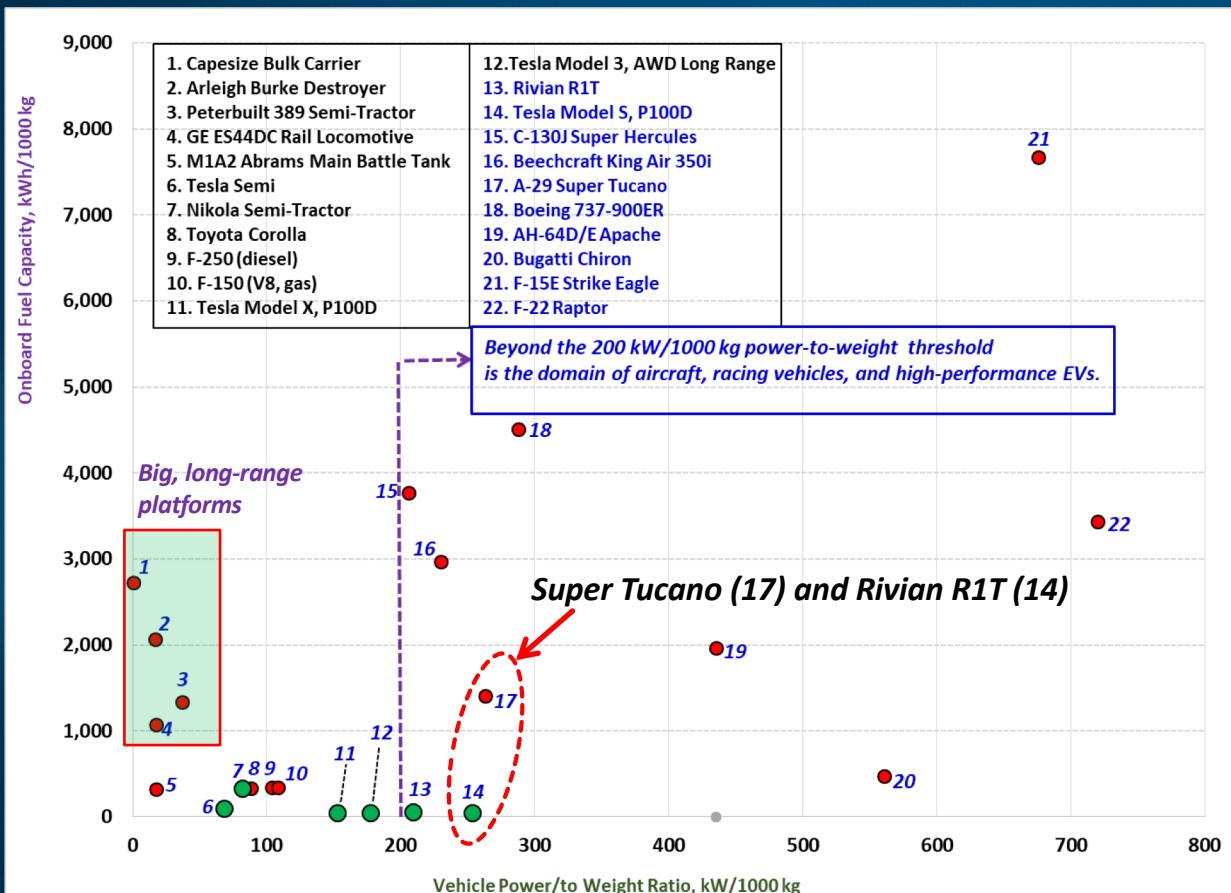


EVs = Power-to-Weight Ratio of an Aircraft, Onboard Fuel of a Subcompact Car

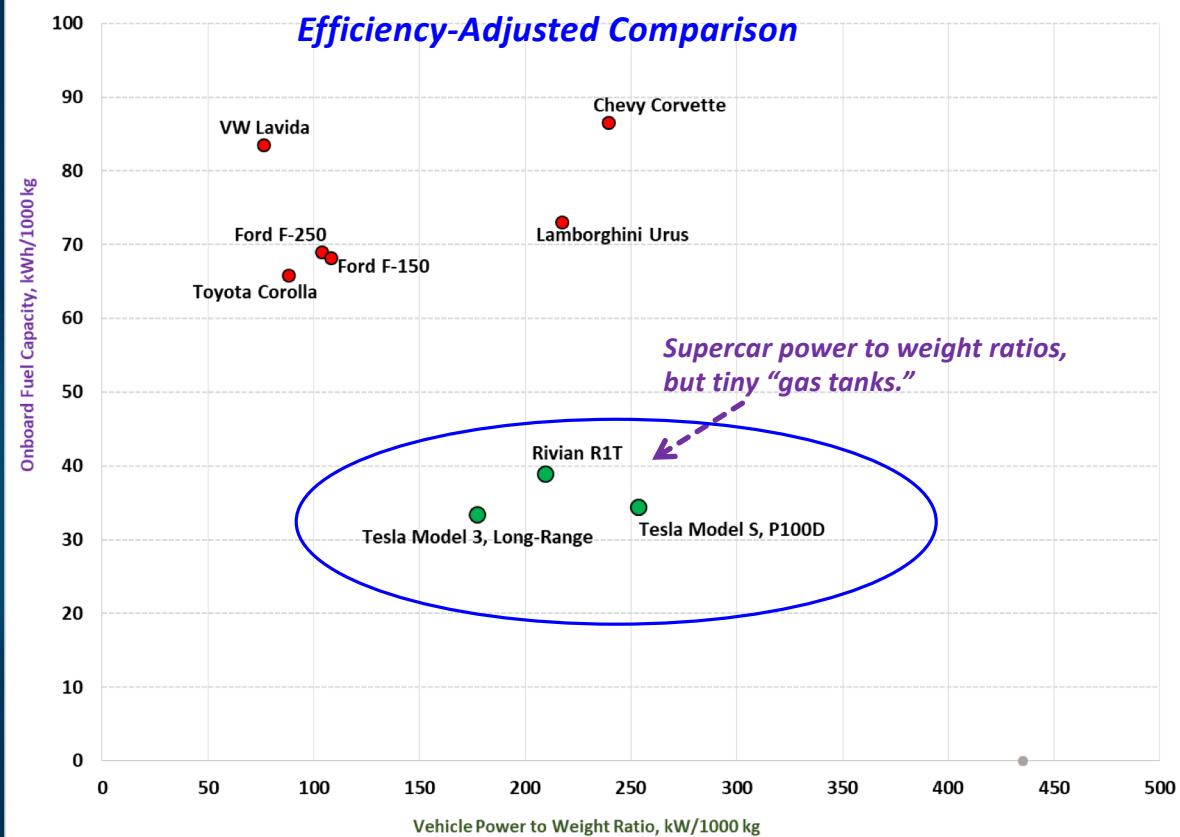


Source: Beechcraft, Car & Driver, EIA, EV Database, GE, Global Security, Man, Nikola, Peterbuilt, Rivian, SNC, Trucks.com, USAF, US Navy

- Electric vehicles' instant torque and high horsepower make the higher-end editions true performance monsters. Their power-to-weight ratios are often on par with turboprop aircraft and many helicopters.
- The fly in the ointment comes from the fact that batteries remain heavy and relative to hydrocarbons and simply cannot store energy nearly as efficiently per unit of mass.
- The power-to-weight/onboard energy density relationship of the Rivian R1T electric truck and A-29 Super Tucano attack aircraft is such that "Rivianizing" the Tucano would mean making its onboard jet fuel stores retain their current energy content, but weigh more per liter than lead metal. Needless to say, the plane's flight endurance and carrying capacity would fall dramatically.
- This estimate assumes the A-29's PT-6 turboprop has a thermal efficiency of about 35%--less than half the R1T's likely capacity to convert fuel into actual propulsive energy.

Please cite as: Gabriel Collins, "The EV Conundrum: High Power Density and Low Energy Density," Baker Institute Research Presentation, 8 January 2020, Houston, TX

Electric Vehicles' Onboard Energy Still Significantly Trails ICE Vehicles On an Efficiency-Adjusted Basis



Source: Carmudi Philippines, Car & Driver, Chevrolet, EIA, EV Database, fueleconomy.gov, Rivian

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Baker Institute Research Presentation, 8 January 2020, Houston, TX

- To make the energy density comparison a bit more fair, we adjust the onboard fuel based on the fact that EVs convert nearly 80% of their battery energy into tractive power at the wheels, while IC vehicles feature efficiencies closer to 20%. (US DOE)
- But even with the adjustment, vehicles running on gasoline or diesel fuel still have about twice the onboard energy density of an EV.
- Battery energy densities have improved in recent years, but a near-term doubling of energy density is unlikely.
- IC vehicles also recharge much more quickly, needing around 5 minutes to fill up even a large pickup truck tank, whereas a state of the art Tesla V3 Supercharger still likely needs about 20 minutes to completely charge a 100 kWh battery pack. In real life, few drivers wait until their tank is nearly empty to fill up and EV drivers will also likely top up in a somewhat similar fashion, but the significant filling speed differential still endures as a matter of electrochemistry. (<https://www.tesla.com/blog/introducing-v3-supercharging>)

Jet Fuel Density Adjustment Calculations

- JP-5 jet fuel contains a minimum energy content of 18,300 BTU/lb, or 40,333 BTU/kg. This equates to 11.8 kWh of energy per kg ($40,333 \text{ BTU} \div 3,412 \text{ BTU/kWh}$) ([Source 1](#))
- A turboprop engine like that of the A-29 Super Tucano likely operates with a thermodynamic efficiency of approximately 35% ([Source 2](#))
- This in turn yields a “usable” JP-5 energy content of 3.5 kWh/kg ($11.8 \text{ kWh} * 35\% \text{ thermo efficiency} * 0.85 \text{ fuel tank weight penalty}$) and 2.7 kWh/liter ($3.5 \text{ kWh/kg} * 0.778 \text{ kg/liter JP-5 density}$).
- The Panasonic 2170 battery cells used in Tesla’s Model 3 have a volume of 24.25 cm^3 , weigh 0.07 kg apiece, and contain 0.0173 kWh of energy apiece ([Source 3](#)). As such, they have a density of 2.9 g/cm^3 and a weight-based energy density of 0.25 kWh/kg, which after imposing a 25% weight penalty for battery pack housing, cooling systems, and other components, yields an energy density of 0.19 kWh/kg. Assuming an EV is 80% efficient in transferring fuel energy into motive force, the “usable” energy density of the pack would thus be 0.15 kWh/kg.
- As such, the JP-5 fuel’s “usable” energy density in mass terms is 23 times higher than the lithium-ion battery’s ($3.5 \text{ kWh/kg} \div 0.15 \text{ kWh/kg}$). Taking the JP-5’s actual density of 0.778 g/cm^3 and multiplying it by 23 to impose the energy density weight penalty would yield 17.9 g/cm^3 , nearly 60% higher than the density of lead metal (11.3 g/cm^3).
- **Source 1:** (National Research Council (US) Subcommittee on Permissible Exposure Levels for Military Fuels. Washington (DC): National Academies Press (US); 1996. 2, Physical and Chemical Properties of Military Fuels, <https://www.ncbi.nlm.nih.gov/books/NBK231234/>
- **Source 2:** National Academies of Sciences, Engineering, and Medicine. 2016. Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions. Washington, DC: The National Academies Press. <https://doi.org/10.17226/23490>.
- **Source 3:** Kyle Field, Tesla Model 3 Battery Pack & Battery Cell Teardown Highlights Performance Improvements, CleanTechnica, 28 January 2019, <https://cleantechnica.com/2019/01/28/tesla-model-3-battery-pack-cell-teardown-highlights-performance-improvements/>