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Energy consumption and GHG emissions of GTL fuel by LCA: Results from eight demonstration transit buses in Beijing

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ABSTRACT

Gas-to-liquids (GTL) as an alternative to diesel is considered to be one of the technical options to reduce petroleum consumption in the on-road transportation sector. Between May and August 2007, a joint demonstration program by Tsinghua University, Beijing Transit, Cummins Corporation and Shell Corporation was carried out in Beijing. The program focused on the supply systems and vehicle use of GTL fuel. The demonstration fleet was formed by four transit buses fueled with GTL and four with diesel. It was demonstrated that GTL has good compatibility with diesel in terms of fuel supply system and vehicle use. This paper compares the energy consumption and GHG emissions of diesel and GTL fuel supply chains by life cycle analysis based on demonstration results. The results indicate GTL's large range (reported 54–70%) in synthesis efficiency, as the key factor in determining energy consumption and GHG emissions within the GTL fuel supply chain. For the probable case (GTL synthesis efficiency: 65%), the life cycle energy consumption and GHG emissions of GTL fuel are 42.5% and 12.6% higher than that of diesel. For two sensitivity analysis cases (GTL synthesis efficiency: 54% and70%), energy consumptions are 74.2% and 31.2% higher and GHG emissions are 27.3% and 7.4% higher than that of the diesel fuel supply chain. If the efficiency of the GTL synthesis process is improved to 75%, then the GHG emissions level of the GTL fuel supply chain can be reduced to the same level as the diesel fuel supply chain.

1. Introduction

With the rapid increase of vehicle stock in China, oil consumption and GHG emissions associated with on-road transportation are rising dramatically [1]. Increasing petroleum demand by the on-road transportation sector in China has raised the import dependence of petroleum from 19.7% in 1995 to 51.3% in 2008 [2]. Technology options for vehicles and fuels are in urgent need to establish a stainable and low-carbon transportation energy supply system.

Gas-to-liquids (GTL) as an alternative to diesel is considered to be one of the technology options to reduce petroleum consumption of on-road transportation [3]. GTL technology is recovering and enjoying growth due to recent technology and catalyst advancements. Current forecasts estimate that the world's GTL capacity could increase from 35,000 B/D to 1–2 million B/D by 2015 [4].

Between May and August of 2007, a joint demonstration program by Tsinghua University, Beijing Transit, Cummins Corporation and Shell Corporation was carried out in Beijing. The demonstration fleet was made up of four transit buses fueled with GTL. Four buses fueled with traditional diesel were also included for comparison purposes. This paper analyzes the demonstration results regarding energy consumption and the associated GHG emissions of diesel and GTL fuel supply chains using life cycle assessment methods.

2. Methodology and data

2.1. Model and system boundary

The LCA analysis section of this study is based on the well-to-wheels (WTW) analysis module of the Tsinghua-CA3EM (China Automotive Energy, Environment and Economy Model) model [5–7], which is an integrated computerized model that includes a specialized module for China's automotive energy supply and demand balance calculation and analysis. The model is based on China's national conditions and integrates the widely known and used transportation energy micro-level computing GREET model [8]. As described in Fig. 1, WTW analysis of GTL fuel chain is divided into well-to-pump (WTP) and pump-to-wheels (PTW) stages.

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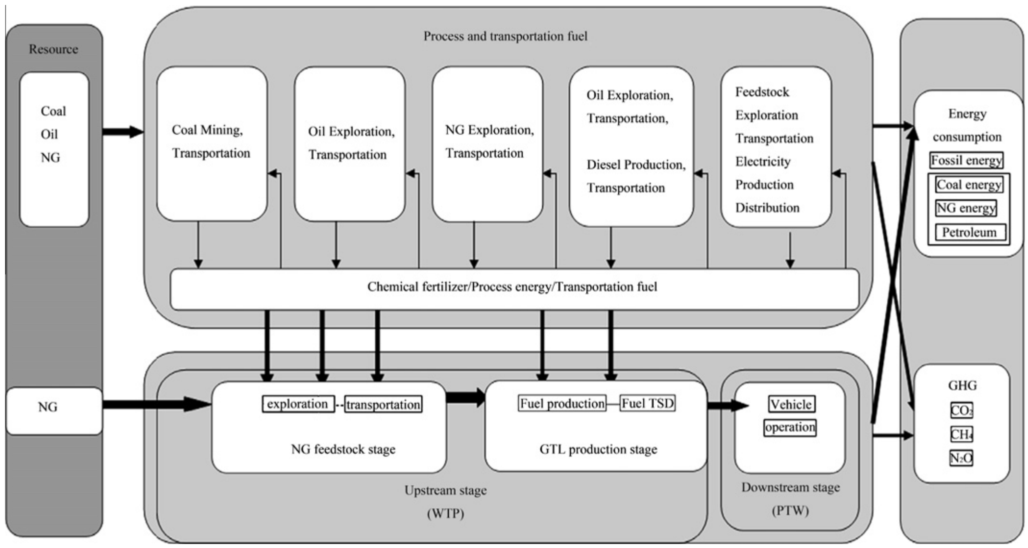

Fig. 1. LCA diagram of GTL fuel chain, adapted from Ref. [5].

Table 1
LCA PE[a] use factors and direct and indirect GHG emission factors for PFs, adapted from Ref. [5].

PF[a]	PE consumption factor			Indirect emission factor			Direct emission factor			
	Coal (MJ/MJ)	NG (MJ/MJ)	Oil (MJ/MJ)	CO_2 (g/MJ)	CH_4 (g/MJ)	N_2O (mg/MJ)	CH_4 (g/MJ)	N_2O (g/MJ)	CC[a] (g C/MJ)	FOR[a]
Crude coal[b]	1.053	0.000	0.002	4.259	0.422	0.062	0.001	0.001	26.35	0.90
Crude NG[b]	0.080	1.011	0.064	11.909	0.072	0.154	0.001	0.001	15.30	0.99
Crude oil[b]	0.097	0.023	1.047	15.998	0.054	0.265	0.002	0.000	20.00	0.98
Coal	1.061	0.001	0.110	5.733	0.425	0.172	0.001	0.001	24.74	0.90
NG	0.081	1.015	0.065	13.544	0.110	0.161	0.001	0.001	24.70	0.99
Diesel	0.156	0.027	1.119	28.287	0.078	0.441	0.004	0.002/0.028[c]	20.20	0.98
Gasoline	0.164	0.049	1.130	30.506	0.086	0.472	0.080	0.002	18.90	0.98
Residual oil	0.139	0.026	1.055	25.323	0.071	0.409	0.002	0.000	21.10	0.98
Electricity	2.506	0.015	0.115	265.218	1.010	3.917	–	–	–	–

[a] PE: primary energy, PF: process fuel, FOR: oxidation rate, CC: carbon content factor.
[b] These fuels are mined and transported but not refined.
[c] For vehicles, the utilization value is 0.002, while for other applications this value is 0.028.

2.2. Basic data

In this study, we use previously conducted research as a source for process fuels' life cycle energy consumption and GHG emissions in China [5–7]. Detailed data are presented in Table 1.

3. GTL supply and its characteristic

3.1. GTL supply

All the GTL fuel consumed by the demonstration buses was supplied by Shell Corporation's Malaysia plant. The GTL fuel was first shipped from Malaysia to Tianjin harbor by ocean tanker, and then distributed to Beijing's Looan fuel storage site by road tankers. A dedicated refueling truck was used to fuel the four GTL transit buses.

Given that the tanks were previously used for storage of regular diesel fuel, the oil tank for GTL storage was treated using a mild cleaning procedure beforehand to eliminate contamination of the GTL fuel. Firstly, both manhole covers and the tank outlet valve were removed. The tank force was vented to remove hydrocarbon vapors. The remaining fluid and sludge were removed by vacuum-pumping. Secondly, a person was lowered into the tank to rinse it with kerosene. All associated pipe work and pumps were flushed with kerosene. The small road tanker and hoses used for local distribution of the GTL were cleaned in the same manner as above. Finally, all associated pipe work, pumps and flexible hoses were back-flushed with GTL fuel before filling the storage tank. About 500 L of GTL fuel was used for flushing of pipe work and associated equipments. All filters in the lines and manifold system were removed and replaced after flushing. To determine the effectiveness of the cleaning process, the storage tank was pre-filled with around one sixth of an ISO tank of GTL fuel. Some of this fuel was run off via the manifold and a visual inspection of color was made until the fuel ran clear and colorless. After cleaning, all manholes were closed to prevent any contamination from dust, rain, etc. before loading the fuel (see Fig. 2).

3.2. GTL characteristic and its influence on vehicle performance

GTL synthetic diesel fuel is derived from the hydrocarbon compounds from natural gas using a Fischer–Tropsch chemical reaction process [9]. It has been demonstrated that GTL has good compatibility with petroleum derived diesel fuel and no vehicle modifications are needed when using GTL on a traditional diesel vehicle [10]. However, due to the different characteristics of the two fuels, vehicle performance can be different. Table 2 presents the characteristics of GTL produced by Shell Corporation in the Malaysia plant and the No. 0 diesel vehicle with sulfur content of 50 ppm produced by Beijing's Yanshan Petrochemical Corporation.