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LIFE CYCLE ASSESSMENT OF A DIESEL AND A COMPRESSED NATURAL GAS MEDIUM-DUTY TRUCK. THE CASE OF TORONTO

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Introduction

Life cycle assessment (LCA) for transportation fuels and vehicles, known as "well-to-wheel" analysis, is a common technique to evaluate life cycle greenhouse gas (GHG) emissions for trucks. The energy consumption and GHG emissions of medium-duty trucks are highly dependent on vehicle characteristics, such as truck configuration, payload and driving conditions (Tong et al., 2015). Few of the previous LCAs of compressed natural gas (CNG) trucks comprehensively capture the impacts of both weight and drive cycle on fuel consumption and life cycle GHG emissions. For example, the fuel consumption estimates in TIAX LLC, (2008) and Kliucininkas et al., (2012), two LCA studies of CNG trucks, do not reflect the impacts of driving conditions. The objective of this study is to estimate the energy consumption, life cycle GHG emissions, and the lifetime costs for a diesel truck and a CNG truck based on real-world medium-duty vehicle drive cycles in Toronto.

Method and Data

We rely on *Autonomie* developed by Argonne National laboratory to simulate fuel consumption for both the diesel and CNG trucks. Vehicle specifications are listed in Table 1. The diesel truck model is similar to a 2009 Ford F-650 (Ford, 2009). The CNG truck model has the same truck body but with a dedicated CNG engine, JohnDeere PowerTech. The CNG truck costs $3800 more than the diesel truck (Berg, 2014).

Table 1 Diesel Truck and CNG truck characteristics

Model	Diesel Truck	CNG truck
Chassis body mass (kg)	3774	3931
Max payload(kg)	7875	7718
Gross vehicle weight rating (kg)	11649	11649
Engine	Caterpillar 3126	JohnDeere
Engine peak power (kw)	188	188

We adopt two simulated real world drive cycles from Amirjamsidi & Roorda (2014) that reflect the traffic demand estimation of 1518 medium-duty trucks in Toronto in the AM peak hours (8:00-9:00): the University drive cycle and Freeway drive cycle (Figure 1).

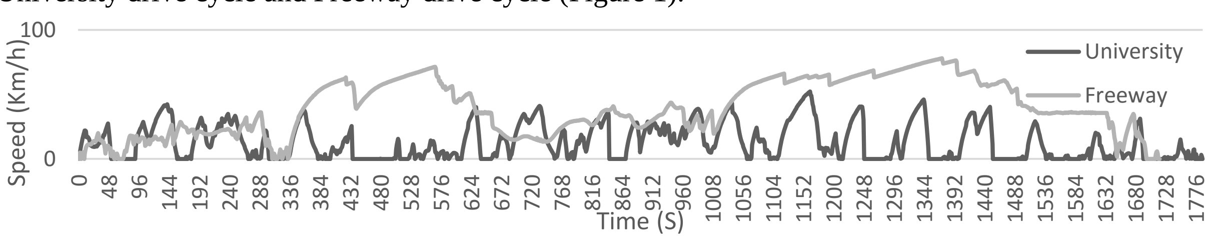

Figure 1. University and Freeway Drive Cycles for Medium-duty Vehicles in Toronto

Scope of the LCA study

We use GHGenius (version 4.03a), a publicly available government tool often used in North America for well-to-wheel analyses (S&T Consultants, 2013). Three phases of the analysis are included: 1) fuel cycle; 2) vehicle operation; and 3) vehicle cycle (vehicle production and transportation). We focus on five GHGs: CO_2, CH_4, N_2O, CFC-12, and HFC-134a, which are converted to CO_2 equivalent emission using the IPCC 2007 100-year Global Warming Potentials (IPCC, 2007). The functional unit is gCO_2e per km travelled per cargo ton (gCO_2e/tonne-km). Payloads of 10%, 50% and 100% are studied to examine the impact of weight on energy consumption. We assume trucks have the same material composition for the powertrain, except for the fuel tank, as shown in Table 2, based on S&T Consultants (2013).

Table 2. Material breakdown by weight percentage for fuel storage system

	Diesel Fuel tank (%)	CNG fuel tank (%)
Virgin plain carbon steel	42	0
Virgin high strength steel	0	10
Virgin stainless steel	40	5
Recycled plain carbon steel	18	0
Advanced composites	0	40
Other plastics	0	20
Virgin aluminum	0	18
Virgin copper	0	8
Total	100	100

Total cost of ownership

The annualized total cost of ownership, expressed in 2014 USD, is a function of annual vehicle kilometres travelled, fuel price, maintenance cost, energy consumption, and discount rate. The ranges of these parameters are summarized in Table 3. Sensitivity analysis are performed. Each parameter has three values: lower bound, best estimate and higher bound. The variables are varied one at a time with all other variables remaining at their best estimate value, and the implications on total cost are examined.

Table 3 Best estimates and ranges for parameters for sensitivity analysis

Parameter	Lower Bound	Best Estimate	Higher Bound	Source
Annual vehicle kilometres travelled	8,000	16,000	32,000	(Natural Resources Canada, 2010)
Lifetime vehicle kilometres travelled	160,000	240,000	320,000	(Antich, 2008)
Diesel fuel price ($/Litre)	0.8	1.0	1.8	(Natural Resources Canada, 2014) (US Energy Information Administration, 2015)
CNG fuel price($/Diesel Litre Equivalent)	0.6	0.8	1.1	(U.S. DOE, 2015).
Diesel Fuel consumption (Litre/100km)	16	27	42	*Autonomie*
CNG Fuel Consumption (Liter diesel equivalent/100km)	20	29	49	*Autonomie*
Discounted Rate	0.0075	0.065	0.14	(Federal Reserve Bank of St.Louis, 2015)

Result and Discussion

Energy consumption

The energy consumption for the diesel truck and the CNG truck are expressed in MJ/tonne-km (Figure 2).

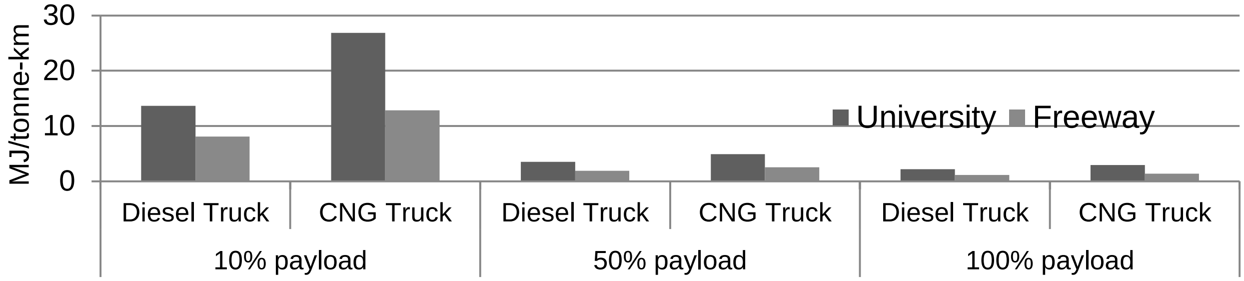

Figure 2 Energy consumption results from Autonomie simulation

Both trucks consume less energy per tonne-km when payload weights are higher, thus they are more load efficient if carry more payload. This is because although the total energy consumption (MJ/km) increases as the truck carries a larger load, the denominator (tonnes) is bigger, thus the load weighted consumption is lower. Both the diesel truck and CNG truck are more energy intensive in the University drive cycle than in the Freeway drive cycle. The CNG truck consumes more energy than the diesel truck (26 – 49% higher in the University and 18 – 37% higher in the Freeway drive cycle).

Life cycle GHG Emissions

For both the diesel truck and the CNG truck, the GHG emissions per tonne-km are higher at low payload and lower at high payload. This is because the energy consumption per tonne-km for both trucks at high payload is lower than at low payload, as indicated in Figure 2. The GHG emissions of the CNG truck are higher or lower than those of the diesel truck depending on the drive cycle and payload. For example, when 10% loaded, the CNG truck has 8% and 22% higher life cycle emissions than the diesel truck in the University and the Freeway drive cycle respectively; but the CNG truck emits 3 - 10% less life cycle GHG emissions than the diesel when 50% and 100% loaded.

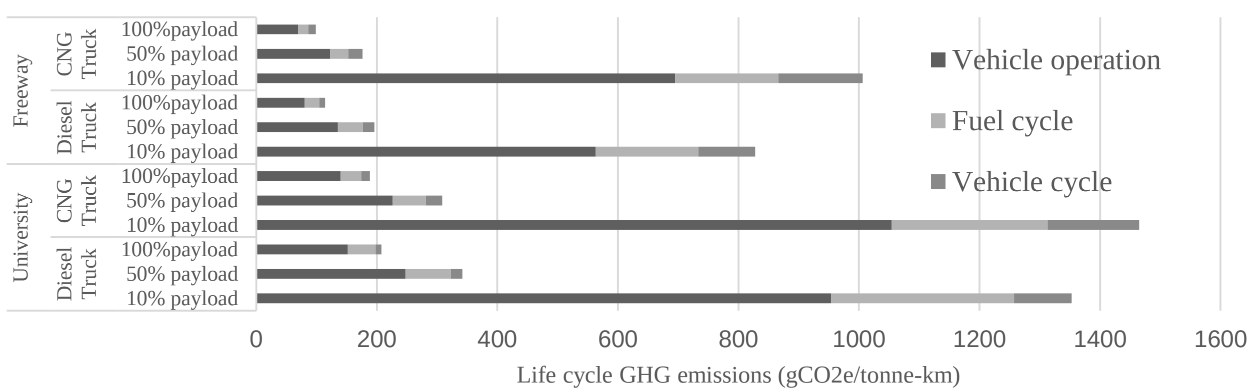

Figure 3 Life cycle GHG emissions of the diesel and CNG trucks

Total cost of ownership

Figure 4 shows the total cost of ownership of the diesel truck and CNG trucks based on the best estimate scenario. The diesel truck fuel cost accounts for nearly half (45%) of the life cycle total cost of ownership. The CNG truck fuel cost is lower, 31% of life time total cost of ownership. Overall, the life time total cost of ownership of the CNG truck is 14% lower than that of the diesel truck.

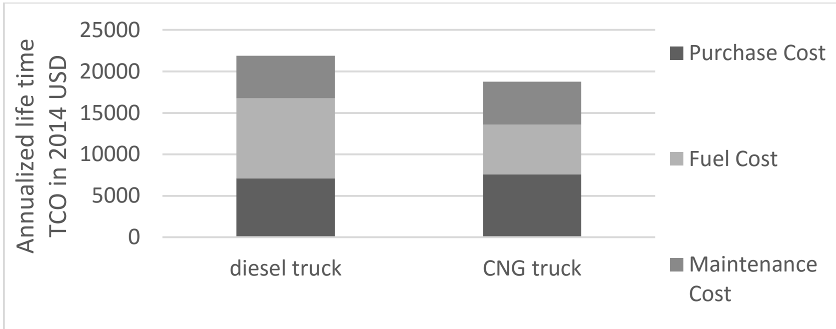

Figure 4. Lifetime total cost of ownership

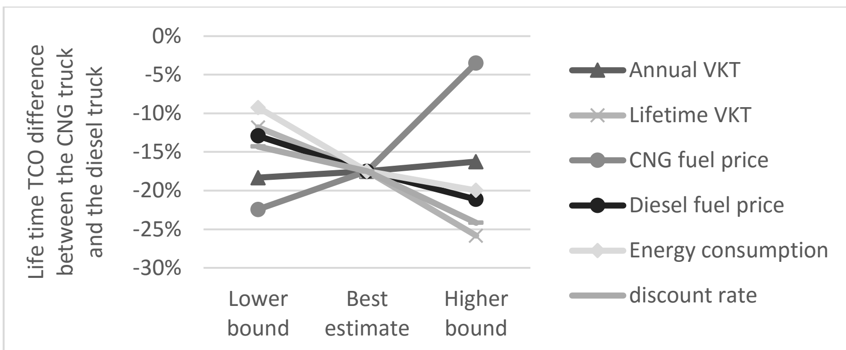

Figure 5. Sensitivity analysis results of life time total cost of ownership difference between CNG truck and diesel truck

The sensitivity analysis (Figure 5) shows the lifetime total cost of ownership for the CNG truck varying from 3 - 26% less than that of the diesel truck. The total cost of ownership difference is most sensitive to the CNG fuel price and lifetime vehicle kilometres travelled. The total cost of ownership difference is least sensitive to the annual vehicle kilometres travelled.

Conclusions

We report results of energy consumption, life cycle GHG emissions and lifetime total cost of ownership for the diesel truck and the CNG truck. This study shows that the CNG truck has no energy savings in replacing a diesel truck in all drive cycles and payload weights. The CNG truck has higher or lower life cycle GHG emissions than the diesel truck depending on the payload weight and drive cycle, but the CNG truck has lower lifetime total cost of ownership in all scenarios. The lifetime total cost of ownership is most sensitive to lifetime vehicle kilometres travelled and CNG fuel price. The results of this work suggest that the CNG truck may not be the best alternative to reduce GHG emissions from fleet, but it can reduce ownership costs for business owners.

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