Indirect CO_2 Credit for DENSO SAS Compressor

April 5, 2013
DENSO International America, Inc.

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Agenda

- DENSO Corporation
- Background / Objective
- SAS Efficiency Improvement Mechanism
- Off-cycle Engineering Analysis Method
- Testing Details
- Test Results
- LCCP Results
- Conclusions

- Time permitting: Cold Storage Evaporator Discussion

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DENSO Corporation

- **Established: Dec. 16, 1949**
- **Capital: US$2.3 billion**
- **Net Sales: US$38.4 billion**
- **Net Income: US$1,086.5 million**
- **Employees: 126,000 in 35 countries**

Data are consolidated base

- As of March 31, 2012
- U.S. dollar amounts have been translated from Japanese yen for convenience only at the rate of 82.19 yen= US$1

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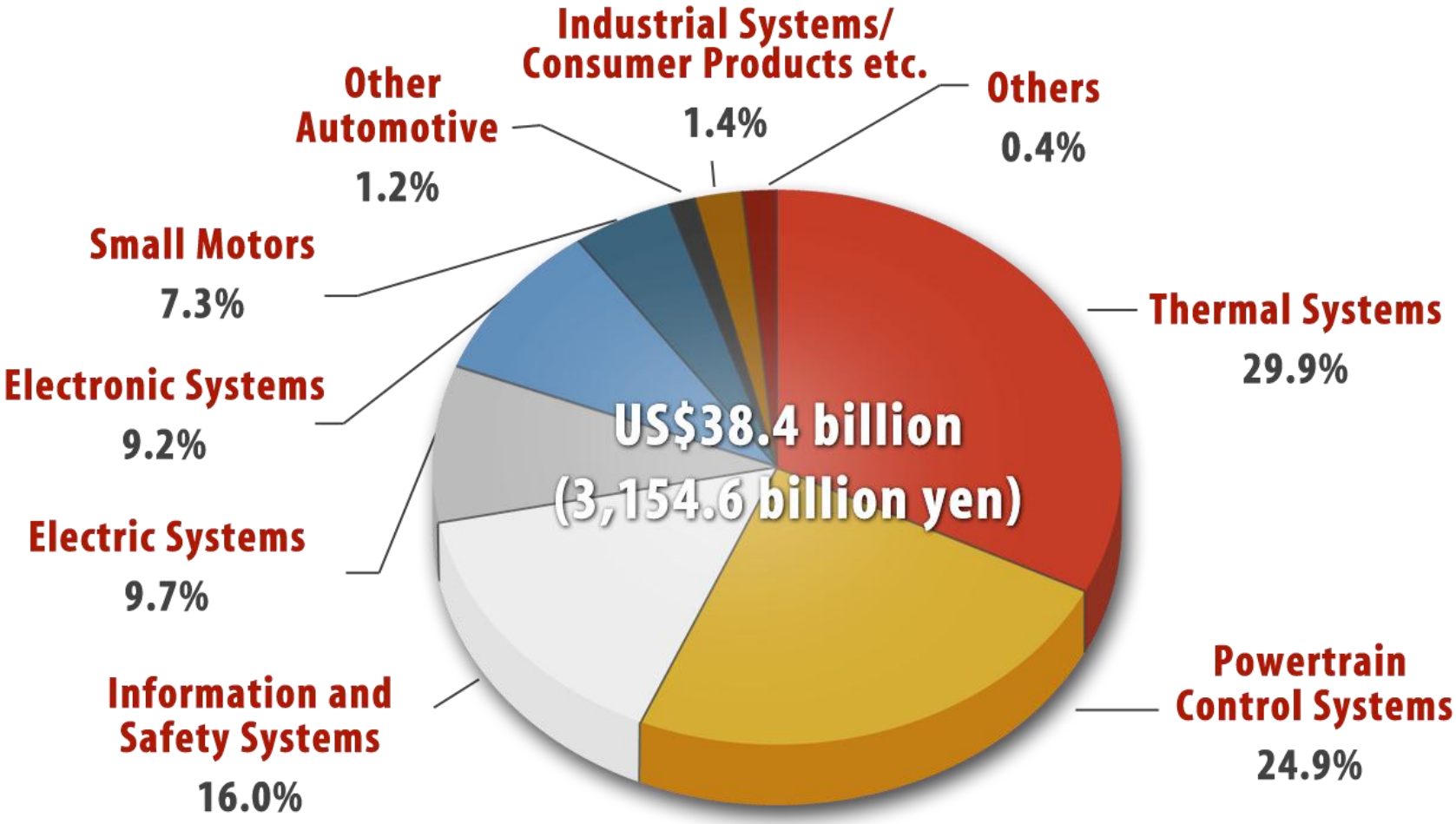
Sales by Business Groups

Consolidated Base



*For fiscal year ended March 31, 2012

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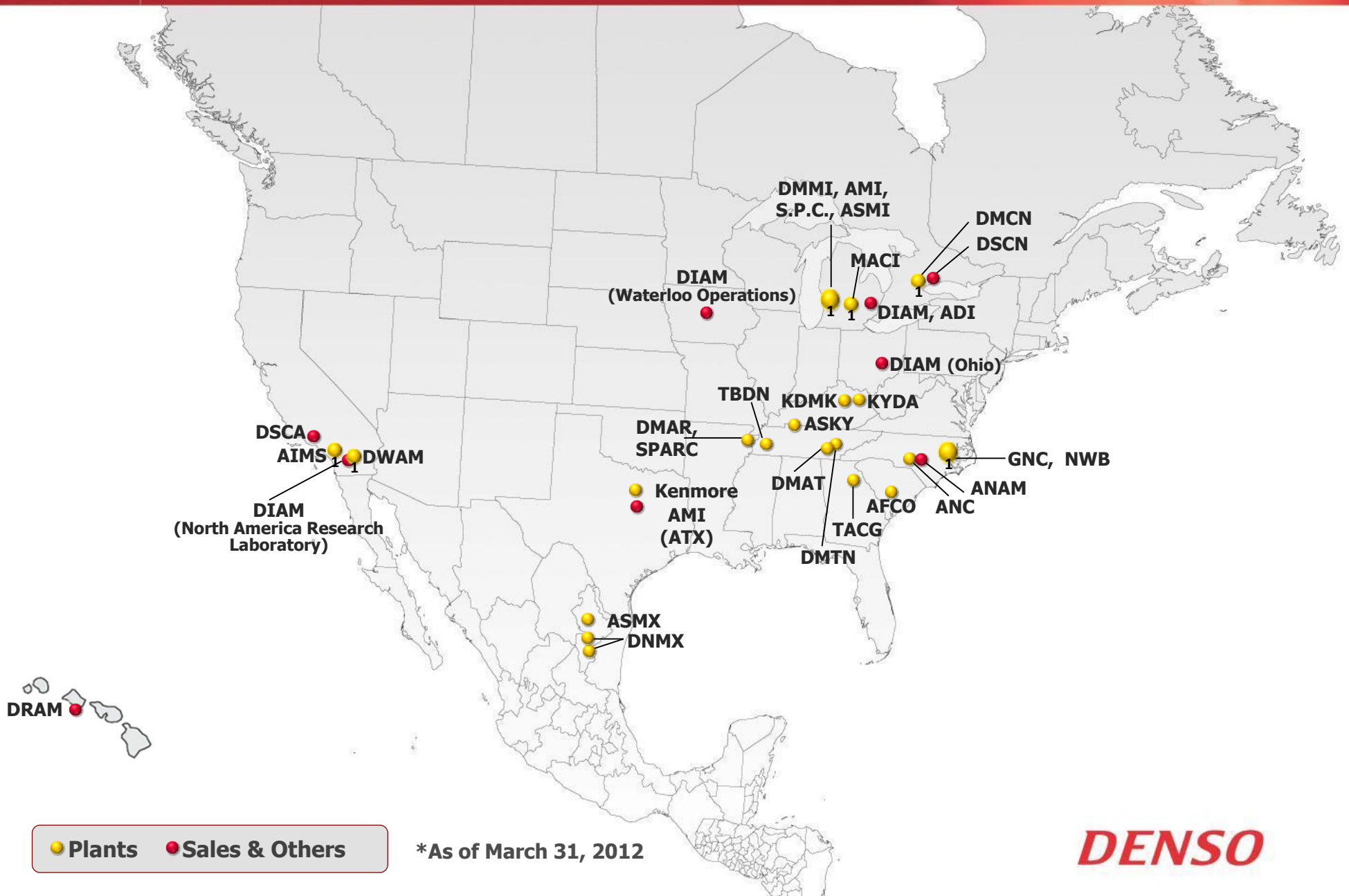
DENSO Operations in North America



*As of March 31, 2012

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Background / Objective

Federal fuel economy tests do not include A/C usage, but A/C usage generates CO_2 and reductions to these emissions benefit the environment.

DENSO's new SAS external variable displacement compressor (EVDC) improves energy consumption compared to current generation technology. Therefore, we feel SAS compressor should qualify for CO_2 off cycle credits.

Objective: Perform an engineering analysis to quantify the amount of indirect CO_2 credit that the SAS compressor should receive. Use this information to support customer applications to the EPA for credit.

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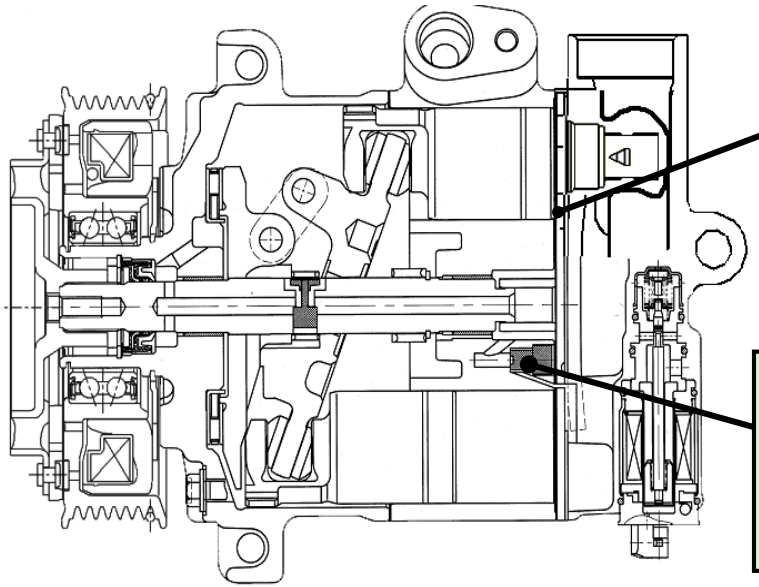
SAS Efficiency Improvement Mechanism

The new SAS compressor has two efficiency improvements over the existing SBU compressor: optimized suction and discharge valves and a CS valve.



<Efficiency>
Change the structure of valve to optimize suction and discharge pressure loss.

<Efficiency at Variable Condition>
Crankcase Suction Valve (CS valve)
(*optimize suction/ discharge pressure loss*)
(quick start-up under full liquid condition)

Clutch less version (called SES) is available and has same internal design.

The optimized valves reduce suction and discharge pressure loss within the compressor, increasing efficiency.

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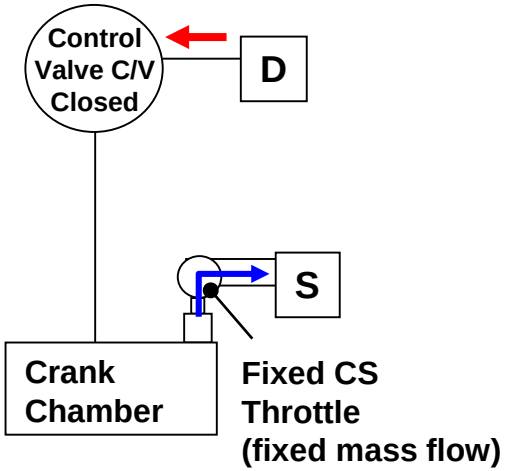
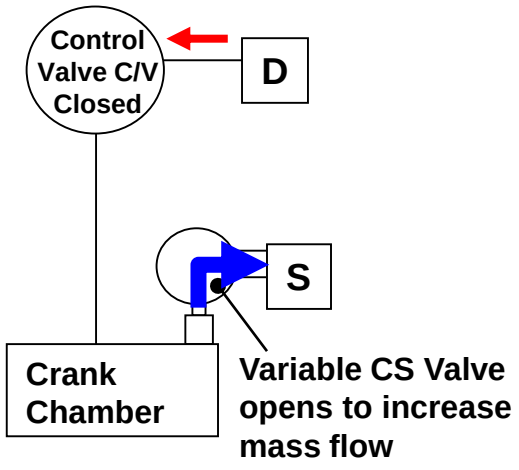
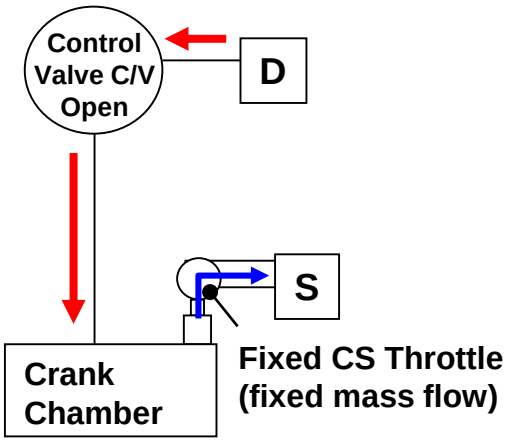
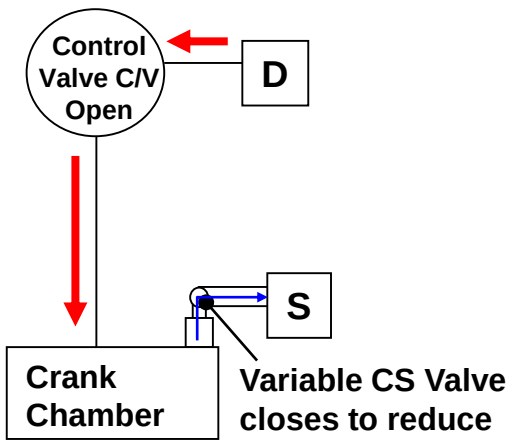
SAS & SES Efficiency Improvement Mechanism

Condition	Current Design (SBU)	New Technology (SAS)	Benefit of Variable CS Valve
Max Capacity and Compressor Start-up			Large opening allows a large mass flow. This allows for a stable max capacity condition and for the compressor to achieve max capacity more quickly at compressor start-up.
Variable (Mid) Capacity			Small opening results in a reduction of contol gas flow through the crank chamber, thus reducing internal compressor losses and **increasing efficiency** at variable condition.

The CS valve increases efficiency of the SAS compressor at mid displacement.

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A/C Indirect CO_2 Credits

For A/C there are three CO_2 credit types available which can be used to meet the fleet average CO_2 emissions requirements:

Leakage credits for low refrigerant leakage rate or low GWP refrigerant.

Menu credits for improving system efficiency.

Off-cycle credits for advanced technology not on the menu. The technology must reduce emissions levels compared to current technology.

DENSO will do testing to show SAS/SES compressor may get off-cycle credits.

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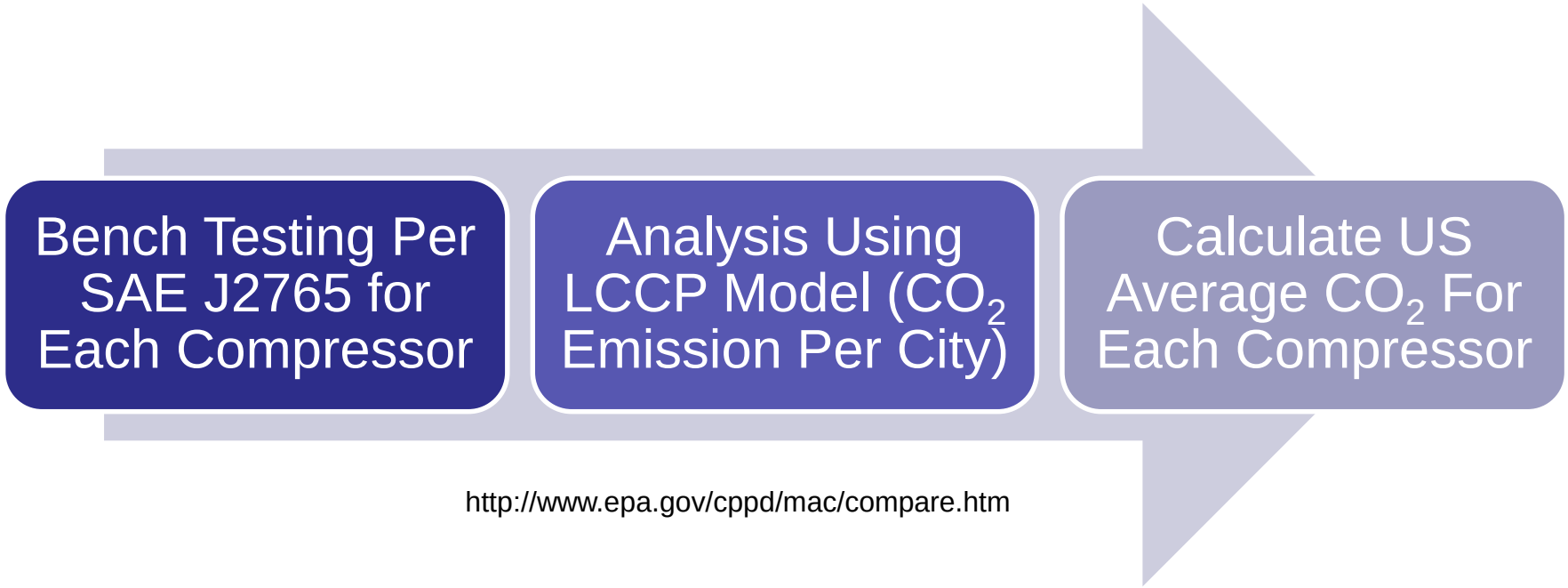
Off-cycle Engineering Analysis Method



http://www.epa.gov/cppd/mac/compare.htm

LCCP is an existing method to estimate CO_2 impact of MAC systems. It was developed by EPA, GM, SAE, and JAMA.

LCCP analysis can be used as an acceptable engineering analysis method for determining the off-cycle CO_2 emissions impact for SAS compressor.

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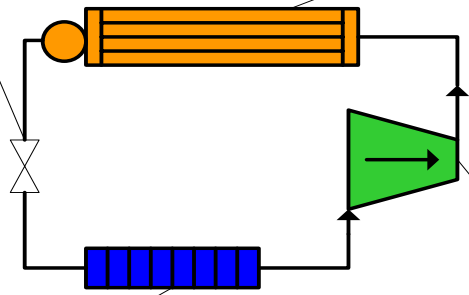
Test Bench System

Condenser
- W600mm x H422.4mm x D16mm
- Fin Height = 5.5 mm
- Tube Thickness = 1.0mm
- Fin pitch ~ 3.15mm
- Configuration: 1 Pass + Sub-cool (55-11)
- Integrated Receiver / Dryer

Thermal Expansion Valve
-Set Point = 2.1kPa @ 0°C (1.0ton)
- Slope = 0.7 bar



Compressor 6SBU14 & 6SAS14
- Pulley Ratio = 2.15
- Oil Amount = 100 g
- Refrigerant Charge:
  R-134a: 650 grams

Evaporator
-W306.5mm x H201mm x D38mm
- Fin Height = 5 mm
- 4 pass : 22-23-23-22
- Tube Thickness = 1.7 mm

All components were common during testing of the 6SBU14 and 6SAS14 compressors.

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Test Conditions (J2765)

Test Name	Simulated Ambient Temp. [C]	Compressor Speed [RPM]	Cond Air In Temp [C]	Cond Face Velocity [m/s]	Evap Air In Temp [C]	Evap Humidity [%]	Air Mass Flow [kg/min]	Air Flow Volume [m3/h]	Air Flow Volume [CFM]	Simulated Air Selection	Evap Air Out Target Temp [C]
I60	45	900	60	1.5	35	25	9.0	475	280	Recirc	3
I45	45	900	45	1.5	35	25	9.0	475	280	Recirc	3
L45	45	1800	45	2.0	35	25	9.0	475	280	Recirc	3
M45	45	2500	45	3.0	35	25	9.0	475	280	Recirc	3
H45	45	4000	45	4.0	35	25	9.0	475	280	Recirc	3
I50a	35	900	50	1.5	35	40	9.0	477	281	OSA	3
I35a	35	900	35	1.5	35	40	9.0	477	281	OSA	3
L35a	35	1800	35	2.0	35	40	9.0	477	281	OSA	3
M35a	35	2500	35	3.0	35	40	9.0	477	281	OSA	3
H35a	35	4000	35	4.0	35	40	9.0	477	281	OSA	3
I40a	25	900	40	1.5	25	80	6.5	337	198	OSA	3/10
I25a	25	900	25	1.5	25	80	6.5	337	198	OSA	3/10
L25a	25	1800	25	2.0	25	80	6.5	337	198	OSA	3/10
M25a	25	2500	25	3.0	25	80	6.5	337	198	OSA	3/10
H25a	25	4000	25	4.0	25	80	6.5	337	198	OSA	3/10
I40c	25	900	40	1.5	25	50	6.5	334	197	OSA	3/10
I25c	25	900	25	1.5	25	50	6.5	334	197	OSA	3/10
L25c	25	1800	25	2.0	25	50	6.5	334	197	OSA	3/10
M25c	25	2500	25	3.0	25	50	6.5	334	197	OSA	3/10
H25c	25	4000	25	4.0	25	50	6.5	334	197	OSA	3/10
I30	15	900	30	1.5	15	80	6.5	322	190	OSA	3/10
I15	15	900	15	1.5	15	80	6.5	322	190	OSA	3/10
L15	15	1800	15	2.0	15	80	6.5	322	190	OSA	3/10
M15	15	2500	15	3.0	15	80	6.5	322	190	OSA	3/10
H15	15	4000	15	4.0	15	80	6.5	322	190	OSA	3/10

All conditions were run for each compressor

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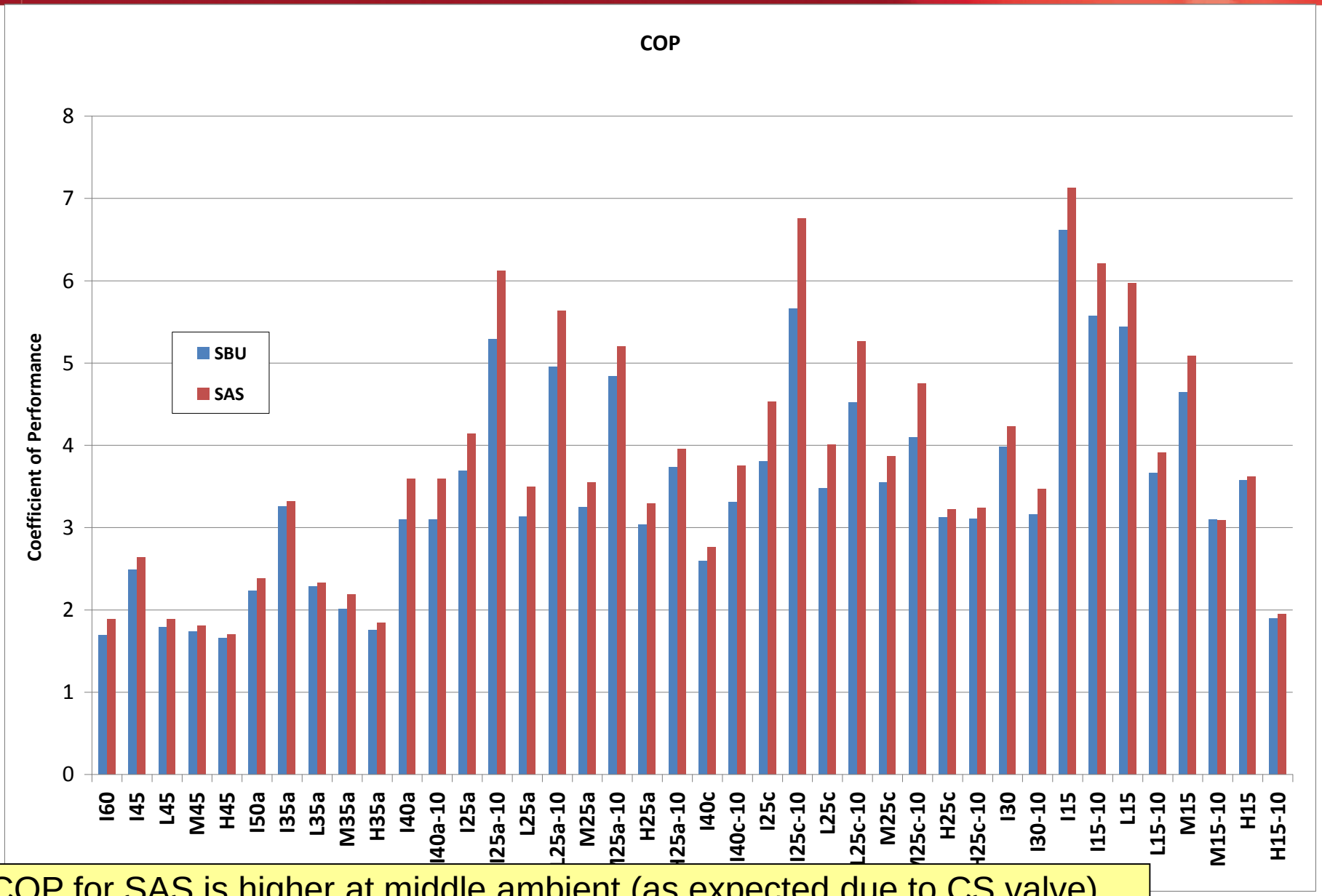
Test Results



COP for SAS is higher at middle ambient (as expected due to CS valve)

These values were entered into the LCCP model.

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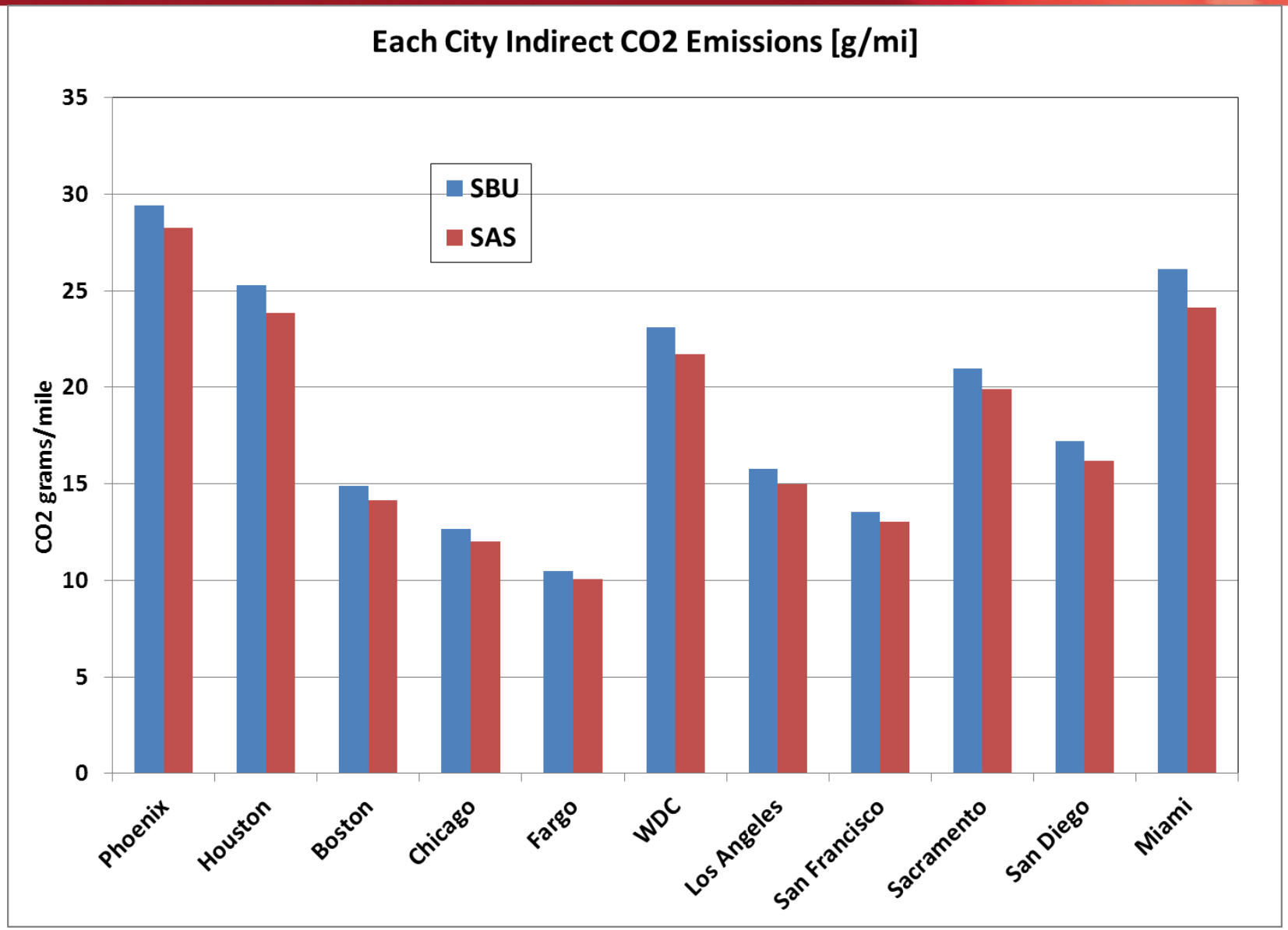
LCCP Results (per city)



Indirect CO_2 emissions for each US city.

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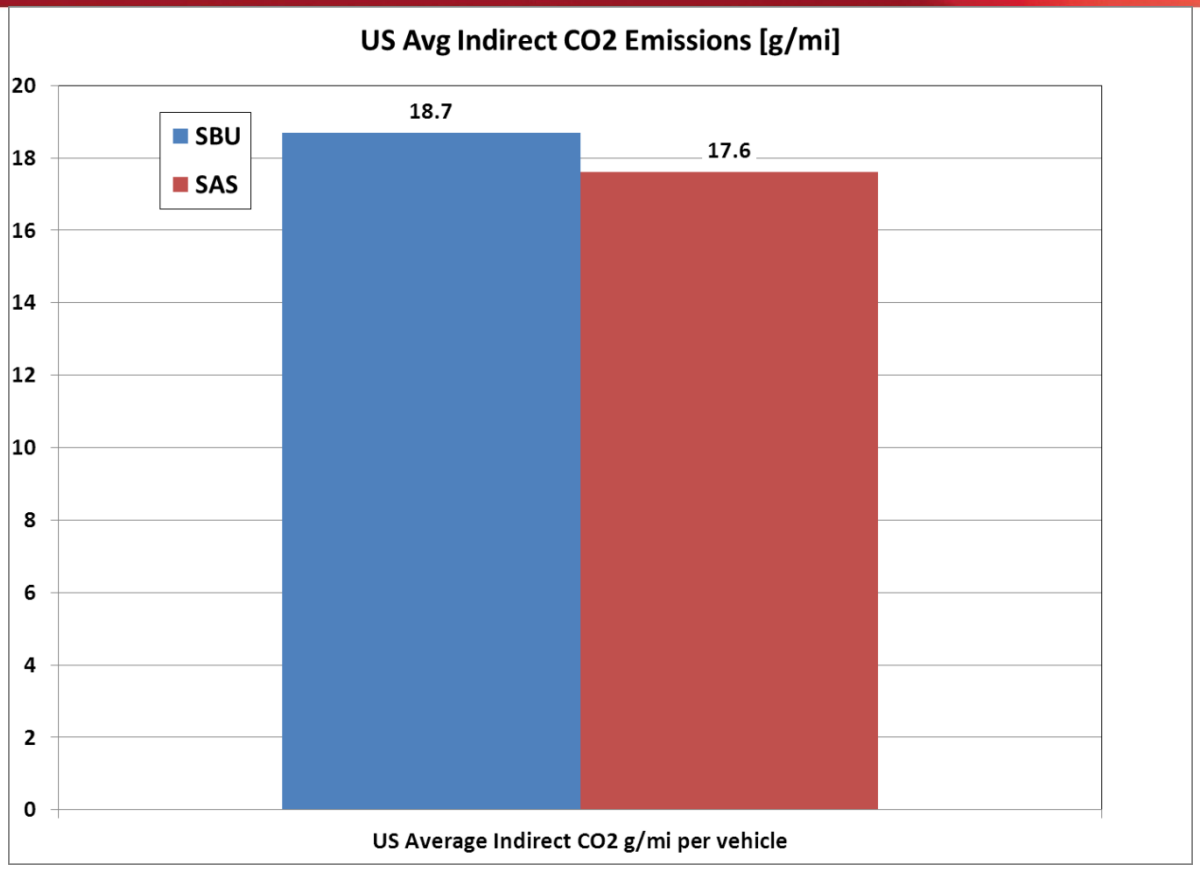
LCCP Results (US Average)



Average US Vehicle Indirect CO_2 Emissions	
SBU compressor	18.7 g/mi
SAS compressor	17.6 g/mi
Benefit of SAS compressor	**1.1 g/mi**

Off-cycle CO_2 credit of 1.1g/mi should be requested for the SAS compressor.

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Conclusion

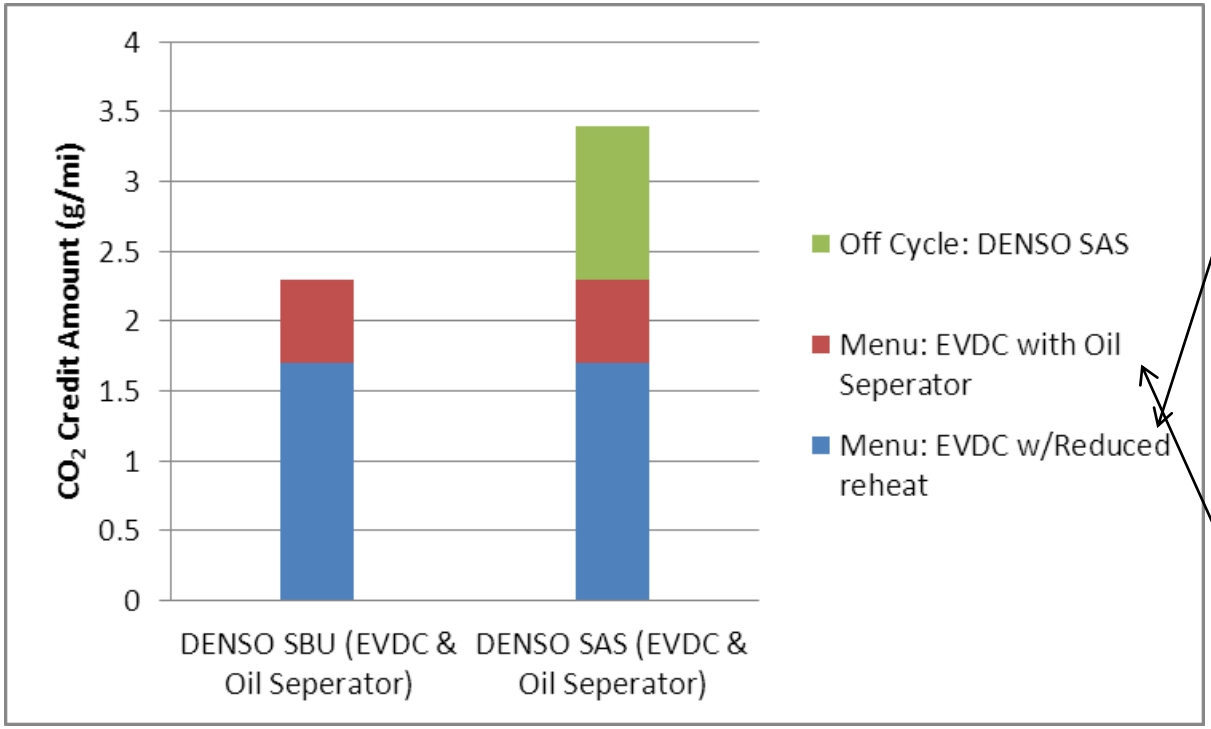

Table III.C.1-2 Efficiency-Improving A/C Technologies and Credits

Technology Description	Estimated Reduction in A/C CO_2 Emissions	A/C Efficiency Credit (g/mi CO_2)
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	1.7
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable-displacement compressor	20%	1.1
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30%	1.7
Default to recirculated air with open-loop control air supply (no sensor feedback) whenever the ambient temperature 75 °F or higher lower temperatures are allowed)	20%	1.1
Blower motor controls which limit wasted electrical energy (e.g., pulse width modulated power controller)	15%	0.9
Internal heat exchanger	20%	1.1
Improved condensers and/or evaporators (with system analysis on the component(s) indicating a COP improvement greater than 10%, when compared to previous industry standard designs)	20%	1.1
Oil Separator (with engineering analysis demonstrating effectiveness relative to the baseline design)	10%	0.6

We believe the total benefit for SAS or SES compressor should be 3.4 g/mi credit (Menu Credits + Off Cycle)

Based on 2012-2016 Regulation

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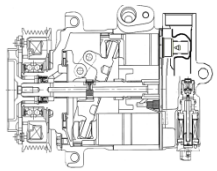
Conclusion

SAS/SES Compressor Off-Cycle (1.1 g/mi)



- OEM A
  - C Segment 6SAS14
  - SUV 7SAS17
- OEM B
  - C Segment 6SAS14
  - Mini – Van 7SAS18
- OEM C
  - C Segment 6SES14

Our assumption is this data supporting the 1.1 g/mi credit can be applied to any vehicle using SAS or SES compressor.

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