



(Photos courtesy Wikimedia Commons)

The Toyota Prius (shown above left) is one of very few cars that have a higher city mpg rating than their highway rating. The 2007 Prius achieved 60 mpg on the EPA city test schedule, but only 51 mpg on the highway test schedule. Even some other hybrids like the Honda Civic hybrid (shown above right) fail to achieve this reversal, scoring 49 mpg on the city test and 51 mpg on the highway in 2007.

Looking at the plots of the EPA city and highway test schedules (see plots on the next page), it is clear that the principle difference between the tests are the many stops and starts required of a car in the city test. The EPA reports that the city test requires an average speed of 21.2 mph over 11.04 miles and 1874 seconds. It includes 23 complete stops, and 18% of the time is spent at rest with the engine idling. Accelerating from rest requires extra power from the engine and tends to reduce mpg ratings, resulting in lower city ratings than highway ratings. Idle time is also usually a problem, since the car is burning gas without going anywhere. Hybrids offset some of these losses by using the electric motor to brake the car, which generates electrical energy, and also by turning off the gasoline motor when the car is at rest.

a.) According to the DOE, one gallon of gasoline provides about 131 MJ of energy. Given that the Prius has a weight of 2900 lbs, estimate how much energy can the car recover if the energy of braking is perfectly transformed into electrical energy in the batteries. For this order-of-magnitude estimate assume all stops are from the average speed of 21.2 mph. Give your answer in gallons of gasoline.

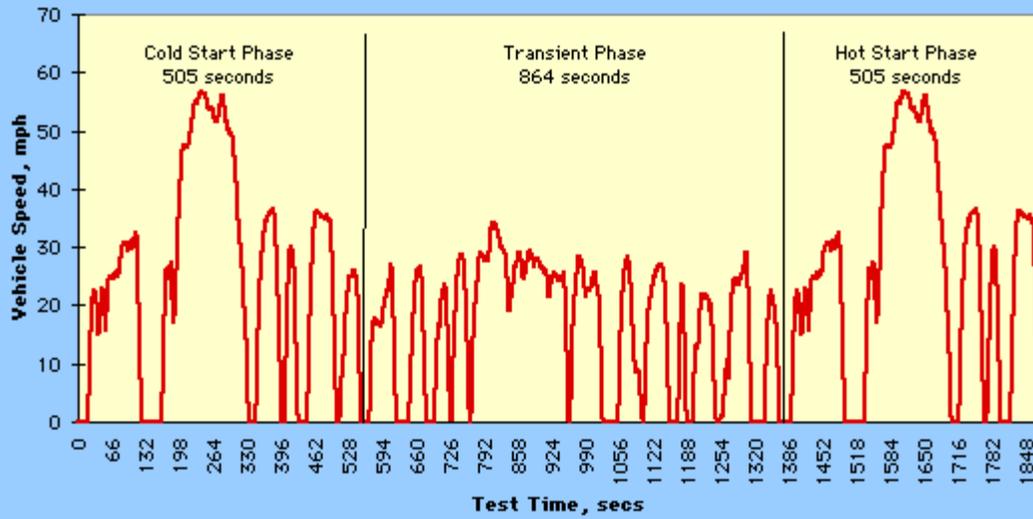
b.) According to the Canadian Office of Energy Efficiency, an idling gasoline engine consumes fuel at the rate of about 0.6 liters of gasoline per hour per liter of engine volume. The Prius has a 1.5-liter gasoline engine, implying a fuel consumption rate of 0.9 L/hr or 0.24 gallons/hr. Using this estimate, how many gallons of gasoline does the Prius save in the city test schedule by stopping its engine instead of idling it?

c.) Using your answers to (a.) and (b.), estimate the mpg rating the Prius would achieve if it did not feature either regenerative braking or engine-off at idle.

d.) Both the Civic and the Prius incorporate regenerative braking and engine-off at idle. The real separation in fuel economy is due to the engine configuration employed. The Prius accelerates from rest up to 15 mph using only its electric motor, which is rated at 67 hp. The 2007 Civic uses both a 95 hp gasoline engine and a 20 hp electric motor in combination. (Because electric motors are much more efficient at producing torque at low rpm than gasoline engines, the Prius actually has better acceleration from rest than the Civic does.) Estimate the number of seconds that would have to be spent accelerating at maximum horsepower in the city test for the Prius to achieve its 11 mpg advantage over the Civic. For your estimate, assume that these cars convert gasoline energy to useful work with an efficiency of 35%. (Recall that the electrical power used in the electric motors ultimately derives from the gasoline engine!)

### EPA Federal Test Procedure

Length 1874 seconds - Distance = 11.04 miles - Average Speed = 21.2 mph



### EPA Highway Fuel Economy Test Driving Schedule

Length 765 seconds - Distance = 10.26 miles - Average Speed = 48.3 mph

