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A comparative life cycle assessment of diesel and compressed natural gas powered refuse collection vehicles in a Canadian city

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HIGHLIGHTS

- ► Life cycle analysis is performed on two alternative refuse collection vehicle technologies.
- ► Real-time operational data obtained by the City of Surrey in British Columbia are utilized.
- ► The life cycle energy use is similar for diesel and CNG RCVs.
- ► A 24% reduction of GHG emissions (CO_2-equivalent) may be realized by switching from diesel to CNG.
- ► CNG RCVs are estimated to be cost effective and may lead to reduced fuel costs.

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ABSTRACT

Consumers and organizations worldwide are searching for low-carbon alternatives to conventional gasoline and diesel vehicles to reduce greenhouse gas (GHG) emissions and their impact on the environment. A comprehensive technique used to estimate overall cost and environmental impact of vehicles is known as life cycle assessment (LCA). In this article, a comparative LCA of diesel and compressed natural gas (CNG) powered heavy duty refuse collection vehicles (RCVs) is conducted. The analysis utilizes real-time operational data obtained from the City of Surrey in British Columbia, Canada. The impact of the two alternative vehicles is assessed from various points in their life. No net gain in energy use is found when a diesel powered RCV is replaced by a CNG powered RCV. However, significant reductions (approximately 24% CO_2-equivalent) in GHG and criteria air contaminant (CAC) emissions are obtained. Moreover, fuel cost estimations based on 2011 price levels and a 5-year lifetime for both RCVs reveal that considerable cost savings may be achieved by switching to CNG vehicles. Thus, CNG RCVs are not only favorable in terms of reduced climate change impact but also cost effective compared to conventional diesel RCVs, and provide a viable and realistic near-term strategy for cities and municipalities to reduce GHG emissions.

1. Introduction

Rising oil prices and growing environmental concerns are driving research into alternative, cleaner, and more efficient ways of producing and using energy (Rose, 2013). According to Natural Resources Canada (2008), the transportation sector is the largest source of greenhouse gas (GHG) emissions in Canada, accounting for more than one third of Canada's total GHG emissions. Additionally, criteria air contaminants (CACs) from the transportation sector are posing significant environmental and health risks for Canadians, particularly for approximately 80% of the population who live and/or work in urban areas (Transport Canada, 2006).

In order to minimize the impact of emissions from the transportation sector, consumers and organizations are seeking viable low-carbon alternatives to conventional gasoline and diesel vehicles. The compressed natural gas (CNG) powered vehicle is a viable alternative to conventional gasoline and diesel powered vehicles and can significantly reduce emissions from the transportation sector. Two studies of CNG and gasoline engines have shown significant reductions of all combustive emissions (Jang

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and Lee, 2005; Zhang et al., 2011). However, Aslam et al. (2006) observed an increase in NO_x emissions. This increase in NO_x is, despite significant reductions in other emissions is also observed in studies comparing CNG to diesel fuel (Jayaratne et al., 2009; Kathuria, 2004; Ravindra et al., 2006). A possible explanation for the increase in NO_x is given by Nylund et al. (2004) who argue that if no special measures are taken, NO_x emissions will be higher than for diesel engines. CNG engines need to operate in a lean-burn operation or in stoichiometric combustion in combination with a three-way catalyst to reduce emissions.

However, to validly evaluate and assess the energy, emissions, and economic effects of alternative fuels and vehicle technologies, a holistic or comprehensive approach has to be considered. The approach, often referred to as life cycle approach, or life cycle assessment (LCA), must include all the steps required to produce a fuel, to manufacture a vehicle, and to operate and maintain the vehicle throughout its lifetime including disposal and recycling at the conclusion of its life cycle. This particular approach provides a better understanding of alternative choices in fuels and vehicle technologies and makes informed selections for the long-term possible. Conversely, without a life cycle approach, false conclusions can be drawn, particularly for alternative vehicle technologies that employ fuels with distinctly varied primary energy sources and fuel production processes. Numerous studies have been conducted on alternative vehicle technologies from the life cycle perspective, often estimating fuel cycle emissions and energy use associated with various transportation fuels and technologies. On the topic of comparative LCA, fuel cell vehicles are compared with conventional vehicles (Collela et al., 2005; Granovskii et al., 2006; MacLean and Lave, 2003; Pehnt, 2001, 2003; Zamel and Li, 2006) and electric vehicles (Cuenca et al., 1998). Others have performed comparative LCAs of different hydrogen production pathways (Row et al., 2002; Spath and Mann, 2001).

LCAs comparing CNG to diesel vehicles have concluded different results, partially due to locale specific data. Comparing CNG and diesel light duty vehicles, Weiss et al. (2000, 2003) have done an LCA study showing higher efficiency and reduction of CO_2 emissions for CNG and a 13% reduction of life cycle energy consumption for diesel compared to gasoline. However, if the diesel fuel is derived from natural gas (Fischer–Tropsch (FT) diesel), an increase in energy demand offsets any GHG reduction in vehicle usage. Previous studies on comparative LCAs of heavy duty CNG and diesel vehicles were focused on transit buses (Ally and Pryor, 2007; Karman, 2006; Kliucininkas et al., 2012; Ryan and Caulfield, 2010). Karman (2006) found significant reductions of CO_2 emissions for vehicles in the city of Beijing, China, when switching to CNG, but stressed the importance of locale specific data for an LCA. Kliucininkas et al. (2012) found a higher environmental impact for CNG compared to diesel in Kaunas, Lithuania, due to a higher consumption of CNG per traveled distance with related upstream emissions. Ryan and Caulfield (2010) found a significant decrease of all pollutants except CO in CNG buses compared to diesel buses on the Euro V norm in Dublin, Ireland. Ally and Pryor (2007) compared CNG, diesel, and H_2 fuel cell driven vehicles and showed that CNG required more energy per distance traveled and resulted in slightly higher GHG emissions compared to diesel driven vehicles. However, vehicles driven by CNG showed lower emissions related to smog, acidification, and soil/water contamination (NO_x, CO, SO_2, and non-methane volatile organic compounds) for Western Australia. On presenting LCA impacts, Kliucininkas et al. (2012) used "milli ecopoints" (mPt) per kilometer traveled. One point is interpreted as one thousandth of the annual environmental load (damage) of one average European inhabitant. Sorensen (2004) has monetized (in Euros) the environmental, social, and other impacts. However, the majority of LCAs present their findings in the quantity of greenhouse gases and pollutants per kilometer traveled for vehicles as well as energy consumed to evaluate efficiency.

The current state of LCA studies of heavy duty vehicles as relating to refuse collection vehicles (RCVs) is, however, largely absent. Therefore, there is a significant need to conduct LCA studies of RCVs and evaluate the results in light of existing studies on transit buses that also employ heavy duty engines. Interestingly, there are conflicting reports of the climate change (or global warming) impact with respect to GHG emissions from CNG and diesel buses. Karman (2006) showed a small decrease of GHG emissions of CNG while Ally and Pryor (2007) showed an increase. The LCA on RCVs presented here is contextualised with respect to above-mentioned transit bus studies to show how a reduction of GHG emissions and climate change impact can be achieved by switching from diesel to CNG RCVs for different vehicle types.

The present study involves a municipal organization in British Columbia, Canada, known as the City of Surrey (hereafter referred to as the City). The City has about 300 vehicles in its engineering vehicle fleet, ranging from light duty passenger and commercial vehicles to rangers (pickups), heavy duty commercial vehicles, buses, and RCVs. The City became interested in finding viable low-carbon alternative fuel vehicles to replace incumbent gasoline and diesel vehicles in order to meet or exceed its goal of reducing GHG emissions from fleet vehicles by 20% by the year 2020. In this regard, the City wants to undertake a holistic or pragmatic approach that can assess low-carbon alternative fuel vehicles from various points in their life cycle. In an attempt to assess viable low-carbon alternative fuel vehicles, this study focuses on heavy duty RCVs powered by CNG as a potential replacement of the diesel powered RCVs presently operated in the City.

The objective of the present study is to conduct a life cycle analysis of a CNG powered RCV and compare it with a diesel powered RCV, utilizing the reliable and real-time operational data provided by the City and its contractor. The findings of this study will enable decision-makers to make an informed selection of CNG vehicles over conventional diesel vehicles based on realistic estimations of life cycle emissions, cost, and energy use.

2. Life cycle assessment methodology

The methodology used to assess different vehicle technologies from various points in their life cycle is often referred to as life cycle assessment (LCA). LCA is a 'cradle-to-grave' approach of assessing systems or technologies by compiling an inventory of relevant inputs and outputs, assessing the potential environmental impacts associated with identified inputs and outputs, and interpreting the results of inventory and impact phases to help make informed decisions (Scientific Applications International Corporation (SAIC), 2006).

A typical life cycle of a vehicle technology is shown in Fig. 1. The life cycle can be classified into two major categories: the fuel cycle and the vehicle cycle. In the fuel cycle, the following stages result, starting from the feedstock production where energy is used and greenhouse gases are released. At this stage in CNG production, for example, the associated input of energy to extract natural gas and the emissions output related to the extraction are accounted for. As for diesel, the extraction of crude petroleum is considered. Next in the fuel cycle is feedstock transport, in which the associated costs of transportation are documented. As with our example, natural gas is transported to gas processing facilities via pipelines or tank trucks requiring energy as well as producing emissions. Conversion of crude oil feedstock to practical fuels is a very energy intensive step of the fuel cycle, generating significant