A WELL-TO-WHEEL ANALYSIS OF ELECTRIC VEHICLES AND GREENHOUSE GAS SAVINGS

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Abstract
The European Union has set a target for 10% renewable energy in transport by 2020, which will be met using both biofuels and electric vehicles. In the case of biofuels, for the purposes of meeting the target, the biofuel must achieve greenhouse gas savings of 35% relative to the fossil fuel replaced. For biofuels, greenhouse gas savings can be calculated using life cycle analysis, or the European Union default values. In contrast, all electricity used in transport is considered to be the same, regardless of the source or the type of electric vehicle. However, the choice of the electric vehicle and electricity source will have a major impact on the greenhouse gas savings. This paper examines different electric-vehicle scenarios in terms of greenhouse gas savings, using a well-to-wheel life cycle analysis.

Introduction

There has been considerable growth in the alternative fuel vehicle sector over the last number of years arising from concerns with global warming and climate change. Internationally many countries have ambitious targets to reduce greenhouse gas emissions and energy demand in transportation [1]. It is expected that the light-duty passenger fleet of the future will consist of a variety of vehicle types including more advanced internal combustion engines using gasoline, biofuels, liquid petrol gas, natural gas and diesel. Other alternative fuel vehicles of the future include fuel cell vehicles (FCV) and electric vehicles (EV). Electric vehicles are further sub-divided into battery electric vehicles (BEV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV). Therefore the traditional tank to wheel (TTW) analysis is no longer sufficient to study all the environmental and energy impacts of the light-duty passenger fleet as the mix of vehicle types and the energy sources has increased. In order to fully examine all the energy and to a limited extent the environmental costs all the pathways from the original energy and material sources to the wheel must be considered. Thus full fuel cycle from the well to tank (WTT) and the TTW must be integrated. This combined approach is called a well to wheel (WTW) analysis.

The European Union has set a target for 10% renewable energy in transport by 2020. This target can be met both by biofuels and by electric vehicles. In the case of biofuels, Directive 2009/28/EC states that in order to be counted for the purposes of meeting the target, the biofuel must achieve greenhouse gas (GHG) savings of 35% relative to the fossil fuel replaced [2]. For biofuels, greenhouse gas savings can be calculated using life cycle analysis (LCA), or the default values contained in the Directive. In contrast, all electricity used in transport is considered to be the same, regardless of the source or the type of electric vehicle and a weighting factor of 2.5 is applied to renewable energy in transport. This includes electricity. However, the choice of the electric vehicle and electricity source will have a major impact on the GHG savings. In this paper some of the worldwide research in well-to-wheel analyses of EV's is examined from a high level. The paper is divided into two main sections. Firstly, the WTT, TWW and WTW technical terminologies are explained. Secondly, some previous studies are briefly compared. Then there is a short discussion and conclusion and the next stage of this research is set-out.

Technical Descriptions

A WTT analysis is associated with the fuel cycle stage from the well to the tank. It accounts for the energy consumed and GHG emissions produced to extract, transport, refine and distribute at the retail level the fuel from the primary raw feedstock source to the vehicle tank. It is the combination of all the steps that turns the natural resource (i.e. crude oil, coal, natural gas, liquid petrol gas, biomass, wind, nuclear, solar, wave and tidal) into a fuel (i.e. liquid, gas and electricity).

One of the most widely used WTT models is the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model developed in 1999 by Argonne National Energy Laboratory to evaluate the impacts of new fuels and vehicle technologies [3]. This model uses drive cycles based on American conditions, with an American full sized General Motors Corporation (GMC) pick-up truck and the pollutant emissions used are from United States Environmental Protection Agency data sets.

A TTW is an analysis of the fuel cycle in terms of vehicle architecture, powertrain and fuel effects of the vehicle drive cycle. It accounts for the energy consumed and GHG emissions produced to move the vehicle. The most common software tools used to carry out a TTW analysis is Powertrain System Analysis Toolkit (PSAT) by Argonne National Energy Laboratory and the US Department of Energy [4] and the Advanced Vehicle Simulator (ADVISOR) by the National Renewable Energy Laboratory and the US Department of Energy [5]. PSAT and ADVISOR simulate fuel economy and performance in realistically, taking into account behavior and control system characteristics for a variety of vehicle and fuel types. Argonne National Energy Laboratory has recently developed a newer more user-friendly piece of software called AUTONMIE [6].

The WTW analysis combines both the WTT and TTW and accounts for the total primary energy consumed by the vehicle for each kWh of energy given at the wheel. Figure 1 illustrates the combined approach, which forms the WTW.

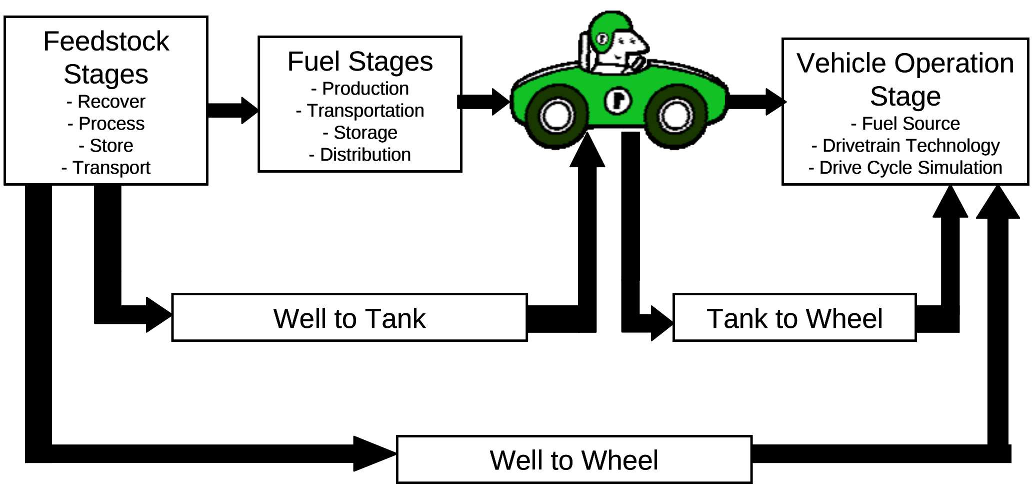

Fig. 1 Combined Cycles from Well to Wheel

Some Previous Studies

In 2002 GMC produced a similar follow-up study to Reference [7], which used GREET, but instead of an American full sized GMC pick-up truck a standard European vehicle was used (i.e. Opel Zafira) in a European Driving Cycle (EDC) mode to European customer performance conditions and with European power plant efficiencies [8]. The other differences included different crude oil refinery scenarios, different natural gas supply scenarios and additional renewable energy sources were explored. The results of both GMC were consistent in terms of fuel-powertrain rankings. Of course the WTW values were lower in Europe because of the lower vehicle mass in Europe.

GREET was also adopted in a number of North American WTW studies, which examine the energy and environmental impact of alternative fuel vehicles including EV's [9, 10, 11 and 12]. In 2005 ADVISOR was used in Reference [13] to undertake a WTW comparative study of a hybrid EV and a FCV. Similar studies were carried out in Europe by References [14, 15, 16 and 17]. Reference [18] provides a comprehensive literature review of the WTW studies and noted that:

- Most of the studies available accounted for energy and GHG emissions impacts.
- Interestingly, most of the studies seem to find that the best energy option did not always correspond to the best GHG emissions option.
- New technologies were predominant in the studies and the limitations such as driving range for EV's were not fully examined.

Similar to Reference [18], it was found that most of the studies were based in North America [19, 20 and 21], Europe [22 and 23] and China [24 and 25]. This is of particular importance when examining EV's as the electricity mix is a key factor in achieving the optimum WTW analysis.

Finally, it must be noted that to truly capture the entire energy and environmental impacts of all vehicles including EV's the full materials lifecycle or LCA, as well as the WTW fuel cycle should be captured from the '*cradle to the grave*'. The European Union has an adapted version of ISO1404, the international standardized LCA methodology, which establishes the system boundaries in a WTW analysis [26 and 27]. This is why some European studies refer to a WTW analysis as an LCA, even though the '*grave*' aspect of the vehicle was not considered [28]. Care must taken when establishing the system boundary.

Discussion & Conclusion

This paper has identified that a number of large scale WTW studies have been undertaken internationally to examine a variety of fuel/vehicle energy pathways and described the terms WTT, TTW and WTW. Smaller studies are very rare. In Europe there has been very little country specific activity specifically in the area of EV's. This is particularly relevant to each European Member State in light of the European Union target for 10% renewable energy in transport by 2020. In North America most of the WTW expertise is concentrated in Argonne National Energy Laboratory and the National Energy Laboratory.

Considering that the government in Ireland intends to achieve European Union renewable energy targets with a number of policies including the 3% biofuels in transport 2010 target and ensuring that 10% of all vehicles in the transport fleet are powered by electricity by 2020 a WTW analysis would be a worthwhile study [29]. In addition, a further target of 40% electricity from renewable sources, predominantly expected to come from variable wind power by 2020 has also been set by the Irish government [30]. This adds another interesting dimension as the electricity generation mix in the EV energy/vehicle pathway will continue to change in Ireland right up to 2020.

In light of these targets and the future growth in alternative fuel vehicles and particularly EV's in Ireland, the next stage of this research is to undertake a WTW analysis to examine the actual total energy consumed and GHG emissions produced. The first step will be to gather the data necessary and use GREET with the Irish electricity mix, fuel conditions and either PSAT or ADVISOR with the Irish fleet profile up to 2020 using the new EDC and driver performance conditions.

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