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Mr. Linc Wehrly, Director
Light Duty Vehicle Center
Compliance Division
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, Michigan, 48105

Request for GHG Off-Cycle Credit for Energy Saving Air Flow Control System (S-FLOW) HVAC Technology

Introduction

Pursuant to 40 CFR § 86.1869-12(d), Toyota Motor Corporation (herein referred to as "Toyota") requests the following greenhouse gas off-cycle credit amounts for the three S-FLOW system variations:

S-FLOW System Variation	CO_2 g/mi Credit
Full (Driver and Front Concentration) S-FLOW	3.3
Front Concentration Only S-FLOW	2.5
Driver Concentration Only S-FLOW	2.0

Table 1.1: S-FLOW Credit Request

This technology reduces the thermal load on the air conditioning system through targeted cooling of only occupied cabin areas and the Toyota request for S-FLOW off-cycle credit is based on the thermal load reduction benefits of the technology similar to existing off-cycle menu credits like active or passive cabin ventilation.

This thermal load reduction technology was first used by Toyota with limited function on the 2013 Lexus GS450h. It was then implemented on the 2015 Lexus NX300h, 2016 Toyota Prius, 2016 Lexus RX450h 2016 Lexus RX350, 2018 Toyota Camry Hybrid, 2019 Toyota Avalon Hybrid, and 2019 Lexus ES300h with the full function of the technology. Toyota anticipates that use of this technology will increase in the future.

Per the recommendation in 40 C.F.R. § 86.1869-12(d)(1), Toyota met with the EPA for informal discussions on four separate occasions (04/20/2016, 06/07/2016, 09/22/2016, 4/20/2017) to review the proposed plan and confirm application direction from the EPA. In each of the meetings the EPA was agreeable with the Toyota proposed method and any comments were reflected in the updated process.

Description of Technology

Most automotive HVAC systems currently heat and cool the entire cabin regardless if that space is occupied. The S-FLOW HVAC system uses vehicle sensors, such as door and seat occupant sensors, to identify which areas of the vehicle are currently occupied and HVAC thermal sensors (cabin temperature, outside ambient temperature, sunload, etc) to direct the conditioned air to occupied areas that require cooling. This in effect allows the system to reduce cooling capacity required to condition the cabin, thereby reducing the compressor load, and consequently reducing the climate system energy consumption.

For conditions where door and or seat occupancy sensors detect there is only a driver in the vehicle, the S-FLOW system will automatically alternate between driver concentrated mode and front concentrated mode based on environmental conditions to maintain the same level of thermal comfort as would be experienced if S-FLOW was off. This provides the benefit of reduced climate system energy consumption.

For conditions where door and or seat occupancy sensors detect there is both a driver and a front passenger in the vehicle, the S-FLOW system will automatically use front concentrated mode. In conditions where there is a rear occupant the climate system will work without any concentration mode.

In some extreme climate conditions, including very high ambient temperatures, the entire cabin will be temporarily conditioned to maintain thermal comfort while the cabin is cooled down. After the cabin reaches an acceptable temperature the S-FLOW will continue to function based on occupant location. This is true as well for very low temperatures, where S-FLOW is disabled during warmup, but low temperature fuel economy savings when using the heater system are beyond the scope of this application.

The S-Flow technology's predominant mode is "ON" and the system defaults back to this position with every ignition cycle. S-Flow can be turned off for the current trip using a button on the HVAC panel, but will default to the predominant mode "ON" position at the next ignition cycle.

In the case of the 2013 Lexus GS450h equipped with S-FLOW a Toyota in-house study showed an annual fuel consumption decrease of 4% with peak benefit being noted in Spring and Fall conditions where a fuel consumption reduction of 5.1% was noted (SAE Technical Paper 2013-01-1499, ISSN: 0148-7191).

Methodology to Determine the Off-Cycle Benefit

The requested credit amount was confirmed through bench testing using SAE J2765 to confirm air-conditioning system power reduction of the technology due to the reduced thermal load for equivalent thermal comfort. The SAE J2766 standard (using the GREEN MAC Life Cycle Climate Performance Model) was used to calculate the normalized grams CO_2 per mile improvement of the technology for the US market. This method is similar to the method Toyota used to successfully apply for off-cycle credit using the alternative method for the Variable Crankcase Suction Valve Technology (EPA-HQ-OAR-2015-0827-5769) in December of 2014. In conjunction with this bench testing and analysis, a customer survey was conducted from current Toyota customers with vehicles equipped with S-FLOW technology to provide customer usage data to prorate the fuel savings based on customer actions which may reduce the fuel savings benefit of the S FLOW technology. These actions include the canceling the function which is otherwise automatically "ON" and use of the passenger front and rear doors to load occupants or other items. To validate the bench data, vehicle testing was conducted using a modified SC03 test pattern in a mild AC on condition in a certified dyno to corroborate the bench testing result. Due to vehicle testing variability and the broad range of required conditions to test, the final application grams CO_2 per mile improvement was derived from the bench test results combined with the customer survey usage percentages. These results were then further categorized to allow for accurate distribution of credits based on different vehicle features.

It has been noted through the process that S-FLOW also has the potential to benefit fuel consumption in heater related conditions. However, due to the complexities of engine warm up fuel efficiency and the lack of an industry accepted model for normalized national heater improvement, Toyota has opted to focus on the air conditioning benefit exclusively for this application. S FLOW technology also reduces electrical power consumption of the HVAC blower by reducing the cooling to only the occupied areas of the cabin. This electrical reduction would provide additional savings, but Toyota chose to focus this application exclusively on AC compressor power reduction. Toyota may consider applying for these additional benefits after subsequent study.

Rationale for using Alternative Methodology Demonstration

The off-cycle program was created to support the creation and adoption of new fuel saving technologies which reduce real world greenhouse gas emissions, but cannot be accurately captured in the traditional two cycle test. In the case of S-FLOW, the air conditioner is off during the EPA`s two cycle testing for both city and highway. S-FLOW technology is primarily designed to reduce the thermal load on the vehicle climate system through targeted cabin cooling, the air conditioner must be switched on to realize the benefit of the technology. S-FLOW is a thermal load reduction technology, not a AC efficiency improvement, that functions by reducing the load on the climate system which reduces the needed compressor displacement and the required compressor power. As noted above, the credit should fall under the 3.0 grams CO_2 per mile LDV and 4.3 grams CO_2 per mile LDT Solar/Thermal Control cap.

Of the EPA`s 5- Cycle tests only the SC03 test includes the use of the air conditioner. The SC03 test is relatively severe test for air conditioning performance as it is conducted at 95 °F (35 °C), 850 W/m², and 40% relative humidity. This in conjunction with the short duration of the test creates a severe evaluation condition for the climate control system. S-FLOW provides the most benefit in mild conditions as shown in the related SAE Technical Paper 2013-01-1499 (ISSN: 0148-7191). This is due to the ability to reduce the climate control system energy consumption significantly using driver concentration mode. In the more severe conditions of the SC03 the S-FLOW system would only be able to operate in front concentration mode or not at all to maintain customer comfort. As shown in the GREEN LCCP model, and national temperature trends, 95°F does not reflect the average conditions experienced by customers. Therefore, the SC03 test in and of itself does not accurately capture the real world benefits of this technology and therefore cannot be solely used to evaluate the grams CO_2 per mile improvement for this technology. This prompted the use of an alternative method to calculate the grams CO_2 per mile benefit.

Proposed Alternative Demonstration Methodology

A. <u>Vehicle and System Selection</u>

The impact of S-FLOW varies from vehicle to vehicle based on a variety of factors. Toyota prioritized each of these factors when determining the ideal vehicle and system to test to be representative of all current and future vehicles.

Ultimately the 2016 Lexus RX350 was selected to be the representative vehicle for all current and future single HVAC vehicles as it is predicted to have the lowest gram CO_2 per mile benefit and as such is "worst case". The Lexus RX350 is not a hybrid, so would not have the benefit from extended EV driving due to the reduced cooler system power consumption. The vehicle also does not feature start and stop technology so the effect of S-FLOW is not amplified through extended engine off time through reduced AC ON requests. The vehicle also uses a variable compressor and not an electric compressor so does not benefit from the electric compressors increased Coefficient of Performance (COP) under lower loads.

The Lexus RX350 cabin size is the largest of potential vehicles to receive this technology except for vehicles that have a rear HVAC. In the case of the larger vehicles with a rear HVAC the potential benefit of turning off the rear HVAC is larger than what would be captured in front or driver concentration mode and would require additional testing later with another application for off-cycle credit to quantify this benefit. Until then those vehicles would be applied for as driver concentration only.

The Denso MRAC HVAC uses a modular design that can adapt in width and required heating/cooling capacity for most cabin sizes using a single front HVAC module. This design allows for most components to be common amongst all units with two main efficiency related components changing based on vehicle need, the HVAC blower motor and the evaporator.

The HVAC blower motor has two main features that would contribute to selecting the "worst case" vehicle for this credit; blower motor electrical efficiency and vehicle airflow volume (AFV). Currently, only thermal load reduction is being considered in this credit application, so any differences between the different HVAC blower motors will have no impact on the requested credits. Based on this blower motor efficiency was removed from the consideration of the "worst case" test vehicle. Vehicle Air Flow Volume (AFV) is a function of the size of the cabin, whereas when the cabin increases in volume so does the required AFV to maintain the same level of comfort. Since S-FLOW functions by reducing a set percentage of AFV there is a potential for a higher AFV vehicle to see higher energy savings. However, the larger cabin associated with this directly offsets the benefit by increasing the required base cooler load on the vehicle to maintain the same comfort level. As a result AFV has been removed from the consideration for worst case

The design of the evaporator used in the MRAC HVAC modules uses one of two basic styles. The first being a cold storage evaporator that uses a phase change material that produces an endothermic reaction as the material melts. This type of evaporator is only used with a "start and stop" engine system, and is designed to provide cold air from the HVAC system even after the engine is automatically turned off. As stated previously, start and stop would not produce a worst-case fuel savings since there would be additional fuel savings through extended stop times. The second type of evaporator uses a standard Denso x-turn refrigerant flow passage and has no phase change material. The only change point between HVAC modules for this type of evaporator is in the width of the unit. While a wider evaporator allows a longer straight flow path and reduces the pressure drop of the system when compared to a shorter and smaller evaporator it requires a higher refrigerant flow rate to meet the larger performance requirement which negatively impacts the efficiency. Based on the difference in flow rate and pressure drop the overall efficiency of the evaporator is essentially the same across all evaporator sizes making the 2016 Lexus RX350 representative of all MRAC style HVAC modules.

Finally, the 2016 Lexus RX350 features rear face vents that allow for the testing to show the potential benefit for all three system variations listed below in *Table 5.1*.

To streamline testing and benefit confirmation, Toyota selected this one vehicle and system to represent the "worst case" when considering the potential grams CO_2 per mile savings. This "worst case" vehicle system was ultimately used with the SAE J2765 and J2766 to calculate the final CO2 benefit of the technology by bench test result. When combined with the following S-FLOW system categories, it allows Toyota to apply for all vehicles with this technology using one set of vehicle and bench data, ultimately reducing the testing burden for Toyota and the review burden for the EPA.

S-FLOW System Variation	Front HVAC	Rear HVAC Vents	Driver Concentration Mode	Front Concentration Mode
Full (Driver and Front Concentration) S-FLOW [Example: RX350]	O	O	O	O
Driver Concentration Only S-FLOW [Example: Prius]	O	X	O	X
Front Concentration Only S-FLOW [Planned for future model]	O	O	X	O

Table 5.1: S-FLOW Grouping Strategy O = Has Feature X = Does Not Have Feature

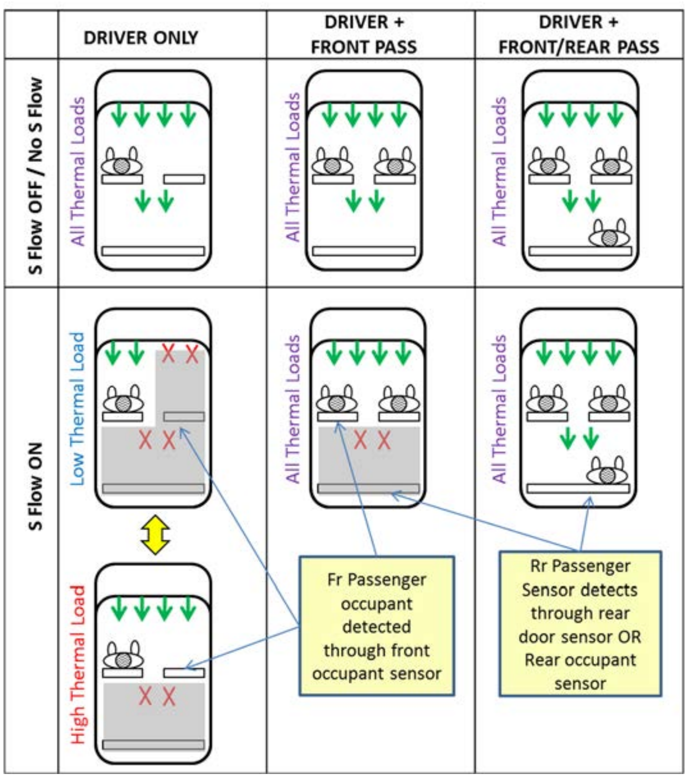


Image 5.1: Full S-FLOW Operation

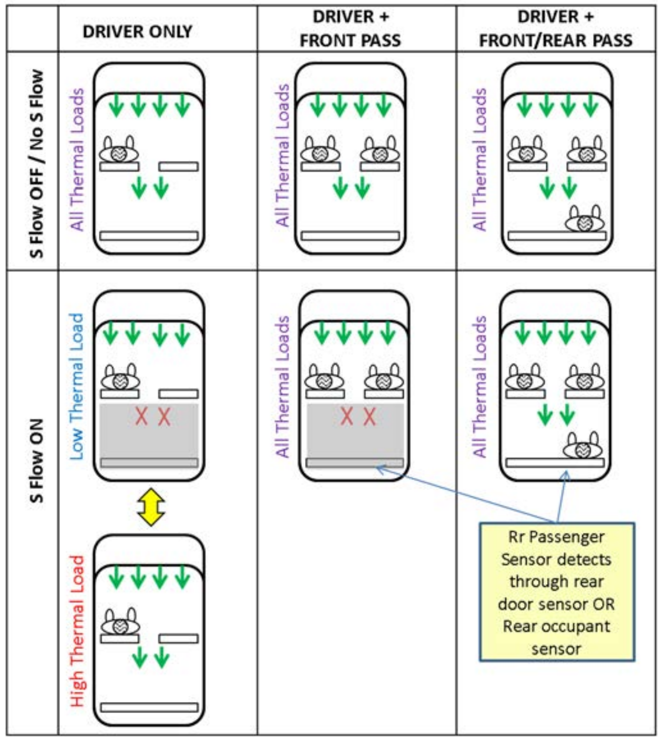


Image 5.2: Front Concentration Only S-FLOW Operation

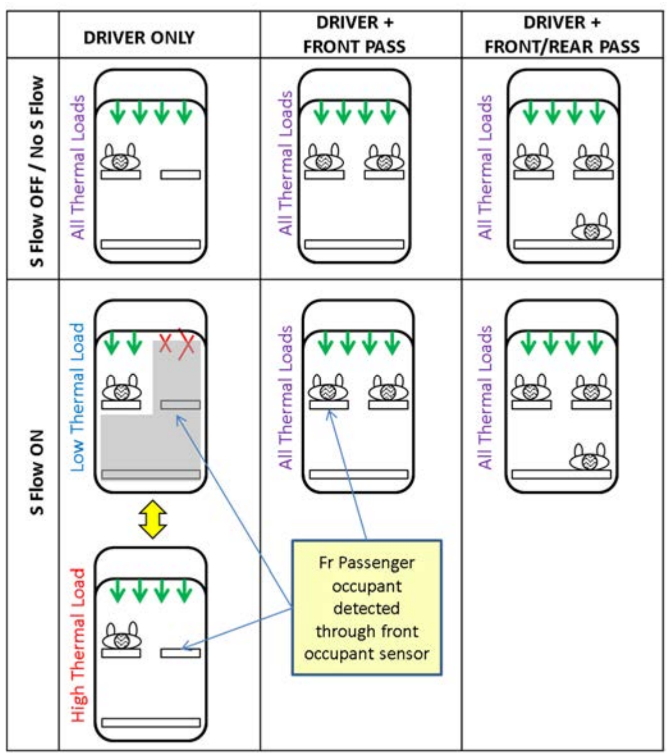


Image 5.3: Driver Concentration Only S-FLOW Operation

B. Bench Testing Methodology and Result

1. *Bench Testing Methodology*

Bench testing was conducted on standard production components from the 2016 Lexus RX350 using the publicly available SAE J2765 standard to determine the air conditioning power reduction between S-FLOW ON and S-FLOW OFF while maintaining equivalent thermal comfort. Of the 40 bench conditions results in SAE J2765, 26 are used in conjunction with the Life Cycle Climate Performance (LCCP) Model to calculate the annual nationwide equivalent CO_2 per mile reduction of a system with the SFLOW technology versus a system without this technology. The LCCP model, which is outlined in SAE J2766 is an existing method to calculate the US average grams CO_2 per mile for climate system usage. It was developed in a collaborative effort between the EPA, General Motors, SAE and the Japanese Automobile Manufacturers Association. This model accounts for a variety of climate and driving statistics from multiple cities to create a simulation for the annual grams CO_2 per mile from the use of an air conditioning system.

Variable compressors are becoming more common in modern automotive HVAC applications due to their ability to reduce displacement to meet the need of the climate system. This in turn reduces the power consumption of the system particularly in mild conditions, improving fuel economy. However, as the displacement of the compressor is reduced the efficiency is also reduced. S-FLOW is a thermal load reduction technology, not a AC efficiency improvement that functions by reducing the load on the climate system which reduces the needed compressor displacement and the required compressor power. While the overall power consumption of the air conditioning system is reduced, the resulting SAE J2765 calculation for COP does not reflect this improvement. Since the LCCP model uses COP to calculate the annual nationwide equivalent CO_2 per mile reduction a small modification to the calculation method needed to be made to accurately determine the actual benefit of the system.

Based on the SAE Technical Paper 2013-01-1499 (SSN: 0148-7191) S-FLOW provides the same thermal comfort for only the occupied spaces as is provided to all spaces when the system is not present. To accurately compare the benefit of the thermal reduction of S-FLOW with the base COP, the S-FLOW driver concentration mode and front concentration mode need to use the same starting Q (heat removed from the cabin) and compare the final energy consumption of the system.

$$COP = \frac{Q}{W}$$

Where:
Q = The heat removed from the system in kW
W = The work required by the climate system in kW

Using this method, the following calculations in conjunction with SAE J2765 bench testing were used to determine the COP for the baseline condition, and the thermal load reduction equivalent COP front concentration S-FLOW mode and driver concentration S-FLOW mode.

$$COP_{Base} = \frac{Q_{Base}}{W_{Base}}$$

$$COP_{Front\ Concentration} = \frac{Q_{Base}}{W_{Front\ Concentration}}$$

$$COP_{Driver\ Concentration} = \frac{Q_{Base}}{W_{Driver\ Concentration}}$$

Both standards (SAE J2765 and SAE J2766) were conducted in full three times to capture the baseline air conditioning greenhouse gas emissions in addition to driver only concentration and front only concentration. In each of the test cases the only change point was related to the airflow volume of the system as shown below in *Table 6.1*. Airflow reduction was based on the airflow reduction percentage in vehicle in the standard SAE J2765/J2766 conditions. In the cases with reduced airflow volume the compressor displacement automatically reduced to the required displacement for the target evaporator outlet temperature due to the reduced climate system load. The performance benefit was derived by considering S-FLOW operation points for driver concentration or front concentration based on the environmental condition. In extreme conditions it was determined that the S-FLOW would not function in driver concentration mode in those conditions due to customer comfort requirements. In those cases the front concentration only performance was used to calculate the benefit of the system.

Test Name	Compresso r Speed [RPM]	Cond Air In Temp [C]	Cond Face Velocity [m/s]	Evap Air In Temp [C]	Evap Humidity [%]	Air Flow Volume [m3/h]	S-Flow AFV Front [m3/h]	S-Flow AFV Dr [m3/h]	Evap Air Out Target Temp [C]
I70	900	70	1.5	35	25	475	365	[redacted]	3
I60	900	60	1.5	35	25	475	365	[redacted]	3
I45	900	45	1.5	35	25	475	365	[redacted]	3
L45	1800	45	2.0	35	25	475	365	[redacted]	3
M45	2500	45	3.0	35	25	475	365	[redacted]	3
H45	4000	45	4.0	35	25	475	365	[redacted]	3
I50a	900	50	1.5	35	40	477	366	278	3
I35a	900	35	1.5	35	40	477	366	278	3
L35a	1800	35	2.0	35	40	477	366	278	3
M35a	2500	35	3.0	35	40	477	366	278	3
H35a	4000	35	4.0	35	40	477	366	278	3
I40a	900	40	1.5	25	80	337	273	225	3/10
I25a	900	25	1.5	25	80	337	273	225	3/10
L25a	1800	25	2.0	25	80	337	273	225	3/10
M25a	2500	25	3.0	25	80	337	273	225	3/10
H25a	4000	25	4.0	25	80	337	273	225	3/10
I40c	900	40	1.5	25	50	334	271	224	3/10
I25c	900	25	1.5	25	50	334	271	224	3/10
L25c	1800	25	2.0	25	50	334	271	224	3/10
M25c	2500	25	3.0	25	50	334	271	224	3/10
H25c	4000	25	4.0	25	50	334	271	224	3/10
I30	900	30	1.5	15	80	322	262	219	3/10
I15	900	15	1.5	15	80	322	262	219	3/10
L15	1800	15	2.0	15	80	322	262	219	3/10
M15	2500	15	3.0	15	80	322	262	219	3/10
H15	4000	15	4.0	15	80	322	262	219	3/10

Table 6.1: LCCP Model Bench Test Conditions

It would be prohibitive to test each new system using the bench test for each of these three conditions. Therefore, Toyota selected the 2016 Lexus RX350 as a "worst case" vehicle and system for bench and vehicle testing to conservatively represent all current and future vehicles.

2. *Bench Testing Results*

Full analysis of the LCCP model (SAE J2766) was conducted on each of the three S-FLOW conditions using the results from the SAE J2765 to determine the annual nationwide equivalent CO_2 per mile reduction of the system. The baseline condition analysis with no airflow concentration resulted in an average US vehicle indirect CO_2 emission of 27.3 grams CO_2 per mile. Using the same LCCP model analysis with the S-FLOW technology in front concentration mode resulted in an average US vehicle indirect $C0_2$ emission of 23.6 grams CO_2 per mile which is 3.7 grams CO_2 per mile lower than the baseline condition. Again, using the same LCCP model analysis with S-FLOW technology in driver concentration mode resulted in an average US indirect CO_2 emission of 21.2 grams CO_2 per mile, which is 6.1 grams CO_2 per mile lower than the baseline condition without the technology active.

Average US Vehicle Indirect CO_2 Emissions		Δ CO_2 Reduction
Baseline	27.3 g/mi	-
S-FLOW Front Concentration	23.6 g/mi	3.7 g/mi
S-FLOW Driver Concentration	21.2 g/mi	6.1 g/mi

Table 7.1: S-Flow LCCP Bench Results

Bench test results for each S-FLOW system variation are in Appendix B.

C. Vehicle Testing Methodology and Result

1. *Vehicle Testing Methodology*

The SC03 5-cycle test, as mentioned previously, is a relatively severe test for the climate control systems and without some modification is not suitable to accurately capture the benefit of the S-FLOW off-cycle technology. The high climate system load would prevent the system from operating in some capacities and the compressor displacement would be unlikely to decrease in this high load. However, the pattern and test procedure is widely accepted and used for air conditioning testing. Toyota used this same pattern and test procedure which provides a relatively severe low engine and compressor RPM, but modified the temperature conditions to be less severe to enable demonstration of the benefit of the technology. Ultimately Toyota used the result from the LCCP model bench test results, that include key AC usage thermal conditions, to determine the grams CO_2 per mile used in this application. Therefore, the vehicle testing conducted to verify the bench test results was conducted using one average or representative temperature and usage condition. Toyota selected to conduct the test at 30 °C (86 °F) and 850 W/m² solar load as it is above the EPA auto recirculation mode logic threshold of 23.9 °C (75 °F) and below the somewhat extreme conditions of the standard SC03 test 35 °C (95 °F). It represents a warm summer day for many US drivers.

Vehicle testing offers a variety of challenges when it comes to confirming the grams CO_2 per mile impact of air conditioning technology particularly when working with a feature related to Automatic HVAC control. The Auto function in the HVAC is designed to continuously monitor multiple environmental and vehicle conditions and decide for how best to adjust the climate system to maintain the comfort of the occupant. All of this occurs with no additional input from the customer. Control logic includes inputs from the temperature set point, the cabin temperature, the outside ambient temperature, the engine water temperature, the vehicle solar load, vehicle speed, air conditioner system pressure, the vehicle occupancy sensors, among others. Each of these inputs can vary slightly from one test to another, while still being well within the required range for a successful SC03 test. This variation is difficult to control in a climatic chamber which is a relatively large setting compared to bench test. These variables can combine and the result of this is fluctuation in the grams CO_2 per mile test result. Given the expected improvement value was small compared to the total grams CO_2 per mile test, capturing repeatable tests was difficult. To help average the variation, Toyota conducted four tests with S-FLOW on and four tests with S-FLOW off.

Bench testing provides a very repeatable method for testing through tightly controlled inputs and outputs. The steady state testing removes the fluctuation in testing that can be seen in cabin cool down conditions. This repeatability and precision testing coupled with the ability to combine with the LCCP model makes it the ideal process to calculate the system grams CO_2 per mile improvement. Nevertheless, vehicle testing was conducted to validate the bench testing.

2. *Vehicle Test Results*

As mentioned above in the Vehicle and System Selection Toyota selected a production 2016 Lexus RX350 to represent the "worst case" vehicle based on a variety of factors. All improvements to fuel economy are a result of thermal reduction while still providing the same comfort level to the customer. As mentioned in the above section, there are a lot of variables in chamber testing that need to be considered in determining the final benefit of this technology. As such the testing was conducted a total of 8 times (4 times S-Flow ON, 4 times S-Flow OFF) to confirm the average grams CO_2 per mile reduction of S-Flow in the 30°C condition.

Testing was conducted over 2 days with the most repeatable results occurring with back to back testing. An alternating pattern of S-Flow ON and S-Flow OFF tests was used to prevent any favorable test conditions for S-Flow ON or OFF. The result of the testing was an average 432.2 grams CO_2 per mile S-Flow OFF and 424.8 grams CO_2 per mile for a total reduction of 7.4 grams CO_2 per mile. The detailed results are contained in Attachment C and the following table summarizes the average savings benefit.

SC03 (30C) Grams CO_2 per Mile	**Test #1**	**Test #2**	**Test #3**	**Test #4**	**Average**
S-Flow ON	428.9	426.4	423.2	420.8	424.8
S-Flow OFF	428.2	440.6	429.9	430.2	432.2
Difference (Credit)	-				**7.4**

Table 9.1: S-Flow Vehicle Result grams CO_2 per mile reduction

As mentioned previously in the Introduction the benefit of S-Flow is not limited to the compressor power reduction due to reduced thermal load in the vehicle, there is additional potential for reduced electrical consumption and improved engine warm up due to reduced cabin heating requirements. Currently, Toyota is only pursuing the benefit specific to compressor power reduction, but further benefit is expected beyond that identified by the LCCP model.

In general, when comparing the vehicle and bench test, the resulting benefit from the vehicle test should be higher than the bench test due to the additional electrical load and engine warm up occurring during vehicle testing but absent from the bench testing (provided that the bench testing set-up/methodology is appropriate). In this case, the vehicle data showed a benefit of 7.4 grams CO_2 per mile on average between S-Flow Off and S-FLOW On that, as expected, is higher than the bench test data of 3.7 grams CO_2 per mile benefit estimated from the LCCP model calculation for front concentration only (Note: the low speed, short test pattern for the SC03 created a cabin cooldown condition resulting in S-Flow operation in front only mode). Therefore, the bench test results are consistent with the expected trend when comparing vehicle versus bench test and are indicative of the fuel economy benefit for this technology. Given the scope of this application is limited to compressor power reduction due to reduced thermal load and accounting for the chamber test variability for vehicle testing, Toyota is basing the credit request on the LCCP model bench test and the customer survey usage results.

D. Customer Survey Methodology and Result

1. Customer Survey Methodology

S-FLOW frequency of operation is directly impacted by customer vehicle use and therefore must be considered when requesting the final grams CO_2 per mile benefit. S-FLOW has been commercially available in vehicles since the launch of the 2013 Lexus GS450h and has since been adopted in the 2015 Lexus NX300h, 2016 Toyota Prius, 2016 Lexus RX450h2016 Lexus RX350, 2018 Toyota Camry Hybrid, 2019 Toyota Avalon Hybrid, and 2019 Lexus ES300h.While this will not be the case for all future off-cycle applications due to vehicle release schedules, it does provide the unique opportunity to survey current customers and clarify the true frequency of use. The survey represented a variety of customer usage conditions including a highly fuel-efficient vehicle typically used for commuting (2016 Toyota Prius) and a larger SUV often used for transporting large quantities and varieties of cargo in addition to larger groups of people (2016 Lexus RX350).

The survey focused on two main customer use conditions to confirm: The first being actions by the customer that will inadvertently cause the S-FLOW to operate in limited capacity or not operate at all. This includes the frequency of having a front passenger, opening the front door to load cargo, or placing heavy items on the front passenger seat. All these actions would result in S-FLOW being limited to front concentration only because of the potential for a front passenger. Rear occupant frequency, door opening and cargo placement was also studied as each of these actions would prevent the S-FLOW from working due to the potential for a rear occupant. The second main customer use condition was the direct cancellation by the customer using the S-FLOW button on the HVAC control panel.

2. *Customer Survey Result*

In total 1038 (344 LDT, 694 LDV) current Toyota and Lexus customers responded to the survey across all five vehicle models that are currently in production and come standard with S-FLOW technology. The mileage data in the survey was not measured directly, but instead reported by the customer as an estimate. In some cases, the estimates were obviously over-stated. Toyota worked with statisticians from Aperio Insights to eliminate erroneous responses resulting in a total of 853 usable responses (274 LDT, 579 LDV).

Responses from the survey were used to determine actions from the customers that would partially or fully disable the S-Flow system including:

1. Direct Canceling of S-Flow through the HVAC panel button = No S-Flow
2. Front Passenger or Rear Passenger Occupancy
   a. Driver Only = Full S-Flow
   b. Driver + Front Passenger = Front Concentration S-Flow Only
   c. Driver + Rear Passenger = No S-Flow
   d. Driver + Front Passenger + Rear Passenger = No S-Flow
3. Front Passenger or Rear Passenger Door Opening
   a. Driver Only = Full S-Flow
   b. Driver + Front Passenger = Front Concentration S-Flow Only
   c. Driver + Rear Passenger = No S-Flow
   d. Driver + Front Passenger + Rear Passenger = No S-Flow

These conditions were used to clarify how often S-Flow could operate in both Full S-Flow (Driver Concentration + Front Concentration) and Front Concentration S-Flow on average for both Light Duty Truck (LDT) and Light Duty Vehicles (LDV) vehicles. A weighted average was then made from these results and the 2016 Toyota US fleet sales ratio of LDT (42.02%) and LDV (56.98%). Details of this analysis are outlined in Appendix D.

S-Flow Function	**LDV**	**LDT**	**Weighted Average**
Driver Only	34.1%	30.3%	32.5%
Driver and Front Passenger	35.4%	34.9%	35.2%

Table 11.1 S-Flow Functional Time

The percentages were then combined with the bench test *Table 7.1* of 6.1 grams CO_2 per mile reduction for Driver Concentration and 3.7 grams CO_2 per mile reduction for Front concentration to calculate (3) S-Flow variation credit values. Calculations for Full S-Flow used the frequency and CO_2 reduction of both driver only conditions and driver and front passenger conditions, while Front Concentration Only S-Flow used the driver and front passenger condition and CO_2 reduction and Driver Concentration Only S-Flow only used only the driver only condition and $C0_2$ reduction. The result of which is listed below and the requested credit for this CO_2 reduction technology.

$$Full\ S-FLOW\ CO_2\frac{g}{mi}=\left(32.5\%*6.1\ CO_2\frac{g}{mi}\right)+\left(35.2\%*3.7\ CO_2\frac{g}{mi}\right)=3.3\ CO_2\frac{g}{mi}$$

$$Front\ Concentration\ S-FLOW\ CO_2\frac{g}{mi}=\left(32.5\%*3.7\ CO_2\frac{g}{mi}\right)+\left(35.2\%*3.7\ CO_2\frac{g}{mi}\right)=2.5\ CO_2\frac{g}{mi}$$

$$Driver\ Concentration\ S-FLOW\ CO_2\frac{g}{mi}=\left(32.5\%*6.1\ CO_2\frac{g}{mi}\right)=2.0\ CO_2\frac{g}{mi}$$

S-FLOW System Variation	CO_2 g/mi Credit
Full (Driver and Front Concentration) S-FLOW	3.3
Front Concentration Only S-FLOW	2.5
Driver Concentration Only S-FLOW	2.0

Table 11.2: S-FLOW Credit Request

Detailed analysis and results are presented in Appendix D.

Durability Assessment

Toyota Mobile Air-Conditioning (MAC) systems including the condenser, compressor, evaporator, thermal expansion valve and HVAC module, are required to pass stringent durability requirements to ensure a useful life time of the components. Testing includes meeting the rigorous 10 years/120,000 mile requirements to achieve the CO_2-related efficiency menu credits for both refrigerant-leakage and high efficiency air conditioning technology. Further durability testing on the HVAC module include door operation durability, vibration durability, thermal shock, high temperature durability, servo motor lock durability, dust durability and oil return.

Based on meeting these internal and EPA MAC durability requirements Toyota is confident that the S-FLOW system can meet the requirements for the vehicle lifetime durability with no degradation in the CO_2 reduction benefit of the S-Flow system. Detailed results of the durability testing are included in Attachment E.

Conclusion

Based on the above bench test and vehicle test results in conjunction with the customer survey usage statistics Toyota hereby requests the following off cycle greenhouse gas credit for each of the (3) S-Flow system types for all vehicles equipped with this technology:

S-FLOW System Variation	CO_2 g/mi Credit
Full (Driver and Front Concentration) S-FLOW	3.3
Front Concentration Only S-FLOW	2.5
Driver Concentration Only S-FLOW	2.0

Table 13.1: S-FLOW Credit Request

These credit values have been conservatively estimated to be representative of the fuel economy improvement and grams CO_2 reduction associated with the use of S-FLOW in the United States based on the Life Cycle Change Performance model. Detailed model year, sales volume and the requested S-FLOW credit are included in Attachment F. Thank you in advance for your consideration.

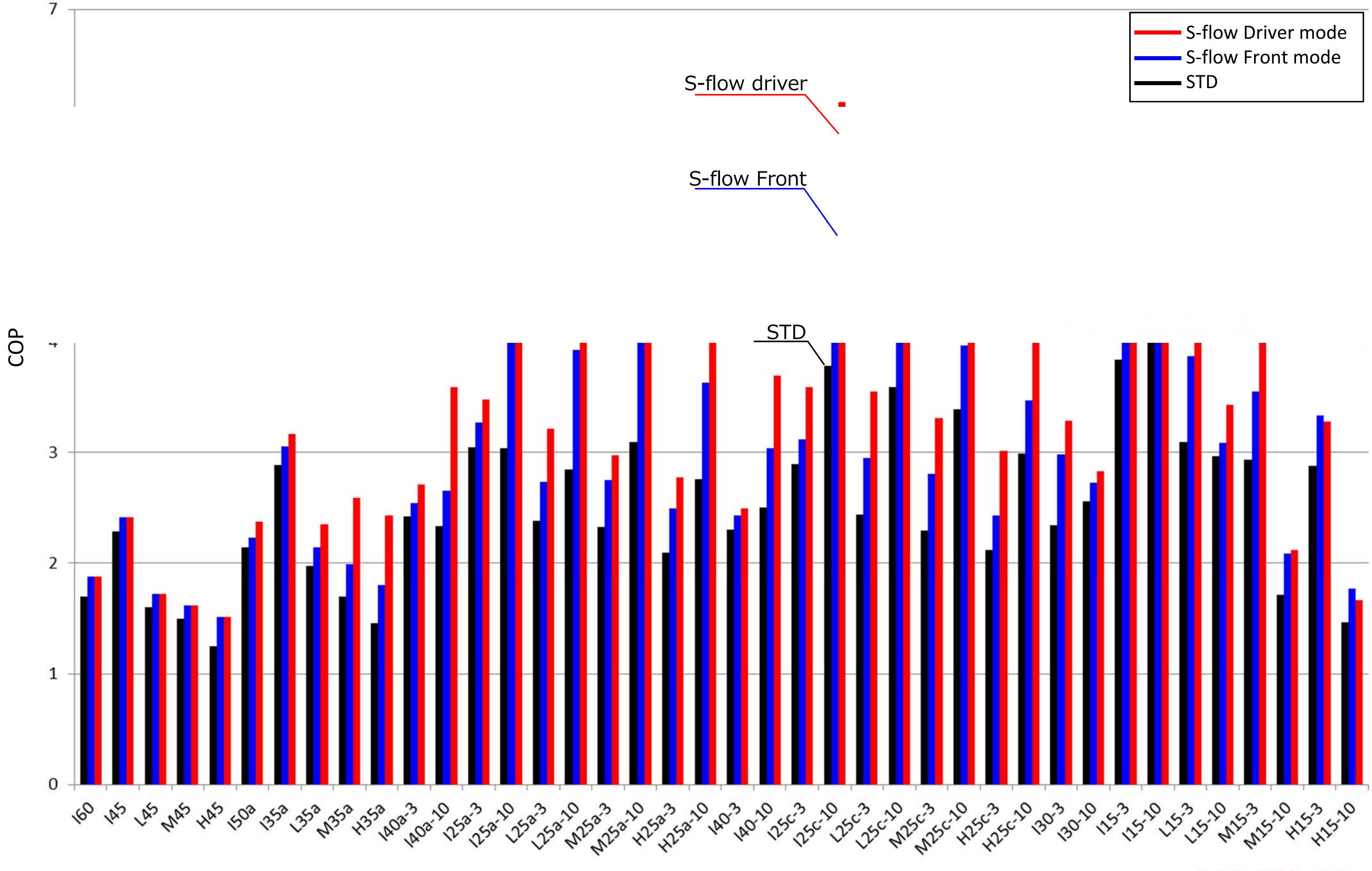
Toyota Motor Engineering and Manufacturing North America

Supporting Materials and Documentation

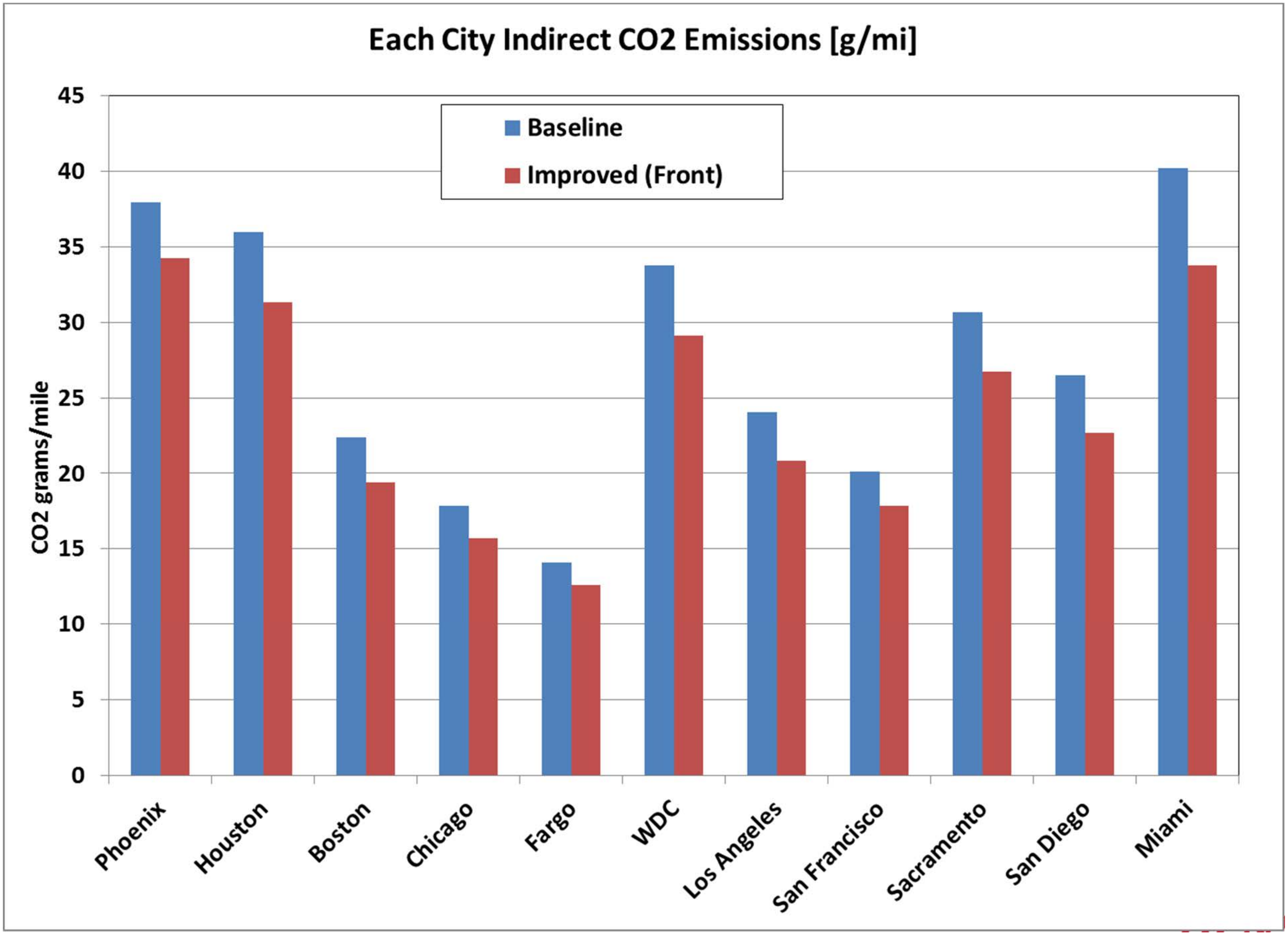
Appendix A: Vehicle Selection Consideration (Confidential)
Appendix B: S-FLOW SAE J2765 Bench Results
Appendix C: 2016 Lexus RX350 Vehicle 30 C SC03 Test Results
Appendix D: Customer Survey Results and Analysis
Appendix E: Durability (Confidential)
Appendix F: Models with S-FLOW (Confidential)
Appendix G: SAE S-FLOW Technical Paper 2013-01-1499, ISSN: 0148-7191 (Confidential)

Test Result (J2765)

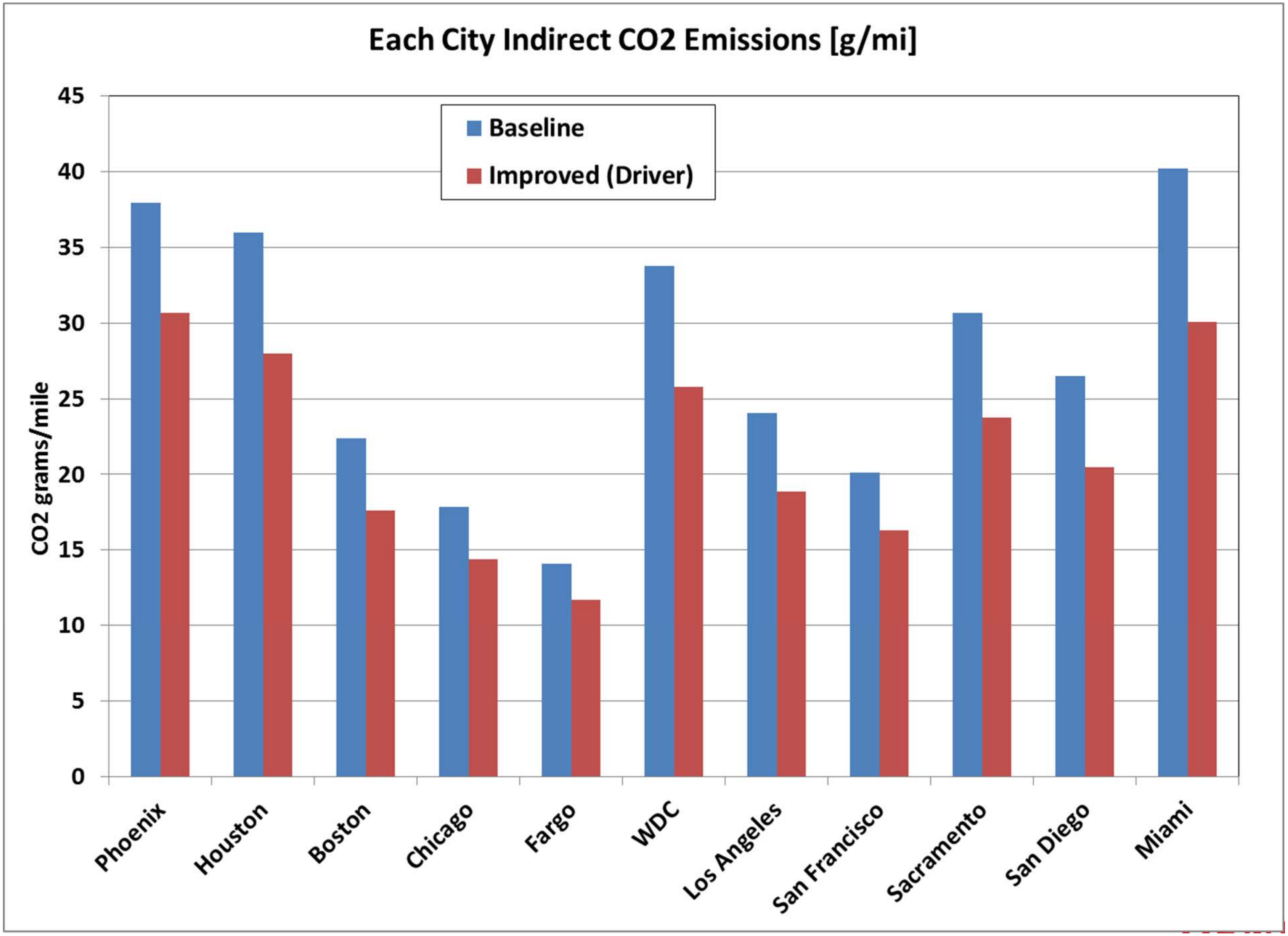
COP assumed same Cooling performance (bench result)



LCCP Results (per city)

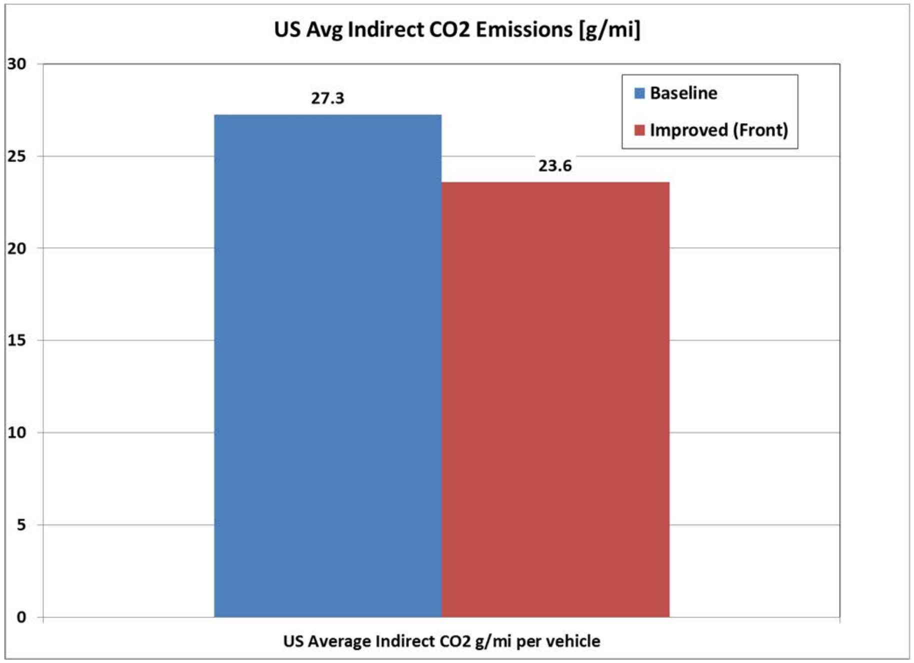


LCCP Results (per city)

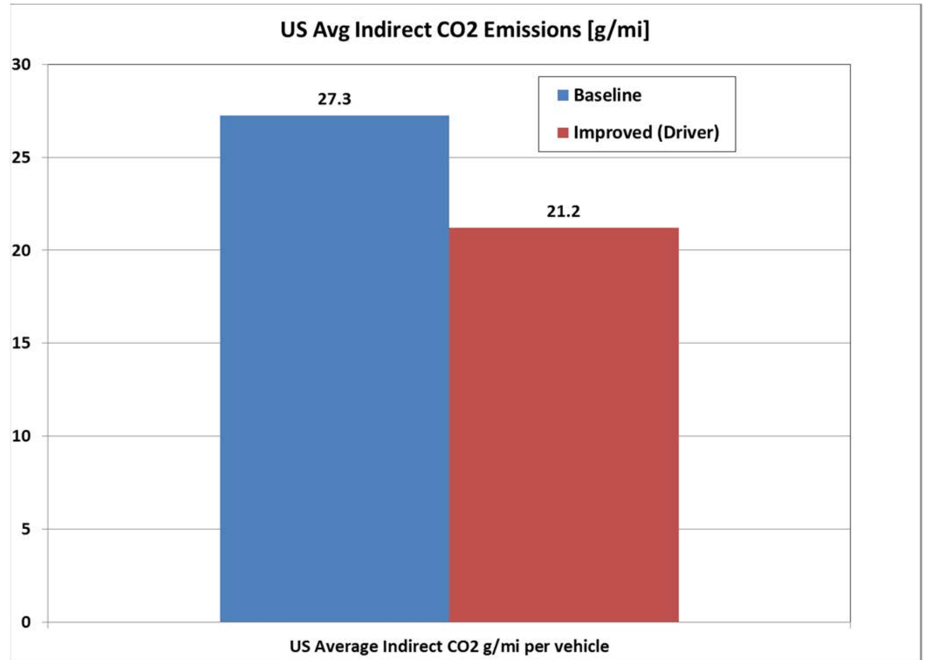


LCCP Results (US Average)

Result of Front mode



Result of Driver mode



CO2 reduction

Average US Vehicle Indirect CO_2 Emissions	CO2 reduction
Min. Benefit of S-flow	**3.7 g/mi**

SC03 - 30 C - 72 Auto Vehicle Test Result

		New Technology	Base Technology	
		S-Flow ON (CO_2 g/mi)	S-Flow OFF (CO2 g/mi)	
	N1	428.9	428.2	
SC03	N2	426.4	440.6	
30 C	N3	423.2	429.9	
72 Auto	N4	420.8	430.2	Delta CO2 g/mi "S-Flow OFF" - S-"Flow ON"
	Ave	424.8	432.2	7.4

Toyota S-Flow Survey Analysis Results and Estimation of Energy Savings

Document #: 002

Revision 1.2

Date: January 26, 2018
Aperio Insights

Jay Rudin, Bob Best

REVISION HISTORY

Revision	Date	Author	Changes
1.0	10-Jan-18	Jay Rudin, Bob Best	
1.1	16-Jan-18	Jay Rudin, Bob Best	Additional calculations for two S-Flow systems.
1.2	26-Jan-18	Jay Rudin, Bob Best	Addition of GS model data into the LTV category. Adjustment to method for treating open door data.

Table of Contents

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1 Executive Summary

The data provided 1038 responses – 344 responses for the LDT, and 694 responses for the LDV.

Mileage was over-stated by the respondents. Many responses were in error in other ways.

Due to responses that were known to be erroneous, only 853 responses could be used - 274 responses for the LDT, and 579 responses for the LDV.

There are three types of S-Flow system. The mean emissions reduction in grams of CO_2 per mile created by the full S-Flow technology is shown in the following table.

Table 1: Overall Emissions Reductions

Per mile	Full S-Flow	Front / Rear Selection	Driver and Passenger
Mean (g/mi)	3.28	2.50	1.98
95% confidence interval	3.05 - 3.50	2.33 - 2.67	1.80 - 2.15

The door opening feature reduced energy savings by roughly 17% in the full S-Flow system.

The ability to turn off the S-Flow feature reduced savings by roughly 12% in the full S-Flow system.

Within the limitations of the data, the calculations show the best estimate for expected savings due to the S-Flow feature.

2 Introduction

Toyota has recently developed a new air flow system called S-Flow (Energy Saving Air Flow Control System). S-Flow (also referred to as "Smart Flow") directs thermal energy selectively to each seating position in the vehicle based on occupancy. This has the potential to conserve energy, as the car provides heat only to select parts of the vehicle's cabin. S-Flow achieves selective energy distribution using a method called SET (Standard new Efficient Temperature), which combines the effects of temperature, airflow velocity, humidity, and other parameters to quantify thermal comfort.

The United States Environmental Protection Agency (EPA) encourages the creation of such technologies by awarding Off-Cycle Credit to auto manufactures that can validate and quantify the energy savings resulting from technologies such as S-Flow.

The energy savings from the S-Flow feature are a random quantity, based on how often the air conditioning is used, and who is in the car. To estimate the reduction in emissions, we must analyze the usage patterns of the cars' drivers.

There are three types of S-Flow system. In all three cases, the system attempts to determine if there are passengers in the front seat and/or the back seat. Based on this decision, the full S-Flow system delivers airflow to the full car, to the entire front seat, or to the driver alone. The Front / Rear selection S-Flow system delivers airflow to the full car, or to the entire front seat. The Driver and Passenger S-Flow with No Rear HVAC Ducts delivers either to the full car, or to the driver alone.

Toyota has conducted a survey of their customers to analyze how often the system saves energy. They surveyed drivers of a Lexus SUV to represent the LDTs (light duty trucks), and drivers of a Toyota Prius or a Lexus GS to represent the LDVs (light duty vehicles).

3 Validation and Verification of the Data

Mileage data was not measured directly. It was all the results of a survey, and represents, not actual mileage, but the driver's guess as to the mileage. Many drivers do not estimate mileage accurately. More importantly, many people do not read surveys carefully. These facts led to some difficulties in preparing the data for analysis.

The questions regarding mileage were split into three segments, describing typical usage on weekdays, weekends, and occasional trips.

The questions for weekdays and weekends (Q2 and Q3) called for the respondent to estimate mileage per day in each of four car configurations.

Table 2: Weekday and Weekend Driving Questions from Survey

Weekday and Weekend Driving Questions
Q2 - How many miles you drive per weekday in each of the following situations.- Driving by yourself: Average total miles per day (Weekday) Driving with only a front seat passenger: Average total miles per day (Weekday) Driving with only rear seat passenger(s): Average total miles per day (Weekday) Driving with BOTH front and rear seat passengers: Average total miles per day (Weekday)
Q3 - How many miles you drive per weekend day in each of the following situations.- Driving by yourself: Average total miles per day (Weekend day) Driving with only a front seat passenger: Average total miles per day (Weekend day) Driving with only rear seat passenger(s): Average total miles per day (Weekend day) Driving with BOTH front and rear seat passengers: Average total miles per day (Weekend day)

But the questions regarding longer road trips (Q4) were asked differently, with separate answers for number of trips per year and length of trips each way. Then the respondents were asked to report how often they drove in each configuration (driver alone, drive with front passenger, driver with rear passenger, and driver with front and rear passengers). The options were:

Every time, Frequently, About half the time, Infrequently, and Never.

Table 3: Occasional Road Trip Questions from Survey

Longer Road Trip Questions
Q4A- In a typical year, how many road trips (longer, less frequent drives) do you go on?
Q4B - How many miles (each way) are these trips?
Q4C - RoadTripPass-No passengers Q4C - RoadTripPass-Only a front seat passenger Q4C - RoadTripPass-Only rear seat passenger(s) Q4C - RoadTripPass-Both front and rear seat passenger(s)

The questions for weekdays and weekends called for total estimates per day. By contrast, the questions for longer trips called for one-way estimates. This could cause respondents who do not read carefully to post round-trip numbers for the trips, since totals were called for earlier.

It also appears that many respondents provide weekly numbers, instead of daily averages, for their weekday mileage.

Since the survey also asked for an estimate of annual mileage, there was an available test of reasonability. Looking at the answers provided, it became clear that mileage in the three categories was greatly over-reported, due to miscoding, misreading, or simply typing in too many zeroes. Here are the averages in each category, showing that the reported results are not consistent with the annual figure also provided.

Table 4: Average Self-Reported Mileage from Survey

Reported Mileage	LDV	LDT
Weekday	32,170	18,831
Weekend	5,885	6,019
Occasional Trips	14,941	3,591
Sum of Above	52,996	28,440
Total	13,103	12,533

Data cleanup was necessary.

The following specific anomalies were identified.

- There are 387 records in which the reported yearly weekday mileage is greater than the reported total yearly mileage.
- There are 126 records in which the reported yearly weekend mileage is greater than the reported total yearly mileage.
- There are 48 records in which the reported yearly occasional trip mileage is greater than the reported total yearly mileage.
- There are 72 responses in which the number of drivers in the household exceeds the total number of people in the household.
- There are four records with two drivers, two total people, and one person under 13 years old.

Many data points were adjusted, as described in the next section. When there was no clear adjustment possible, the record was eliminated from the study.

3.1 Data Cleanup: Weekday and Weekend Mileage Questions

Here is the distribution of the reported daily mileage for weekdays and weekends. Some drivers might be driving more than 100 miles per day, but it’s unlikely to be 14-19% of them, as shown in this graph.

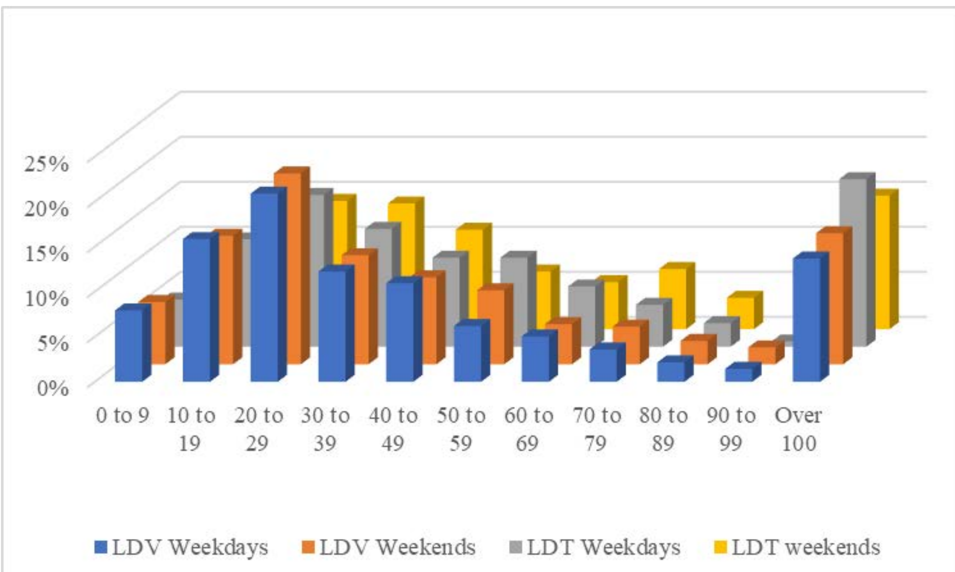

Figure 1: Self-reported Weekday Mileage Distribution

Likely causes of over-reporting including entering weekly numbers when the question called for daily numbers, and simply mistyping, such as adding an extra zero.

Respondents who reported daily mileage greater than their estimated total annual mileage had their weekday mileage multiplied by 20%, on the assumption that they are likely to have reported weekly mileage, rather than daily. If the weekday mileage was still more than they reported for total mileage, then their responses were not used in the study.

If weekend mileage was greater than their estimated total annual mileage, then their responses were not used in the study.

3.2 Data Cleanup: Occasional Trips

Occasional trips were reported, with separate answers for number of trips per year, and length of trips each way. If the total for the occasional trips was greater than their estimated total annual mileage, then their responses were not used in the study.

Then the respondents were asked to report how often they drove in each configuration (driver alone, drive with front passenger, driver with rear passenger, and driver with front and rear passengers). The list of options were:

Every time, Frequently, About half the time, Infrequently, and Never

Many combinations that are impossible were reported, including listing all four configurations as “Every time” or “About half the time,” etc.

The responses with impossible combinations were also not used in the study. The ones that were used were translated into estimated numbers, following rules described in detail in Appendix 1.

3.3 Data verification and validation

The following table shows the results of the data grooming

Table 5: Total Survey Responses

	LDV	LDT	Total
Total	694	344	1,038
Used	579	274	853
Rejected	115	70	185
% rejected	17%	20%	18%

This table shows that the reduced data set is large enough to provide a reliable estimate.

We acknowledge that some misreported numbers are likely left in. This table shows average reported mileage for the reduced data set.

Table 6: Total Mileage Reported (Reduced Data Set)

Weekday Mileage	7,774	8,361	7,963
Weekend Mileage	4,959	4,371	4,770
Occasional Trip Mileage	3,382	3,407	3,390
Sum of Above	16,114	16,140	16,123
Annual Mileage Reported Directly	12,836	12,399	12,696

Overall mileage is still over-reported; some inflated numbers are still included. Inflated numbers cannot always be identified. When a respondent records 100 miles per weekday, we have no way to tell if that is an actual 50 mile commute each way, or if it's a weekly figure for a 10 mile commute.

We are looking for a result expressed in gram of CO_2 emission per mile. Over-reporting is not a problem, as long as it occurs in all configurations equally.

There is no reason to assume otherwise. We conclude that this data set can provide an acceptable and unbiased estimate for CO2 emission reduction from the S-Flow feature.

3.4 Number of Household Members

The number of household members was also slightly misreported. The same question was asked two different ways. In the demographics section, they were asked for "Household Makeup", and later they were asked "How many people (including yourself) live in your household?" In both cases, their options were 1, 2, 3, 4, or 5+. The answers were usually the same, but not always, as shown below.

Table 7: Two Sets of Answers for the Same Question

Number of Household members		
1	142	148
2	378	372
3	84	86
4	63	60
5+	27	28

The anomaly was only seen in the LDV data. As this question was not necessary for the analysis, the anomaly was noted and ignored.

4 Calculation Procedure

For each respondent, an estimated mileage was calculated for each of four configurations.

- Driver only
- Driver and front seat passenger
- Driver and back seat passenger
- Driver, front, and back seat passengers

The weekday totals were calculated by multiplying the daily mileage in each configuration by 5 to make it weekly, then by 50 to represent the number of weeks. (52 was not used, because most people don't follow their weekday routine for 52 weeks of the year, due to vacations and holidays.) Changing this assumption by two weeks in either direction would cause a change of less than .006 grams of CO_2 emission per mile.

Weekend totals were calculated by multiplying the daily mileage in each configuration by 2, then by 52. Changing this assumption by 2 weeks would change the results by less than .01 grams of CO_2 emission per mile.

Trip totals were calculated by multiplying the overall mileage given by a factor taken from the reported frequencies in each configuration: Every time, Frequently, About half the time, Infrequently, and Never.

The total mileage in each configuration was found by adding the results for weekdays, weekends, and occasional trips. Form that, we calculated the percentage of mileage in each configuration.

4.1 Door Openings and the S-Flow Logic

If a car door is opened, then the computer assumes that somebody will be sitting in the corresponding seat, and turns off the S-Flow feature. Therefore it's not enough to calculate how often somebody is sitting in each seat. For calculating emission reduction, we need to know how often the computer assumes that somebody is sitting there, and turns off the S-Flow feature.

Respondents were asked to report how often the passenger doors were opened. The list of options included:

Every time, Frequently, About half the time, Infrequently, and Never

The amount of time in each configuration was modified to account for this aspect of the feature.

We had the following estimates:

A = the probability that the driver was alone
B = the probability that the driver had a front seat passenger.
C = the probability that the driver had a backseat passenger.
D = the probability that the driver had both front and back seat passengers.
E = the probability that the front passenger door had been opened.
F = the probability that one or both back passenger doors had been opened.

Based on these, we calculated the probability that the computer assumed the car was in each configuration.

For instance, the probability that the car assumed there were both front and rear seat passengers was taken as the maximum of D, EF, E(C + D), and F(B + D). The other three probabilities were calculated with similar logic.

Then the mileage for each respondent in each configuration was calculated.

This factor reduced total savings an estimated 17% in the full S-Flow system

5 Results

The above procedure provided a mileage figure for the car in each of four configurations. We then adjusted for whether they turned off the S-Flow feature. Respondents who answered “Yes- Some of the Time” were given credit for 50% of their mileage in each configuration, and those who responded “Yes- All of the time” were included in the average, but with 0 credited mileage

They reported turning it off a (weighted) average of 12% of the time for the full S-Flow system.

The following table shows the effects of the adjustments.

Table 8: Adjustments to % Mileage in Each Configuration for the full S-Flow system

% Mileage	Driver Only			Driver and Front Passenger		
	LDV	LDT	Weighted Average	LDV	LDT	Weighted Average
Actual	51.3%	50.5%	51.0%	35.3%	39.1%	36.9%
Adjusted for doors	37.2%	36.7%	37.0%	38.8%	40.4%	39.5%
With S-Flow turned on	34.1%	30.3%	32.5%	35.4%	34.9%	35.2%

The calculated percentage in the driver-only configuration for each sample was multiplied by 6.1 g/mi. The calculated mileage in the driver-and-front-passenger configuration was multiplied by 3.7 g/mi. These factors were supplied by Toyota, and represent the reduction in CO2 emissions due to the S-Flow feature.

Table 9: Configuration Energy Credit per Mile

Configuration	Emissions reduction
Driver alone	6.1 g/mi
Driver and front passenger	3.7 g/mi

Note that calculations for the full S-Flow system uses both of these values. Calculations for the Front / Rear Selection S-Flow used 3.7 g/mi whenever flow was cut off to the back seat. The Driver and Passenger S-Flow with No Rear HVAC Ducts used the 6.1 g/mi when the driver was deemed to be alone.

With values for each respondent, we calculated the following total CO_2 emission reductions of in g/mi for each car type. Then a weighted average was calculated, based on Toyota’s fleet distribution of 56.98% LDVs, and 43.02% LDTs.

Because the mean was calculated using the Toyota fleet percentages, the result is not the overall mean of the two samples together. So the standard deviation is not based on an overall sample of 833, but on a weighted average of two sample standard deviations.

002

Table 10: Emission Reductions per Mile (Full S-Flow System)

Per mile	LDV	LDT	Weighted Average
Mean (g/mi)	3.39	3.14	3.28
Standard Deviation (g/mi)	2.55	2.09	2.37
sd of mean (g/mi)	0.11	0.13	0.12
Sample Size	579	274	*
95% confidence interval	3.18 - 3.60	2.89 - 3.38	3.05 - 3.50

The 3.28 g/mile reduction for the full S-Flow system represents an estimated average of 32.5% of all driving with the S-Flow feature in driver-only mode (at a savings of 6.1 g/mi), and 35.2% in the driver-and-passenger mode (at an emissions reduction of 3.7 g/mi).

Table 11: Estimated S-Flow Usage

	LDV	LDT	Weighted Average
Driver only	34.1%	30.3%	32.5%
Driver and front passenger	35.4%	34.9%	35.2%

These figures were then modified to calculate emissions reductions for the two alternate S-Flow systems as well. Calculations for the Front / Rear Selection S-Flow used 3.7 g/mi whenever flow was cut off to the back seat. The Driver and Passenger S-Flow with No Rear HVAC Ducts only used the 6.1 g/mi when the driver was deemed to be alone. The results are presented below.

Table 12: Emission Reduction Results: Alternate S-Flow Systems

Front / Rear Selection S-Flow			
Per mile	LDV	LDT	Combined
Mean (g/mi)	2.57	2.41	2.50
95% confidence interval	2.41 - 2.73	2.22 - 2.59	2.33 - 2.67

Driver and Passenger S-Flow with No Rear HVAC Duct			
Per mile	LDV	LDT	Combined
Mean (g/mi)	2.08	1.85	1.98
95% confidence interval	1.91 - 2.24	1.65 - 2.03	1.80 - 2.15

Based on this analysis, we conclude that the S-Flow feature will reduce emissions for the Toyota fleet at an overall rate of 3.28 grams of CO_2 emissions per mile in the full S-Flow system, a rate of 2.50 grams per mile in the Front / Rear Selection system, and a rate of 1.98 grams per mile in the Driver and Passenger system.

6 Limitations of the Study

The emissions saved by the S-Flow feature are random, based on the driving habits of the car's driver(s). Each car will save a different amount. So the study cannot find a single correct answer. It can only determine a best estimate based on incomplete information.

The study used responses of a sample of drivers. It is therefore dependent on the accuracy of the reported information. We know that many responses were inaccurate.

Much of the information is incomplete. When we are told that a driver turns off the S-Flow feature "Infrequently", that could indicate 5% or 40%.

The reported standard deviations and confidence intervals are purely the variation caused by using a sample, and cannot take into account the vagaries of the data.

While self-reported data can be biased, there is no reason to believe that any respondent in this study had a reason to falsify information. There is also no motivation for respondent to all err in the same direction.

While mileage was over-reported, the over-reporting should have affected all configurations equally, and should not affect the overall results, which are primarily based on the percentage of mileage driven in each configuration with the S-Flow feature on.

Within the limitations of the data, the calculations show the expected savings due to the S-Flow feature.

7 Appendix 1: Translation of Non-numeric Responses

Several of the questions were asked in a form that gave non-numeric answers that had to be translated into estimated numbers in order to use them. The following approaches were used on those questions.

7.1 Occasional Trips

Occasional trips were reported, with separate answers for number of trips per year, and length of trips each way. Then the respondents were asked to report how often they drove in each configuration (driver alone, drive with front passenger, driver with rear passenger, and driver with front and rear passengers). The list of options were:

Every time, Frequently, About half the time, Infrequently, and Never

Many combinations that are impossible were reported, including listing all four configurations as "Every time" or "About half the time," etc.

The responses with impossible combinations were not used in the study, with one exception. If all four categories were listed as "Never", and the total vacation mileage was reported as 0, that record was included.

The ones that were used were translated into estimated numbers, via the following rules:

1. If translating "Infrequently" to 25%, "About half" to 50%, "Frequently" to 75%, and "Every time" to 100% added up to 100%, those numbers were used.
2. If there were two "About half" responses and one or two "Infrequently" responses, then the "Infrequently" responses were assigned 10%, and the remaining 80 or 90% were split between the two "About Half" responses. The same method was used with two "Frequently" categories and one or two "Infrequently" categories.
3. If one category was coded "Every time" and one, two, or three of the others were listed as "Infrequently", each "Infrequently" response was given a weight of 5%, and the remaining 85, 90, or 95% was assigned to the "Every time" response.
4. With three or four "Infrequently" responses, they were each assigned 25% or 33.3%, to add up to 100%.
5. A single "About half" and a single "Infrequently" were given ratings of 62.5% and 37.5%, respectively.
6. A single "About half" and a single "Frequently" were given ratings of 40% and 60%, respectively.
7. A single "About half", a single "Frequently", and a single "Infrequently" were given ratings of 40%, 55% and 5%, respectively.
8. One or two "Frequently" ratings were coded as 100% or 50%, respectively.

7.2 Opening Doors

When a passenger door is opened, the computer assumes that a person is in the corresponding seat and adjusts the S-Flow to provide air conditioning. Respondents were asked how often they opened the doors. There were three questions, corresponding to opening the front passenger door, a single back door, or both back doors. The available responses were:

Every time, Frequently, About half the time, Infrequently, and Never

The response of “Never” was translated as opening the door (and thereby turning off the S-Flow) 0% of the time; “About half” was treated as 50%; “Frequently” as 75% and “Every time” as 100%.

But a response of “Infrequently” was handled differently, due to the distribution of the responses. Below is a chart of the numbers in each category.

Table 13: Frequency Distribution of Responses to Open Door Question

	Front Passenger door	One rear door	Both rear doors
Never	103	266	459
Infrequently	507	464	359
About half…	98	63	20
Frequently	75	58	15
Every time …	70	2	0
Total	853	853	853

Note that the distribution is very heavily weighted to the left. A strong majority of respondents gave the answer of “Never” or “Infrequently”, as shown in Figure 2.

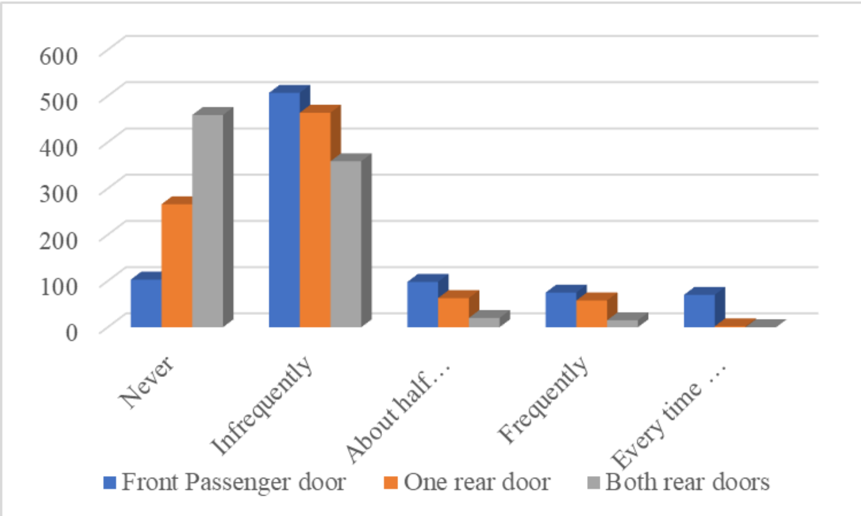

Figure 2: Distribution of Responses to "How often do I open the door?"

For the front door, there were about as many in the “Never” category (12.1%) as in the “About half” category (11.5%). This indicates that the data between them (in the “Infrequently” category) was probably distributed more-or-less symmetrically within its range. So it was coded as 25%.

By contrast, in the two rear door categories, 85-95% of all data was in the “Never” or “Infrequently” categories. Also, the response of “Infrequently” was 4 to 10 times more common than the three higher categories combined. These facts suggest that responses of “Infrequently” were not distributed symmetrically within that category. They were far more likely to represent numbers near the bottom of the category than the top, and couldn’t be fairly represented by the midpoint of 25%. More precise measurements were unavailable. A value of 12.5% was assigned to those responses.

Based on the responses, we know that the respondents treated these categories as if they overlap. Therefore the maximum of the two back door responses was used to represent how often the S-Flow assumed somebody was in the back seat based on an open door.

7.3 Turning off the S-Flow Feature

The respondents were also asked how often the driver turned off the S-Flow feature. The following responses were available:

Before now I was unaware of this feature
I do not have this feature
No
Yes- All of the time
Yes- Some of the time

Since all respondents did in fact have this feature, if the respondent answered, “I do not have this feature”, it was assumed that the feature was never turned off. So respondents who answered “Yes- All of the time” were treated as if their S-Flow was never on. Respondents who said, “Yes- Some of the time” were treated as if their S-Flow was on half the time. All others were treated as if the feature was on 100% of the time.

8 Appendix 2: Demographic breakdowns

The following slides show the demographic distribution. They also show estimated savings for each subgroup. Confidence intervals for these estimates were not calculated in this study.

These graphs were used primarily to determine that the data grooming did not have unexpectedly large effects on the demographics of the sample, and can be trusted to represent the population being sampled. All emissions reductions in this appendix are for the full S-Flow system.

8.1 Gender

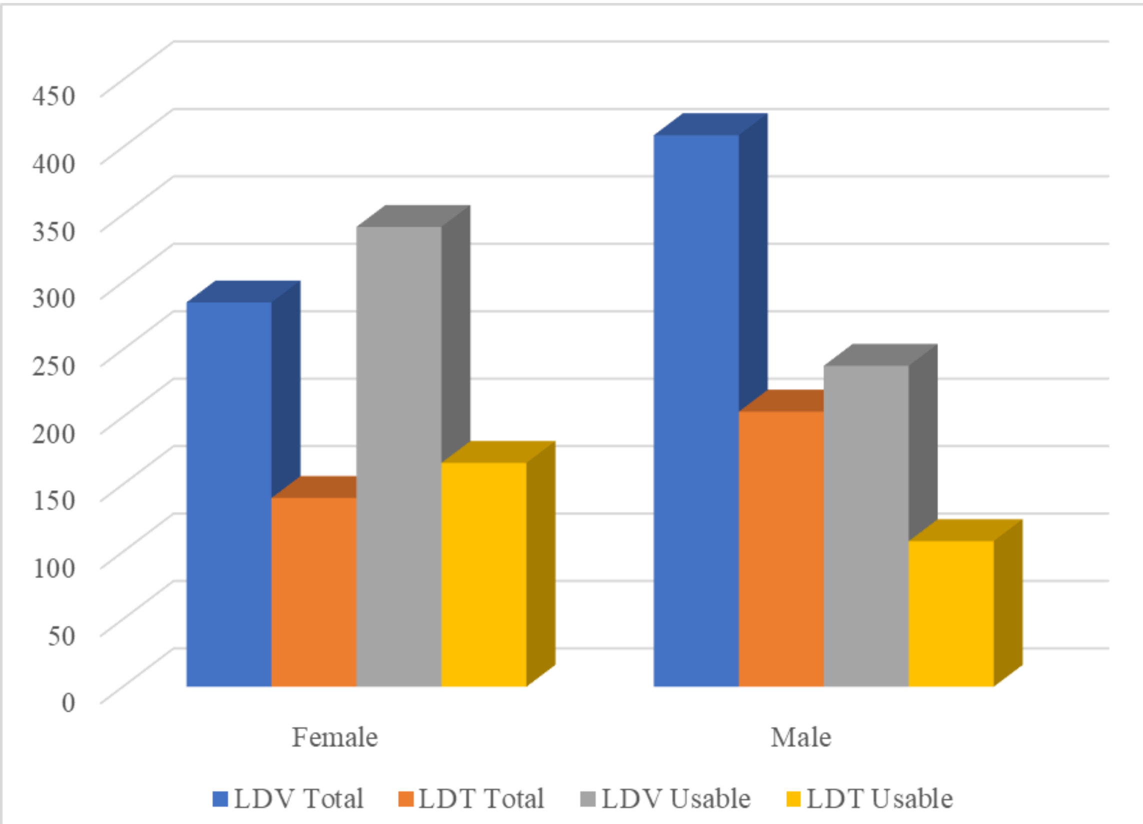

Figure 3: Distribution by Gender

Table 14: Emissions Reduction (g/mi) by Gender

Gender	LDV	LDT
Male	3.32	3.14
Female	3.52	3.13

8.2 Age

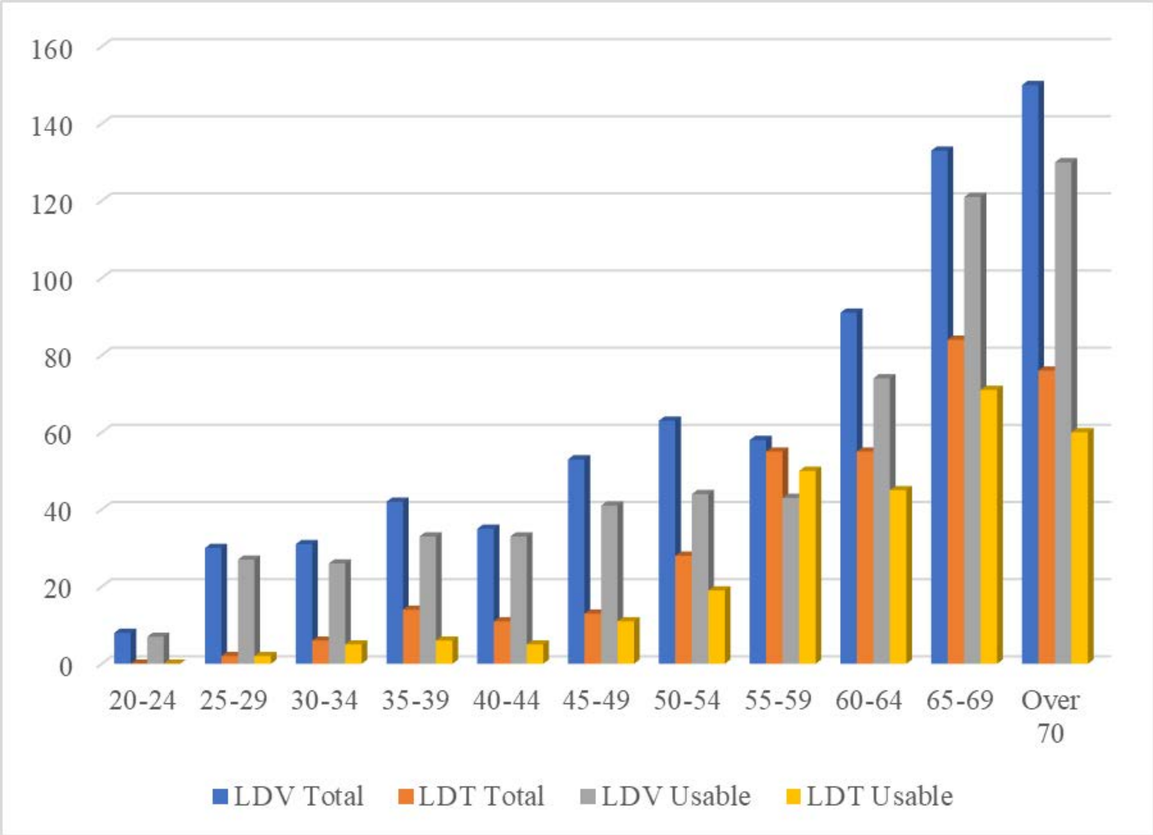

Figure 4: Distribution by Age

Table 15: Emissions Reductions (g/mi) by Age

Age Break	LDV	LDT
20-24	4.14	-
25-29	2.80	2.36
30-34	3.00	2.56
35-39	3.28	3.63
40-44	2.94	3.10
45-49	3.29	2.66
50-54	3.43	2.71
55-59	3.49	2.83
60-64	3.56	2.92
65-69	3.42	3.25
Over 70	3.60	3.76

The greatest energy savings are in the oldest age range, when families are smaller.

8.3 Education

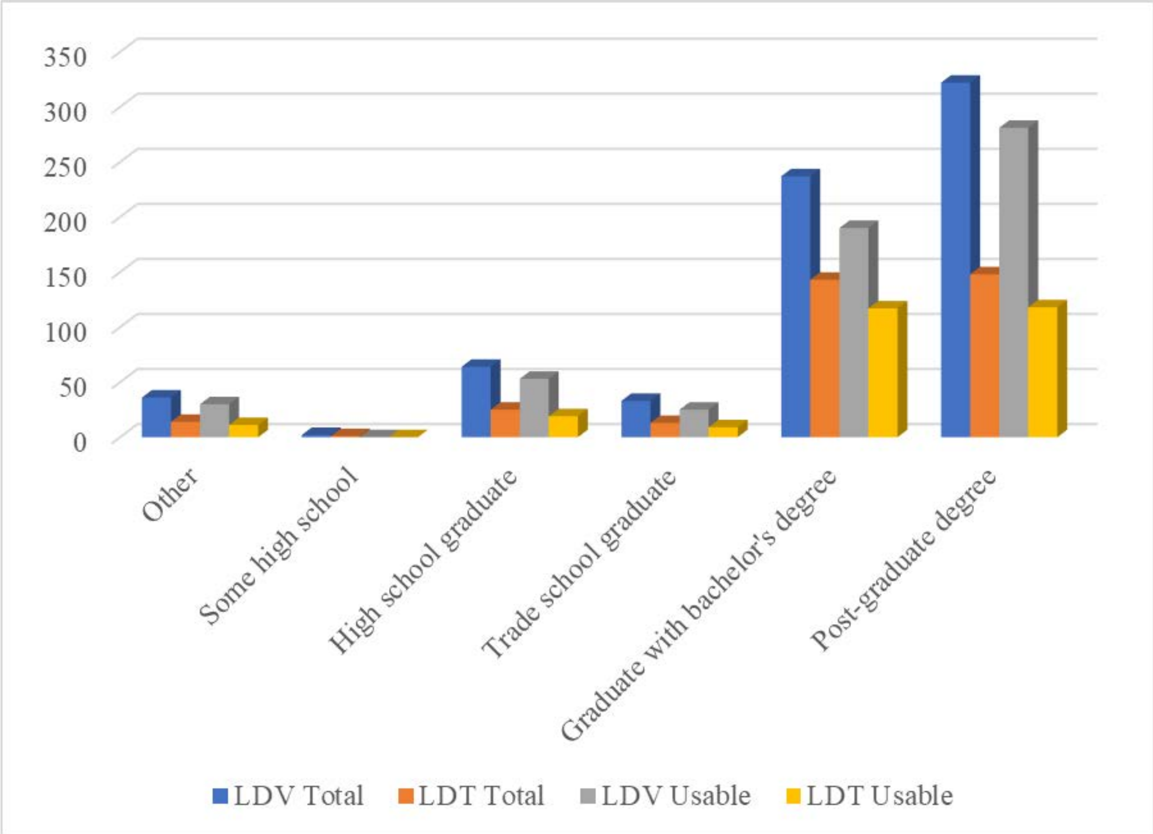

Figure 5: Distribution by Education Level

Table 16: Emissions Reductions (g/mi) by Education Level

Education	LDV	LDT
Other	3.72	2.60
Some high school	-	-
High school graduate	3.17	2.72
Trade school graduate	2.95	3.73
Graduate with bachelor's degree	3.18	3.14
Post-graduate degree	3.60	3.19

Reliable results require a large sample size. In the above chart, the categories “Other” and “Trade school graduate “do not have a large enough sample size to provide reliable results.

8.4 Employment

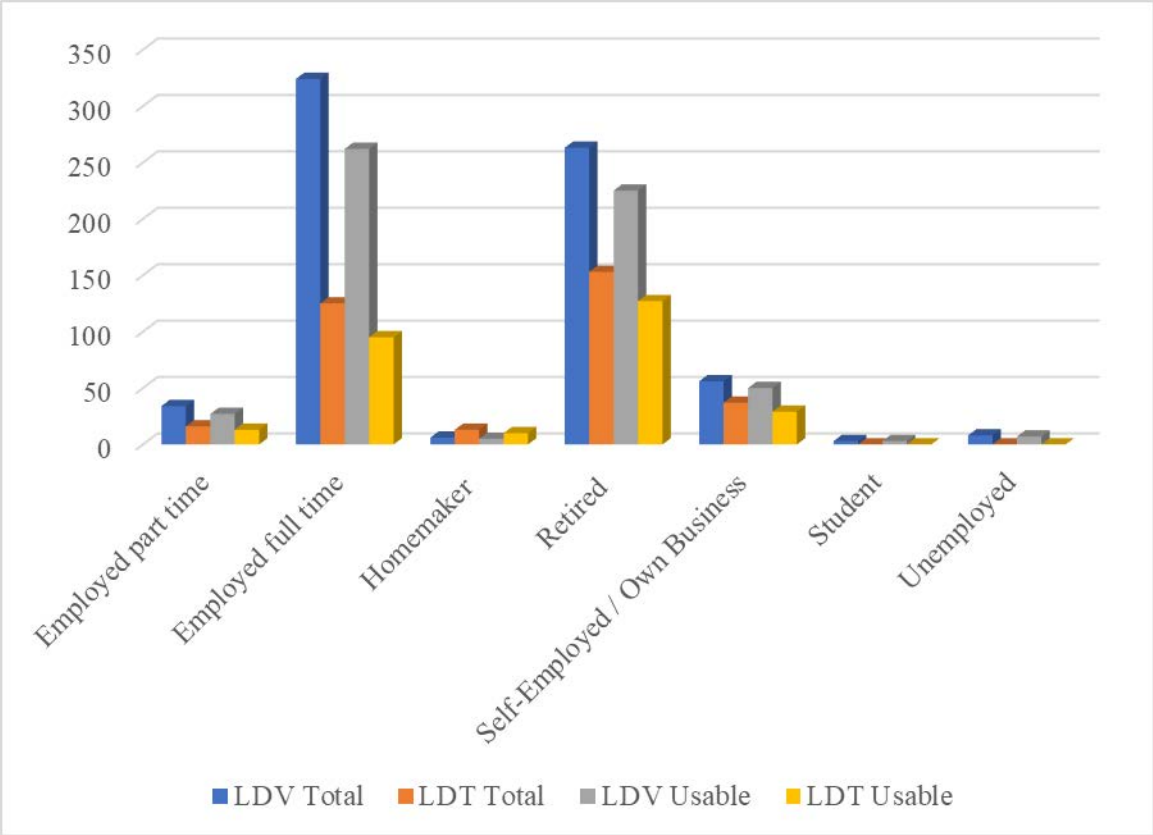

Figure 6: Distribution by Employment Status

Table 17: Emissions Reductions (g/mi) by Employment Status

Employment Status	LDV	LDT
Employed part time	3.60	3.11
Employed full time	3.36	2.90
Homemaker	1.57	2.88
Retired	3.41	3.32
Self-Employed / Own Business	3.38	3.30
Student	4.42	-
Unemployed	3.43	-

Only the three largest segments provide reliable results.

8.5 Ethnicity

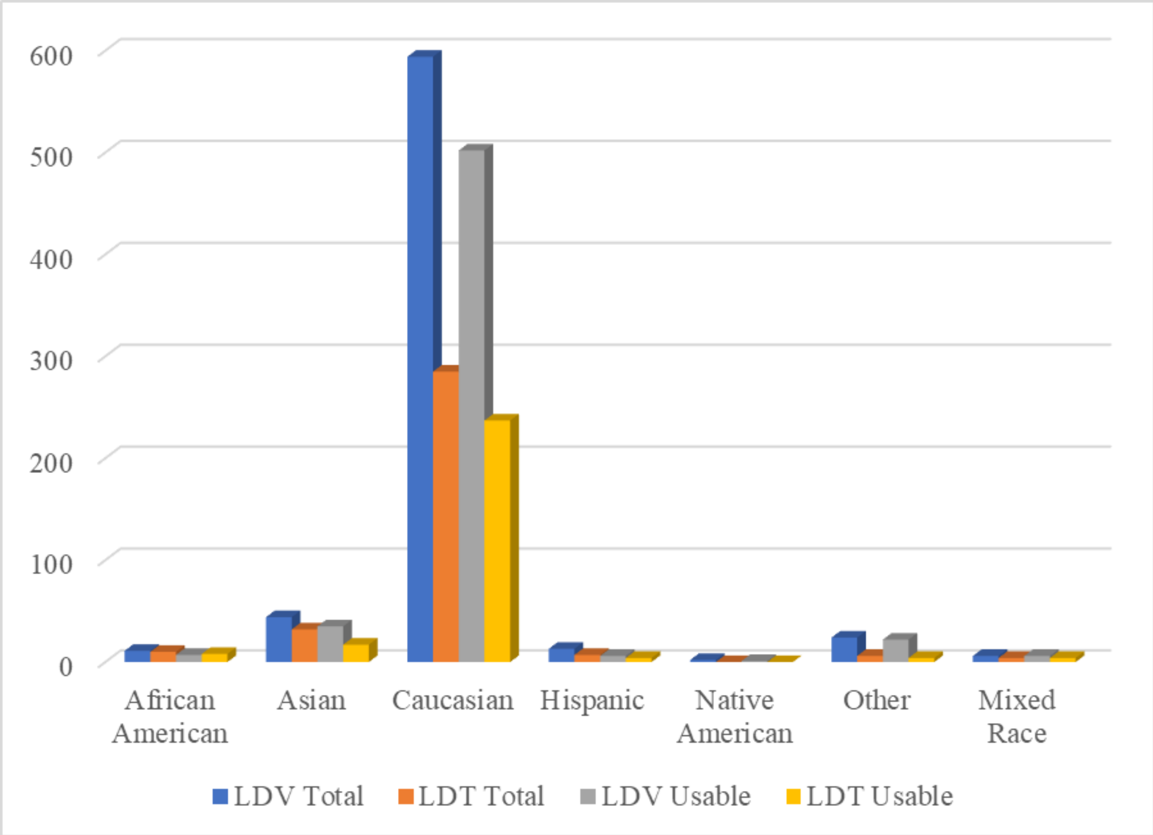

Figure 7: Distribution by Ethnicity

Table 18: Emissions Reductions (g/mi) by Ethnicity

Ethnicity	LDV	LDT
African American	1.82	2.33
Asian	3.02	3.40
Caucasian	3.45	3.14
Hispanic	3.43	3.41
Native American	0.27	-
Other	3.20	3.59
Mixed	4.22	2.42

The anomalous result for Native American energy savings only indicates the problems of a small sample size. That number represents a single car, driven with passengers in the back seat 96% of the time. No category has reliable results except Caucasian and possibly Asian. There just isn't that much data.

8.6 Generation

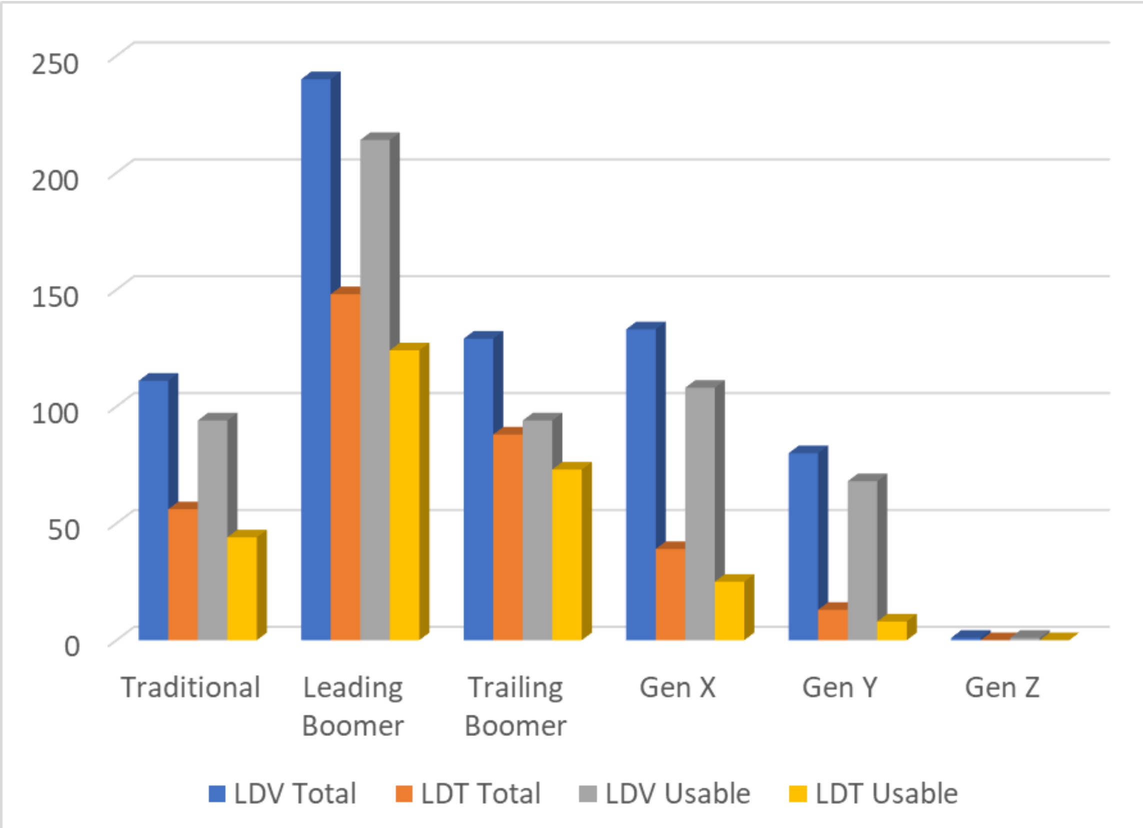

Figure 8: Distribution by Generation

Table 19: Emissions Reductions (g/mi) by Generation

Generation	LDV	LDT
Traditional/Mature/Senior	3.67	3.85
Leading Boomer	3.43	3.12
Trailing Boomer	3.49	2.90
Gen X	3.21	2.89
Gen Y	3.04	2.57
Gen Z	3.70	-

As also seen in the breakdown by age, the S-Flow feature has the greatest value for the older drivers, who are more likely to drive without passengers.

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8.7 Household Income

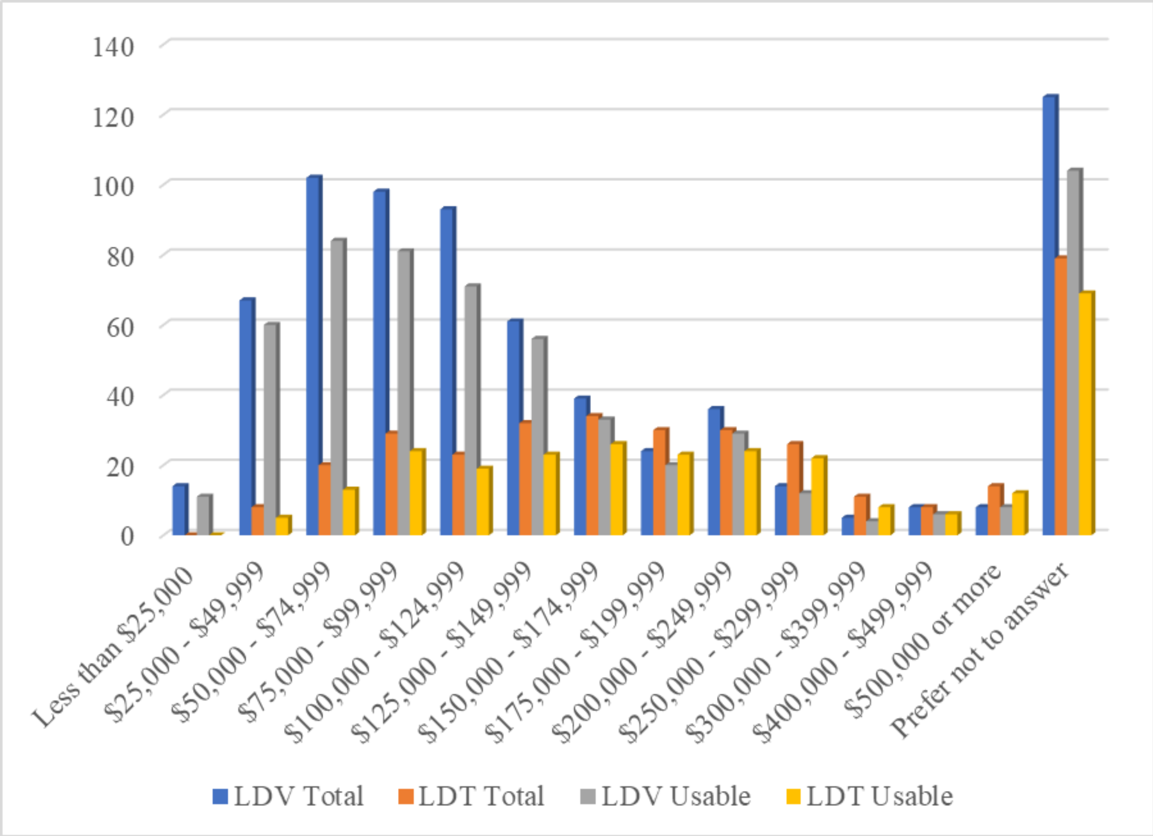


Figure 9: Distribution by Household Income

Table 20: Emissions Reductions (g/mi) by Household Income

HH Income	LDV	LDT
Less than $25,000	3.16	-
$25,000 - $49,999	3.50	1.11
$50,000 - $74,999	3.63	3.15
$75,000 - $99,999	3.21	3.00
$100,000 - $124,999	3.61	3.38
$125,000 - $149,999	3.25	3.45
$150,000 - $174,999	3.48	3.06
$175,000 - $199,999	4.02	3.21
$200,000 - $249,999	2.49	3.47
$250,000 - $299,999	3.60	2.45
$300,000 - $399,999	3.37	4.08
$400,000 - $499,999	2.86	2.92
$500,000 or more	3.03	3.54
Prefer not to answer	3.37	3.12

8.8 Household Size

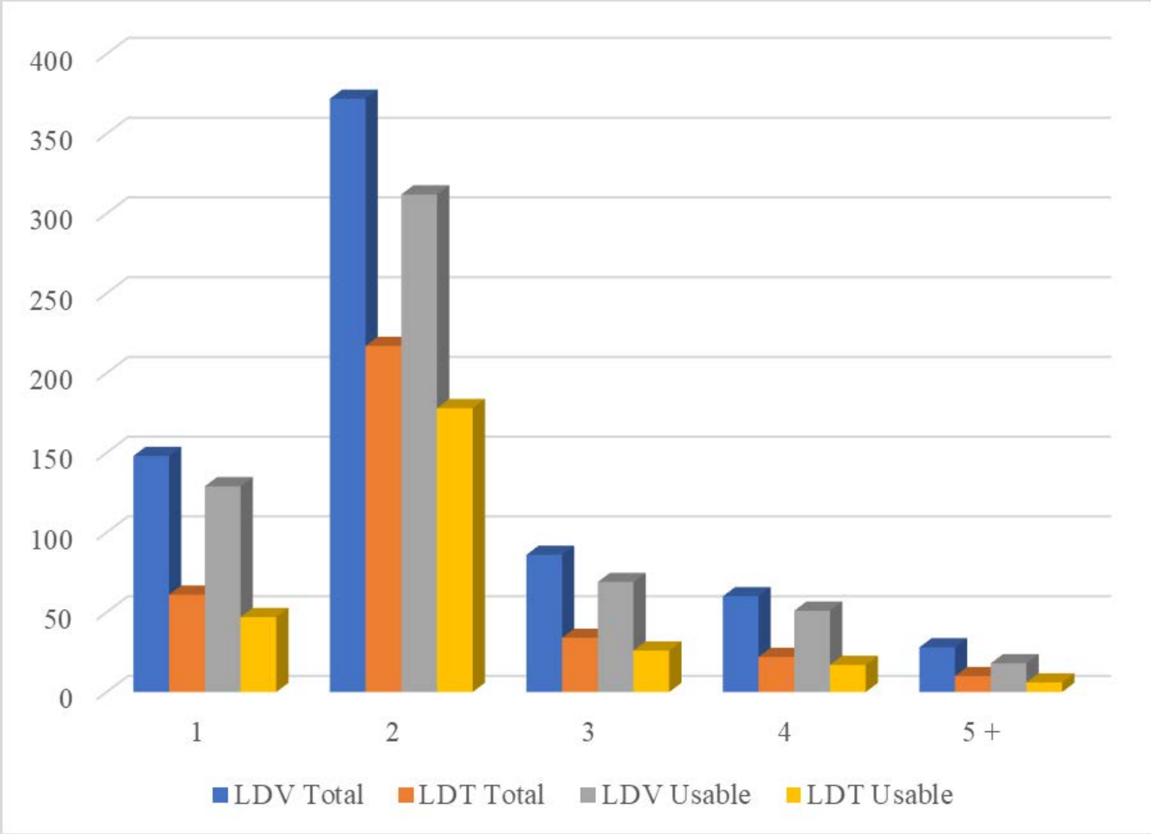


Figure 10: Distribution by Household Size

Table 21: Emissions Reductions (g/mi) by Household Size

Household size	LDV	LDT
1	3.83	3.33
2	3.43	3.19
3	3.30	2.80
4	2.82	3.28
5 +	2.40	1.43

The smaller the household size, the more often the passenger seats are empty, and the more energy is saved.

8.9 Marital Status

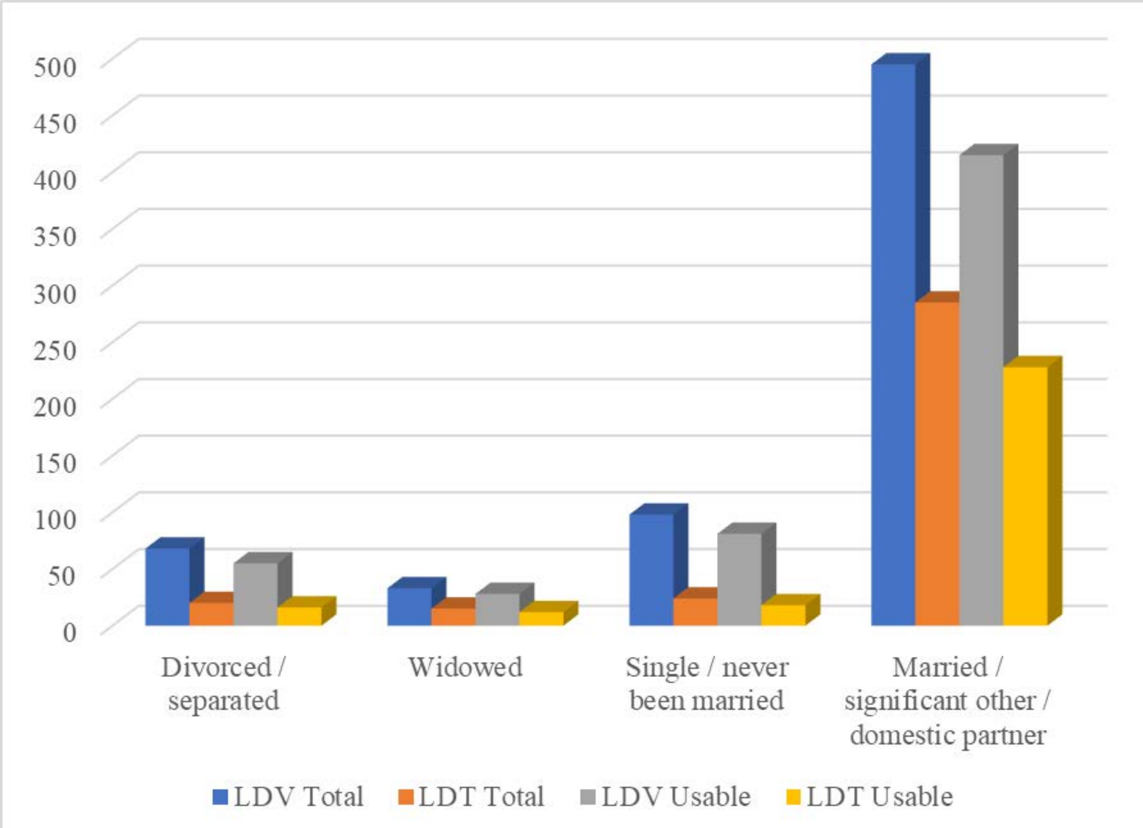


Figure 11: Distribution by Marital Status

Table 22: Emissions Reductions (g/mi) by Marital Status

Marital Status	LDV	LDT
Divorced / separated	3.20	3.42
Widowed	3.36	3.42
Single / never been married	3.99	2.85
Married / significant other / domestic partner	3.33	3.12

Most respondents are married.

8.10 U. S. State

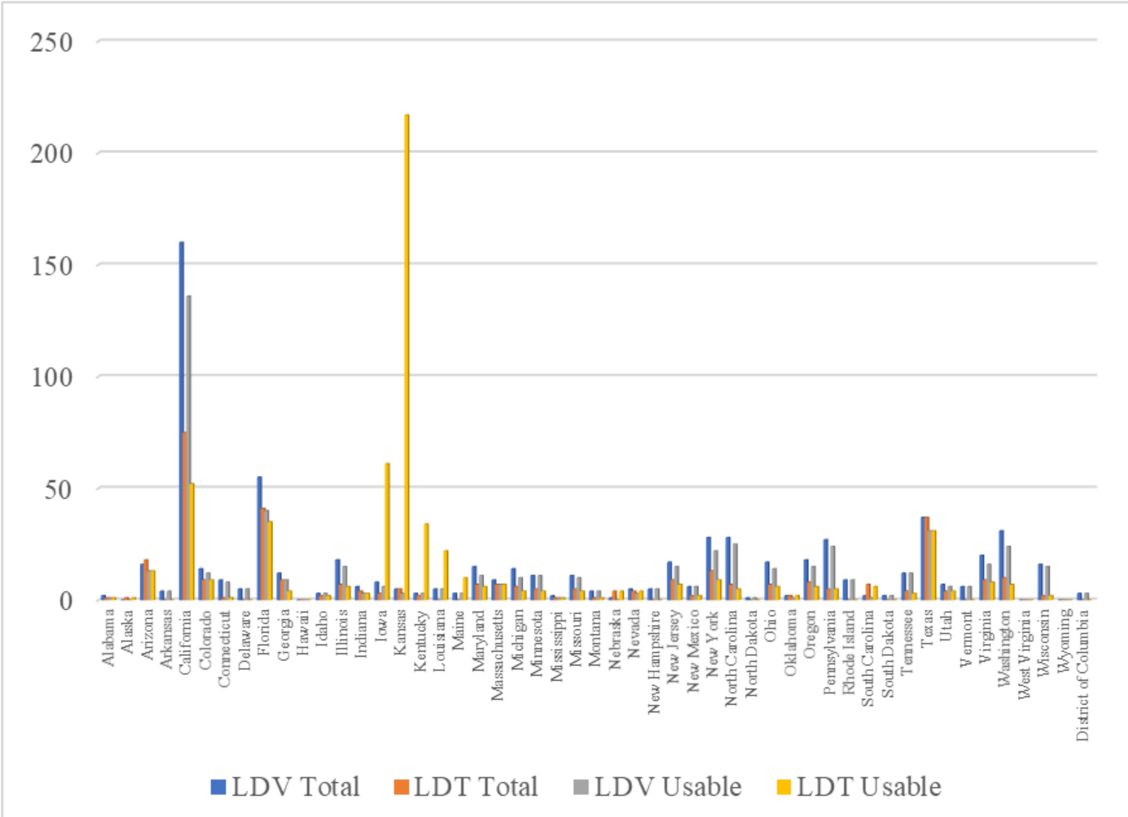


Figure 12: Distribution by U.S. State

Table 23: Emissions Reductions (g/mi) by State

State	LDV	LDT
Alabama	4.77	4.81
Alaska	-	4.72
Arizona	4.17	2.78
Arkansas	3.10	-
California	3.34	3.15
Colorado	3.72	2.45
Connecticut	4.22	4.11
Delaware	4.66	-
Florida	2.89	3.06
Georgia	3.42	3.58
Hawaii	-	-
Idaho	2.43	4.03
Illinois	4.12	3.81
Indiana	4.13	3.17
Iowa	2.68	1.70
Kansas	5.17	3.59
Kentucky	1.89	0.00

State	LDV	LDT
Louisiana	2.68	-
Maine	4.87	-
Maryland	3.63	2.80
Massachusetts	4.48	2.37
Michigan	4.09	3.93
Minnesota	3.47	3.14
Mississippi	3.25	1.85
Missouri	3.66	2.10
Montana	3.49	3.76
Nebraska	-	3.81
Nevada	4.09	3.35
New Hampshire	3.81	-
New Jersey	3.68	3.61
New Mexico	2.37	3.57
New York	3.22	3.28
North Carolina	2.89	3.23
North Dakota	1.87	-

State	LDV	LDT
Ohio	2.97	3.65
Oklahoma	1.95	3.09
Oregon	4.00	3.27
Pennsylvania	3.40	2.96
Rhode Island	3.36	-
South Carolina	4.73	3.07
South Dakota	2.51	-
Tennessee	3.27	2.59
Texas	3.16	3.05
Utah	3.28	3.74
Vermont	2.88	-
Virginia	3.49	3.00
Washington	3.65	3.37
West Virginia	-	-
Wisconsin	3.55	4.34
Wyoming	-	-
District of Columbia	3.10	-

8.11 Number of Drivers

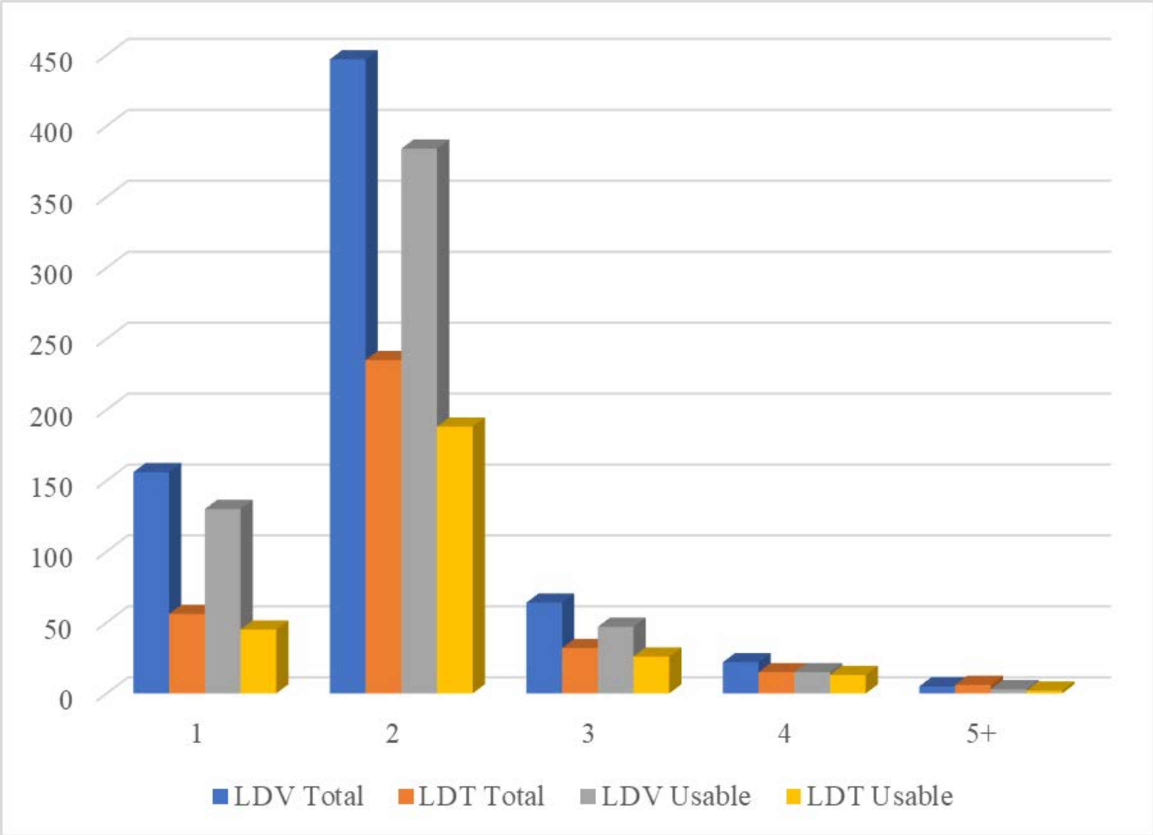


Figure 13: Distribution by Number of Drivers

Table 24: Emissions Reductions (g/mi) by Number of Drivers

# of Drivers	LDV	LDT
1	3.75	3.33
2	3.25	3.16
3	3.78	2.94
4	3.35	2.76
5+	2.06	1.69

8.12 Market Segment

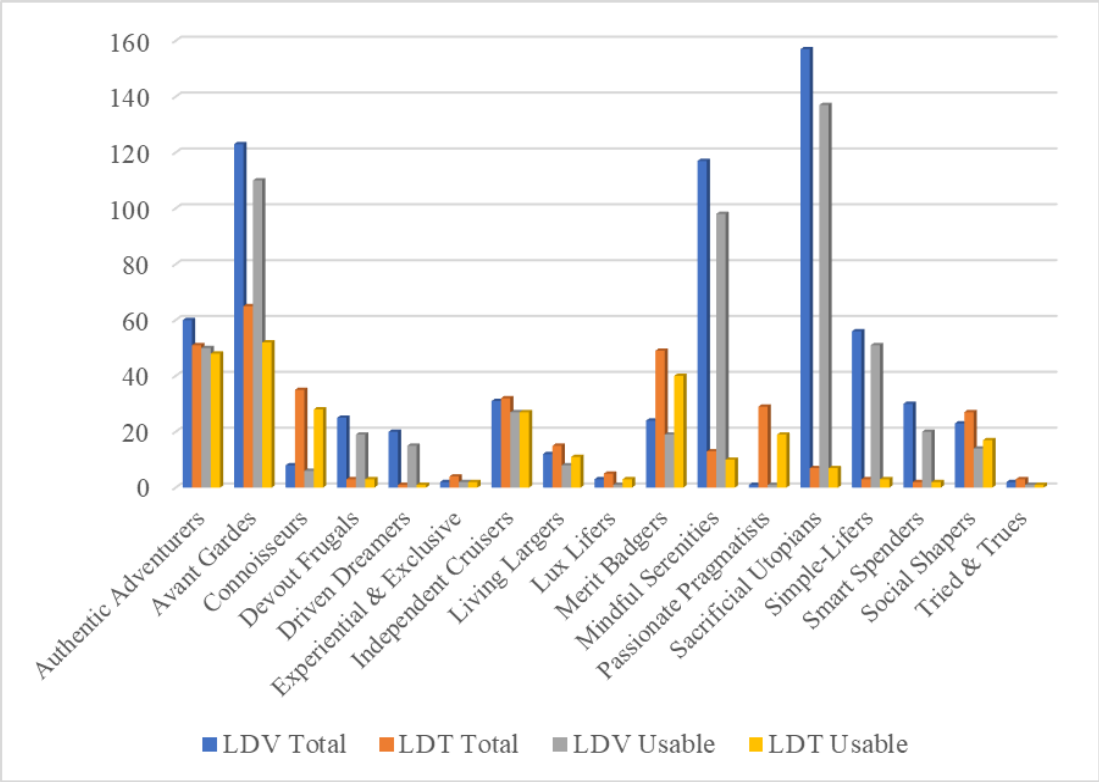
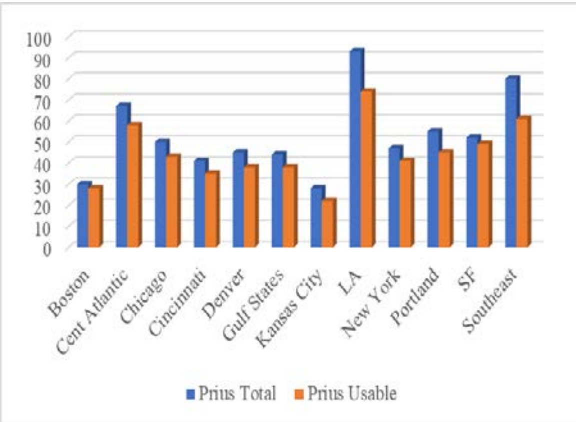


Figure 14: Distribution by Market Segment

Table 25: Emissions Reductions (g/mi) by Market Segment

Segment	LDV	LDT
Authentic Adventurers	3.12	2.73
Avant Gardes	3.45	3.33
Connoisseurs	4.47	3.05
Devout Frugals	3.53	3.12
Driven Dreamers	3.52	0.46
Experiential & Exclusive	4.81	0.48
Independent Cruisers	3.04	3.62
Living Largers	3.35	3.19
Lux Lifers	4.97	2.56
Merit Badgers	2.67	3.07
Mindful Serenities	3.29	2.92
Passionate Pragmatists	4.81	3.51
Sacrificial Utopians	3.85	3.49
Simple-Lifers	3.47	2.40
Smart Spenders	3.24	2.65
Social Shapers	1.79	3.61
Tried & Trues	-	2.41

8.13 Sales Region



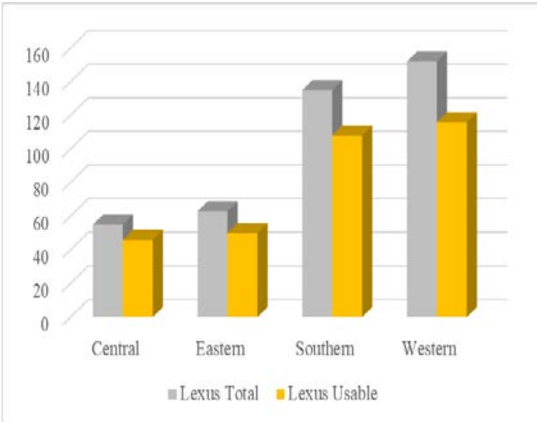


Figure 15: Distribution by Sales Region

Table 26: Emissions Reductions (g/mi) by Sales Region

Toyota Regions	Prius
Boston	3.75
Cent Atlantic	3.57
Chicago	3.80
Cincinnati	3.29
Denver	3.56
Gulf States	3.14
Kansas City	3.34
LA	3.17
New York	3.57
Portland	3.61
SF	3.48

Lexus Regions	Lexus
Central	3.33
Eastern	3.06
Southern	3.07
Western	3.13

In previous sections, Prius and Lexus LDVs are grouped together as a single data set.

But the Lexus GS models are sold at Lexus dealerships, not Toyota dealerships. Accordingly, the data in this section (alone) has been split into Toyota and Lexus data sets, not LDV and LDT data sets.