SUMMARY OF DOCTORAL'S DISSERTATION

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Title

Forecasting Life Cycle CO_2 Emissions of Passenger Vehicles and Needs for Automotive Lubricants Considering Vehicle Use Environment in Japan

Abstract

CO_2 emissions reduction is one of the major drivers of change in the automotive industry. In order to meet the tightening CO_2 emissions regulations, the electrification of automobiles has been accelerated in recent years, and the electrification of automobiles will bring drastic structural change of the automotive industry. For example, when shifting from conventional internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs), it is inevitable that lubricants in use for ICEVs have significant impacts. Meanwhile, BEVs and fuel cell vehicles (FCVs), which do not emit any tailpipe CO_2 emissions during vehicle operation, contribute to produce a significant amount of CO_2 emissions during vehicle production as well as electricity and hydrogen generation.

Therefore, this study was performed to determine (1) future life cycle CO_2 ($LCCO_2$) emissions of passenger vehicles that take into account heating, ventilation, and air conditioning (HVAC) and the future electricity generation mix from 2008 up to 2030 in Japan and (2) future needs for automotive lubricants. The following are the findings of this research:

(1) A comparative $LCCO_2$ emissions analysis of passenger vehicles is conducted. ICEVs, hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs) as well as BEVs and FCVs are investigated. The results show that the HVAC energy consumption has significant impact on vehicle $LCCO_2$ emissions, and the HVAC energy consumption is correlated with only outside air temperature. In other words, the HVAC energy consumption is unaffected by the difference of powertrain systems, and the impact of the HVAC energy consumption on the conclusion of the comparative vehicle $LCCO_2$ emissions analysis is insignificant. Meanwhile, HEVs effectively reduce $LCCO_2$ emissions with the current Japan's energy mix which heavily relies on thermal power generation. In contrast, PHEVs show the most competitive $LCCO_2$ emissions in 2030, when nuclear and renewable power generation are expected to widely replace oil-fired power

generation. FCVs also show competitive $LCCO_2$ emissions in comparison with ICEVs. However, the limited number of hydrogen-stands will be critical barrier of the market penetration of FCVs in the future. BEVs show higher $LCCO_2$ emissions compared to HEVs and PHEVs even in 2030 due to high CO_2 emissions in battery pack production. Consequently, it is expected that PHEVs are obtaining considerable market shares in the future. Meanwhile, the environmental benefit of cascading reuse of BEV’s lithium-ion battery in stationary energy storage system (ESS) with the use of photovoltaic system (PV) after automotive use has been investigated. If the suppression of PV output is limited, the repurpose of BEV’s lithium-ion battery in ESS negatively affects to the CO_2 emissions.

(2) The investigation of the environmental impact of a comprehensive set of lubricants is carried out. In comparison with the conventional viscosity lubricants, the latest low viscosity lubricants have been contributing vehicle $LCCO_2$ emission reduction effectively. However, as the vehicle fuel efficiency improves, the contribution of vehicle CO_2 emissions reduction by lowering viscosity of lubricants decreases. Regarding the kinematic viscosity at 100°C of future low viscosity engine oil taking into consideration of the volatility limit, it is estimated that the lower limit of the viscosity of synthetic engine and mineral engine oil will be 4.6 mm^2/s and 5.3 mm^2/s, respectively. Moreover, it is confirmed that the cost-effectiveness of future low viscosity mineral engine oil is high, and the market share of low viscosity mineral engine oils will contentiously grow in the further. On the other hand, the synthetic engine oils, which requires both higher CO_2 emissions in the oil production and higher material cost, lose the effect of vehicle $LCCO_2$ emissions reduction by 2030 if the oil drain interval (ODI) is set to 7500 km as same as mineral engine oils. When taking into account superior anti-oxidation property of synthetic engine oils and extend the ODI to 15,000 km. the synthetic engine oils become cost-competitive alternative compared to low viscosity mineral engine oils. In other words, the popularization of synthetic engine oils toward 2030 will require the consideration of both viscosity reduction and ODI extension. Meanwhile, it is expected that the future engine oil will hit the lower viscosity limit which comes from the limitation of current engine design such as volatility property and surface roughness of engine parts. In order to maintain cost-competitiveness of engine oils, the development of lower volatility base-stocks and dedicated oils for electrified vehicles are required.

Key Word:
Clean energy vehicle, CO_2, Electricity generation mix, Electrification, Life cycle assessment, Lubricants