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Justification of Hydrogen Economy for Zero-Emission Vehicles (ZEVs)

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INTRODUCTION

Though it was subtitled as a "non-technical review", the UNEP report, "**The Hydrogen Economy (2006)**" and Ulf Bossel's energy efficiency calculation cited by Lisa Zyga (***PhysOrg***) set the building blocks for an anti-hydrogen economy. The UNEP report stated that the hydrogen economy was based on a widespread misconception. Ulf Bossel concluded that the hydrogen economy was a "wasteful economy." Quoting from the article, "The large amount of energy required to isolate hydrogen from natural compounds (water, natural gas, biomass), package the light gas by compression or liquefaction, transfer the energy carrier to the user, plus the energy lost when it is converted to useful electricity through fuel cells, leaves around 25% for practical use — an unacceptable value to run an economy in a sustainable future."

Both battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (FCVs) were born as solutions for zero-emission vehicles (ZEVs), the prevention of earth warming, and removal of carbon footprints in transportation sector. With the rapid growth of the BEV industry, it looks like many supporters of EV foresaw future competition with FCV makers, and attempted major assaults on FCVs **[A]** **[B]** **[C]** **[D]** **[E]** **[F]**. All attacks on the hydrogen economy and FCVs are based on the UNEP report and Ulf Bossel and are very categorical in their conclusion.

In this article, we'll be working towards proving that FCVs can provide a better path to ZEVs than BEVs with better energy efficiency.

Energy Efficiency is All That Counts

In my **previous article**, I proved that EVs charged by grid-tied charge station is a CO_2 amplifier to generate more CO_2 than California Standard ICE fossil fuel vehicles in most US states. To achieve ZEVs with no carbon footprint, I suggested a solar/wind energy direct EV charging infrastructure. Grid-tied hydrogen generation will be accompanied by a large carbon footprint and a low WTW energy efficiency just as with EVs. Hence, grid-tied EV charging stations and FCV refueling stations should be avoided to prevent further global warming.

Figure 1. shows the components involved in "well to wheel" electric power transmission. Assuming the efficiency of each component to be 90%, the WTW energy efficiency is $0.9^{10} = 0.35$, or 35%. With a CO_2 emission multiplication factor f = 2.87, BEVs work as an amplifier of CO_2 emissions as proved in my **previous article**.

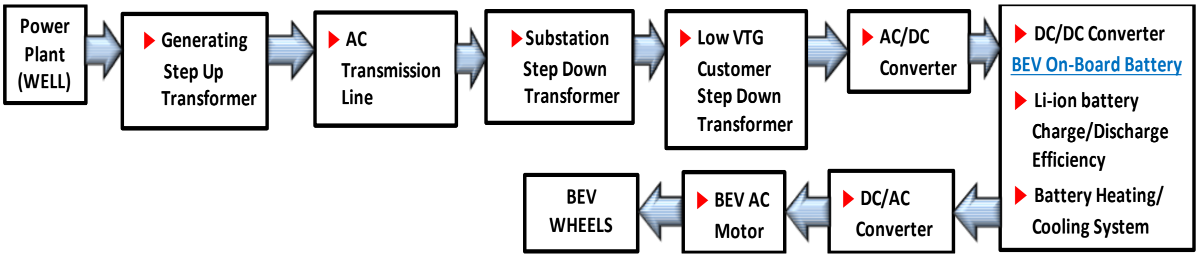

Figure 1. Power and power electronic components affecting WTW efficiency of BEVs

In case where solar PV energy is added to power mix, 11 power or power electronic components are involved as shown in Figure 2. WTW of BEVs will be 0.9^{11} = 0.31, or 31%. It is evident that it is not wise to connect valuable carbon free solar energy to grid for EV charging.

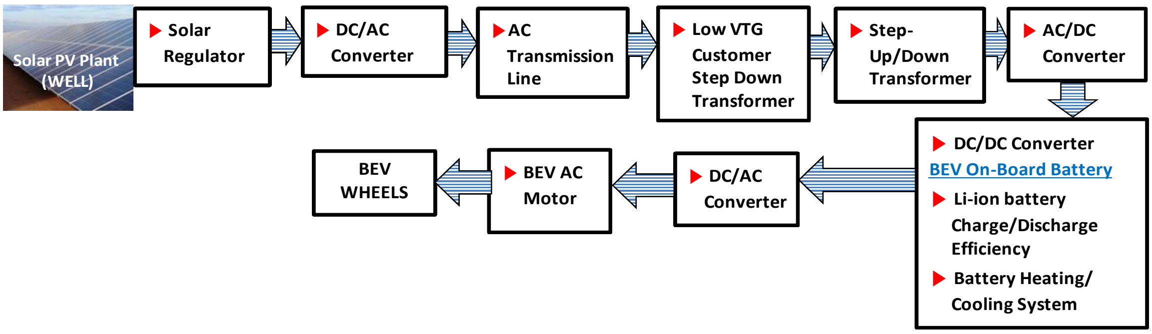

Figure 2. Power and power electronic components affecting WTW efficiency of BEVs when Solar PV energy is connected to grid

Grid connectivity is an important requirement in the siting of large scale solar PV plants. Depending on the grid connection point, WTW efficiency of solar PV energy may be increased or decreased greatly. If the connection requires a generating step-up transformer, the WTW efficiency of a solar PV plant may drop to 28%, or 0.9^{12}. If the connection point requires a low VTG customer step down transformer, the WTW efficiency of EVs would be increased to 43%, or 0.9^{8}. If the connection point of a large-scale solar plant requires a generating step-up transformer and grid-tied battery storage for an EV charging stations, the WTW efficiency would drop below 20%, or 0.9^{15}. Borrowing an anti-hydrogen economist's statement, this is an unacceptable value to run an economy in a sustainable future.

Electric power from large scale solar PV plants should be connected to grid near the end user to make greener power generation sector. Of course, grid-tied EV charging works as CO2 amplifier disregarding grid connection points.

Justification of FCVs by WTW Efficiency

As suggested in the previous article, solar/wind energy direct EV charging should be adopted to be free from carbon footprint. Solar direct EV charging needs battery storage. Figure 3. shows power electronic components involved in solar PV energy direct EV charging. Assuming 90% energy efficiency for all the components, WTW efficiency = 0.9^9 = .39, or 39%.

Hydrogen should be generated directly by solar/wind energy at refueling stations with an electrolyzer. With the direct application of solar/wind energy to water electrolysis, there would be no loss of efficiency through AC/DC conversion and compressed gas transportation. This process would include 3 processes as shown in Figure 4. Modern water electrolysis systems include subsystems (electrolyte cooling, gas purification, operation control & water treatment, compression), and provide an **overall efficiency of 80%**. Therefore, the WTW efficiency of FCVs would be 0.8 x 0.6 (efficiency of PEM fuel cell for transportation application) x 0.9 = 0.43, or 43%. Compared to the 39% WTW efficiency of solar direct EV charging, solar direct FCV refueling would provide 4% higher WTW energy.

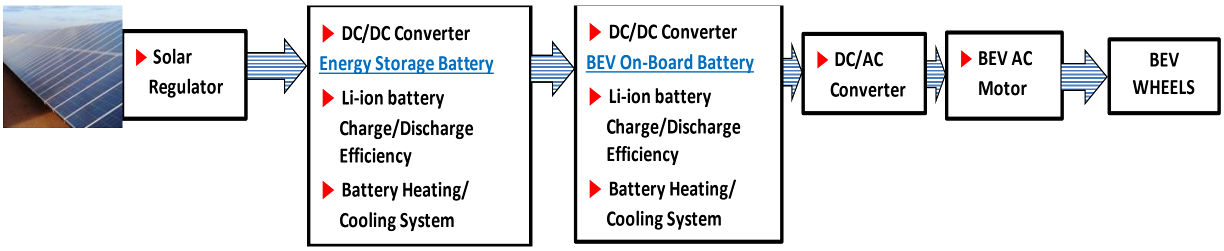

Figure 3. Power electronic devices affecting the WTW efficiency of solar direct EV charging

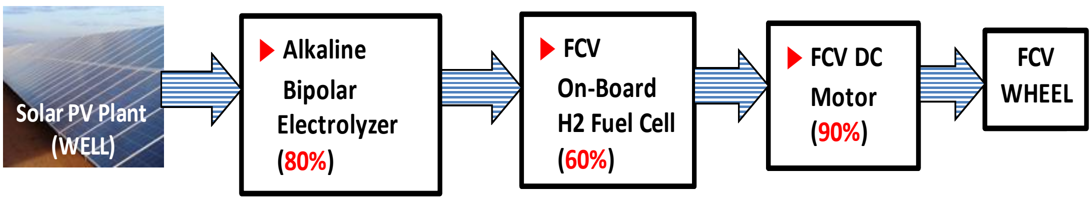

Figure 4. Components affecting the WTW efficiency of solar direct hydrogen refueling station

Most land-based wind turbines generate AC electric power. With a variable output of wind turbine and dependence of the efficiency of DC/AC converters on input fluctuation, DC power generation would be beneficial. Currently, Tesla is the only BEV manufacturer using induction motors. With considerations for efficiency, it would be beneficial to use DC motors both for FCVs and EVs.

Conclusion

Separating EV charging and H2 refueling stations from grid, decarbonization in transportation will be realized. Hence, both EV charging and H2 refueling should be separated from grid.

Solar/wind direct H2 refueling stations would provide higher WTW efficiency than solar/wind direct EV charging stations. With considerations for energy efficiency, DC generating wind turbines may be beneficial. It would also be beneficial for FCVs and EVs to use DC motors rather than AC motors to maximize WTW efficiency.

For large scale solar and wind power plants, the overall efficiency depends on connection point. To maximize the utility of solar and wind energy, it would desirable to connect solar PV or wind energy sources closer to end-users.

For a decade, FCVs have been ostracized by anti-hydrogen economists based on misleading information. In this article, it was proven that FCVs provide a better path toward ZEVs than EVs in WTW energy efficiency.