Well-to-Wheel Analysis of Automotive Fuels in Indian Context

Yash Nandola (Presenting Author), Mechanical Engineering, IISc, yashnandola@alum.iisc.ac.in
Uttam Krishna, Santanu Pramanik, Prasad Boggavarapu, Himabindu M., R. V. Ravikrishna

1. INTRODUCTION

India's dependence on crude oil imports for energy needs and the burgeoning pollution problems associated with present-day vehicle technologies makes it imperative to assess potential future fuel and propulsion systems. Such a study can be achieved by analyzing the complete cycle of the fuel from production to use in the propulsion system, also termed as a Well-to-Wheels (WTW) analysis. The study consists of three parts, the Well-to-Tank (WTT) analysis, Tank-to-Wheel (TTW) analysis, and the combined WTW analysis. The WTT part computes the energy use and emissions generated during the fuel production stage, whereas the TTW stage concerns the energy use and CO_2 emissions associated with vehicle operation over a typical Indian drive cycle. Both the WTT and TTW results are integrated to provide the final WTW estimates of energy use and CO_2 emissions. WTW analysis is also repeated for two other electricity generation scenarios for the year 2030. Thus, the three scenarios for which the analysis is performed are: 1. Current (transmission and distribution (T&D) loss=20.7%, share from non-fossil sources=25%) 2. 2030 Conservative (T&D loss=16%, share from non-fossil sources=29%) 3. 2030 Aggressive (T&D loss=9.9%, share from non-fossil sources=44%).

2. FORMULATION

WTT analysis was performed using equations used by Patil et al. [1] and updated data for recent years. The current WTW analysis involves studying five fuels and twelve fuel-vehicle technology combinations for four-wheeler vehicles. WTT and WTW analysis is performed using GREET software developed by Argonne National Laboratory. The mathematical model for each drivetrain configuration is prepared using the Autonomie® Software. Rolling resistance, drag force, drive cycle, and grade are kept constant for all the configurations to compare energy use and CO_2 emissions. Toyota Yaris is selected as the base vehicle model for the study. This study involves comparing the performance of a Toyota Yaris-like vehicle with 12 different fuel-powertrain configurations, including conventional, series hybrid electric vehicle (HEV), series plug-in HEV (PHEV) using gasoline, diesel and CNG, series HEV & PHEV using a hydrogen fuel cell, and battery-powered configuration. When preparing models of new powertrain configurations, the components are sized using the scaling option of Autonomie® such that they meet the same performance criteria as the base vehicle: **time from 0-100 kph = 14.7s, top speed = 189 kph, at least 6% gradeability at 100 kph.** After the sizing of vehicle components is done, the vehicle model simulation is run over MIDC, according to prescribed standards (one MIDC for all other configurations, multiple MIDC cycles for PHEVs) for different powertrain configurations to obtain fuel economy. 80% charging efficiency is assumed to calculate electrical energy consumed from the grid to charge the battery. The TTW energy use is the energy consumed from the battery and/or as fuel to drive the vehicle. The TTW CO_2 emissions is calculated using estimated fuel economy, density, and carbon ratio of the fuel. The TTW efficiency is the ratio of energy available at wheel and TTW energy use from battery and/or engine [2]. Results of the WTT and TTW analyses are integrated to estimate WTW analysis results using equations used by Patil et al. [1].

3. RESULTS AND DISCUSSION

Production of gasoline, diesel and CNG show similar WTT energy efficiency (~84%) and CO_2 emission (~11 g/MJ of fuel) values. The current electricity generation mix is least efficient (28.7%) and most CO_2 emitting (263 g/MJ of fuel) because of close to 70% dependence on coal which causes the Battery Electric vehicles (BEVs) to be just as efficient as conventional gasoline or CNG powered four-wheeler with similar WTW CO_2 emissions. The study also shows that hybridization tends to significantly improve WTW efficiency and reduce WTW CO_2 emissions, mainly attributed to efficient operating points of the engine, the lower engine running time, and regenerative braking. Simulations of the aggressive scenario for the year 2030 (44% electricity generated from non-fossil based sources and India meets NDC targets) show that there is a dramatic increase in the WTW efficiency of the BEV and plug-in series hybrids.

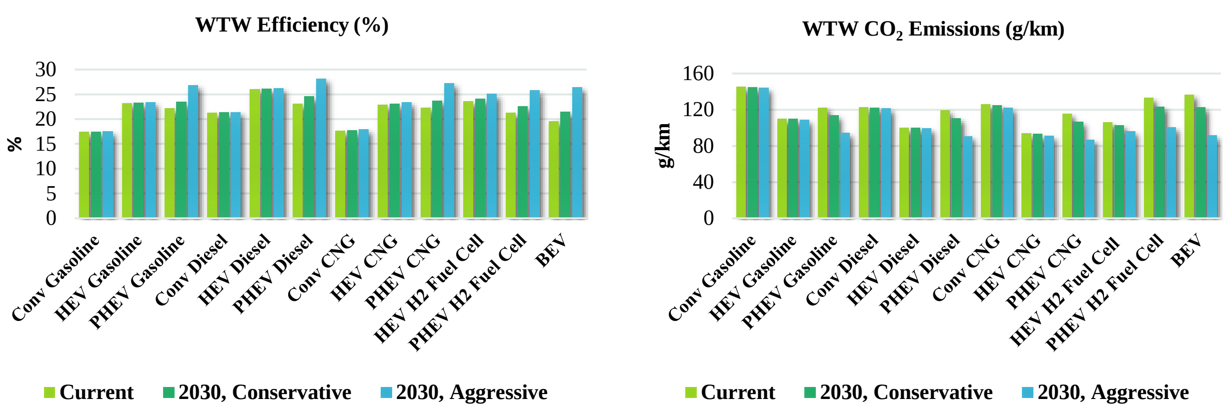

Fig 1: (a) WTW Efficiency (left) and (b) WTW CO_2 Emissions (right) for Electricity Generation Scenarios

Owing to the reduction in WTW energy use, there is a corresponding reduction in WTW CO_2 emissions for plug-in hybrids and battery electric powertrain configuration. For the 2030 aggressive scenario, plug-in hybrids exhibit CO_2 emissions comparable with those of battery-electric and lower than those associated with other powertrain configurations.

4. CONCLUSION

There is an urgent need for India to consider alternatives to crude oil imports for the transportation industry, which will also have a minimum environmental impact. The WTW analysis clearly shows that unless the electricity mix in India moves aggressively towards renewables while significantly lowering T&D losses, four-wheeler BEVs will not be different from conventional diesel, gasoline and CNG powered vehicles in terms of energy efficiency and CO_2 emissions.

References

[1] Patil V, Shastry V, Himabindu M, Ravikrishna RV. Life-cycle analysis of energy and greenhouse gas emissions of automotive fuels in India: Part 2 – Well-to-wheels analysis. Energy 2016;96:699–712.

[2] Gupta S, Patil V, Himabindu M, Ravikrishna RV. Life-cycle analysis of energy and greenhouse gas emissions of automotive fuels in India: Part 1 – Tank-to-Wheel analysis. Energy 2016;96:684–98.