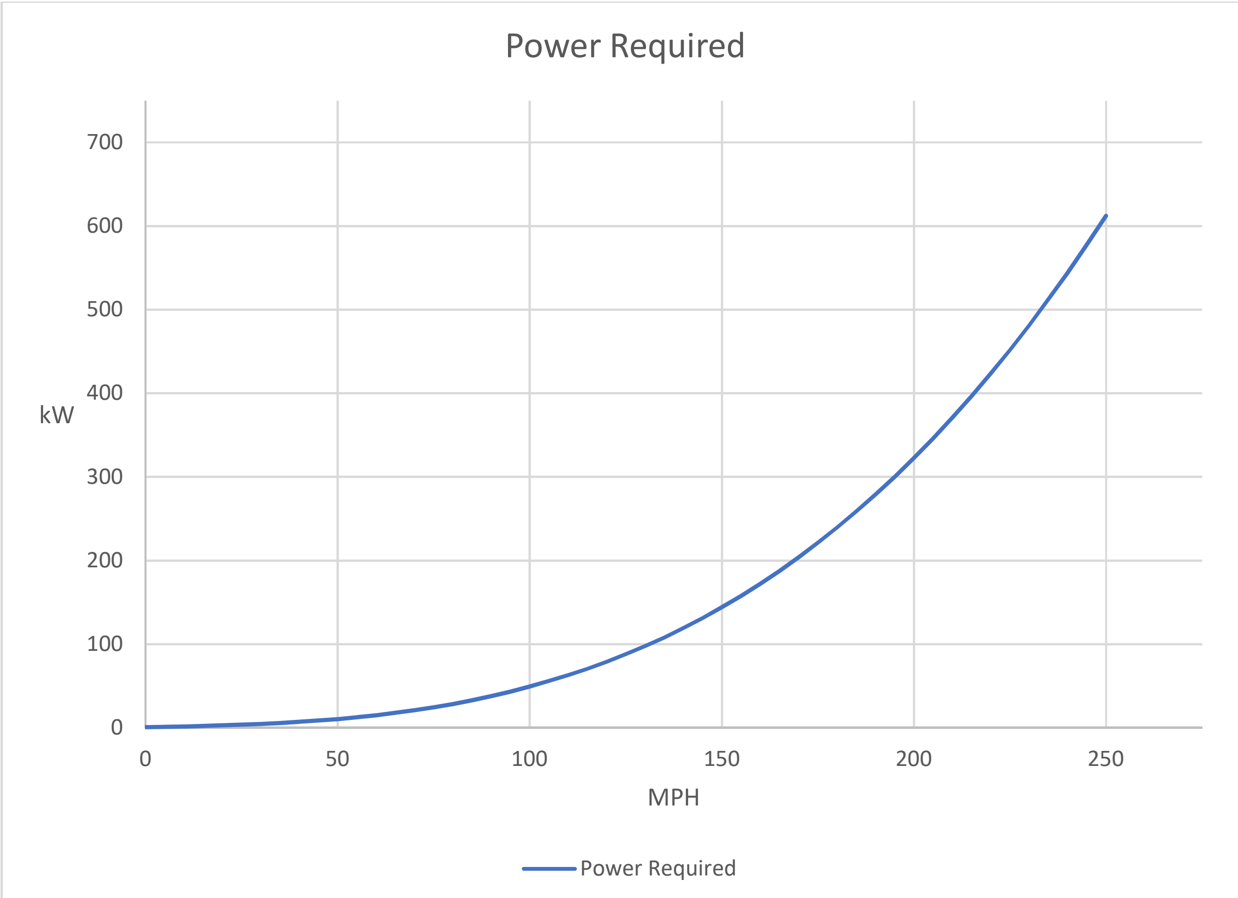
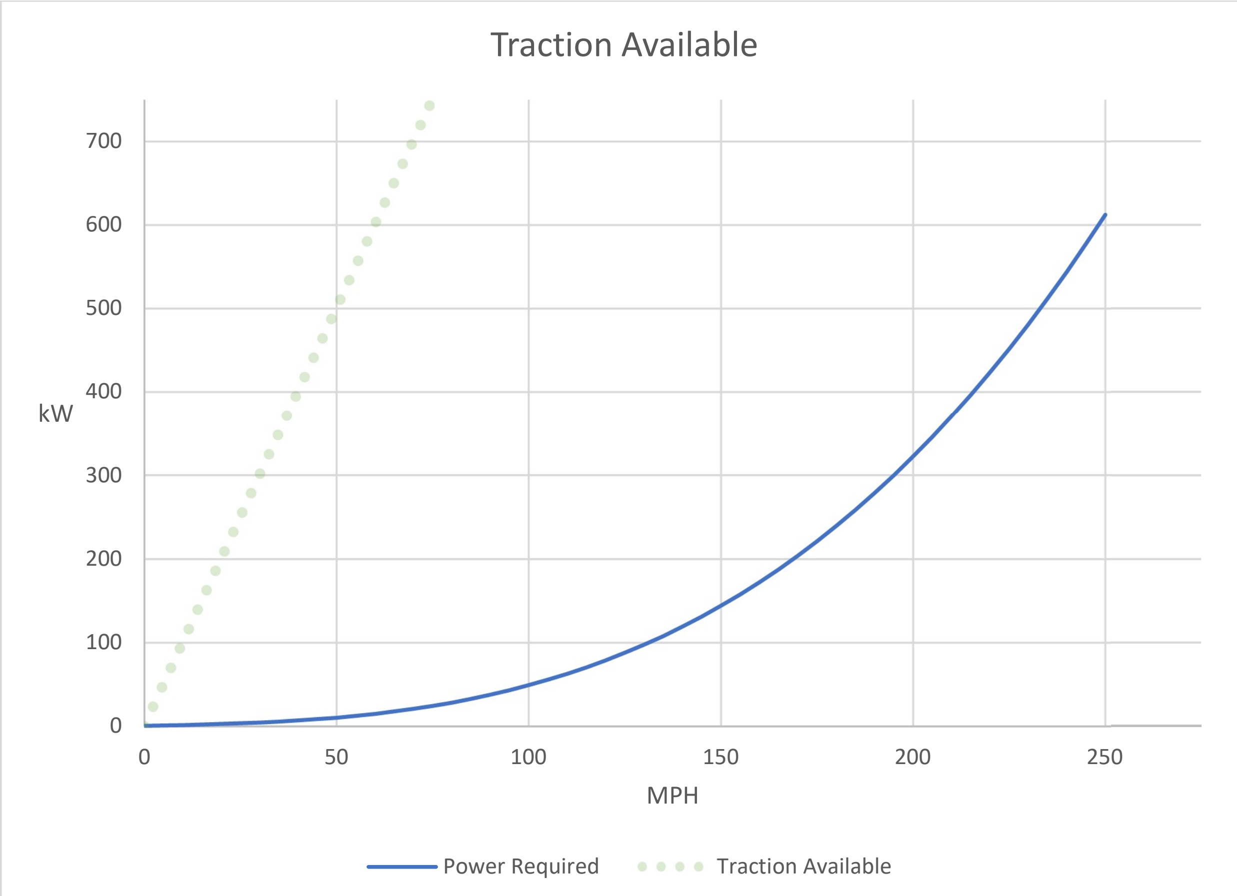
Should Electric Cars Have Multiple Gears

Updated 07-30-2020

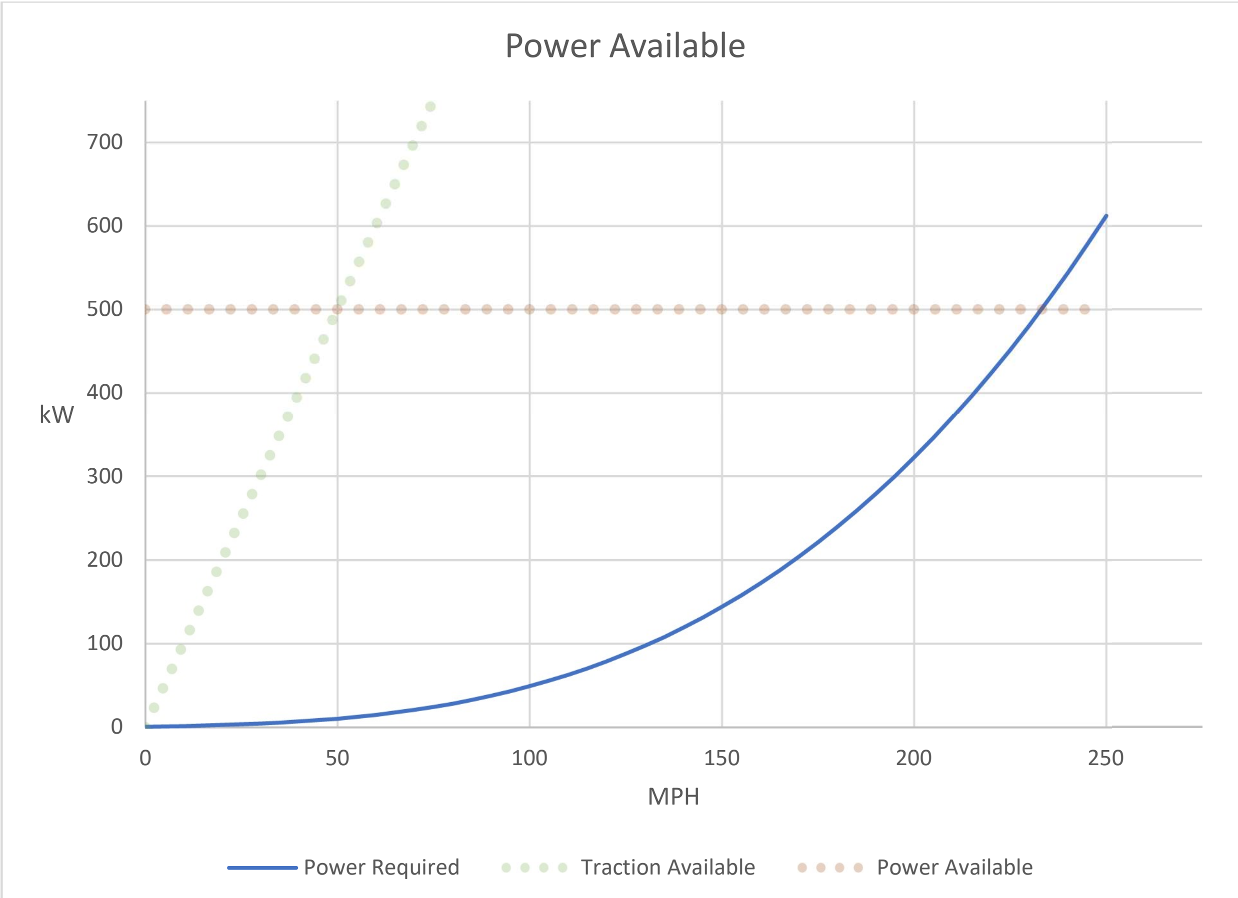
I’ve seen many debates on how a Battery Electric Vehicle (BEV) would benefit from a multi-speed transmission for many years. I’ve had the same stance since around 2006 when I was part of a team putting together an electric drivetrain for a large corporation. It’s difficult to explain my stance on multi-speed transmissions in simple terms, so I decided to write up a document that I could share on social media.



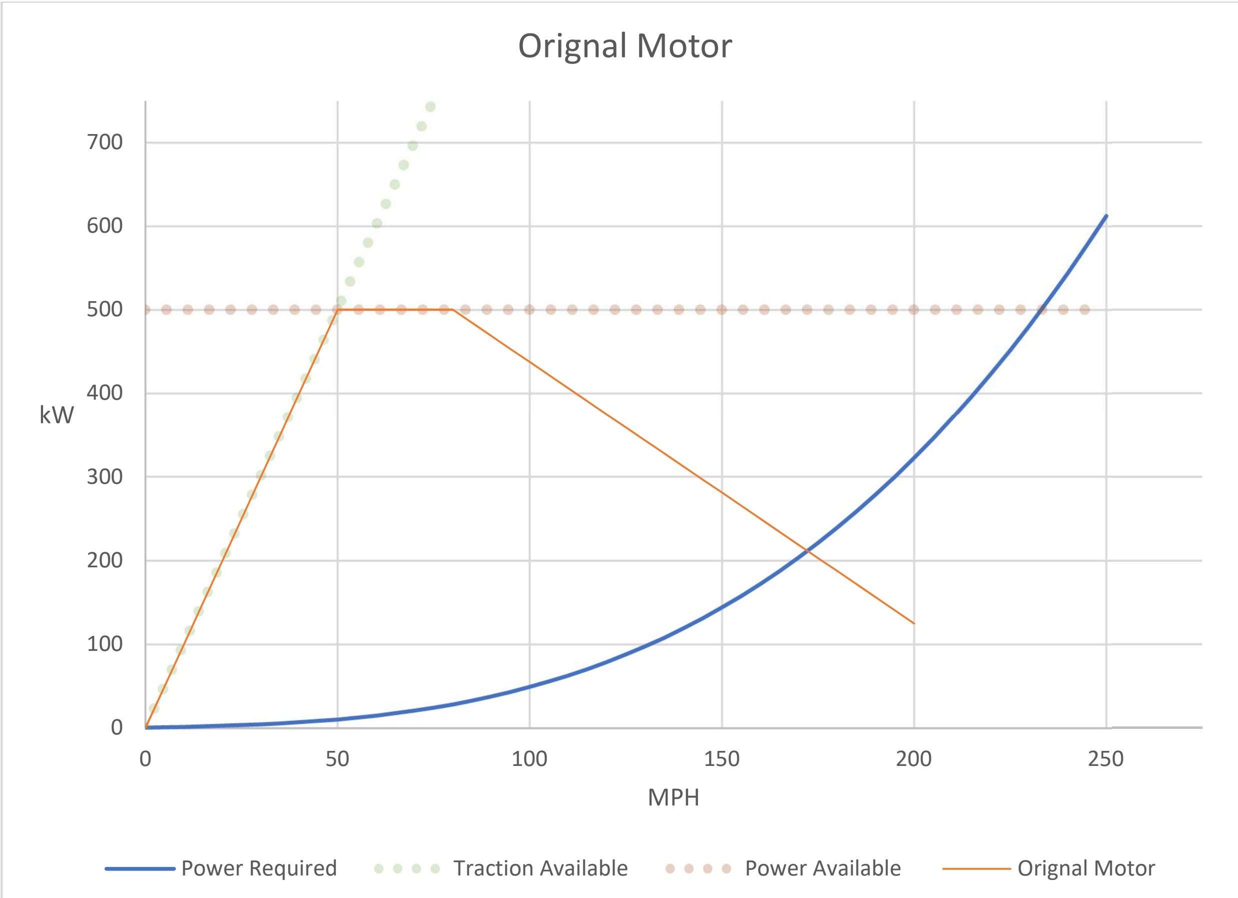
Since the biggest benefit to a multi-speed transmission in a BEV is in top speed, I'll start with the power requirements for going fast. This curve isn't for a specific car, but it gets the point across. It's probably pretty similar to what a Tesla Model 3, Ioniq, or maybe a sportscar would experience. Different cars would have different curves, but that would mostly only change the actual top speed the car would reach and wouldn't affect the rationale behind a two-speed transmission. You can see that the power requirements go up very quickly at higher speeds.



Next, we'll plot out the traction available to the car. Any more power applied to the tires than this diagonal line will only cause the tires to spin and won't accelerate the car more quickly. A heavier car or tires with better grip will make this line more vertical, but that won't change our results. The same can be said for non-linear changes in traction caused by things like downforce.



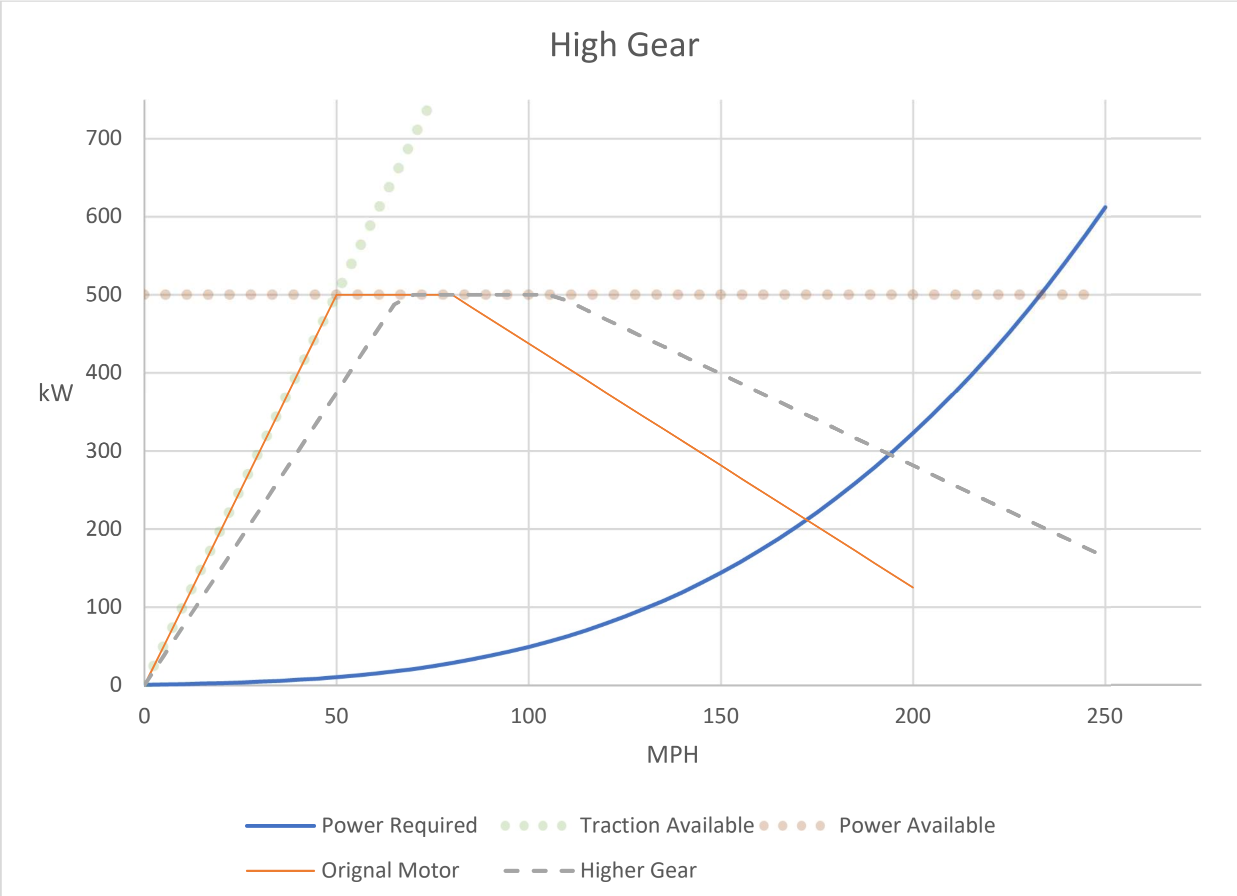
We’ll also need to define the amount of power the battery can safely deliver. I choose 500kW for the nice round number. This isn’t as high as a Porsche Taycan or a Performance Tesla Model S or X, but It’s probably higher than most other BEV’s. This value will change with temperature and state of charge but it will stay a horizontal line which is all the matters to this example.



Now we have to choose a motor for our car. Conveniently, motors have constant torque at lower RPM's that, with the correct gearing, will line up with the traction available extremely well. This is mostly why BEV's are so unbeatable off the line. If the BEV has as much traction as another vehicle, there's no amount of power that can be applied to accelerate faster.

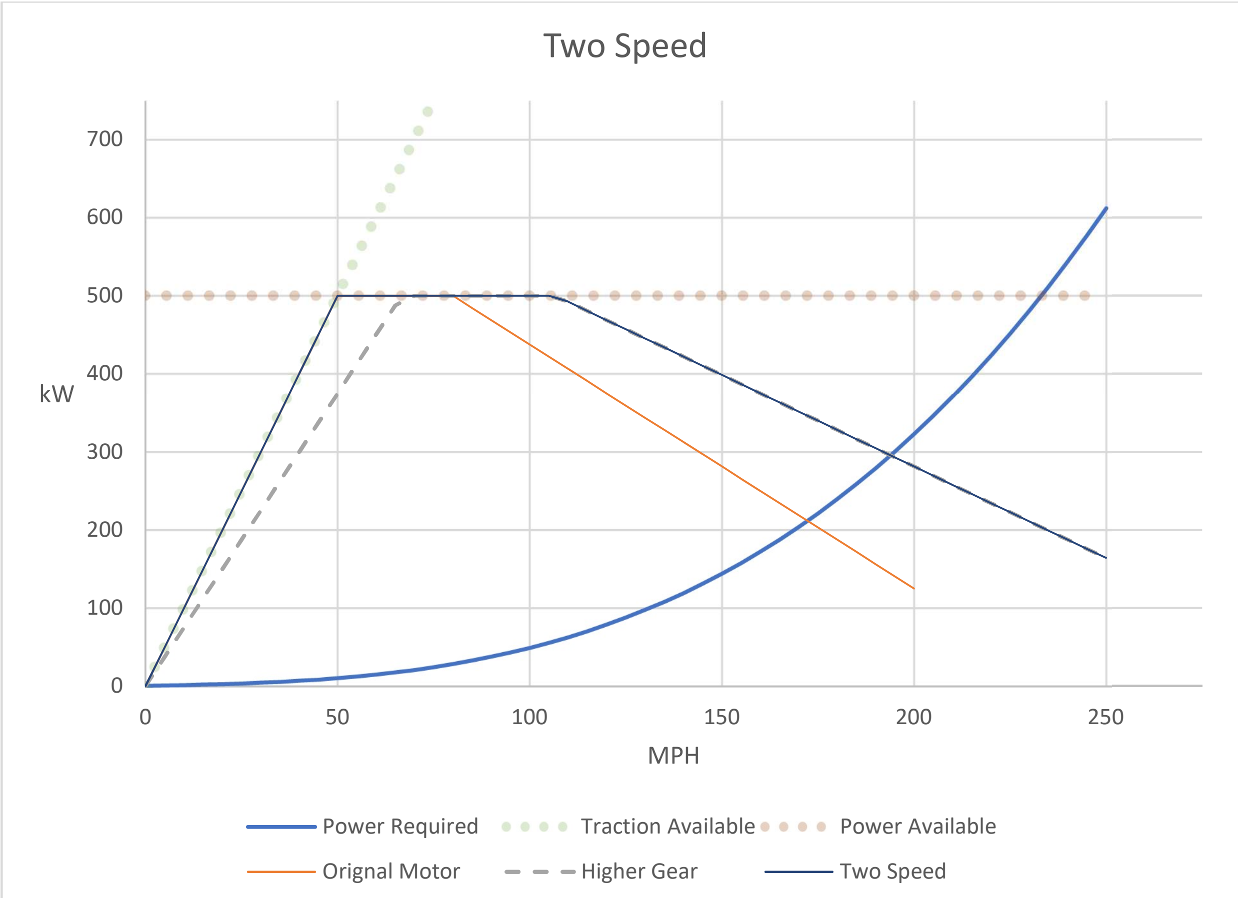
Most motors also have constant power after peak power is reached, and that can line up with the power available just as well. Some motors will stay at peak power for longer, while others will start to drop right away, and the loss of power won't always be linear, but those other curves won't change the outcome much.

As the power drops and the power required to go a given speed increases, we reach a point where the motor doesn't have enough power to go any faster. In this case the car tops out at 175 MPH.

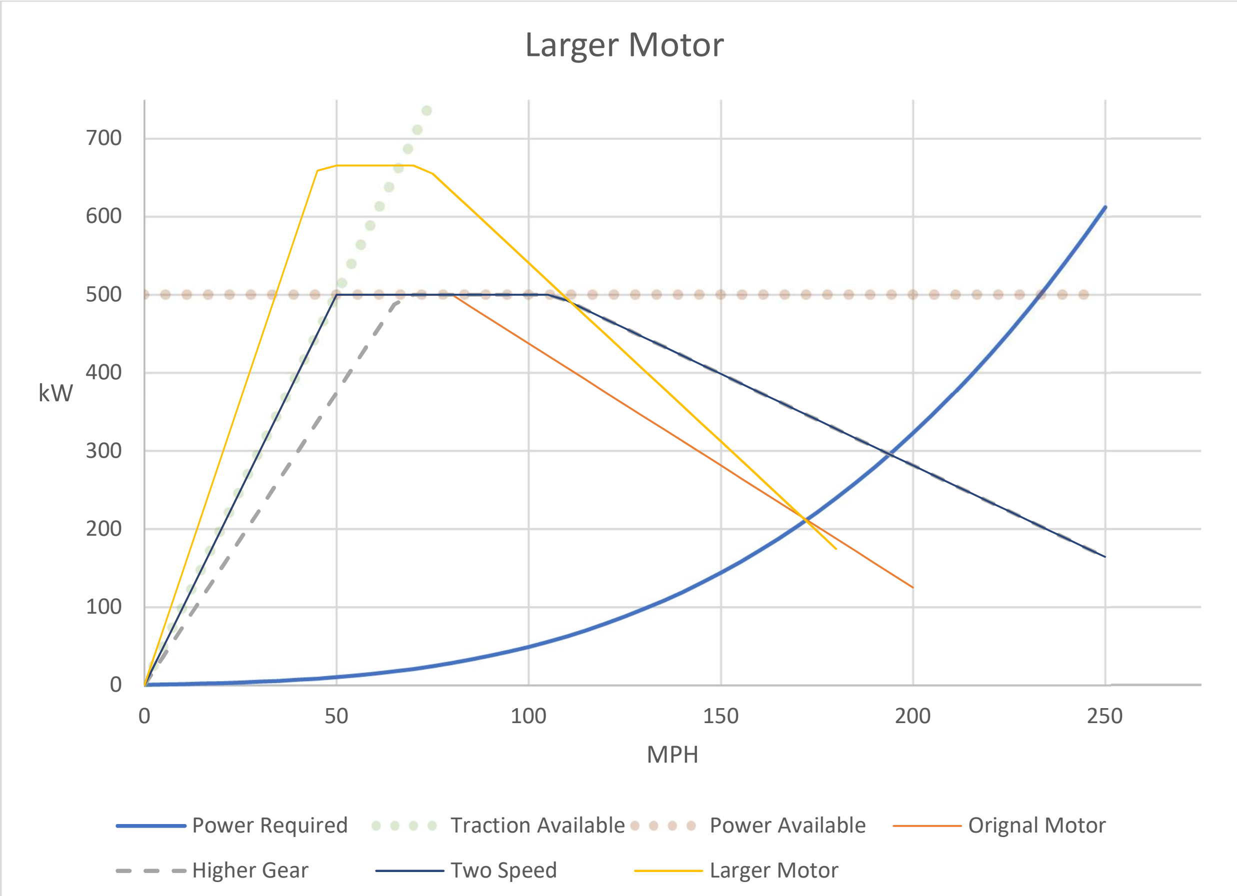


Nobody says that the car has to be geared right to the edge of traction though. What happens if we increase the gear ratio by a third?

You can see that speeds above 80MPH the car is capable of putting more power to the ground and ends up with a higher top speed of 195MPH. The downside of doing this is the lower performance of the car below 70MPH. It's not hard to argue that performance below 70MPH is more important than performance above 80MPH.



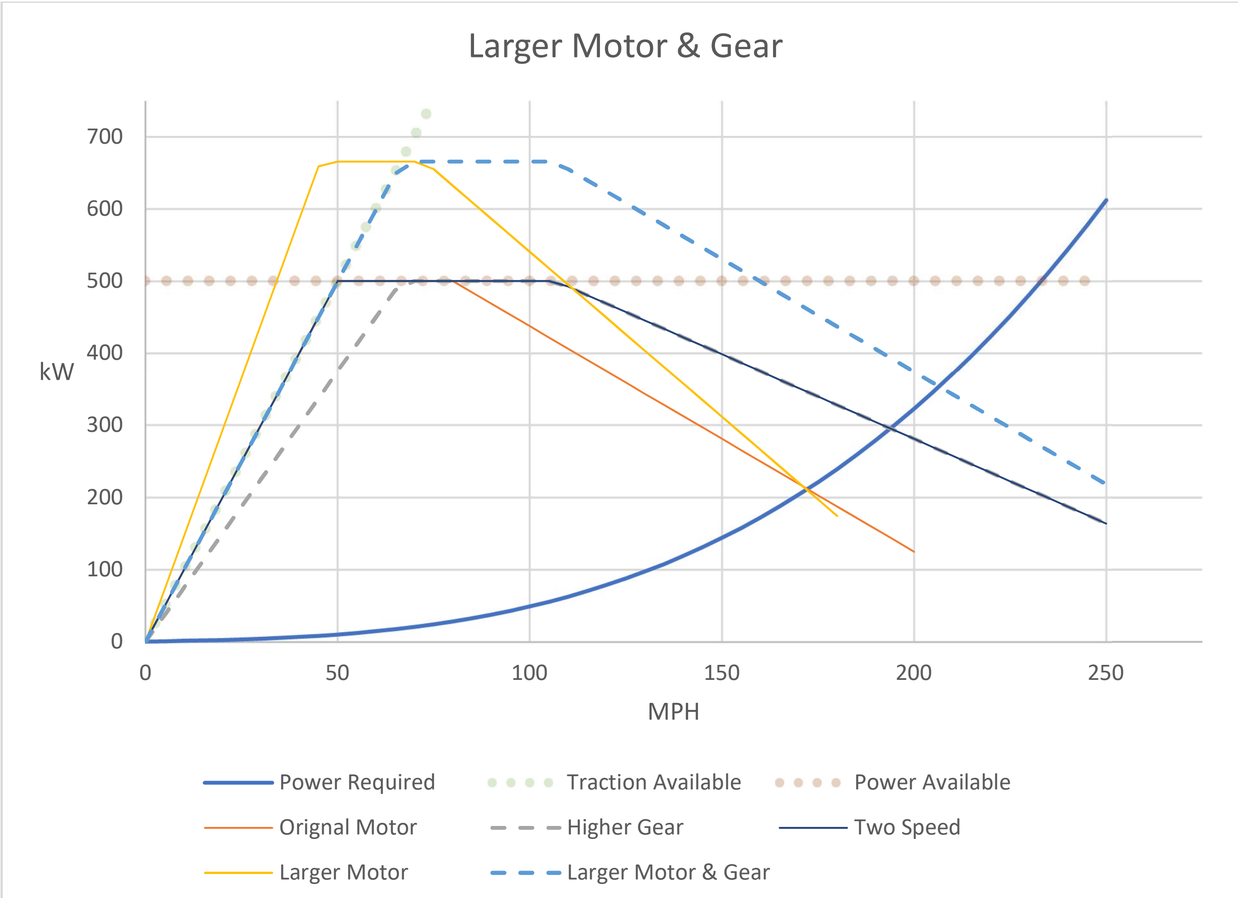
The obvious solution is to put in a two-speed gearbox. As long as the transmission shifts between 70 and 80 MPH, you get the full benefit of both gears. The only downside is the relatively small weight and added complexity of the two-speed transmission. It's looking like a slam-dunk for two speed transmissions and many engineers would stop the analysis here, but were going to go a little further, just to be sure.



What if we took the space and weight of the two-speed transmission and put that into a bigger motor. Let's just scale up the motor we've got by 10%. That means 10% longer, 10% larger diameter, and 33% more weight.

The 10% larger diameter means 10% lower RPM, 21% higher torque. Overall, the maximum power will increase 33%.

When we hook that up, we gain the ability to produce a lot more tire smoke. Peak power is never reached because the battery can't provide that much power. The larger rotor just can't turn as fast, so we end up with the same top speed of 175MPH. The only thing we gained with the added weight is faster acceleration above 80MPH, but not as fast as a two-speed transmission. It doesn't beat the two speed at all, except maybe a tiny bit around 110MPH.



With the bigger motor, a higher gear can be driven. When we increase the gear ratio of the larger motor to line up with the traction available, an amazing thing happens. The battery still caps the power output of the motor to 500kW, but the motor can provide that output all the way up to 160MPH. The higher gear ratio allows a slower decay of power output and the end result is a top speed of 210MPH.

A three-speed transmission on the original motor could meet or exceed the performance of the larger motor, but with a greater penalty to weight and cost. If that additional weight and cost were dumped into an even larger motor, that motor would extend the top speed even further, maybe all the way to the 230MPH limit of the battery output.

Another advantage of the larger motor is that it's easier to cool a large motor that's running at 75% of its capacity than a smaller one that's running at 100%.

Instead of going to a larger motor, you could get the same results by using more of the same motor. Going from 2 motors to 3 motors would be about like scaling up the motor size by 15%, without having to design a new motor.

This all leads to the conclusion that R&D should be focused on motor, inverter, and battery development as opposed to the development of multi-speed gearboxes. It seems unlikely that a better designed or larger motor will ever be out performed by a two-speed that is less heavy, takes up less space, or is less expensive to design, and they'll never be more reliable, or more efficient than a single speed gearbox.