Life Cycle Analysis of Battery Electric Vehicle and Hydrogen Fuel Cell Vehicle in China

(中国におけるバッテリー電気自動車と水素燃料自動車のライフサイクル分析)

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Abstract

In China, the explosion of the vehicle market has caused a series of environmental concerns such as energy security, climate change and air pollution. The growth of light-duty passenger vehicles (LDPVs) is the most significant. To reduce the environmental pressures caused by LDPVs, vehicle electrification has been rapidly promoted in China. Battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (HFCVs) are the two leading vehicle electrification technologies with no pollutant emitted from tailpipe. Chinese government has launched some policies and incentives to accelerate the development of BEVs, HFCVs and the related industries. However, the energy consumption and pollutant emission in the process of upstream fuel production for BEVs and HFCVs cannot be ignored. The potential environmental impacts of BEVs and HFCVs need to be investigated from the life cycle perspective.

Therefore, the objectives of this study are to (1) estimate the energy consumption, greenhouse gas (GHG) emissions and air pollutants emissions of volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), sulfur oxide (SO_x), and particulate matter ($PM_{2.5}$ and PM_{10}) from individual BEV and HFCV in China for the current and near future; (2) assess the impact of the deployment of BEVs and HFCVs on the energy consumption and emission of GHG and air pollutants in the future.

Firstly, this study presented a well-to-well (WTW) analysis (i.e. vehicle fuel life cycle analysis) of individual BEV charged by gird electricity mix for the current (2017) and near future (2030) scenarios. The "Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model" was applied to simulate the WTW results. The results were also compared with the gasoline-fueled internal combustion engine vehicle (gasoline-ICEV). The results show that BEV could achieve significant reductions in terms of fossil fuel consumption (by 52%), especially petroleum consumption (by 99%), compared with gasoline-ICEV in 2017. BEV could also reduce the WTW emissions of GHG (by 39%), CO (by 92%) and VOCs (by 81%). However, in terms of

NO_x, SO_x, PM_{10} and $PM_{2.5}$, BEV could produce more emissions on a WTW basis for both current and future scenarios.

Similarly, a WTW analysis was conducted to investigate the fossil fuel consumption and emissions of GHG and air pollutants for HFCV under various hydrogen (H_2) supply pathways in China for the current (2017) and near future (2030) scenarios. Hydrogen produced from fossil feedstock including coal and natural gas, water electrolysis using grid electricity and renewable electricity, and industrial by-product derived from coke oven gas (COG) and chlor-alkali process were considered. The results show that the fossil fuel energy saving and emission reduction of GHG and air pollutants of different H_2 supply pathways vary significantly. HFCV can reduce fossil fuel consumption by 11−92%, compared with gasoline-ICEV in 2017, with one exception that HFCV based on on-site water electrolysis with grid electricity in which fossil fuel consumption increased by 10% instead. Regarding GHG emissions, HFCV based on water electrolysis using the renewable electricity performs the best while that based on on-site water electrolysis using grid electricity performs the worst in 2017. Remarkably, HFCV based on all H_2 pathways can achieve a significant reduction of WTW VOCs and CO emission, compared with gasoline-ICEV in 2017. Also, it can achieve a 29−79% WTW NO_x emissions reduction, except HFCV based on on-site water electrolysis with grid electricity. Regarding SO_x, $PM_{2.5}$ and PM_{10}, HFCV based on coal gasification, COG and on-site water electrolysis with grid electricity have no emission reduction benefits. Moreover, due to increased share of renewable electricity and improvement in the fuel economy, reductions in WTW fossil fuel consumption and pollutants emissions are expected by 2030.

Finally, a bottom-up model was established to assess the impacts of the deployment of BEVs and HFCVs on the energy consumption and emissions of GHG and air pollutants from LDPV fleet in the future (2017-2040). According to the latest plan formulated by the government and industry associations, three scenarios were designed to reflect the deployment of BEVs and HFCVs: reference scenario (REF), business as usual scenario (BAU) and aggressive scenario (AGG). The results show that the total LDPV stock will increase from 182 million in 2017 to 492 million in 2040. The LDPV fleet is dominated by gasoline vehicles in the REF scenario. In the BAU scenario, which reflect the current policies and plans, the vehicle stock of BEVs and HFCV will reach 229 million and 25 million in 2040, respectively. Regarding WTW energy consumption, BAU scenario and AGG scenario can significantly reduce fossil fuel consumption relative to REF scenario. Regarding GHG emission, BAU scenario and AGG scenario can reduce 13% and 40% GHG emissions by 2040, respectively. What’s more, the GHG emissions in BAU scenario and AGG

scenario will reach a peak earlier and lower than the REF scenario, indicating that the accelerating the development of BEVs and HFCVs could help China achieve the goal of carbon emission peaking before 2030. As for air pollutants emissions, BAU scenario and AGG scenario can significantly reduce the WTW CO, VOCs and NO_x emissions in the long term compared with REF scenario. However, BAU scenario and AGG scenario would cause more WTW SO_x, PM_{10} and $PM_{2.5}$ emissions than REF scenario due to the upstream emissions from electricity and H_2 production and distribution. Overall, these results suggest that besides the stringent emission controls for gasoline-ICEVs, high BEV and HFCV penetration, more measurements should focus on cleaner electricity and H_2 supplies to guarantee a successful electrification future in China.

Keywords: Well-to-wheel analysis; Battery electric vehicle; Hydrogen fuel cell vehicle; Energy consumption; Greenhouse gas; Air pollutants