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Carbon and energy footprints of refuse collection trucks: A hybrid life cycle evaluation

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ABSTRACT

Refuse collection trucks, due to the frequent stop-and-go nature of their operation, have considerably lower fuel economy and larger amounts of tailpipe emissions. In this study environmental burdens of refuse collection vehicles, including diesel, compressed natural gas, hydraulic hybrid, and plug-in battery electric powered trucks are analyzed. A hybrid life cycle assessment consisting of an environmentally extended input–output analysis and a process-based analysis is conducted to evaluate the life cycle carbon footprints and energy consumption levels of different types of refuse collection trucks. To comprehensively reflect the real-world performance or impacts of the operation of refuse collection trucks, a Monte Carlo Simulation is used to take into account the inherent uncertainties associated with each of the key parameters in this analysis. In addition, the influence of the U.S.'s various regional electric power mixes on the upstream emissions of battery electric trucks is also considered, so as to explore whether or not each particular region is suitable for the adoption of electric trucks. The results indicate that both the all-electric and the CNG refuse trucks generate approximately 1200 tons of GHG emissions over their respective life cycles, while the GHG emissions of the diesel truck amount to slightly less than 1000 tons. The hydraulic hybrid truck demonstrates the best overall environmental performance, while the CNG truck has significant impacts in terms of energy consumption (more than 25 trillion joules). In addition, the regional analysis indicates that the electricity source(s) available in any given region are the primary deterministic factor for the performance of an all-electric truck.

Keywords: Hybrid input–output life cycle assessment; Refuse collection trucks; Regional analysis; Battery electric refuse collection trucks

1. Introduction

In the year 2014, greenhouse gas (GHG) emissions from the US transportation sector accounted for about 26% of all US GHG emissions (US Environmental Protection Agency, 2016), while trucks and passenger cars accounted for about 84% of GHG emissions from the transportation sector in the year 2012. Although trucks are the second largest vehicle type in the US, the overall GHG emissions from medium duty and heavy duty trucks have increased dramatically since 1990 (US Environmental Protection Agency, 2015). At the same time, there are about 250 million tons of municipal solid waste generated in the US each year, most of which is sent to landfills while the remaining waste is either recycled, incinerated, or composted; all of these waste management methods, in one way or another, depend heavily on refuse collection trucks. Currently, about 179,000 refuse collection trucks are being operated by both public and private entities, about 90% of

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which are diesel-powered trucks, while the remaining trucks are powered by compressed natural gas (CNG) (Vock DC.A Quiet Revolution, 2014). Usually operating in urban areas, these class-8 heavy duty refuse collection trucks have the lowest fuel economy (2–3 miles per gallon) among all vehicle types, and also tend to have annual utilization levels as high as 25,000 miles per year (Gordon et al., 2003). In addition, due to their frequent stop-and-go driving nature, large payloads, and use of on-board devices (lift, compactor, etc.), refuse collection trucks consume significantly more fuel even compared to other types of heavy duty trucks; current literature shows that refuse collection trucks consume as much as 1.2 billion gallons of diesel each year (Shea, 2011), and the combustion of such large amounts of fuel leads to significant environmental impacts. To reduce these environmental impacts and simultaneously reduce the operation costs of diesel-powered refuse collection trucks, alternative fuel-powered vehicles (CNG trucks, hydraulic hybrid trucks, electric trucks, etc.) have been introduced into waste collection fleets in recent years. Some of these newly-adopted types of refuse collection trucks may be able to reduce or completely eliminate tailpipe emissions by improving the fuel efficiency of the average truck and/or by using stored electricity as a power source, but, whether or not the alternative fuel powered fleets are able to adequately mitigate these environmental impacts from a life cycle perspective remains unclear. In this regard, based on publicly available data, an environmentally-extended hybrid life cycle assessment (LCA) is conducted in this study in order to evaluate the upstream and downstream GHG emissions and energy consumption levels of diesel, CNG, hydraulic hybrid, and all-electric refuse collection trucks, and a separate analysis of the different electricity mixes in each of the North American Electric Reliability Corporation (NERC) regions in the US is performed in order to determine which regions have the best potential to maximize the resulting environmental impact mitigation from the deployment of all-electric refuse collection trucks. Following this section, a literature review is conducted in Section 2 to summarize the results from previous refuse truck studies. Next, a detailed explanation of the methodology and calculations to be employed in this study is provided in Section 3. Afterward, the comprehensive and regional results for these analyses are presented in Section 4. Lastly, the findings of this study and any relevant conclusions and recommendations are briefly discussed in Section 5.

2. Literature review

About 10% of all refuse collection trucks currently in use in the US are powered by compressed natural gas, and half of all newly purchased refuse trucks are CNG trucks (Vock DC.A Quiet Revolution, 2014). A US Department of Energy report has shown that the studied CNG refuse truck fleets saved about 50% in fuel costs and 1800 tons of GHG emissions compared to diesel fleets (Burnham and Laughlin, 2014), while another Department of Energy report also found that the observed CNG trucks reduced tailpipe emission by 20% and made less noise during operation (Shea, 2011). However, one of the key limitations observed in the latter report with respect to CNG as an alternative fuel for refuse truck fleets is the lack of readily available refueling infrastructure, as the construction of a CNG station to support 20–30 trucks may prolong the trucks' payback period by 3–4 years (Burnham and Laughlin, 2014), while the construction of such a refueling station also has its own environmental impacts that must be taken into account. Another relatively new technology is the hydraulic power regeneration system, which has been designed and tested exclusively for refuse collection trucks. Hydraulic hybrid refuse collection trucks are able to regain up to 70% of the truck's braking energy compared to conventional trucks (Canter, 2008), thus improving the fuel economy of the truck. In two notable real-world examples, the city of Oberlin, Ohio has currently adopted three hydraulic hybrid trucks, and a refuse collection fleet in Miami-Dade, Florida has recently deployed 29 new hydraulic hybrid trucks. In addition, the first all-electric refuse truck was delivered to the city of Chicago in 2014 (Motiv, 2014), and the large-capacity battery packs onboard this truck ensure a 60-mile range for the truck and can be slowly charged overnight. However, the aforementioned hybrid and all-electric trucks are usually two to three times as expensive as conventional diesel trucks.

A process-based LCA has been performed to evaluate the energy consumption and GHG emissions of diesel, bio-diesel, and CNG refuse collection trucks in the city of Madrid (López et al., 2009), and the results of this study indicated that CNG trucks have slightly lower environmental impacts than other truck types. A similar LCA method applied to a refuse collection fleet in Canada has suggested identical GHG emission results, but found that CNG trucks have higher levels of energy consumption (Rose et al., 2013). On the other hand, a combined study of diesel and CNG trucks with respect to conventional air pollution and GHG emissions concluded that CNG refuse trucks have lower NO_x and Particular Matter (PM) emissions, but also have higher CO and GHG emissions (Fontaras et al., 2012). Other studies have also been published that focus on the economic aspects (Johnson, 2010) and implementation feasibility of CNG truck fleets (Burnham and Laughlin, 2014).

In addition to the process-based LCA method, there are also input–output LCA, and hybrid LCA. Input–output LCA methods attribute the life cycles of a product or a process into one or more corresponding industrial sectors, the inputs or outputs of which are then multiplied by the relevant environmental impact multipliers. Researchers have also integrated the two LCA methods into a hybrid LCA methodology, thereby combining the merits of both approaches. Hybrid LCA methodologies are now commonly used to evaluate the alternative fuel powered vehicles of various classes, including passenger cars (Onat et al., 2015), medium duty commercial delivery trucks (Zhao et al., 2016; Lee et al., 2013), transit buses (Ercan and Tatari, 2015), and heavy duty freight trucks (Sen et al., 2017).

However, there are still several gaps in current literature that must be addressed. Firstly, the newly-introduced truck types previously discussed (e.g. hydraulic hybrid and all-electric trucks) have not yet been discussed or analyzed in comparison to more prevalent truck types e.g. diesel and CNG trucks. Secondly, although the use of all-electric powertrains has a great deal of potential to improve fuel efficiency and reduce tailpipe emissions, the influence of regional electricity grid mixes as a deterministic factor with respect to environmental performance has not yet been considered in LCA analyses of electric refuse trucks. Third, due to potential variations in driving cycles, calculations based on any single data point may lead to biased results. Therefore, a comprehensive LCA is conducted in this study with respect to diesel, CNG, hydraulic hybrid, and all-electric trucks, with data ranges for key parameters integrated via Monte Carlo Simulation,