW GHG emissions, while the parallel hybrid diesel drivetrain has the lowest TOC. In the third contribution, a dynamic vehicle adoption model was developed to project the diffusion rate of alternative drivetrains HDT up to 2050 considering two zero emission vehicle (ZEV) mandates and various infrastructure roll-out scenarios. The HDT market was split into short and long haul segments. The vehicle adoption model was combined with a Monte Carlo analysis to evaluate the collective impact of input parameter variations on GHG emissions and market share projections. Both considered ZEV mandates included a linear adoption rate for ZEV drivetrains starting from 25% in 2025 and reaching 100% by 2040. They were also distinguished based on a constraint on the level of plug-in hybrid adoption. It was found infrastructure density increases the probability of meeting the 2050 target on both short and long haul HDTs. However, the increase in the probability is much higher for the short haul segment. Among various infrastructure roll-out scenarios, rapid deployment of hydrogen fueling stations was found to have the highest positive impact on GHG emissions reduction for both short and long haul markets. Both battery electric and hydrogen fuel cell drivetrains can succeed in the short haul market, depending on whether the infrastructure development is toward charging or H_2 station deployments. A similar result was found for the long haul market, except in most scenarios plug-in hybrid diesel has a higher chance of market penetration.