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The Potential for Vehicle Integrated Photovoltaics

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The transport sector accounts for 23% of global CO_2 emissions with road transport accounting for the majority (73.9%) of that sector, split roughly half between heavy duty vehicles and light passenger vehicles [1]. Electrification of road transport is anticipated to be the principle means for decarbonising the sector with renewable electricity used to charge battery electric vehicles or produce hydrogen for fuel cell electric vehicles. A less obvious opportunity exists for providing photovoltaic electricity from the vehicle itself. In 2016 Toyota demonstrated a modified Prius vehicle that could achieve 30km/day from conventional c-Si PV panels mounted on the vehicle [2] and last year, demonstrated 50km/day from another Prius with 34% III-V multi-junction solar cells on the vehicle [3]. While these distances sound modest, 30km/day covers over 70% of vehicle journeys in Japan and even in Australia, the average commuting distance is 16km [4]. Photovoltaic power generation from the bodywork of an electric vehicle therefore has the potential to significantly reduce the number of times an EV needs to be recharged. A recent IEA-PVPS Task 17 report has extensively documented the present state of the art in this emerging Vehicle Integrated PV (VIPV) opportunity [5]

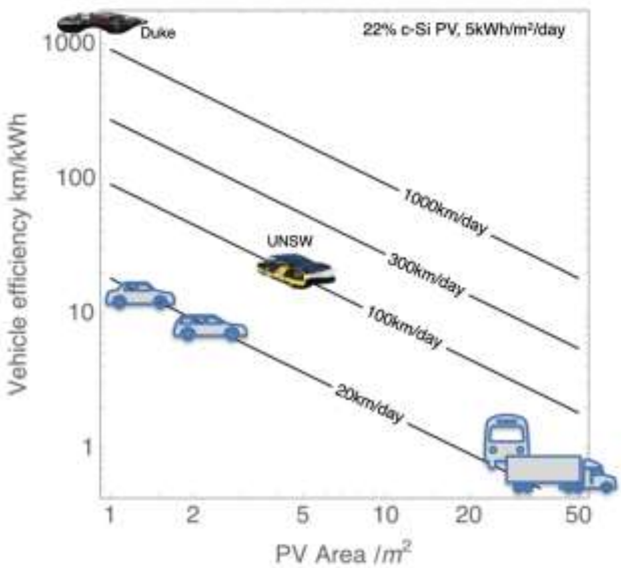

Figure 1. Solar EV range as a function of available area on the vehicle and the vehicle drive efficiency.

Since the area available on a vehicle is limited, the efficiency of the PV technology used and the vehicle drive efficiency are the principle factors for determining the overall solar range of an EV. Figure 1 shows the estimated solar range for vehicles of different area and drive efficiency assuming a 22% photovoltaic technology. Small EVs typically have an electric drive efficiency around 10km/kWh. Heavy vehicles, such as public buses and trucks typically achieve efficiencies around 1km/kWh. The larger area available for PV on the heavy-duty vehicles is almost exactly cancelled out by their lower drive efficiency, so all these vehicles sit on the same 20km/day line. Two pathways for increasing the solar range are evident. If the PV efficiency is increased, the solar range will increase proportionally. At some point in the future it is conceivable that manufacturable PV technologies with an efficiency double of that today might be available. Improvements in vehicle drive efficiency are also possible. Toyota's prototype solar Prius is already operating at 17km/day drive and the UNSW 'cruiser class' solar car racer built by the SunSwift student team achieves 34km/kWh, delivering a solar range over 100km/day. To illustrate the dramatic potential for improved vehicle efficiency, it is worth noting that the world record for vehicle efficiency was set by Duke University, achieving 1283km/kWh [6].

On a passenger vehicle, the restricted space places a strong premium on the efficiency of the PV technology. Figure 2 (taken from the recent IEA-PVPS T17 report [5]) indicates the PV capacity available on typical vehicle. There is a clear premium for the efficiency of the PV technology used and a clear merit for any PV technology capable of surpassing 30%. While tandem PV technologies exist that operate in the 30-40% efficiency [7] their cost is presently higher than the acceptable cost for a VIPV array [8]; approximately $5/Wp.

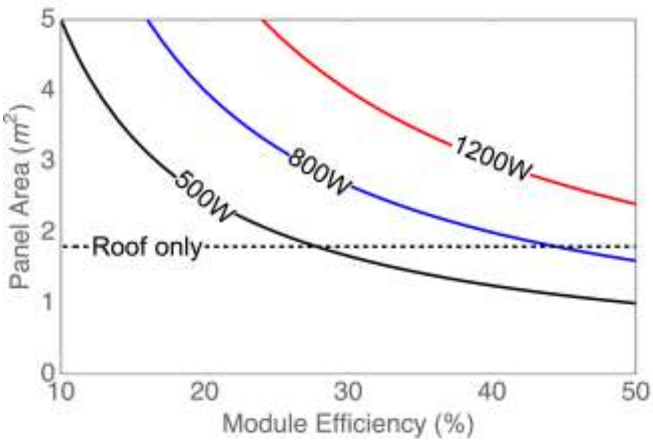

Figure 2 : PV capacity as a function of area and efficiency. A typical EV has less than 2m^2 of available area on the roof. Figure reproduced from [5]

To perform a real-world trial of VIPV in Australia, a BMW i3 EV has been purchased and retrofitted with different PV technologies that will be monitored throughout 2021 together with the incident irradiance using wireless datalogging and irradiance measurement hardware [9]. This initial phase of the project will simply monitor the electrical power generated by PV modules located on the roof and sides of the vehicle. In the second phase of the project, anticipated to begin in 2022, the PV power will be delivered to the EV battery pack providing true solar charging of the EV.

In summary, VIPV represents a new application for PV where, with present PV and EV technologies, a solar range up to 20km/day can be achieved from the vehicle surface. Improvements in vehicle drive efficiency and PV efficiency can significantly increase this distance, potentially reducing the density for on-street charging points. Consumer perception surveys suggest that VIPV technology is viable today and could become a standard feature in future electric vehicles.

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