TOYOTA

Toyota Motor North America, Inc.
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Ann Arbor, Michigan 48105

January 14, 2020

Mr. Linc Wehrly
Compliance Division
Light-Duty Vehicle Center
U.S. Environmental Protection Agency
2000 Traverwood Dr.
Ann Arbor, MI 48105

Subject: Request for 2016-2019 Model Year and later Off-Cycle Credits related to application of the Electric Scroll Type B (ESB) Compressor Technology

This correspondence represents Toyota's application for Off-Cycle credit of 1.9 grams CO_2 per mile for the use of the ESB Compressor Technology. The credit amount has been determined using the alternative methodology outlined in 40 CFR §86.1869-12(d), details of which can be found on the following pages of this correspondence.

Per 40 CFR §86.1869-12, vehicle manufacturers may obtain off-cycle credits for the use of a CO_2-reducing technology whose benefits are not adequately captured on the Federal Test Procedure and/or the Highway Fuel Economy Test. This application is submitted in accordance with the provisions of subsection (d), which enables manufacturers to earn credits by demonstrating that the applicable technology provides GHG reduction benefits via an alternative EPA-approved methodology.

If you have any questions regarding this matter, please contact Mr. Arvon Mitcham of my staff at (734) 995-5587 or email: arvon.mitcham@toyota.com at your earliest convenience.

Sincerely,

William Meschievitz
Group Manager
Powertrain Certification and Compliance

Attachment(s): [2]
ESB Compressor Application (CBI and FOIA versions)

December 6th, 2019

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 DENSO Electric Scroll Compressor Pressure Adjusting Valve Technology

Introduction

Pursuant to 40 CFR § 86.1869-12(d), 49 CFR § 531.6(b), and 49 CFR § 533.6(c)Toyota Motor Corporation (herein referred to as "Toyota") requests the following greenhouse gas off-cycle credit amount for the DENSO Electric Scroll Air Conditioning Compressor Variation B (ESB) with pressure adjusting valve technology.

Technology	CO_2 g/mi Credit
ESB Compressor	1.9

Table 1.1: ESB Compressor Credit Request

This technology improves the efficiency of the electric scroll compressor using a pressure adjusting valve to optimize back pressure on the fixed scroll and reduce mechanical losses. This is similar to the off cycle alternative method technology for the belt driven DENSO SES / SAS compressor which was granted to Toyota for 1.1 grams CO_2 per mile in June 2018 (EPA-420-R-18-014).

This ESB compressor technology was first used by Toyota in the 2016 Toyota Prius. It was then implemented on the 2017 Toyota Prius Prime, 2018 Toyota Camry, 2017 Lexus LC500H, 2018 Lexus LS500H, 2019 Lexus ES300H and 2019 Toyota Avalon HV. Toyota anticipates that use of this technology will increase in the future on additional electric and hybrid models.

Per the recommendation in 40 C.F.R. § 86.1869-12(d)(1), Toyota met with the EPA for informal discussions on 12/12/2018 and 11/13/2019 to review the proposed plan and confirm application direction from the EPA. In these meetings the EPA was agreeable with the Toyota proposed method and any comments were reflected in the updated process.

Description of Technology

E-compressor, different from belt driven compressor (i.e., SAS or SES compressors) subject to engine operation, can be driven by electric power independent of engine drive. DENSO ES compressor is an electric, variable-speed, scroll compressor designed to meet cooling capacity for compact, mid-size and full-size passenger cars and light-duty trucks. ES compressor is composed of inverter, suction joint, discharge joint, motor, fixed scroll, orbiting scroll, oil separator, back pressure valve and castings. The inverter converts DC power supply to AC three-phase power and drives the motor which controls the compressor speed. The motor drives the orbiting scroll to generate displacement between the orbiting and fixed scrolls for refrigerant to flow in, then develop the volume into a closed, shrinking chamber to compress refrigerant, then develop into the discharge chamber. The compressed refrigerant is then discharged through oil separator. In this way, the compressor completes the task to bring the refrigerant from low temperature low pressure condition to high temperature high pressure condition. Due to high pressure in the chambers between orbiting scroll and fixed scroll, a press load is needed on orbiting scroll to keep orbiting scroll always closely contacting fixed scroll, so no leakage path will result. In ES compressor, a pressure differential valve is used as back-pressure valve to supply a constant back pressure. However, in the condition of low cooling load, the preset back pressure is excessive, which results in unnecessary mechanical loss. To improve mechanical efficiency, DENSO ESB compressor has been designed utilizing a thrust valve as back-pressure valve to set back pressure based on suction pressure. Once back pressure drops, the two scrolls will start separating. Scroll separation will open thrust valve, to raise back pressure, which realize a self-adjusted back pressure and maintains a constant, small difference between actual back pressure and necessary back pressure. This reduces mechanical losses, thus improving the overall system efficiency.
For Example:

(1) Under high compression ratio conditions, the variable thrust valve can increase the back pressure to prevent compression failure and achieve the maximum performance of the system
(2) Under low compression ratio conditions, the variable thrust valve can reduce the back pressure to reduce excess mechanical drag increasing the efficiency at variable compression ratio conditions
(3) The optimized fixed scroll back pressure reduces excess mechanical losses within the air conditioning (A/C) compressor

As a result, the addition of the variable thrust valve offers efficiency improvements to the compressor over the current fixed spring type pressure valve electric scroll compressor design.

Additional details of the system are documented in the Attachment A.

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 mechanical losses in the compressor. 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. Due to vehicle testing variability and the broad range of required conditions to test, the EPA agreed that vehicle testing was not required for this application in addition to the bench testing to confirm the CO_2 gram per mile reduction. The final application grams CO_2 per mile improvement was derived from the bench test results.

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 the ESB compressor, the A/C is off during the EPA`s two cycle testing for both city and highway. The ESB pressure adjusting valve technology is primarily designed to improve compressor efficiency in low load conditions, the A/C must be switched on to realize the benefit of the technology.

Of the EPA`s 5- Cycle tests only the SC03 test includes the use of the A/C. The SC03 test is relatively severe test for A/C 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. The ESB compressor pressure adjusting valve provides the most benefit in mild conditions. This is due to the ability to reduce mechanical loses in low compression ratio conditions. In the more severe conditions of the SC03 the ESB compressor would be at higher compression ratio conditions 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>System Selection</u>

Both the previous generation electric scroll (ES) compressor and the ESB compressor are produced in multiple sizes to meet the system capacity needs of different vehicle systems. The variations of these compressor sizes are listed below with the number following the letters representing the displacement volume of the compressor in cubic centimeters (i.e ESB27 has a displacement of 27 cc).

Vehicle Size	ES	ESB	Comment
Small	ES14	ESB20	Different Sizes
	ES18		
Medium	ES27	ESB27	High Sales Volume
Large	ES34	ESB34	Low Sales Volume

Table 2.1: ES and ESB Compressor Sizes

Using the same displacement compressor was critical for a direct A to B comparison for the purposes of efficiency comparison on this application. For this application the smallest size compressors ES18 and ESB20 could not be used due to inability to make a direct comparison. Further, the ESB27 coefficient of performance (COP) or efficiency is highest of all the ESB compressors; which would result in a lower benefit from a more efficient system. Given the ESB27's high frequency of use compared to the ESB34 in the Toyota and Lexus vehicle lineup and the higher COP, it was selected to be the most representative of the fleet for this application.

For bench testing the ESB was combined with a production 2018 Toyota Camry Hybrid A/C system including the HVAC module, AC lines and condenser. The production 2018 Toyota Camry Hybrid system does not achieve the full AC Efficiency cap of 5.0 grams CO_2 per mile with a total AC credit of 4.8 grams CO_2 per mile. To ensure that the testing represented the worst case condition, Toyota combined the existing production Camry Hybrid AC system with the IHX A/C lines from the Toyota Camry for a system that met and exceeded the LDV 5.0 CO_2 g/mi cap with a total of 5.8 CO2 g/mi. This represents the most efficient AC system and, therefore, the system that would provide the least opportunity for fuel economy savings from AC usage. This was considered the most severe condition for the Toyota and Lexus fleet.

B. <u>Bench Testing Methodology and Result</u>

1. *Bench Testing Methodology*

Bench testing was conducted on standard production components from the 2018 Toyota Camry and 2018 Toyota Camry Hybrid using the publicly available SAE J2765 standard to determine the A/C power reduction between the ES compressor series and ESB compressor series. Of the 40 bench conditions results in SAE J2765, 26 conditions of varying temperature, humidity, and evaporator target temperature 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 ESB pressure adjusting valve 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 A/C system.

2. *Bench Testing Results*

Full analysis of the LCCP model (SAE J2766) was conducted on both the ES and ESB compressor systems 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 using the ES compressor with no pressure adjusting valve resulted in an average US vehicle indirect emission of 31.8 grams CO_2 per mile. Using the same LCCP model analysis with the ESB variable pressure adjusting valve technology resulted in an average US vehicle indirect emission of 29.9 grams CO_2 per mile which is 1.9 grams CO_2 per mile lower than the baseline condition.

Bench test results for each compressor system variation are in Appendix B.

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 A/C 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 ESB compressor can meet the requirements for the vehicle lifetime durability with no degradation in the CO_2 reduction benefit of the ESB compressor. Detailed results of the durability testing are included in Attachment C.

Conclusion

Based on the above bench test results Toyota hereby requests the following off cycle greenhouse gas credit for all vehicles equipped with this technology:

Technology	CO_2 g/mi Credit
ESB Compressor	1.9

Table 3.1: 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 ESB compressor in the United States based on the Life Cycle Change Performance model. Detailed model year, sales volume and the requested ESB credit are included in Attachment D. Thank you in advance for your consideration.

Toyota Motor Engineering and Manufacturing North America

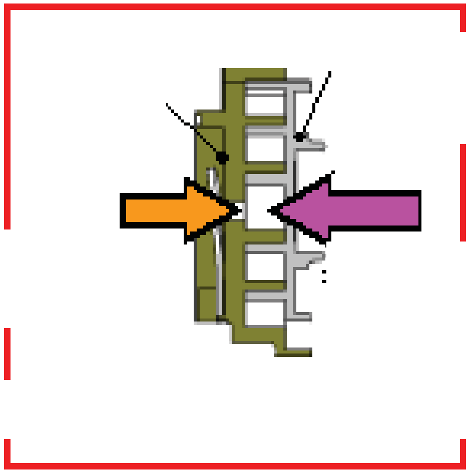
Supporting Materials and Documentation

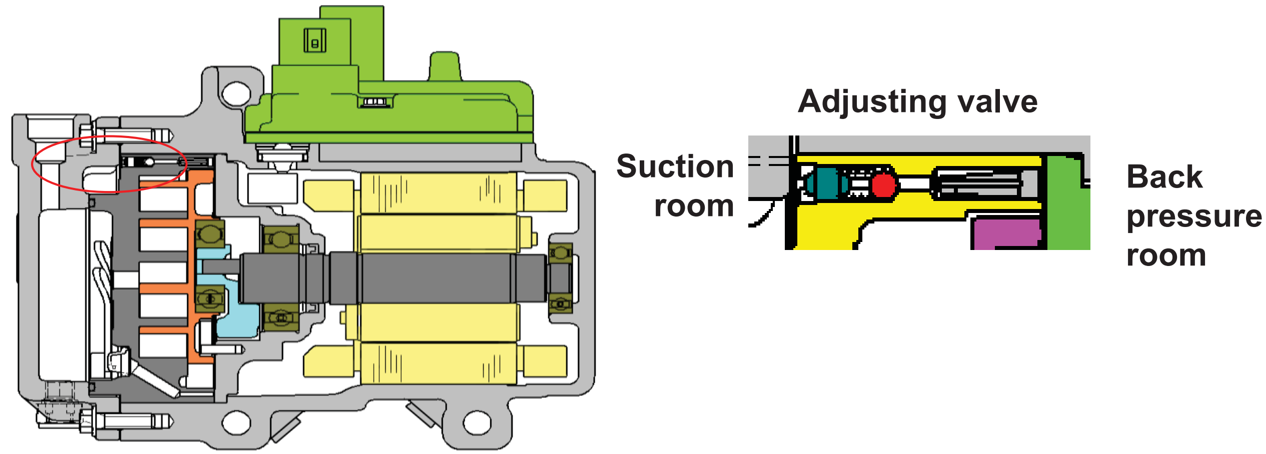
Appendix A: ESB Technology Description
Appendix B: ES and ESB SAE J2765 Bench Results
Appendix C: Durability (Confidential)
Appendix D: ESB Compressor Adoption (Confidential)

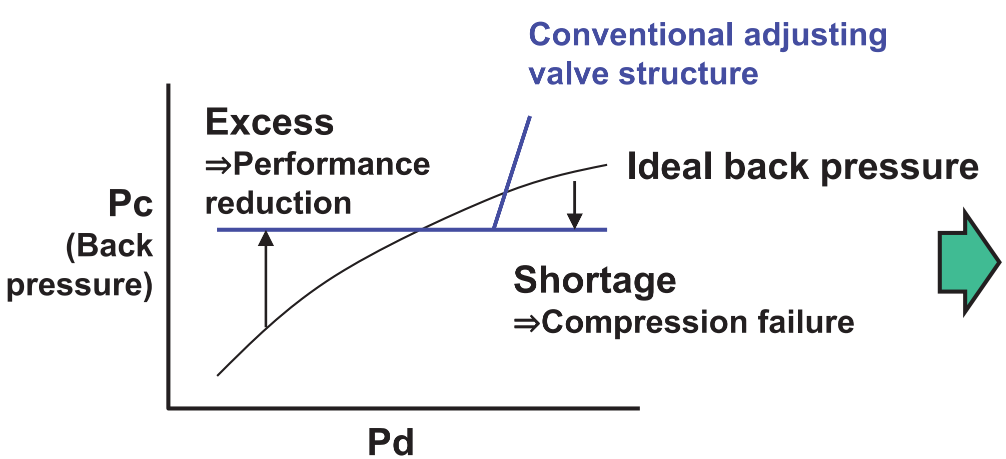
Technical differentiation [Back pressure structure]

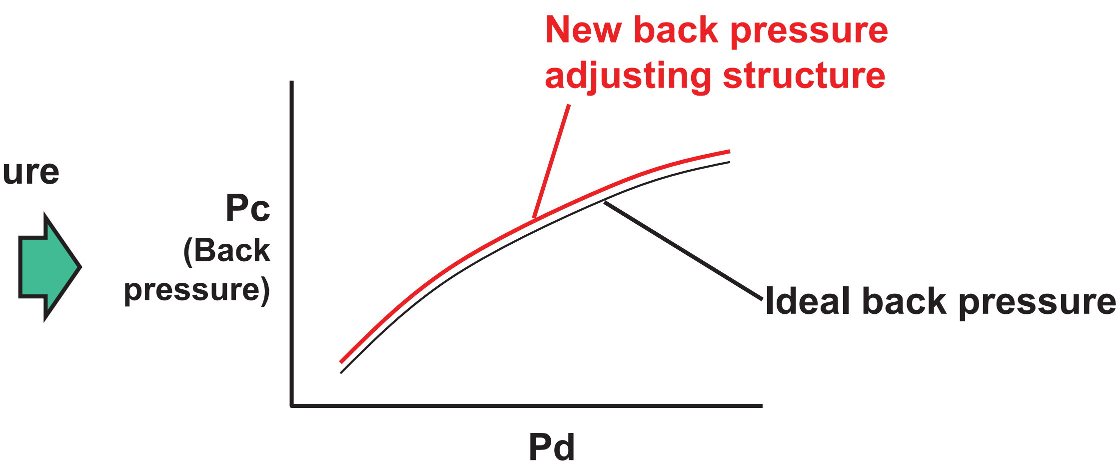
Conventional adjusting method of back pressure

➔ To control constant pressure as back pressure by using adjusting valve method









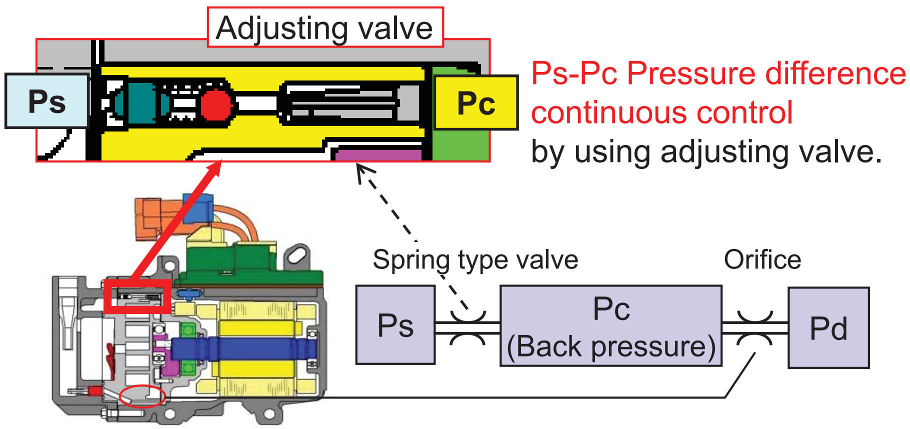
The structure that can adjust the back pressure automatically in order to become optimize both compression thrust force and back pressure force.

Technical differentiation [Structure and principle of Thrust valve]

〔Challenge to higher performance〕

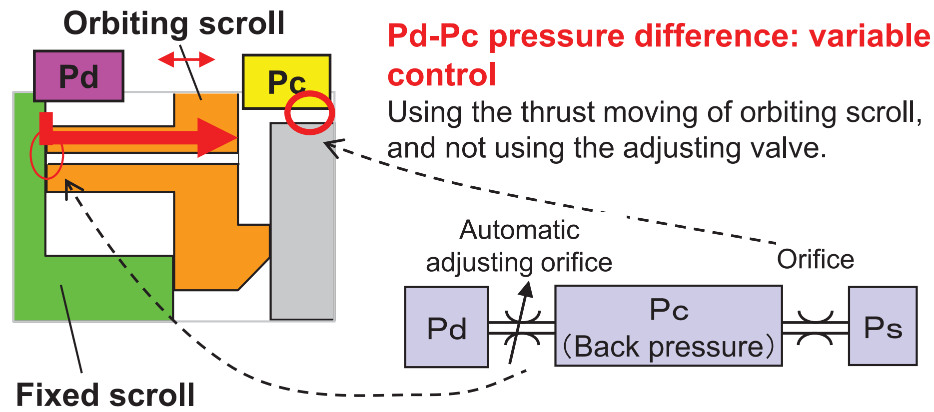
Structure

Conventional — Back pressure adjusting valve



Ps-Pc Pressure difference: continuous control by using adjusting valve.

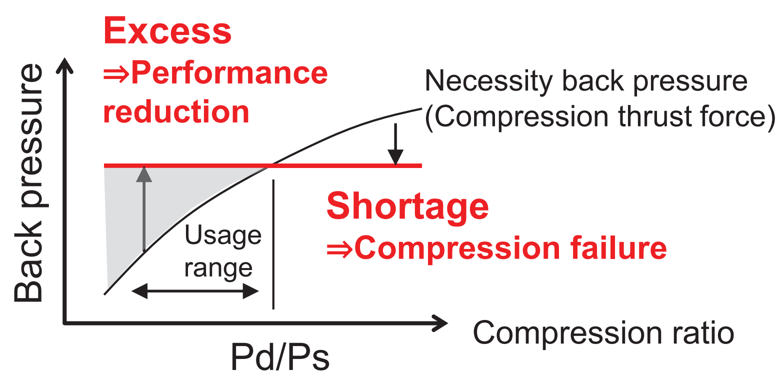
Next Gen. (ESA/ESB series) — Thrust valve（Back pressure adjusting structure）



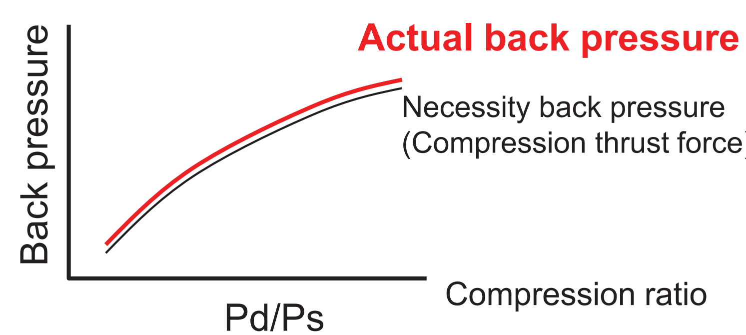
Pd-Pc pressure difference: variable control
Using the thrust moving of orbiting scroll, and not using the adjusting valve.

Back pressure

Conventional



Next Gen. (ESA/ESB series)



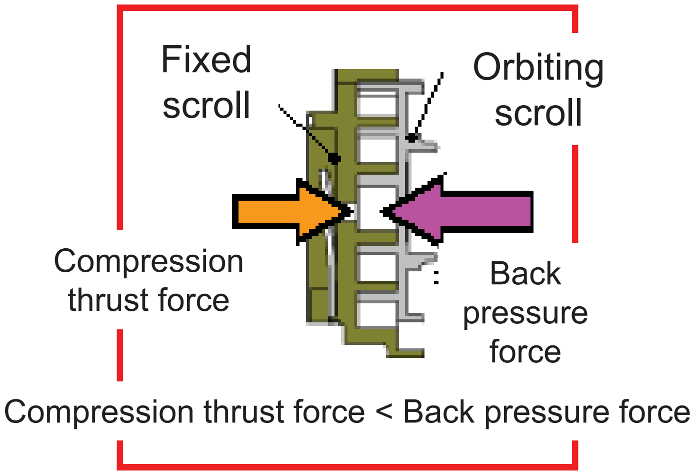
Characteristic

Conventional: The back pressure become excess and mechanical loss become large, when compression ratio decrease.

Next Gen. (ESA/ESB series): **The mechanical loss is small because the back pressure become optimal according to compression ratio.**

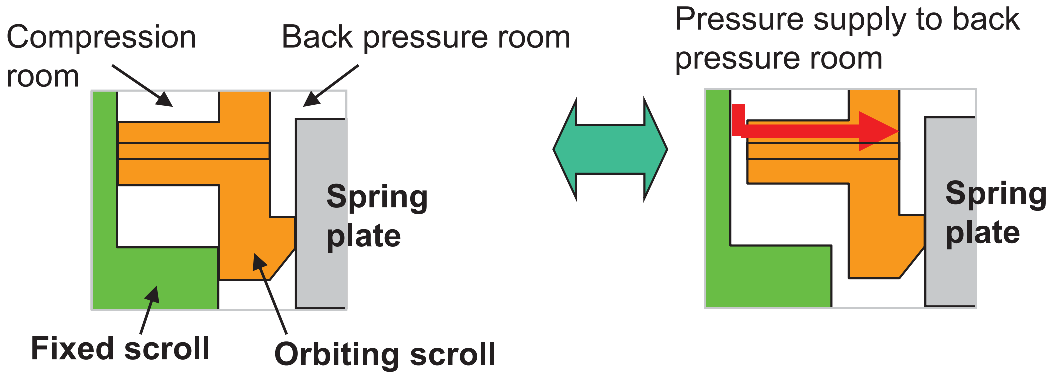
The thrust valve can be increased performance and supplied ideal back pressure continually.

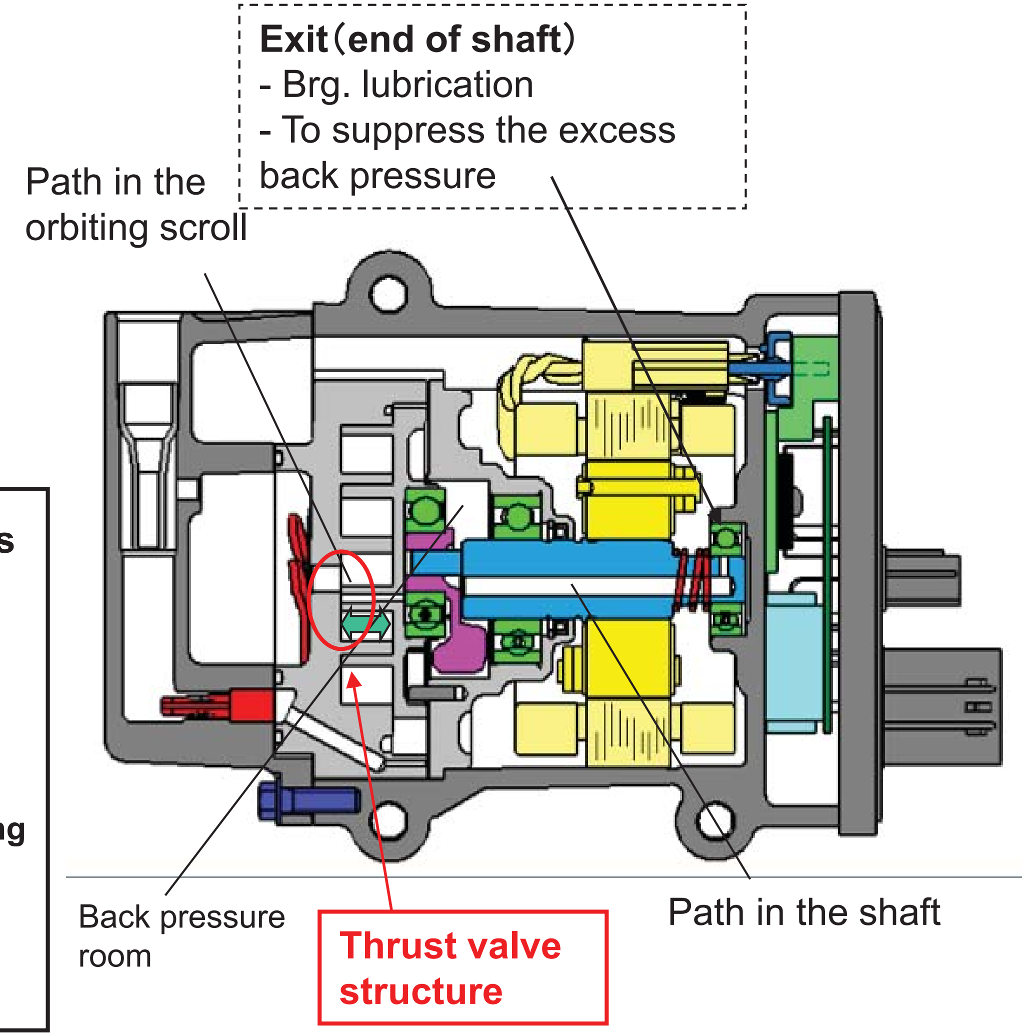
Technical differentiation [Structure and principle of Thrust valve]



①:If the back pressure is sufficient

:If the back pressure is not enough





①:If the back pressure is sufficient:

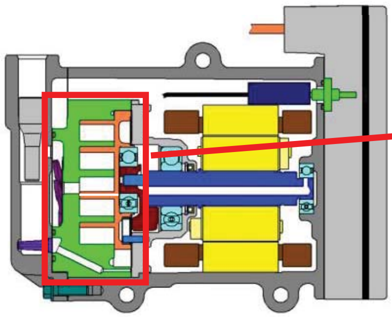
Thrust valve is in close with fixed scroll and stop supplying Pd.

:If the back pressure is not enough:

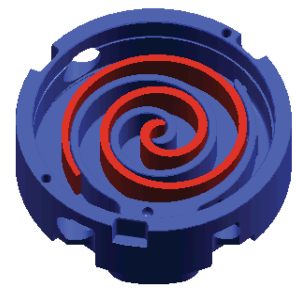
Thrust valve is open and supply Pd to back pressure room

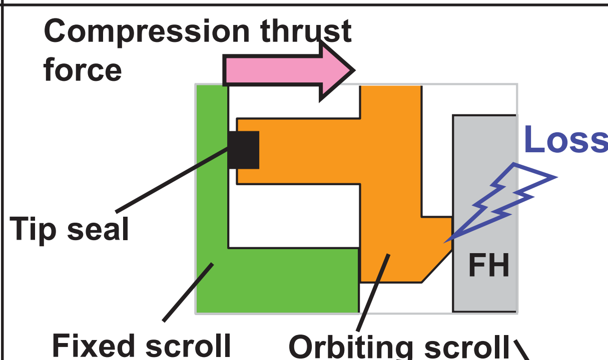
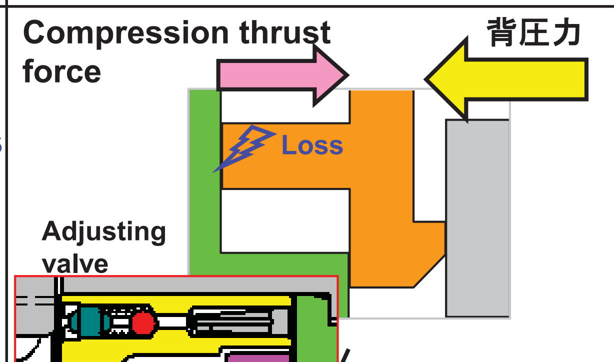
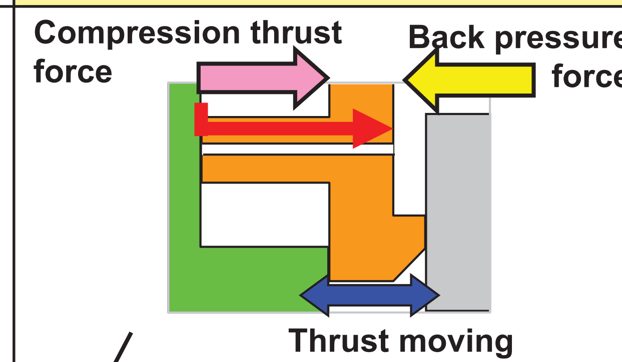
⇒Automatically adjusting back pressure

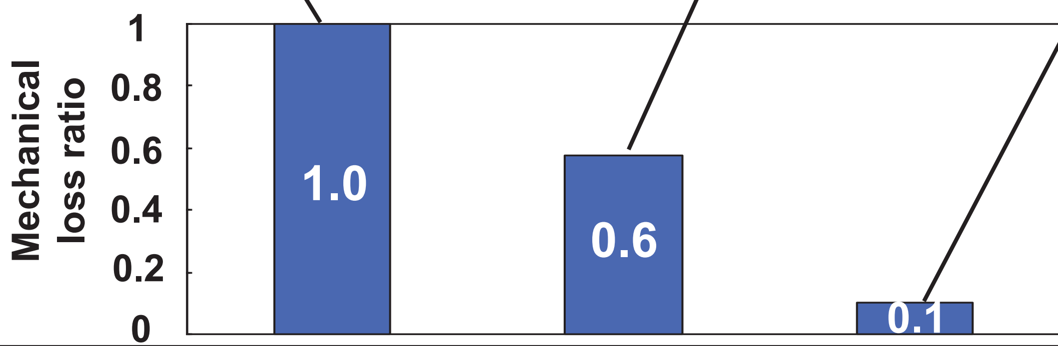
The comparison between ES and ESA/ESB [Thrust valve]



【Compressor】



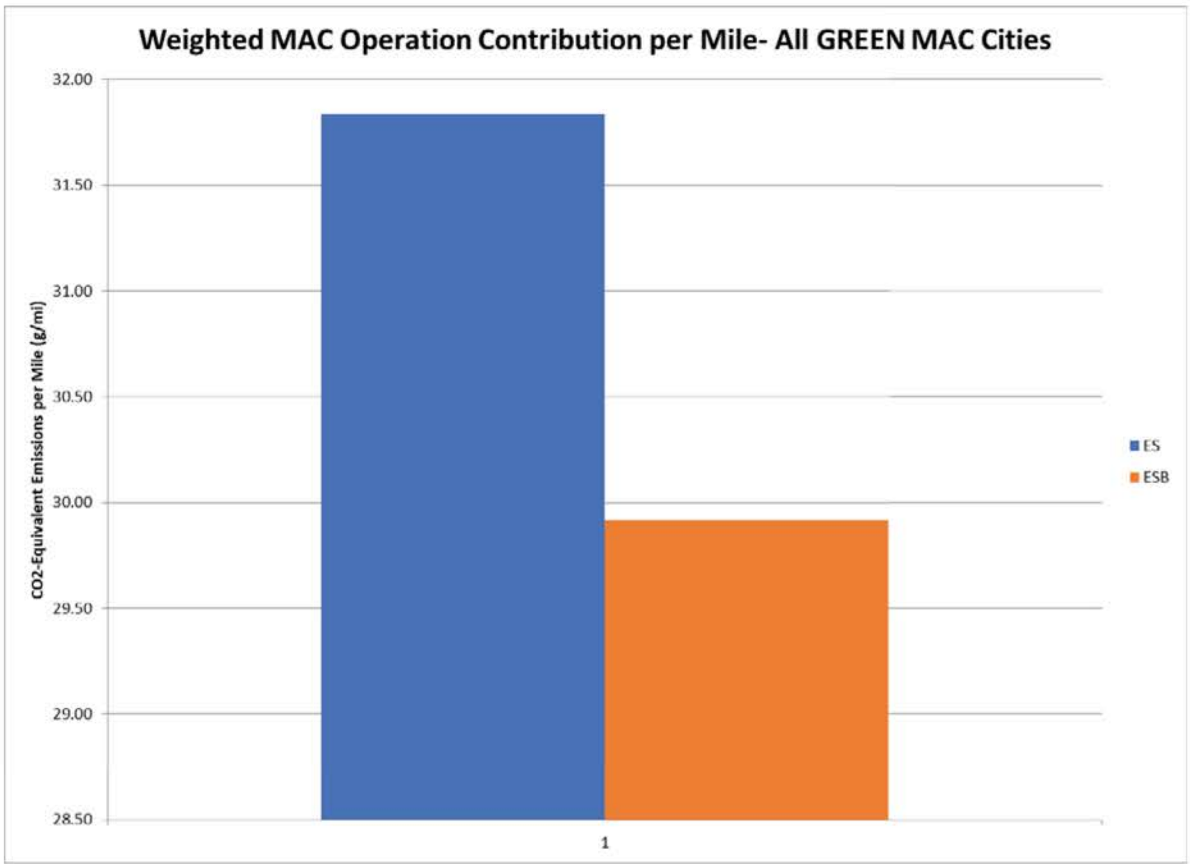
	Conventional		Next Gen.
Compressor	ES20（2002年L/O 、Small vol.）	ES18（2003年L/O、Mass production）	ESA34（2012年L/O）
Pc control	N/A	Adjusting valve	Thrust valve
Structure			

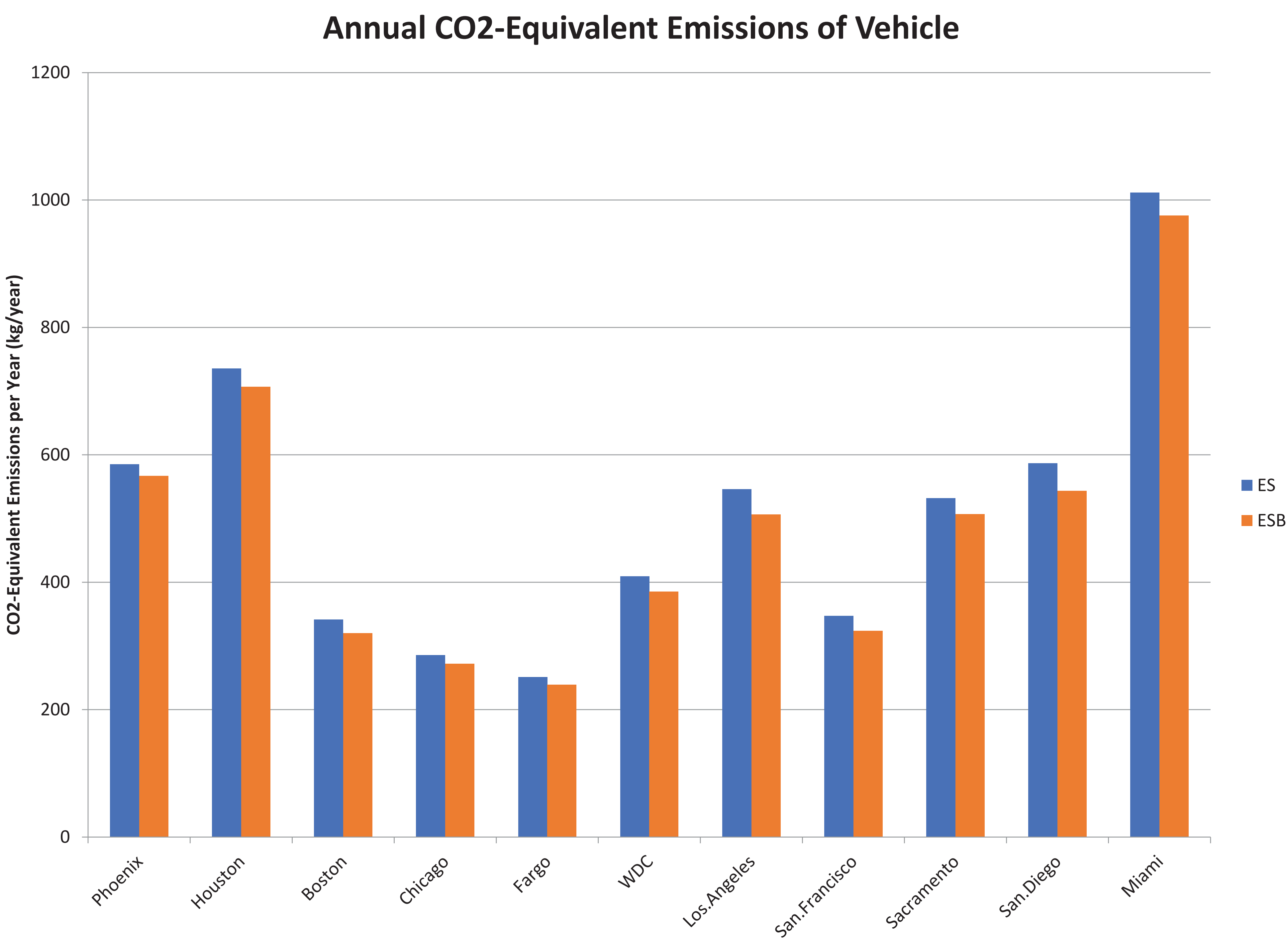


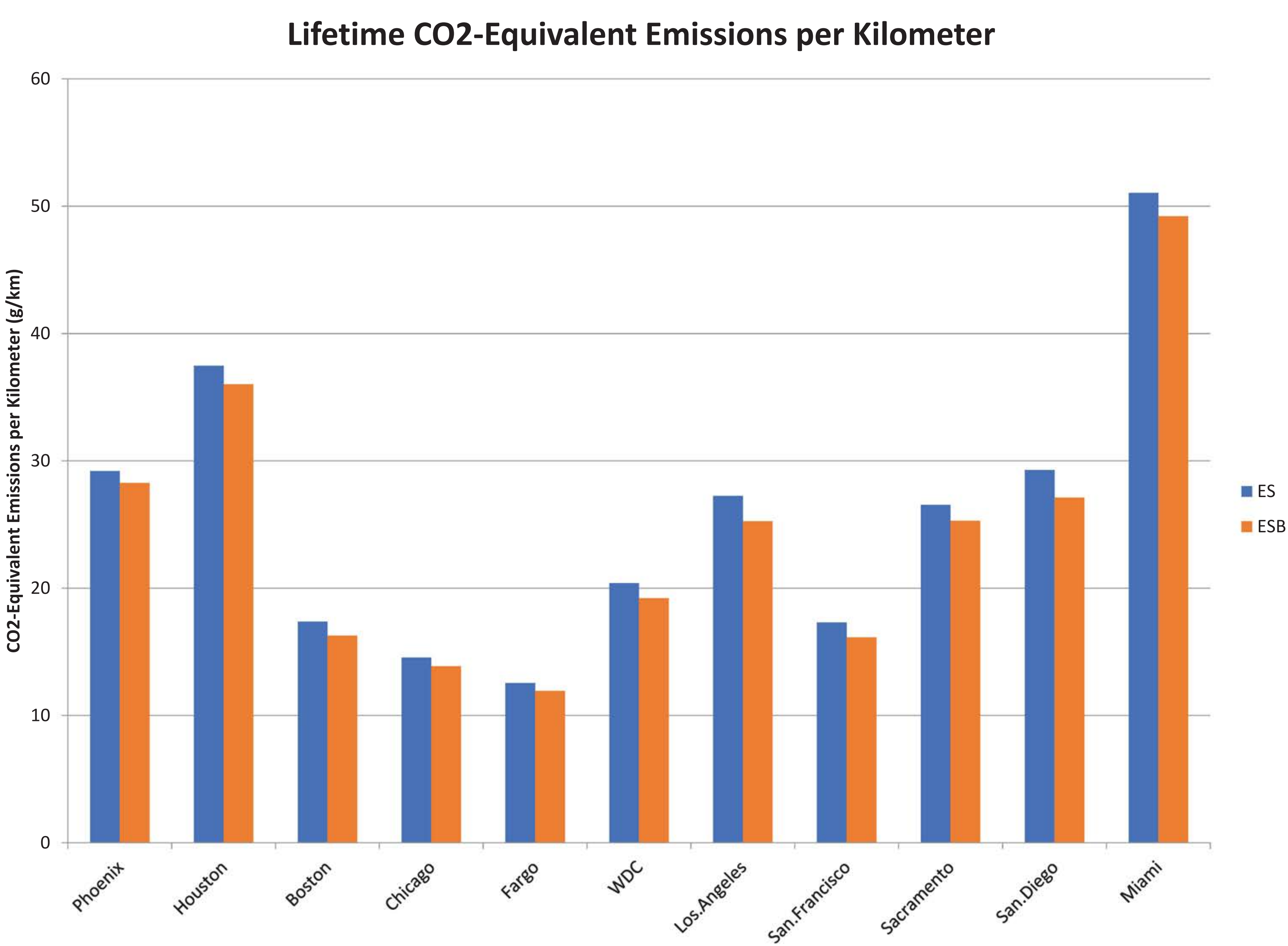
Thrust valve method can get 90% smaller of mechanical loss than tip seal method.

Appendix B: ES and ESB SAE LCCP Model Results

Indirect Contribution, Weighted (GREEN-MAC USA Cities)	Phoenix	Houston	Boston	Chicago	Fargo	WDC	Los Angeles	San Francisco	Sacramento	San Diego	Miami	Sum
Percent of total vehicles in these cities	4.5%	16.3%	13.2%	22.5%	4.5%	12.4%	5.0%	5.7%	5.0%	5.0%	5.8%	**100%**
Driving Distance (km/yr)	20,050	19,635	19,665	19,635	20,050	20,050	20,050	20,050	20,050	20,050	19,832	
Annual MAC Operation Contribution (kg CO2/year)												
ES	497.2	649.0	255.0	199.1	163.8	321.1	458.4	259.1	444.3	499.0	925.1	
ESB	478.8	620.6	233.6	185.6	151.5	297.4	418.3	235.7	419.1	455.6	888.6	
Weighted MAC Operation Contribution per Mile (g CO2/mi)												Weighted Average
ES	1.80	8.67	2.75	3.67	0.59	3.19	1.84	1.19	1.78	2.00	4.35	**31.84**
ESB	1.73	8.29	2.52	3.42	0.55	2.96	1.68	1.08	1.68	1.83	4.18	**29.92**
												1.92




Annual CO2-Equivalent Emissions of Vehicle
CO2-Equivalent Emissions per Year (kg/year)
1200
1000
800
600
400
200
0
Phoenix
Houston
Boston
Chicago
Fargo
WDC
Los.Angeles
San.Francisco
Sacramento
San.Diego
Miami
ES
ESB


Lifetime CO2-Equivalent Emissions per Kilometer
CO2-Equivalent Emissions per Kilometer (g/km)
60
50
40
30
20
10
0
Phoenix
Houston
Boston
Chicago
Fargo
WDC
Los.Angeles
San.Francisco
Sacramento
San.Diego
Miami
ES
ESB