# 2010 Toyota Prius
## Hybrid electric vehicle

# Test Results Report

**February 2012**

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## EXECUTIVE SUMMARY

The 2010 Toyota Prius, despite being a mid-size car, is the most fuel-efficient vehicle across all-classes in Canada in 2010. The Prius is a one of the first full production hybrids to be introduced to the Canadian market. The first model was sold in Japan in 1997 and North America in 2001. Currently the 2010 Prius is a third generation model.

Transport Canada's ecoTECHNOLOGY for Vehicles (eTV) program selected the 2010 Prius for testing and evaluation because it is the most fuel efficient mid-sized vehicle available in Canada. Hybrids are designed to reduce fuel consumption by taking advantage of technologies such as advanced energy storage systems and regenerative braking, which help lower greenhouse gas (GHG) and exhaust emissions. In addition to these systems, the 2010 Prius also uses exhaust gas re-circulation to reduce $NO_x$ emissions, a solar panel moonroof to aid in air circulation/cooling, and a "beltless" engine that further improve engine efficiency. The eTV program selected this vehicle for testing and evaluation because of its fuel efficiency, advanced technologies and advanced hybrid drive-train.

In acquiring the Prius, the eTV program wanted to quantify how it performed under a variety of Canadian climatic conditions, particularly in city driving and in cold weather. The vehicle was tested and evaluated over three phases: laboratory fuel consumption and exhaust emissions; dynamics testing; and on-road evaluations. The following is a summary of the results obtained from these evaluations.

<table>
<tr><th>Criteria</th><th>Results</th></tr>
<tr><td>Fuel consumption (L/100 km)</td><td>Corrected 2-cycle and 5-cycle fuel consumption values can be compared in the table below.<br><table><tr><th>Testing cycle</th><th>City</th><th>Highway</th><th>Combined</th></tr><tr><td>Corrected 2-cycle</td><td>4.2</td><td>4.3</td><td>4.2</td></tr><tr><td>5-cycle</td><td>5.3</td><td>5.2</td><td>5.3</td></tr></table></td></tr>
<tr><td>$CO_2$ emissions</td><td>In combined city and highway testing, the Prius obtained a value of 97 g $CO_2$/km (1950 kg $CO_2$ / year), which is 13% less than the second best in the mid-size class (Ford Fusion Hybrid) and a 57% reduction over the average of all mid-sized cars in 2010 [226.4 g/km (4528 kg $CO_2$ / year)].</td></tr>
<tr><td>Exhaust Emissions</td><td>With regard to non-$CO_2$ exhaust emissions; emissions testing showed that the 2010 Prius meets Tier 2, Bin 3 standards for North America. Results from the regulated emissions for are found in the table below.<br><table><tr><th></th><th colspan="5">FTP-75 Emissions (g/mi)</th></tr><tr><th></th><th>CO</th><th>NMOG</th><th>$NO_x$</th><th>PM</th><th>HCHO</th></tr><tr><td>2010 Toyota Prius</td><td>0.05</td><td>0.007</td><td>0.011</td><td>N/A</td><td>N/A</td></tr><tr><td>Tier 2, Bin 5</td><td>3.40</td><td>0.075</td><td>0.05</td><td>N/A</td><td>0.015</td></tr><tr><td>Tier 2, Bin 3 *</td><td>2.1</td><td>0.055</td><td>0.03</td><td>0.01</td><td>0.011</td></tr></table>*Vehicle full useful life (100,000 miles or 10 years, whatever comes first)</td></tr>
</table>

<table>
<tr><th>Criteria</th><th>Results</th></tr>
<tr><td>Dynamic Performance Testing</td><td>The vehicle performed adequately during all dynamics performance evaluations conducted at the Motor Vehicle Test Centre. The following is a summary of the results from the tests conducted:<br><br>
<table>
<tr><th>Test Parameter</th><th>Result</th></tr>
<tr><td>Acceleration</td><td>0-100 km/h in 11.5 seconds</td></tr>
<tr><td>Maximum speed ($V_{max}$)</td><td>183.4 km/h (top speed overall)</td></tr>
<tr><td>Maximum lateral acceleration</td><td>Skid pad: 7.6 $m/s^2$ (0.77G)<br>Emergency lane change: 9.5 $m/s^2$(0.97 G)</td></tr>
<tr><td>Noise (exterior) –<br>CMVSS 1106</td><td>Acceleration – 62.0 dB (pass)<br>Deceleration – 59.1 dB (pass)</td></tr>
<tr><td>Noise (interior)</td><td>Idle - 49.3 dB<br>Acceleration – 76.8 dB<br>Constant speed (100 km/h) – 70.9 dB</td></tr>
<tr><td>Braking distance –<br>CMVSS 135</td><td>From 50 km/h – 11.5 m (pass)<br>From 80 km/h – 26.9 m (pass)<br>From 100 km/h – 40.7 m (pass)<br>From 110 km/h – 49.3 m (pass)</td></tr>
</table>
<br>* Lateral acceleration results from these tests should be taken with caution because the driver was dictating the pull-out before the vehicle was nearing roll over. For future testing, outriggers would likely have to be affixed to the vehicle to provide more accurate results.</td></tr>
<tr><td>Driver Evaluations</td><td>The majority of the evaluators reported that they were comfortable with the 2010 Prius in all traffic conditions. There were no reported issues with the vehicle’s performance or operation.</td></tr>
</table>

**Potential Barriers to the Introduction of Hybrid vehicles into the Canadian Market**

As a fully Canada Motor Vehicle Safety Standards (CMVSS) compliant model vehicle that has been for sale in Canada for close to 10 years there are no regulatory barriers impeding the sale of the Toyota Prius in Canada.

One of the principal barriers to the introduction of advanced gasoline technologies, such as hybrids, is overcoming the consumer’s desire to minimize the initial purchase price of a new vehicle, often at the expense of longer-term operating costs and environmental impacts.

Conversely, innovative technologies that improve fuel efficiency often increase the initial purchase price of a vehicle. When confronted with the choice of paying more for advanced vehicle technologies such as hybrid vehicles, consumers often opt for a lower initial purchase price, either due to financial considerations, or the lack of information regarding the potential fuel savings that the technology might offer, among other reasons.

## 1.0 INTRODUCTION

Hybrid-electric vehicles (HEVs) are an innovative example of how vehicle manufacturers can integrate gasoline-powered engines with more efficient electric motors to reduce vehicle fuel consumption. HEVs are often equipped with regenerative braking systems to recapture kinetic energy that would otherwise be lost as the vehicle slows and use it to charge the batteries – in conventional vehicles, this energy is lost as heat.

Several aspects of hybrid vehicle technology are being improved, such as using the Atkinson combustion cycle to improve how efficient the engine converts heat energy into mechanical energy. In addition, the 2010 Prius eliminates some loads depending on the engine operation such as water pumps, air conditioning, and alternators.

Ultimately, perfecting the synergy of more efficient engines and enhanced batteries will yield more efficient hybrid electric vehicles available for consumers.

## 2.0 TESTING PROGRAM

The testing program was designed to provide a fair assessment of a hybrid electric vehicle as well as the vehicle's fuel consumption, exhaust emissions and overall handling. Tests were based on practices used by the Canadian *Motor Vehicle Fuel Consumption Standards Act*, the U.S. Environmental Protection Agency (EPA), the International Organization for Standardization (ISO) and SAE International (SAE). See the *2010 Prius Test Plan* for further details.

The Prius was evaluated over three distinct phases:

- Phase I - Laboratory fuel consumption and exhaust emissions testing
- Phase II - Vehicle dynamics testing
- Phase III - On-road evaluations

Together, these various phases were designed to realistically assess the 2010 Prius' overall performance and compare the environmental benefits of this vehicle relative to the average vehicle in the Canadian fleet.

## 3.0 TESTING LOCATIONS

Phase I testing was performed in partnership with Environment Canada at the Emissions Measurement and Research Section (ERMS) located in Ottawa, Ontario. All testing was performed in a controlled laboratory, using a vehicle chassis dynamometer. The laboratory environment ensures that testing is completed to within ± 1 degree Celsius of the required test temperature. Vehicles are tested according to separate driving cycles and are maintained to within ± 1.5 km/h of the required speed.

Phase II testing was performed at Transport Canada's Motor Vehicle Test Centre (MVTC) in Blainville, Quebec. The controlled environment was necessary to ensure that testing was performed on a gradient of ± 1%. The test track is equipped with over 25 kilometres of road, including both a high-speed and low-speed circuit, which allowed for a variety of tests to be conducted. Testing was performed between September 15 and October 23, 2009. Tests were carried out only in weather conditions that were favourable to evaluation and testing standards.

Phase III vehicle evaluations were performed by Transport Canada staff between May and August 2010.

# 4.0 VEHICLE OVERVIEW


***Figure 1: 2010 Toyota Prius***

The 2010 Prius is the most fuel-efficient mid-sized vehicle available in Canada. The 1.8-litre engine is larger than previous models of the Prius and offers an increase in engine/electric power from 110 hp to 134 hp. It is expected that this increase in power will not only improve the quarter mile acceleration of the vehicle, but also will offer improved fuel consumption over previous models due to several innovations that reduce load on the engine.

In addition to technologies such as low rolling resistance tires and regenerative braking seen in regular hybrids, the 2010 Prius also features exhaust gas re-circulation to reduce $NO_x$ emissions, a solar panel moonroof to aid in air circulation/cooling, and a "beltless" engine that further improve engine efficiency, among other advanced technologies. The result is a combined Canadian fuel consumption label value of 3.8 L/100 km. The specifications for the vehicle are shown in Table 1.

*Table 1: Specifications for the 2010 Prius*

| | | | |
|---|---|---|---|
| **Weight** | 1380 kg | **Drive Type** | Front-wheel |
| **Length** | 4.46 m | **Engine** | 1.8 L (Atkinson Cycle) |
| **Width** | 1.75 m | **Transmission** | Continuously Variable (CVT) |
| **Height** | 1.48 m | **Torque** | 142 Nm / 105 lb-ft @ 4000 rpm |
| **Seating** | 5 | **Power** | 100 kW / 134 hp (net) |
| **Fuel Type** | Gasoline | **Fuel Efficiency (label)**<br>**City**<br>**Highway**<br>**Combined** | <br>3.7 L/100 km<br>4.0 L/100 km<br>3.8 L/100 km |
| **Engine Displacement** | 1800 $cm^3$ | **Fuel Tank Capacity** | 45 L |
| **Top Speed** | 180 km/h | **Driving Range** | 1154 km |
| **Acceleration** | 0-100 in 9.8 seconds | **Brakes** | Disc |
| **$CO_2$ Emissions** | 91.2 g/km | **Drag Coefficient** | 0.25 |

## 5.0 PHASE I – FUEL CONSUMPTION AND EMISSIONS TESTING

The 2010 Prius was subjected to a run-in period of 3,500 kilometres, in accordance with emissions testing procedures. Prior to testing the vehicle in the laboratory, it was allowed to sit for eight hours to attain a uniform temperature. This is to ensure that the vehicle's test temperature is controlled for comparison against other test vehicles undergoing the same emissions and fuel consumption evaluations.

Emissions and fuel consumption tests were performed, as per Code of Federal Regulations (CFR) procedures. Evaluations were performed over the five duty cycles listed in Table 2.

*Table 2: Chassis Dynamometer Test Schedule*

| Test Parameter | Testing Standard | Number of Tests (Cell Temperature) | Location |
|---|---|---|---|
| Urban Driving | U.S. FTP-75 | 2 (25°C) | ERMS (Ottawa, ON) |
| Highway Driving | U.S. HWFET | 2 (25°C) | ERMS (Ottawa, ON) |
| Cold Urban Driving | U.S. FTP-72 | 1 (-7°C) | ERMS (Ottawa, ON) |
| Aggressive Driving | US06 (SFTP) | 1 (25°C) | ERMS (Ottawa, ON) |
| Electrical Load | US SC03 | 1 (25°C) | ERMS (Ottawa, ON) |

The vehicle was mounted on a chassis dynamometer. A chassis dynamometer allows the vehicle's drive wheels to turn while the vehicle is stationary, and provides a resistance that is equivalent to what the vehicle would experience travelling on actual roads (essentially a treadmill designed for automobiles).

ERMS collected and analyzed exhaust emissions for each of the duty cycles listed in Table 2.

The exhaust emissions were analyzed for:

- carbon monoxide (CO);
- carbon dioxide ($CO_2$);
- total hydrocarbons (THC);
- oxides of nitrogen ($NO_x$);
- non-methane organic gases (NMOG); and,
- particulate matter (PM).

### 5.1 2-CYCLE VS. 5-CYCLE FUEL CONSUMPTION CALCULATIONS

Fuel consumption estimates for vehicles are based on either the“2-cycle” city and highway values, or the calculated “5-cycle” city and highway values that have been adjusted with data from supplemental test cycles for cold (-7°C) city driving (U.S. FTP-72), aggressive driving, and driving with an electrical load. Test cycles are designed to simulate real-world driving conditions, including driving activity, trip length, stopping frequency, and idling time

The 2-cycle uncorrected fuel consumption values for vehicles are obtained as a result of the tested urban driving cycle (U.S. FTP-75) and the highway driving cycle (HWFET). The city and highway fuel consumption values are adjusted upwards by 10% and 15% respectively to account how they perform on the road versus on the dynamometer. The combined fuel consumption rating is determined using a ratio of 55% city and 45% highway. The result is the Canadian corrected label value for city, highway, and combined fuel consumption. These are the procedures followed by Natural Resources Canada to determine the values published in the annual *Fuel Consumption Guide*[1] and also the values found on a vehicle EnerGuide label – see http://oee.nrcan.gc.ca.

The 5-cycle test method is used to supplement the 2-cycle test method. It takes into account several factors that affect fuel consumption and which are not addressed in the 2-cycle test method. The U.S. Environmental Protection Agency (EPA) began to implement 5-cycle testing in 2006. Starting with the 2011 model year, manufacturers in the U.S must report 5-cycle fuel economy (either by testing over the 5-cycle method, or by testing over the 2-cycle method and adjusting these values for a 5-cycle value).

Fuel consumption values for the 5-cycle method is approximately a 10-20% higher for the same make and model than the 2-cycle method. The 5-cycle method includes testing over a wider range of driving patterns and temperature conditions than those tested under the current standard. Figure 2 shows how the 2-cycle label value and 5-cycle label value are obtained from testing.

[1] Natural Resources Canada’s Fuel Consumption Guide. http://oee.nrcan.gc.ca/transportation/tools/fuel-consumption-guide/fuel-consumption-guide.cfm.

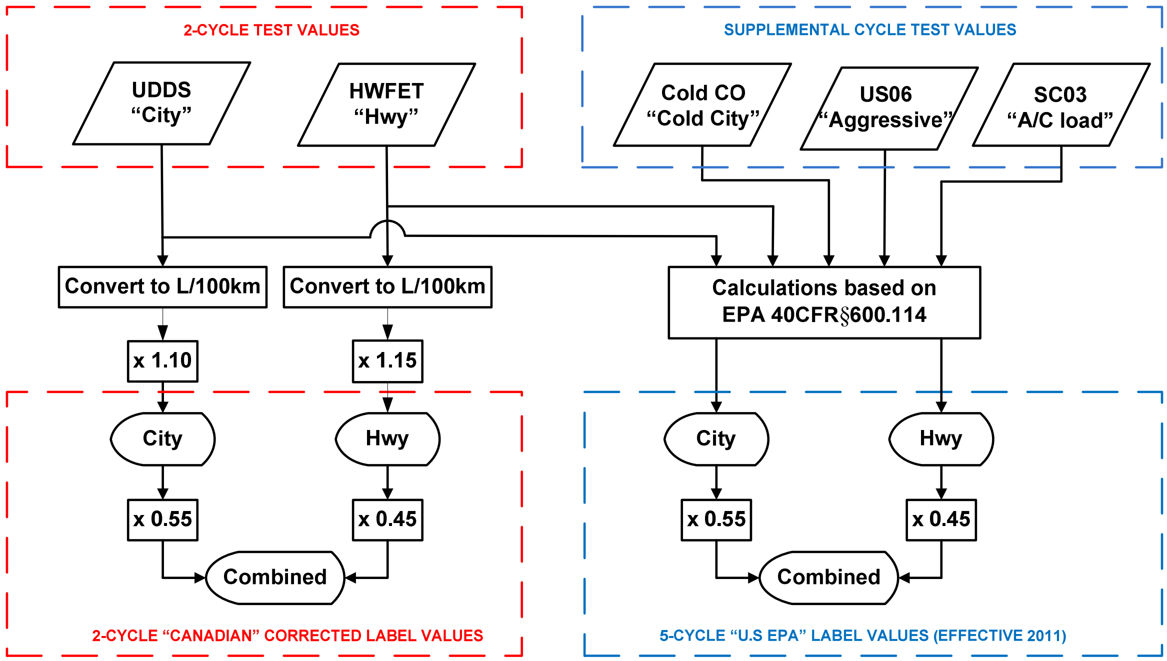


***Figure 2: How 2-cycle (Canadian) fuel consumption values and 5-cycle (US EPA) fuel economy values are calculated***

In some real-world driving conditions, vehicles may be driven more aggressively (e.g. with greater acceleration and at higher speeds) than the existing 2-cycle test cycles simulate. The US06 aggressive driving cycle takes this into account. Furthermore, drivers often use air conditioning in warm and/or humid conditions. The US SC03 test cycle reflects the added fuel needed to operate the air conditioning system. For these reasons, the 5-cycle method may offer a more accurate representation of the vehicle's fuel consumption and overall performance than the 2-cycle method, when these conditions apply.

### 5.1.1 2-Cycle Fuel Consumption Results

The Prius was tested twice against the FTP-75 city cycle and the HWFET highway cycle, according to current Canadian standards for fuel consumption testing. The results were averaged for each cycle.

This vehicle was tested by the eTV Program in accordance with standard fuel consumption test procedures. The number of kilometres accumulated on the Prius for a 1$^{st}$ round and 2$^{nd}$ round of fuel consumption tests were 1,534 km and 6,361 km respectively. The normal break-in accumulation prior to fuel consumption evaluation is 3,500 km, however the accumulation used by the eTV program is considered acceptable.

The results for the fuel consumption of the Prius based on the 2-cycle calculations (adjusted 10% and 15% respectively) are 4.2 L/100 km for the city and 4.3 L/100 km for the highway. These values are 14% and 7% higher than the city and highway values reported by Toyota in 2010 for the Prius. A combined fuel consumption value, using a 55% and 45% weighting for the city and highway respectively, is 4.2 L/100 km. The values reported by Toyota yield a combined value of 3.8 L/100 km.

A value of greater than 10% over the manufacturer claimed fuel consumption value for a city or highway test is considered a failure. Thus, the reported highway value is not considered a failure while the city value would be. Most vehicles perform within plus or minus 10% of a manufacturer's claims, but it is not uncommon for an individual vehicle/test result to be above or below the manufacturer's claims by plus or minus 10%, particularly hybrid vehicles.

It is important to note some of the challenges regarding fuel consumption testing of hybrid vehicles. Historically, data from Transport Canada's Fuel Consumption Program[2] indicates a higher degree of variability in tests results for hybrids (versus conventional vehicles), specifically with respect to the fuel consumption values submitted by manufacturer and the results of audit testing. This is a trend for hybrid vehicles across all manufacturers, and variability can be either above or below the manufacturer's claimed fuel consumption values.

This is, in part, due to several technical challenges with respect to how hybrid vehicles are both tested and operated on the dynamometer. In order to help address some of these issues, Transport Canada's eTV program has engaged with SAE international committees studying at these issues. For example, eTV provided data and contributed to the SAE International document, *SAE J1711 Recommended Practice for Measuring Exhaust Emissions and Fuel Economy for Hybrid Electric Vehicles, Including Plug-In Hybrid Vehicles*, which addresses the difficulties inherent in determining the fuel economy of vehicles that have an on-board energy source. Primarily this is accomplished by determining the state of charge (SOC) of the battery pre and post test is within acceptable range.

Additionally, eTV has participated on the SAE International committee studying drive quality evaluation. This committee is developing a document titled '*SAE J2951 Drive Quality Evaluation for Chassis Dynamometer Testing*,' which addresses some of the drive quality issues that can have a greater impact on hybrid electric vehicles than conventional vehicles.

Because of the values obtained for the eTV tested Prius, we must notice that this vehicle is still the 2010 mid-sized class award winner by a significant margin.

***Table 3: 2-Cycle Fuel Consumption Values***

| 2- Cycle Fuel Consumption (L/100 km) | | | |
|---|---|---|---|
| | **City** | **Highway** | **Combined** |
| **Uncorrected Values** | 3.8 | 3.7 | 3.8 |
| **Corrected (Label) Values** | 4.2 | 4.3 | 4.2 |
| **Published Label Value** | 3.7 | 4.0 | 3.8 |

[2] On April 1, 2009 the Government of Canada announced that new Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations would be developed to limit greenhouse gas emissions from the automotive sector under the Canadian Environmental Protection Act (CEPA), 1999. Beginning in model year 2011, the motor vehicle industry will submit data to Environment Canada. As a result, on March 31, 2010 Transport Canada's Fuel Consumption Program (FCP) ended.

Figure 4 shows the unadjusted[3] 2-cycle combined fuel consumption value of 4.0 L/100 km versus the fleet average for model year 2010, as well as the Company Average Fuel Economy (CAFE) standards in the US, and Canadian Company Average Fuel Consumption (CAFC) standards. In the United States, CAFE standards are based on the vehicle's footprint (the product of the vehicle's track and wheelbase). It can be seen that the Prius is more than 40% below the 2010 model year CAFC standard of 8.6 L/100 km and more than 26.5% below the actual fleet average achieved by all new cars in 2010.

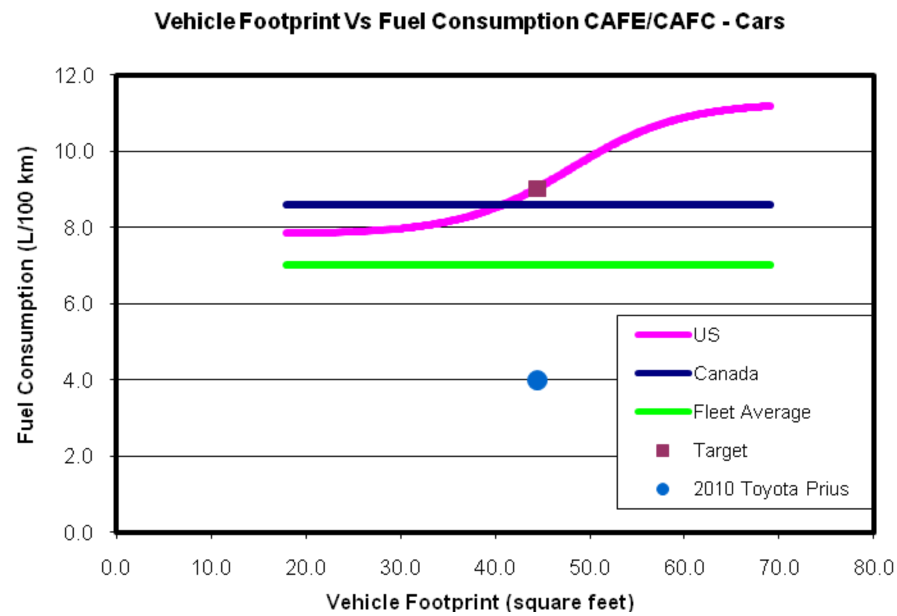


*Figure 3: Unadjusted fuel consumption against Canadian and US standards*

### 5.1.2 5-Cycle Fuel Consumption Results

Each of the 5-cycles is divided into phases, also referred to as bags, because each phase sample is bagged and analyzed separately, without interruption, during the test.

The following equations are derived from 40 CFR Parts 86 and 600, to determine both the city and highway fuel economy[4] results for a vehicle.

$$City\ FE = 0.905 \times \frac{1}{(Start\ FC + Running\ FC)} \quad (Equation\ \#1)$$

where,

[3] Fuel consumption standards are compared to unadjusted values in both Canada and the U.S. Adjusted values are used for labelling purposes only.
[4] The term "fuel economy" is used here to reflect the fact that 5-cycle testing is a U.S. standard and not a Canadian standard. In Canada, the term "fuel consumption" is used.

$$Start\ FC = 0.33 \times \left(\frac{0.76 \times Start\ Fuel_{75} + 0.24 \times Start\ Fuel_{20}}{4.1}\right) \quad (Equation\ \#2)$$

$$Running\ FC = 0.82 \times \left(\frac{0.48}{Bag4_{75}\ FE} + \frac{0.41}{Bag3_{75}\ FE} + \frac{0.11}{US06\ City\ FE}\right) + 0.18 \times \left(\frac{0.5}{Bag2_{20}\ FE} + \frac{0.5}{Bag3_{20}\ FE}\right) + 0.133 \times 1.083 \times \left[\frac{1}{SC03\ FE} - \left(\frac{0.61}{Bag3_{75}\ FE} + \frac{0.39}{Bag4_{75}\ FE}\right)\right] \quad (Equation\ \#3)$$

$$Start\ Fuel_{75} = 3.6 \times \left[\frac{1}{Bag1\ FE_{75}} - \frac{1}{Bag3\ FE_{75}}\right] + 3.9 \times \left[\frac{1}{Bag2\ FE_{75}} - \frac{1}{Bag4\ FE_{75}}\right] \quad (Equation\ \#4)$$

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag1\ FE_{20}} - \frac{1}{Bag3\ FE_{20}}\right] \quad (Equation\ \#5)$$

Where: Bag # FE is the fuel economy in miles per US gallon of fuel during the specified bag of the FTP test conducted at an ambient temperature of 75ºF or 20ºF

Under the vehicle specific 5-cycle formula, the highway fuel economy value would be calculated as follows:

$$Highway\ FE = 0.905 \times \frac{1}{(Start\ FC + Running\ FC)} \quad (Equation\ \#6)$$

where,

$$Start\ FC = 0.33 \times \left(\frac{0.76 \times Start\ Fuel_{75} + 0.24 \times Start\ Fuel_{20}}{60}\right) \quad (Equation\ \#7)$$

$$Running\ FC = 1.007 \times \left[\frac{0.79}{US06\ Highway\ FE} + \frac{0.21}{HFET\ FE}\right] + 0.133 \times 0.377 \times \left[\frac{1}{SC03\ FE} - \left(\frac{0.61}{Bag3_{75}\ FE} + \frac{0.39}{Bag4_{75}\ FE}\right)\right] \quad (Equation\ \#8)$$

$$Start\ Fuel_{75} = 3.6 \times \left[\frac{1}{Bag1\ FE_{75}} - \frac{1}{Bag3\ FE_{75}}\right] + 3.9 \times \left[\frac{1}{Bag2\ FE_{75}} - \frac{1}{Bag4\ FE_{75}}\right] \quad (Equation\ \#9)$$

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag1\ FE_{20}} - \frac{1}{Bag3\ FE_{20}}\right] \quad (Equation\ \#10)$$

The results for the fuel consumption of the Prius, based on the 5-cycle calculations above, are shown in Table 4 below.

***Table 4: 5-Cycle Fuel Consumption Values***

| **5- Cycle Fuel Consumption (L/100 km)** | | | |
|---|---|---|---|
| | **City** | **Highway** | **Combined** |
| **Calculated Values** | 5.3 | 5.2 | 5.3 |
| **US 5-Cycle Label Value** | 4.6 | 4.9 | 4.7 |

Although these fuel consumption values are higher than those obtained during the 2-cycle testing, the 5-cycle testing includes several additional duty-cycles that are designed to approximate additional real-world driving conditions, e.g. aggressive driving, electric load, that are not included in the 2-cycle testing procedure. When compared against the city and highway values for the 2-cycle calculation, the 5-cycle fuel consumption values are 13% and 18% higher for city and highway driving respectively.

The 5-cycle label values published by the US EPA are 15% and 6% lower than those achieved by the eTV test vehicle. (*See 5.1.1 for a discussion of hybrid vehicle testing challenges*).

In real-world use, the United States Department of Energy (DOE) and the Environmental Protection Agency (EPA) report an average fuel consumption of 49.3 MPG for the 2010 Prius versus a combined label value reported at 50 MPG. These values are the real-world driver submitted fuel consumption for 152 separate vehicles to the DOE and EPA's co-sponsored website on fuel consumption.

## 5.2 GHG EMISSIONS VERSUS OTHER REGULATED EMISSIONS

It is important to consider the difference between the products of combustion of fossil fuels. Figure 4 shows the regulated emissions associated with the combustion of fossil fuels such as gasoline and diesel.

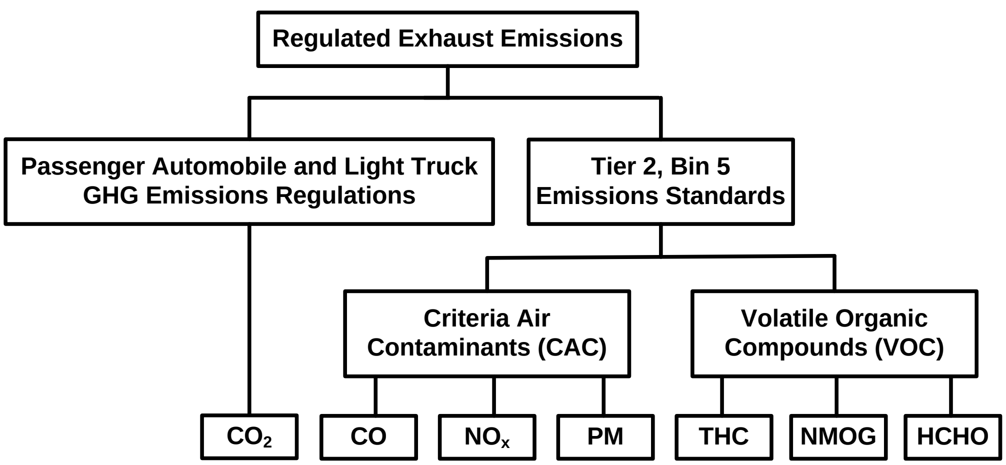


***Figure 4: Regulated products of combustion***

As the name implies, GHG emissions are gases that are responsible for the green house effect, or global warming. Although they consist mostly of water vapour ($H_2O$), $CO_2$, and methane ($CH_4$), the most volatile of the three is $CO_2$. $CO_2$ emissions come directly from the combustion of fossil fuels, therefore they can only be reduced by burning fuels with a lower carbon content, or by burning less fuel altogether.

Air issues such as smog and acid rain result from the presence of, and interactions between, a group of pollutants known as Criteria Air Contaminants (CAC) and some related pollutants[5]. CO is a colorless, tasteless, odourless gas that is highly toxic to humans. $NO_x$ contributes to ground level smog concentrations that can result in respiratory ailments, and have also been linked to depleted ozone and acid rain. PM emissions can lead to several health effects, such as asthma, lung cancer, cardiovascular issues, birth defects, and premature death. While some particulate matter can be filtered in the nose and throat, some PM emissions (below 10 micrometers) can penetrate deep into the lungs and throat. The smallest PM emissions (below 2.5 micrometers) can travel into the gas exchange regions of the lung. CACs must be considered for large urban areas. Therefore FTP-75 (city cycle) emissions are regulated under the Tier 2 standards.

Volatile organic compounds (VOC) are organic chemical compounds that can affect the environment and human health. There are several thousand chemicals, synthetic and natural, that can be called VOCs. Of these, over 900 have been identified in indoor air. High levels of THC (including methane) in the atmosphere can interfere with oxygen intake by reducing the amount of available oxygen through displacement[6]. Non-methane organic gases are substances that could lead to the formation of ozone, which also contributes to the green house effect. Finally, HCHO, slowly emitting from several building materials such as paints, and ceiling tiles, can irritate the mucous membranes to make a person uncomfortable. VOCs during the FTP-75 (city cycle) are also regulated under Tier 2 standards.

### 5.2.1 $CO_2$ Emissions Results

The results of the city and highway tests show that the Prius generates 104 g $CO_2$/km. The next best performing vehicle for the same model year, currently available on the Canadian market emitted 156 g $CO_2$/km. Thus, technologies such as those found in the Prius could offer a 33% reduction in $CO_2$ emissions. The national average of $CO_2$ emissions for all mid-sized cars available in Canada in the 2010 model year was reported to be 161 g $CO_2$/km. In comparison, the Prius offers a 35% reduction in $CO_2$ emissions over all models within its class.

### 5.2.2 Regulated Emissions Results

With regard to non-$CO_2$ exhaust emissions; emissions testing showed that the 2010 Prius meets Tier 2, Bin 3 standards for North America. Results from the regulated emissions for are found in Table 5.

***Table 5: Exhaust emissions relative to Tier 2 emissions standards***

| | FTP-75 Emissions (g/mi) | | | | |
|---|---|---|---|---|---|
| | **CO** | **NMOG** | **$NO_x$** | **PM** | **HCHO** |
| 2010 Toyota Prius | **0.05** | **0.007** | **0.011** | **N/A** | **N/A** |
| Tier 2, Bin 5 | 3.40 | 0.075 | 0.05 | N/A | 0.015 |
| Tier 2, Bin 3 | 2.1 | 0.055 | 0.03 | 0.01 | 0.011 |

[5] "Criteria Air Contaminants and Related Pollutants". Environnent Canada: http://www.ec.gc.ca/air/default.asp?lang=En&n=7C43740B-1.
[6] "Pollutants and Health Effects". http://www.coalitionforcleanair.org/air-pollution-pollutants.html.

## 6.0 PHASE II – DYNAMICS TESTING

The 2010 Prius underwent dynamics and performance testing in September and October 2009. Most aspects of the tests performed were for general assessment purposes and not as a measure of compliance with the Canada Motor Vehicle Safety Standards (CMVSS). Concerns about fuel-efficient vehicles are not always limited to exhaust emissions and greenhouse gas reduction. Vehicle dynamics testing was performed because the eTV program wished to assess how well smaller, more fuel-efficient vehicles function in various road situations, with a view to identifying any possible issues.

As mentioned previously, vehicle dynamics testing was performed at Transports Canada's Motor Vehicle Test Centre (MVTC) in Blainville, QC. An aerial view of the test track is shown in Figure 9Figure 5.

***Figure 5: Transport Canada's Motor Vehicle Test Centre (MVTC)***

### 6.1 ACCELERATION EVALUATION

The maximum acceleration was determined by starting the vehicle from a standing start and following the procedure set out below.

1. The vehicle was evaluated by accelerating to the maximum attainable speed in a quarter of a mile (402.3 m).
2. The vehicle was evaluated by accelerating to the maximum attainable speed in a kilometre (1000 m).

To account for variations in wind, the vehicle was driven in both directions on the test track, with the results averaged.

***Table 6: Average speed results for specified distance***

| Distance | Speed ( km/hr ) |
|---|---|
| 1/4 mile (402.3 m) | 126.2 |
| 1000 m | 161.6 |

The 2010 Toyota Prius established a speed of 126.2 km/hr after a quarter mile, and 161.6 km/hr after 1000 meters. These are acceptable speeds for the vehicle to attain within these distances at maximum acceleration, and show that the vehicle can accelerate to highway speeds within an appropriate distance.

### 6.2 MAXIMUM SPEED

The 2010 Prius is equipped with a type of continuously variable transmission (CVT). A CVT has an "infinite" number of gear ratios available for the transmission to access. This is advantageous because the more gear ratios there are, the more choices the vehicle has in setting the engine RPM for any given speed. As a result, both power and cruising requirements are met by raising or lowering the engine RPM. This allows the engine to operate at a speed that minimizes fuel consumption, regardless of vehicle speed.

The maximum speed attainable was tested and recorded for each test run. The vehicle was accelerated until a top speed was recorded. Since speed is affected by wind, tests were performed in both directions and averaged. Tests took place on October 23, 2009, and the recorded wind speed was 15 km/h. Table 8 lists the maximum speed obtained in two separate trials in opposite directions.

During testing, the 2010 Prius reached a maximum speed of over 183 km/h in approximately 50-70 seconds. Thus, the vehicle has the ability to meet and exceed all minimum speed requirements on public roads throughout Canada. Additionally, the acceleration compares favourably to typical results in the mid-size class, and allow for the type of highway merging and overtaking that most Canadians have come to expect from their vehicles.

The maximum speed and speed versus time are shown graphically in Figure 6.

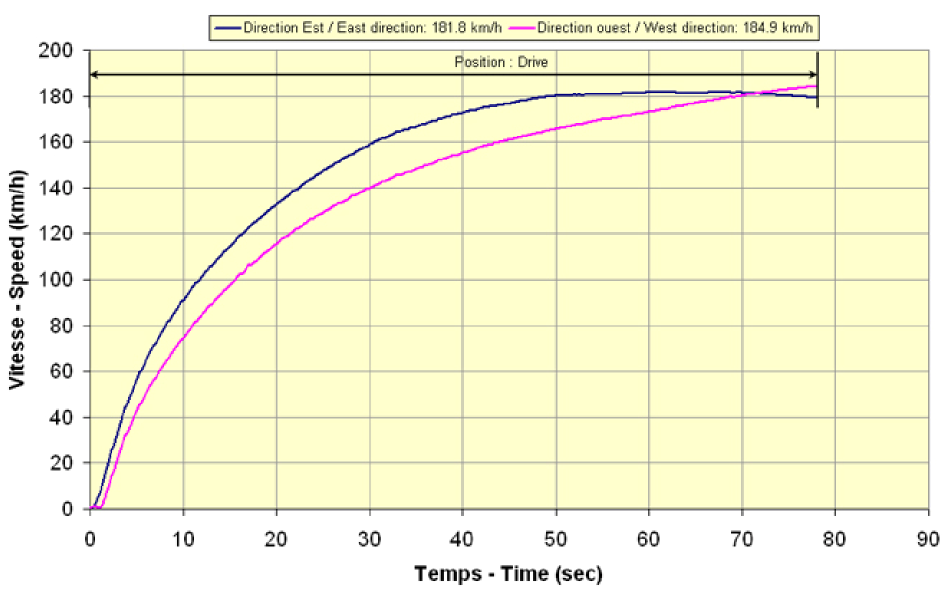


*Figure 6: Maximum speed*

## 6.3 HANDLING

### 6.3.1 Lateral Skid Pad

Procedure

The skid pad test was used to test the vehicle's steady state road holding ability. When vehicles reach their cornering limit, they lose traction on the curve by either under-steering or over-steering. In this particular test, when the vehicle was about to lose traction, the maximum lateral acceleration was recorded.

In order to measure the vehicle's lateral and longitudinal displacement, speed and lateral acceleration, the vehicle was equipped with a combined GPS and accelerometer-based data acquisition system. All measurements refer to the vehicle's centre of gravity.

Tires were warmed up and conditioned by using a sinusoidal steering pattern at a frequency of 1 Hz, a peak steering-wheel angle amplitude corresponding to a peak lateral acceleration of 0.5–0.6 G, and a speed of 56 km/h. The vehicle was driven through the course four times, performing 10 cycles of sinusoidal steering during each pass.

Testing was performed under the following conditions:

- The vehicle was equipped with new tires;
- Tire pressure was adjusted to conform to the manufacturer's recommendations;
- The vehicle's weight was only the driver and instrumentation;
- The skid pad was 61 metres in diameter.


***Figure 7: 2010 Prius on counter-clockwise run***

Results

The results presented in Table 7 show that the maximum speed that the vehicle can achieve in a cornering situation is 55 km/h. At higher speeds, the vehicle's electronic stability control (ESC) self-activates and does not allow the vehicle to exceed 55 km/h.

*Table 7: Skid pad test results*

| Clockwise | | Counter-Clockwise | |
|---|---|---|---|
| **Speed (km/h)** | **Stay Inside Corridor? (Yes/No)** | **Speed (km/h)** | **Stay Inside Corridor? (Yes/No)** |
| 50 | Yes | 50 | Yes |
| 55 | Yes | 55 | Yes |
| 60 | No – 55 km/h (ESC engaged) | 60 | No – 55 km/h (ESC engaged) |

The maximum lateral acceleration is 7.6 $m/s^2$ (0.77G) based on a peak friction coefficient of 0.98.

### 6.3.2 Emergency Lane Change Manoeuvre

Procedure

The emergency lane change manoeuvre with obstacle avoidance test was performed based on ISO 3888-2. During this test, the vehicle entered the course at a particular speed and the throttle was released. The driver then attempted to negotiate the course without striking the pylons. The test speed was progressively increased until instability occurred or the course could not be negotiated.

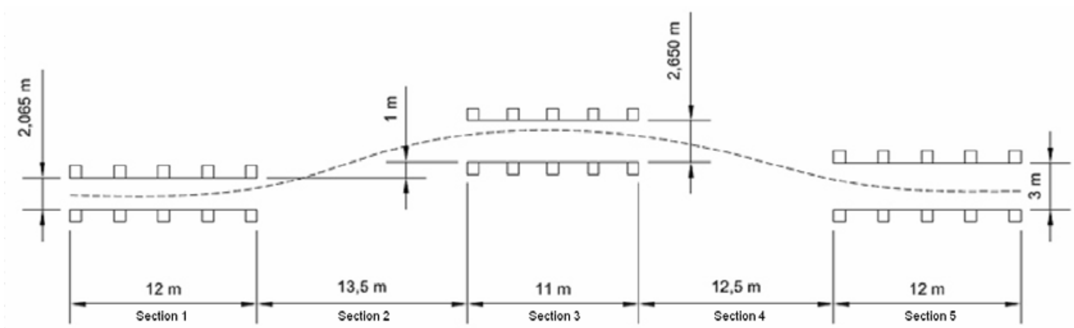


***Figure 8: Emergency lane change course (not to scale)***

As illustrated in Figure 8 above, section 4 of the course was shorter than section 2 by one metre in order to get maximum lateral acceleration at this area. Tests were performed in one direction only. If any pylons were hit, the run was disallowed.


***Figure 9: 2010 Toyota Prius during emergency lane change manoeuvre test***

Results

Several tests were necessary to determine at which speed the Prius was able to negotiate all the way through the prescribed course without hitting a pylon. Table 8 below lists all runs in increasing order, by speed.

***Table 8: 2010 Prius emergency lane change results***

| Initial Speed (km/h) | Pylon Hit? |
|---|---|
| 50 | **No** |
| 55 | **No** |
| 60 | **No** |
| 62 | **No** |
| 65 | **Yes** |

The maximum successful entry speed through the course was recorded as 62 km/h. The lateral acceleration during the test is shown in Figure 10.

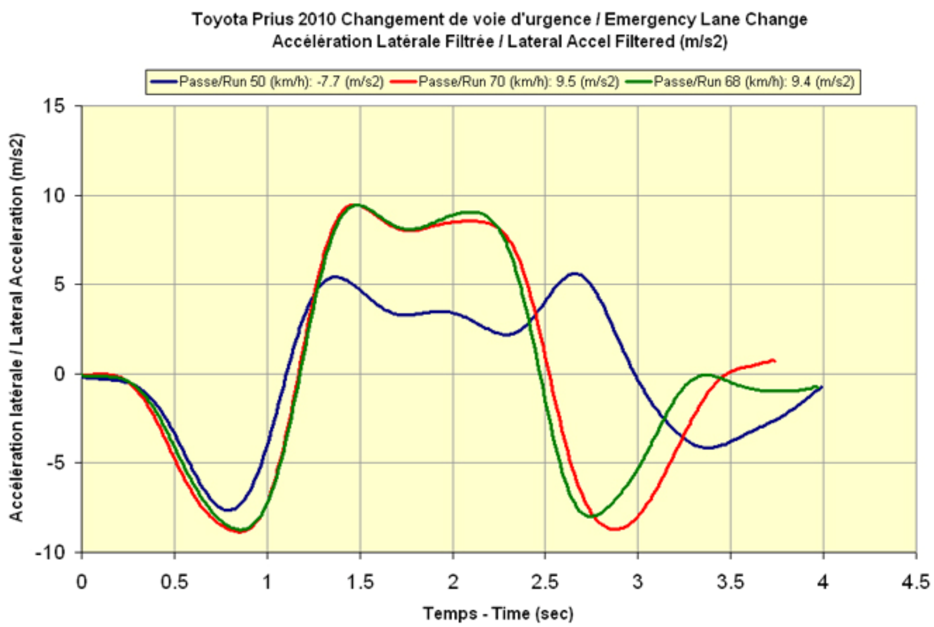


***Figure 10: Lateral acceleration during emergency lane change manoeuvre***

Analysis

Figure 10 illustrates a couple of key points. The blue data series shows that the driver can negotiate the course several ways at low speeds. From Figure 10, the lateral acceleration in the emergency lane change manoeuvre was 9.5 $m/s^2$ (0.97 G).

## 6.4 NOISE EMISSIONS TESTS

It is known that hybrid-electric and fully electric vehicles can, at low speeds, be much quieter than conventional vehicles. In order to address this potential safety issue for visually impaired people and other pedestrians, Transport Canada is working in collaboration with the US National Highway Transportation Safety Administration (NHTSA) to help develop future minimum noise emissions standards for hybrid-electric and fully electric vehicles. Minimum noise emissions standards, at low speeds, will be developed over 2012 and 2013 and do not form part of the testing performed on the 2010 Prius.

What follows are the current CMVSS tests that determine compliance with maximum noise emission standards at higher speeds.

### 6.4.1 Exterior Noise (CMVSS 1106)

Procedure

The 2010 Toyota Prius was tested in accordance with the CMVSS 1106 Noise Emissions Test, SAE Recommended Practice J986, Sound Level for Passenger Cars and Light Trucks, and SAE Standard J1470, Measurement of Noise Emitted by Accelerating Highway Vehicles.

In order to measure noise emitted from the engine and exhaust, microphones were set up as shown in Figure 11.

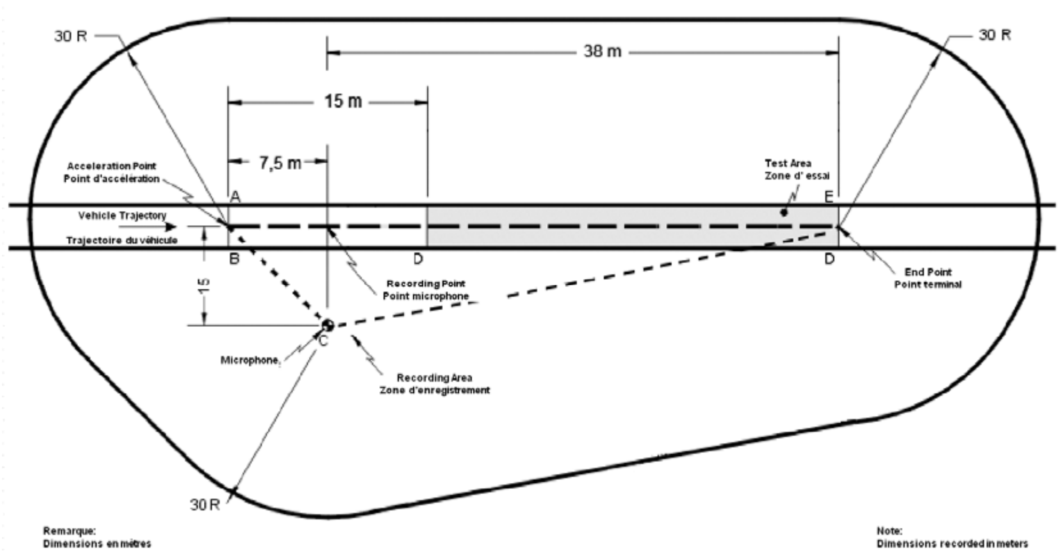


*Figure 11: Noise emissions set-up (not to scale)*

Testing was performed under the following conditions:

- The vehicle test weight, including driver and instrumentation, did not exceed the vehicle's curb weight by more than 125 kg;
- The vehicle's engine was idled for a period of one minute, with the transmission in neutral, in order to stabilize transmission and exhaust system temperatures prior to the first test run.

The test procedure for the acceleration tests was as follows:

- The vehicle was brought to a speed of 48 km/h ± 1.2 km/h.
- At the acceleration point (Figure 9) the throttle was opened wide.
- The vehicle was allowed to accelerate until it had exited the test zone.
- The sound meter was set to fast dB (A).

The deceleration tests followed the same procedure as above, except that at the acceleration point (Figure 11) the throttle was released, and the vehicle allowed to decelerate to half its initial speed (or until it had exited the test zone).

<u>Results</u>

Results from all tests show that the ambient noise levels are within the limits of the CMVSS 1106 standards. Due to the logarithmic nature of the decibel scale, a level of 64 dB is significantly lower than the 93.8 decibel limit. Generally 60 dB is considered to be the level of normal human conversation while 90 dB would be the sound generated by a typical gas powered lawn mower. Most of the noise being generating from the vehicle is due to tire and wind, which is acceptable and similar across any vehicle power train platform.

***Table 9: Exterior noise (approaching 48 km/h)***

| Test | Approaching Speed (km/h) | Approaching RPM | End Speed (1) (km/h) | RPM max (1) | Noise level dB (A) | Calibration dB (A) |
|---|---|---|---|---|---|---|
| **Right Side – 1** | 48 | 1300 (3) | 67 | (Note) | 64,1 | 93,9 |
| **Right Side – 2** | 48 | - | 67 | - | 64,6 | 93,9 |
| **Right Side – 3** | 48 | - | 67 | - | 63,4 | 93,9 |
| **Right Side – 4** | 48 | - | 67 | - | 63,9 | 93,9 |
| | | **Average** | 67 | | **64,0** | |
| **Left Side – 1** | 48 | - | 67 | (Note) | 62,6 | 93,9 |
| **Left Side – 2** | 48 | - | 67 | - | 63,8 | 93,9 |
| **Left Side – 3** | 48 | - | 67 | - | 63,5 | 93,9 |
| **Left Side – 4** | 48 | - | 67 | - | 63,4 | 93,9 |
| | | **Average** | 67 | | **63,3** | **Results:** **Pass** |
| | | | | **Results – Highest average – 2dB** | **62,0** | |
| | | | | **Ambient noise level (2)** | **44,7** | |

(1) Throttle full open until the entire vehicle has vacated the test zone
(2) Ambient noise level less than the measured vehicle noise level by at least 10 dB (A).
(3) When the gasoline engine was on.

*Table 10: Exterior noise (approaching 67 km/h)*

| Test | Approaching Speed (km/h) | Approaching RPM | End Speed (1) (km/h) | RPM max (1) | Noise level dB (A) | Calibration dB (A) |
|---|---|---|---|---|---|---|
| **Right Side – 1** | 67 | N/A | 61 | N/A | 61,4 | 93,8 |
| **Right Side – 2** | 67 | - | 61 | - | 60,5 | 93,8 |
| **Right Side – 3** | 67 | - | 61 | - | 61,2 | 93,8 |
| **Right Side – 4** | 67 | - | 61 | - | 60,8 | 93,8 |
| | | **Average** | 61 | | **61,0** | |
| **Left Side – 1** | 67 | N/A | 61 | N/A | 61,6 | 93,8 |
| **Left Side – 2** | 67 | - | 61 | - | 61,0 | 93,8 |
| **Left Side – 3** | 67 | - | 61 | - | 60,9 | 93,8 |
| **Left Side – 4** | 67 | - | 61 | - | 61,1 | 93,8 |
| | | **Average** | 61 | | **61,1** | **Results: Pass** |
| | | | | **Results – Highest average – 2dB** | **59,1** | |
| | | | | **Ambient noise level (2)** | **44,7** | |

(1) Throttle returned to its idle position until the entire vehicle has vacated the test zone
(2) Ambient noise level less than the measured vehicle noise level by at least 10 dB(A).

### 6.4.2 Interior Noise

Procedure

Interior noise emitted from the vehicle was evaluated at different constant speeds in order to determine the levels experienced by the driver of the vehicle. The sound level meter was positioned as stated in the *2010 Toyota Prius test plan*.

*Table 11: Interior noise*

| Test # and targeted test speed | Calibration dB (A) | Noise level dB (A) | Transmission selection |
|---|---|---|---|
| **Idle** | 93,8 | **49,3** | Neutral |
| | **Ambient** | **32,0** | Engine off |
| **Full acceleration – 1** | 93,8 | 77,4 | 25 s – 129 km/h |
| **Full acceleration – 2** | 93,8 | 76,3 | 25 s – 129 km/h |
| **Full acceleration – 3** | 93,8 | 76,7 | 25 s – 129 km/h |
| | **Average** | **76,8** | 25 s – 129 km/h |
| **110 km/h – 1** | 93,8 | 73,0 | Drive |
| **110 km/h – 2** | 93,8 | 72,9 | Drive |
| **110 km/h – 3** | 93,8 | 73,1 | Drive |
| | **Average** | **73,0** | Drive |
| **100 km/h – 1** | 93,8 | 71,6 | Drive |
| **100 km/h – 2** | 93,8 | 71,1 | Drive |
| **100 km/h – 3** | 93,8 | 70,0 | Drive |
| | **Average** | **70,9** | Drive |
| **80 km/h – 1** | 93,8 | 69,4 | Drive |
| **80 km/h – 2** | 93,8 | 67,9 | Drive |
| **80 km/h – 3** | 93,8 | 68,3 | Drive |
| | **Average** | **68,5** | Drive |
| **50 km/h – 1** | 93,8 | 64,1 | Drive |
| **50 km/h – 2** | 93,8 | 65,2 | Drive |
| **50 km/h – 3** | 93,8 | 64,2 | Drive |
| | **Average** | **64,5** | Drive |

Interior noise emitted by the vehicle was evaluated at different constant speeds in order to determine the levels experienced by the driver of the vehicle. The Prius experienced a higher dB within the vehicle than the values recorded externally, as expected. This is because noise readings measured outside of the vehicle were measured at a greater distance.

## 6.5 BRAKING

### 6.5.1 Light Vehicle Braking Systems (CMVSS 135)

The original vehicle had to pass all required braking tests in order to satisfy the requirements set out in the CMVSS. It was therefore decided that testing according to the strict and resource-intensive procedures set out in CMVSS 135 - Light Vehicle Brake Systems was unnecessary. Therefore, a simplified brake test procedure was performed to determine the stopping distance for abrupt stops from the following speeds:

- 50 km/h (30 mph) to 0 km/h / (mph) – 6 stops, averaged
- 80 km/h (50 mph) to 0 km/h / (mph) – 6 stops, averaged
- 100 km/h (60 mph) to 0 km/h / (mph) – 6 stops, averaged
- 110 km/h (70 mph) to 0 km/h / (mph) – 6 stops, averaged

The vehicle total braking distance in metres and time in seconds were recorded. Since the test vehicle was equipped with ABS brakes, the test driver fully depressed the brake pedal, allowing the computer to modulate the callipers. If the wheels locked, the result was disregarded.

The braking tests were conducted under the following conditions:

- Vehicle load: lightly loaded vehicle mass
- Transmission Position: neutral
- Initial Brake Temperature: ≤ 100°C
- Pedal Force: as necessary to activate ABS
- Number of runs: 6
- Test Surface: Maximum coefficient of friction of 0.9

Figure 12 summarizes the braking results for the 2010 Toyota-Prius. The threshold values are the limits that determine failure from given initial speeds. The best stopping distance recorded (out of the six trials) is indicated for each initial speed.

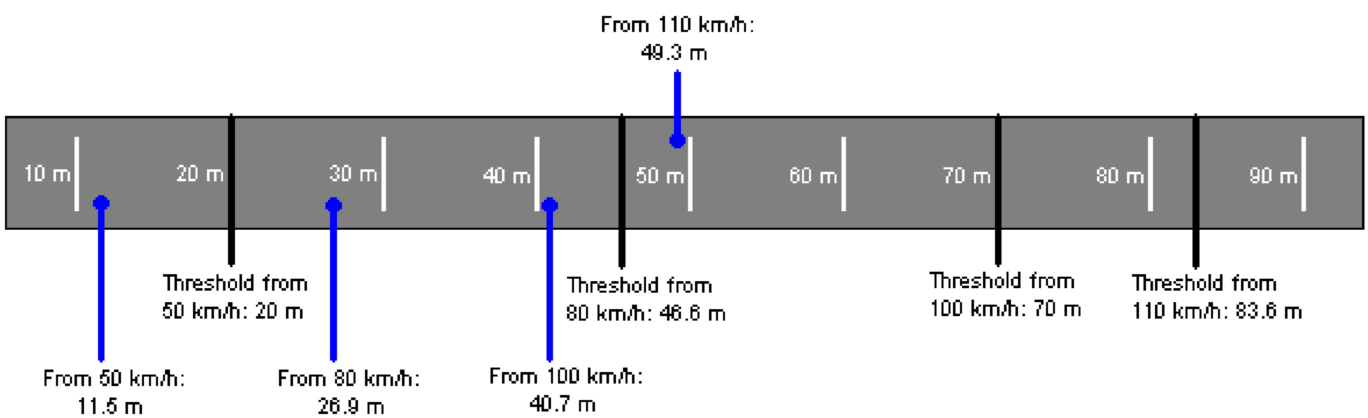


***Figure 12: 2010 Toyota Prius Braking Performance***

From the results, it is clear that there are no concerns about the vehicle's braking performance under normal driving conditions. Usually, all vehicles exceed the distance prescribed by the high-speed braking standard much further than the one prescribed by the low-speed braking standard. At lower speeds, the reaction time of the driver is higher relative to the time it takes to stop the vehicle.

## 7.0 PHASE III - ON-ROAD EVALUATIONS

The eTV engineering team and other Transport Canada staff had the opportunity to evaluate the 2010 Toyota Prius on the streets of Ottawa. After test-driving the vehicle, drivers were asked to complete a two-page questionnaire to determine their general assessment of the vehicle and its performance as a HEV. The majority of the evaluators reported that they were comfortable with the 2010 Prius in all traffic conditions. There were no reported problems with the vehicle's performance, or operation.

## 8.0 CONCLUSIONS

The corrected 2-cycle fuel consumption values are 4.2 L/100 km for the city, 4.3 L/100 km for the highway and 4.2 L/100 km for combined city/highway. The 5-cycle fuel consumption values for the 2010 Prius were 5.3L/100 km in the city and 5.2 L/100 km on the highway, with a combined fuel consumption of 5.3 L/100 km.

In combined city and highway testing, the Prius obtained a value of 97 g $CO_2$/km (1950 kg $CO_2$ / year), which is 13% less than the second best in the mid-size class (Ford Fusion Hybrid) and a 57% reduction over the average of all mid-sized cars in 2010 of 226.4 g/km (4528 kg $CO_2$ / year).

In dynamic tests, the Prius reached an average maximum speed of 183.4 km/h in approximately 40 seconds, which makes it more than capable of travelling on Canadian roads. The maximum lateral acceleration on the lateral skid pad was 7.6 $m/s^2$ (0.77 G), limited by the vehicle's electronic stability control (ESC). The maximum lateral acceleration in the emergency lane change manoeuvre was 9.5 $m/s^2$ (0.97 G), again limited by the vehicle's ESC. External and internal noise levels were below limits set out in the CMVSS. All braking tests were compliant with the CMVSS 135 standard, as expected.

It should be noted that this vehicle is one of the few eTV vehicles that is a fully CMVSS compliant model procured from a Canadian dealership, which therefore must meet all CMVSS regulations. Of the various CMVSS standards, eTV tested against the noise and brake standards, which the 2010 Prius met without issue.

## 9.0 WHAT DOES THIS MEAN FOR CANADIANS?

One of the principal barriers to the introduction of advanced gasoline technologies, such as hybrids, is the consumer's desire to minimize the initial purchase price of a new vehicle, often at the expense of longer-term operating costs and environmental impacts.

The fuel savings that may result in choosing a 2010 Prius versus any other mid-sized vehicle is in the order of $400 to $1,000 per year (assuming 20,000 kilometres per year). Also, the Prius shows that advanced technologies can allow a medium-sized vehicle to obtain a fuel consumption that is as low or lower than that of a vehicle from smaller classes. Thus allowing a viable option for those drivers who wish to minimize their fuel use, but need more space than that which is available in the compact and sub-compact classes.

Additionally, by testing several hybrid vehicles, including the 2010 Prius, the eTV program was able to identify and help mitigate technical barriers with respect to fuel consumption procedures for hybrid vehicles. Using historical data from Transport Canada's Fuel Consumption Program, eTV identified a higher degree of variability in tests results for hybrids (versus conventional vehicles), specifically with respect to the fuel consumption values submitted by manufacturer and the results of audit testing. This trend was consistent across hybrid vehicles from all manufacturers. Variability was identified both above and below the manufacturer's claimed fuel consumption values.

In order to help address some of these technical barriers, Transport Canada's eTV program engaged SAE international committees studying at these issues. For example, eTV provided data and contributed to the SAE International document, *SAE J1711 Recommended Practice for Measuring Exhaust Emissions and Fuel Economy for Hybrid Electric Vehicles, Including Plug-In Hybrid Vehicles*, and participated on the SAE International committee studying drive quality evaluation.

Changes to procedures and methodologies developed by these committees should help improve the accuracy and repeatability of results for hybrid electric vehicles, and provide Canadians with the information they need to make informed decisions when purchasing a vehicle.