IMPACT OF ACTIVE CLIMATE CONTROL SEATS ON ENERGY USE, FUEL USE, AND CO2 EMISSIONS

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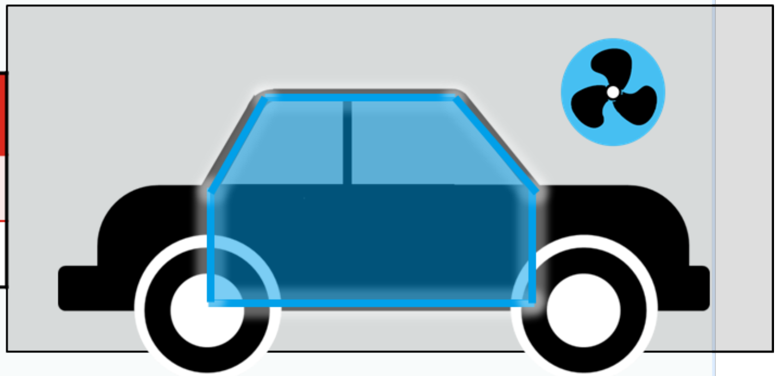
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Thermal Off Cycle Credits for MY 2017 - 2025

Maximum Light-Duty A/C Emissions Impact

Maximum A/C Impact ($g\ CO_2/mi$)	
Car	13.8
Truck	17.2



A/C Emissions Impact Determination

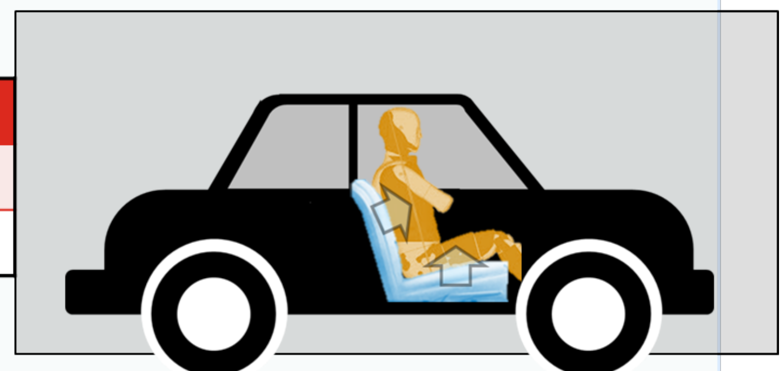
- Fixed 27°C and 60% RH Ambient
- Fixed displacement compressor
- SC03 Drive Cycle

Seat Credit Determination

- Based on active ventilated seating without sub-ambient cooling
- 7.5% A/C emissions reduction (from NREL study)
- Percentage applied to EPA A/C fuel use values

Active Seat Ventilation

Credit ($g\ CO_2/mi$)	
Car	1.0
Truck	1.3

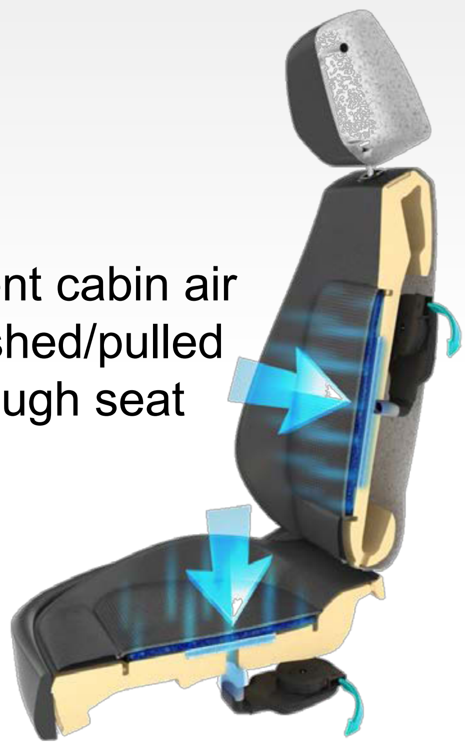


Data Source: U.S. Environmental Protection Agency and Department of Transportation. *Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards. Available at: https://www3.epa.gov/otaq/climate/documents/420r12901.pdf , Accessed 7/2016*

Comparison of Climate Control Seat Technologies

Active Seat *Ventilation*

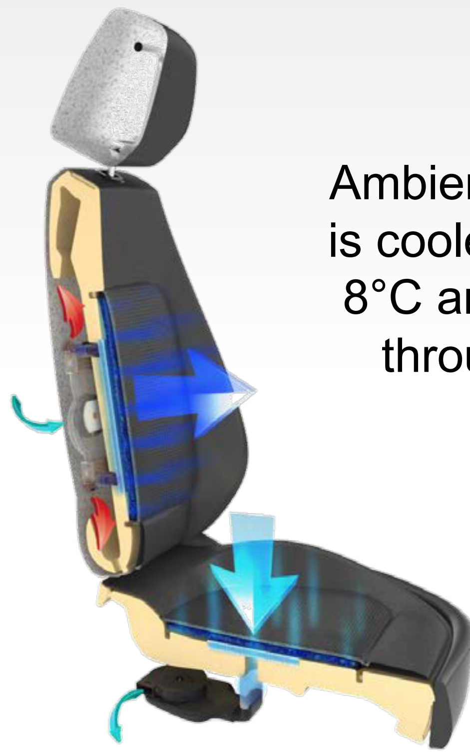
Ventilated Back
Ventilated Seat



Ambient cabin air is pushed/pulled through seat

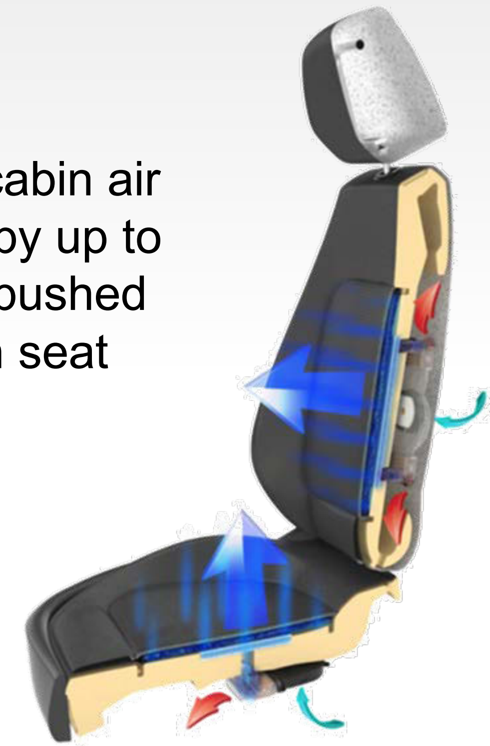
Active Seat *Cooling*

Cooled Back
Ventilated Seat



Ambient cabin air is cooled by up to 8°C and pushed through seat

Cooled Back
Cooled Seat



Performance of Actively Cooled Seating

Active seat ventilation credit established in the Final Rule

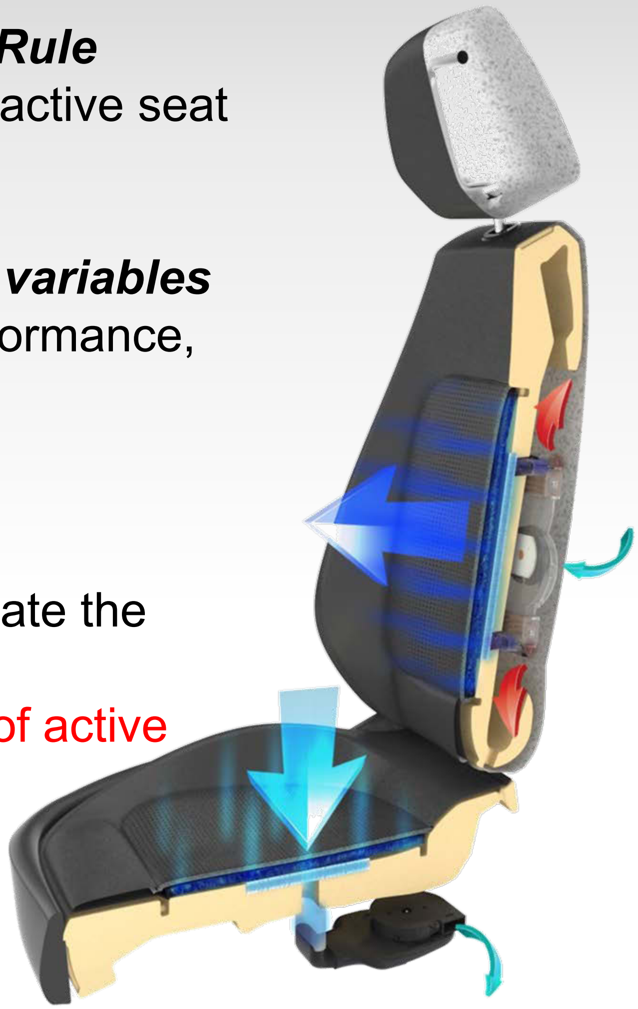
- Active seat cooling technologies meet the definition of active seat ventilation (credit eligible).

Seating performance is dependent upon a number of variables

- Occupants, environmental conditions, A/C system performance, vehicle usage, drive cycle, vehicle platform

Questions driving further investigation:

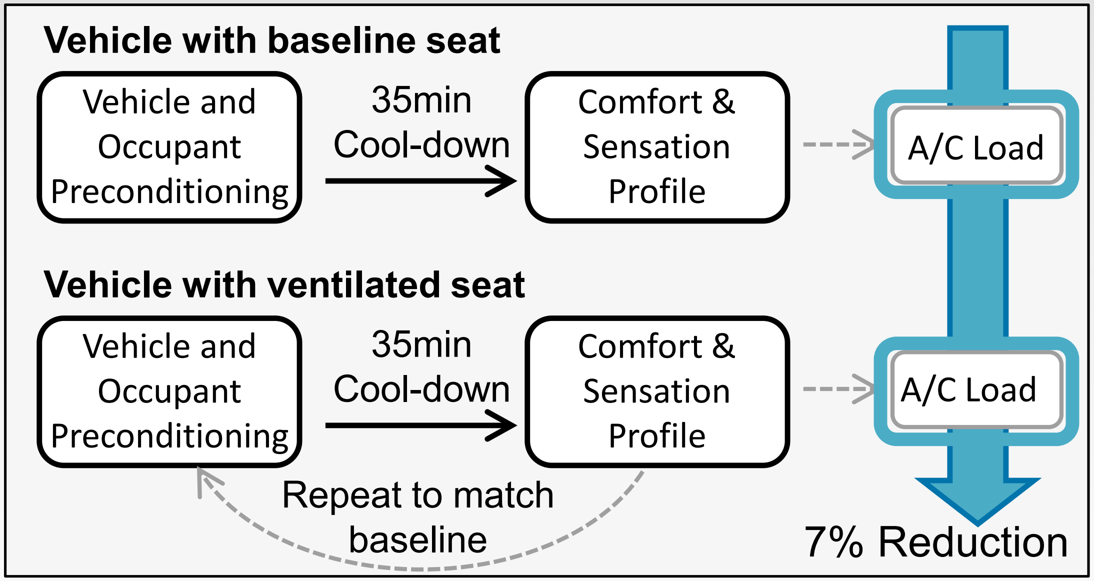
1. Can experimentation and/or analysis be used to estimate the performance of actively cooled seats?
2. Is the benefit of actively cooled seats larger than that of active seat ventilation?



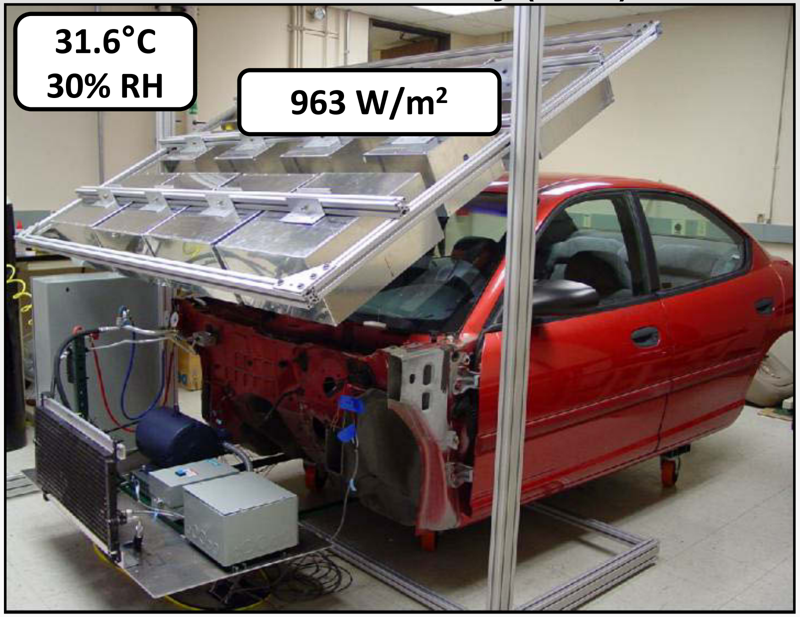
Gentherm CCS™

Method Used for Determination of Existing Ventilated Seat Off-Cycle Credit

- Tests completed with human subjects & NREL manikin

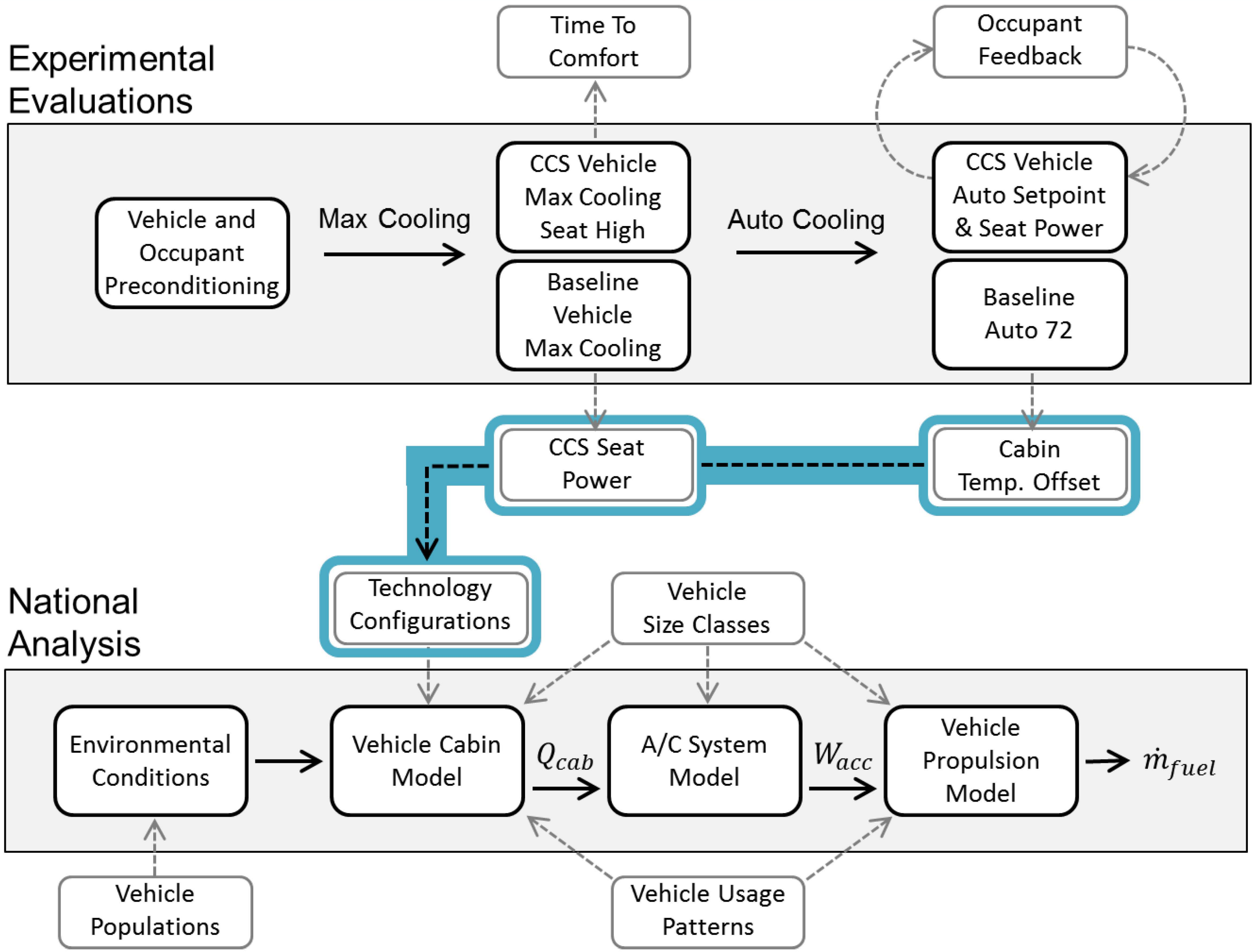


NREL Vehicle Climate Control Laboratory (2005)



- Using NREL's 2005 A/C fuel use model, 7% reduction equated to 7.5% national A/C reduction
  - Analysis used environment, mean radiant temperature, and Fanger model in place of a vehicle cabin model
- Off-cycle credit was established by the regulating authorities from NREL's published 7.5% reduction applied to their estimated A/C emissions impacts of 13.8 and 17.2 g CO2 / mi, arriving at the 1.0 and 1.3 g/mi credits for ventilated seating

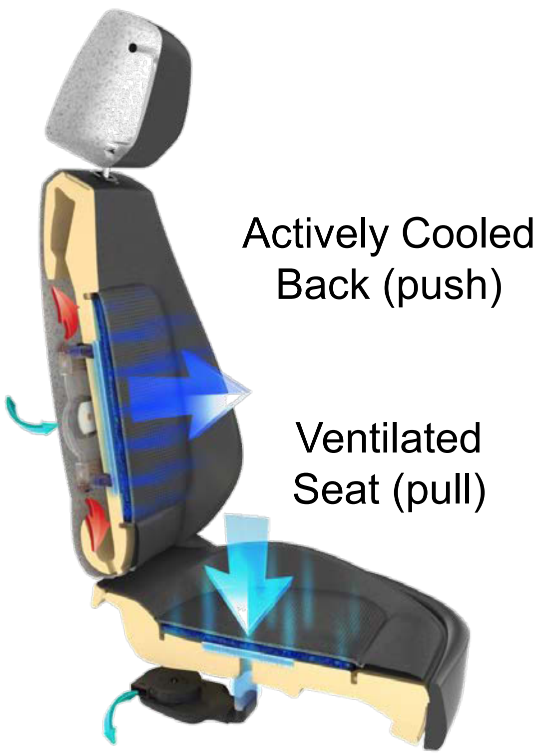
New Method Development for Evaluation of Actively Cooled Seats – Combining Experimentation and Analysis



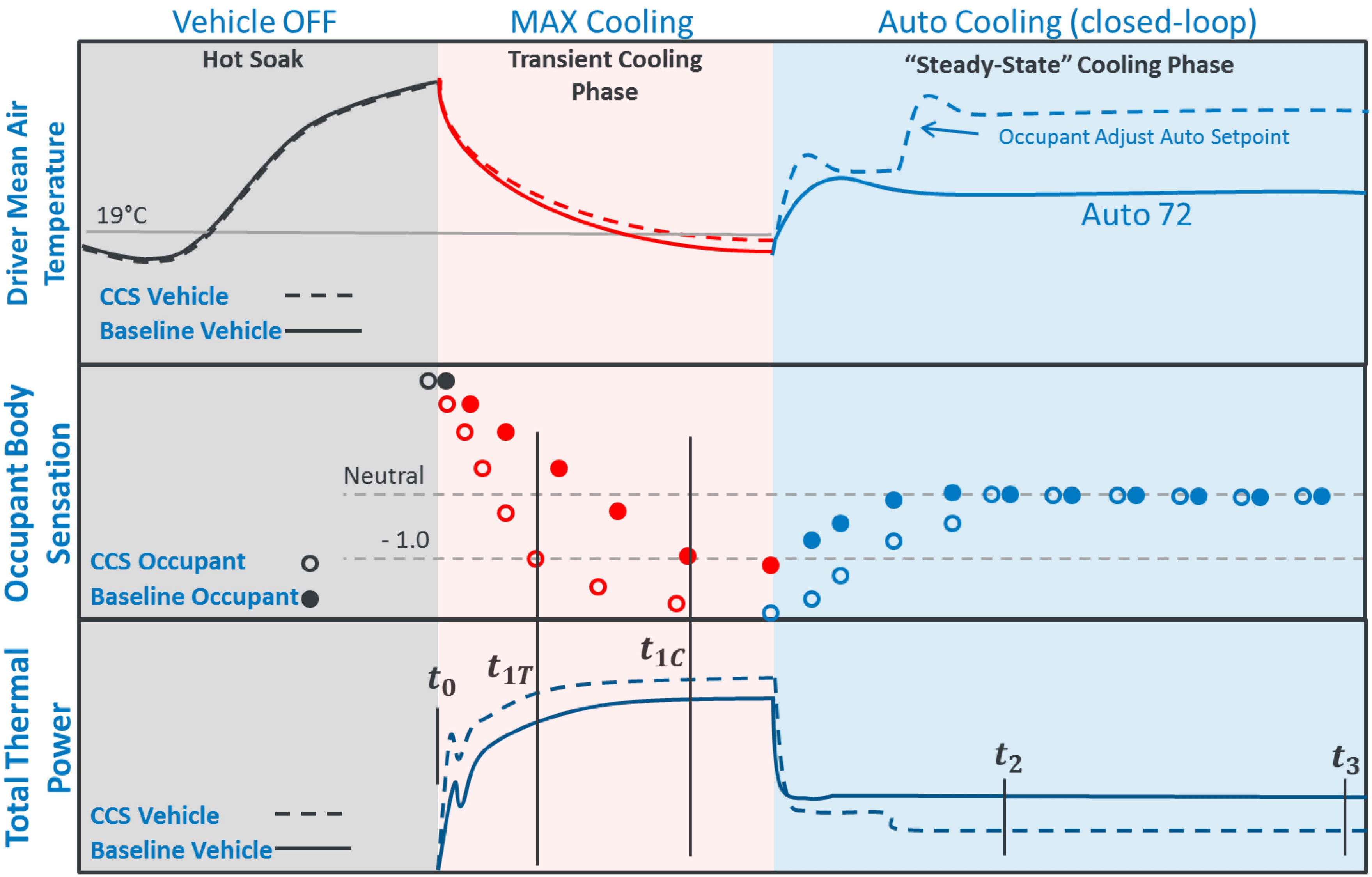
Method Development: Experimental Evaluations

- 2012 Pre-production Ford Focus Electric vehicles were used
- Vehicles instrumented with k-type surface & air TCs, calibrated to U95 = 0.18°C
- Mean air temperature = Avg. of 4 breath & 4 footwell air temperature measurements

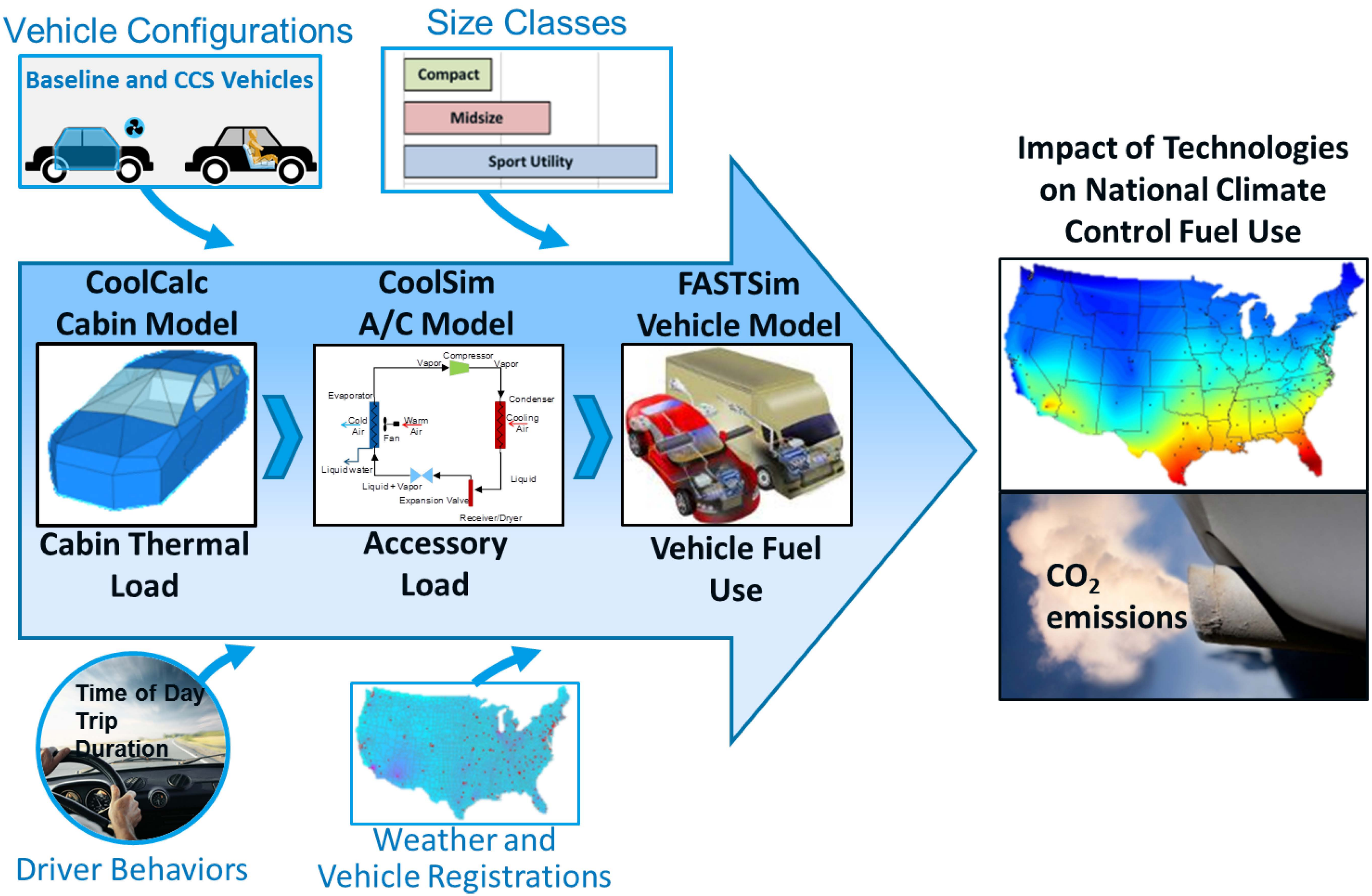
Gentherm CCS™



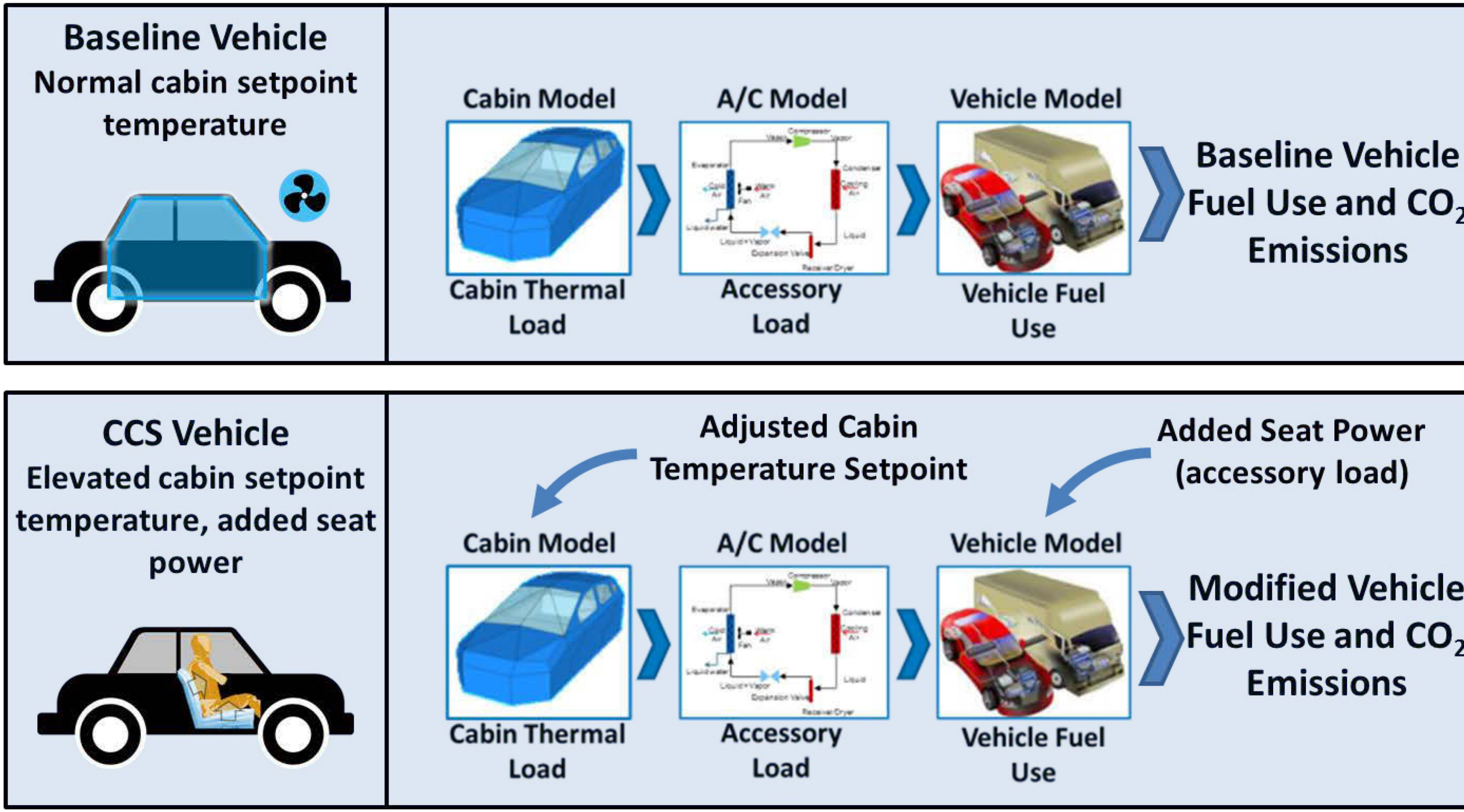
Method Development: Experimental Evaluations (Cartoon description of process)



Method Development: Analysis Approach



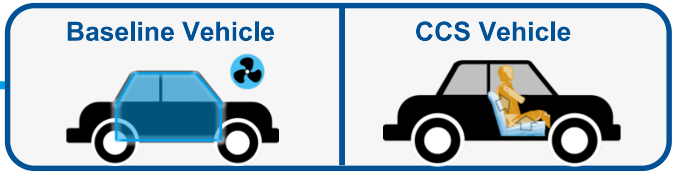
Method Development: Analysis Approach



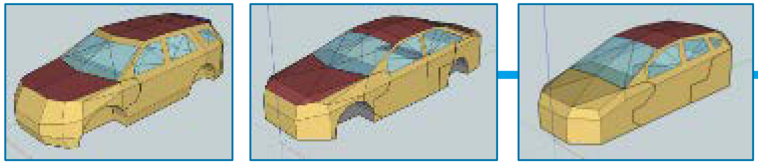
Baseline Vehicle Fuel Use & CO_2 Emissions − **Modified Vehicle Fuel Use & CO_2 Emissions** = **Technology Fuel Use Savings CO_2 emissions reduction**

Method Development: Analysis Approach

Two Vehicle Configurations



Three Representative Vehicle Platforms



Two Representative Soak Conditions

Time Range (min)	[0 – 50)	[50 – end]
Average Time (min)	17.0	232 (~4 hr)
Weighting Factor	0.5	0.5

Three Representative Drive Durations

Time Range (min)	[0 – 15)	[15 – 30)	30 +
Average Time (min)	7.2	18.4	49.4
Weighting Factor	0.508	0.31	0.182

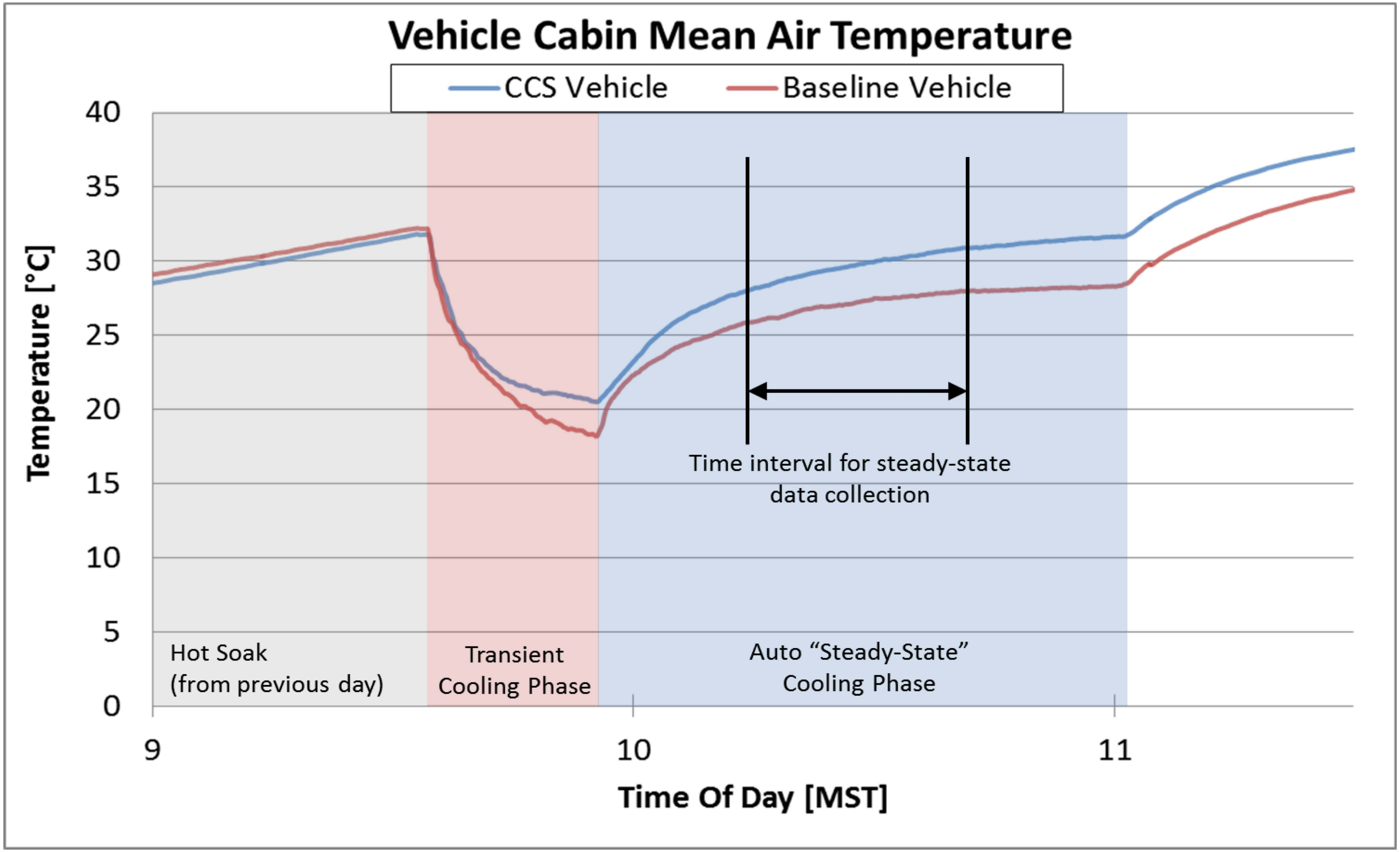
206 Representative Locations

Three Representative Drive Start Times

Time Range	[0:00 – 9:00)	[9:00 – 16:00)	[16:00 – 24:00)
Average Time	7:06	12:35	18:26
Weight Factor	18.3%	47.6%	34.1%

2 configurations * 3 platforms * 3 durations * 2 soaks * 3 start times * 206 locations
= 22,248 annual CoolCalc simulations

Results – Experimental Evaluations



Results – Experimental Evaluations

Sept. 18	Sept. 19	Sept. 20	Sept. 21	Sept. 23	Sept. 26	Sept. 27	Sept. 29
26°C 19% RH	27°C 19% RH	26°C 19% RH	23°C 27% RH	23°C 40% RH	19°C 29% RH	21°C 29% RH	20°C 36% RH

	Time to target sensation [min]				
	Baseline Vehicle		CCS Vehicle		
Occupant	Test 1	Test 2	Test 1	Test 2	Improvement [%]
Occupant A	20.9	17.4	14.8	16.1	19.1
Occupant B	19.8	15.9	16.7	14.7	12.1
Occupant C	29.1		16.2		44.4
Occupant C: Poor Test Day		~~19.0~~		~~17.8~~	~~6.3~~
Occupant D	18.7		12.5		32.9
Occupant D: Poor Test Day		~~17.6~~		~~21.0~~	~~19.1~~
Good Weather Group Test Average (Weighted)					**23.3%**

Results – Experimental Evaluations

	Average Climate Seat Power [W]		Vehicle Mean Air Temp. (MAT) [° C]		
Test Date	Transient Phase	Steady-state Phase	Baseline Vehicle	CCS Vehicle	Increase in MAT from CCS [° C]
9/18/2016	84.5	86.4 (high)	26.7	30.5	3.78
9/19/2016	85.1	39.7 (med)	27.6	30.6	3.01
9/20/2016	83.3	8.0 (low)	24.5	28.5	4.03
9/21/2016	86.2	39.1 (med)	25.0	28.3	3.33
9/23/2016	85.0	39.5 (med)	27.8	29.8	1.98
9/26/2016	87.1	84.4 (high)	27.2	29.9	2.60
9/27/2016	86.4	39.7 (high)	28.5	31.0	2.54
9/29/2016	87.4	54.8 (med/high)	28.7	30.4	1.72
Good Weather Average	**85.9**	**54.8**	**27.8**	**30.4**	**2.61**
Standard Dev.	**1.18**	**23.71**	**0.75**	**0.45**	**0.74**
90% Confidence Low Bound	**84.9**	**35.3**	**27.1**	**30.0**	**2.00**
90% Confidence High Bound	**86.9**	**74.3**	**28.4**	**30.7**	**3.21**

Results – Experimental Evaluations

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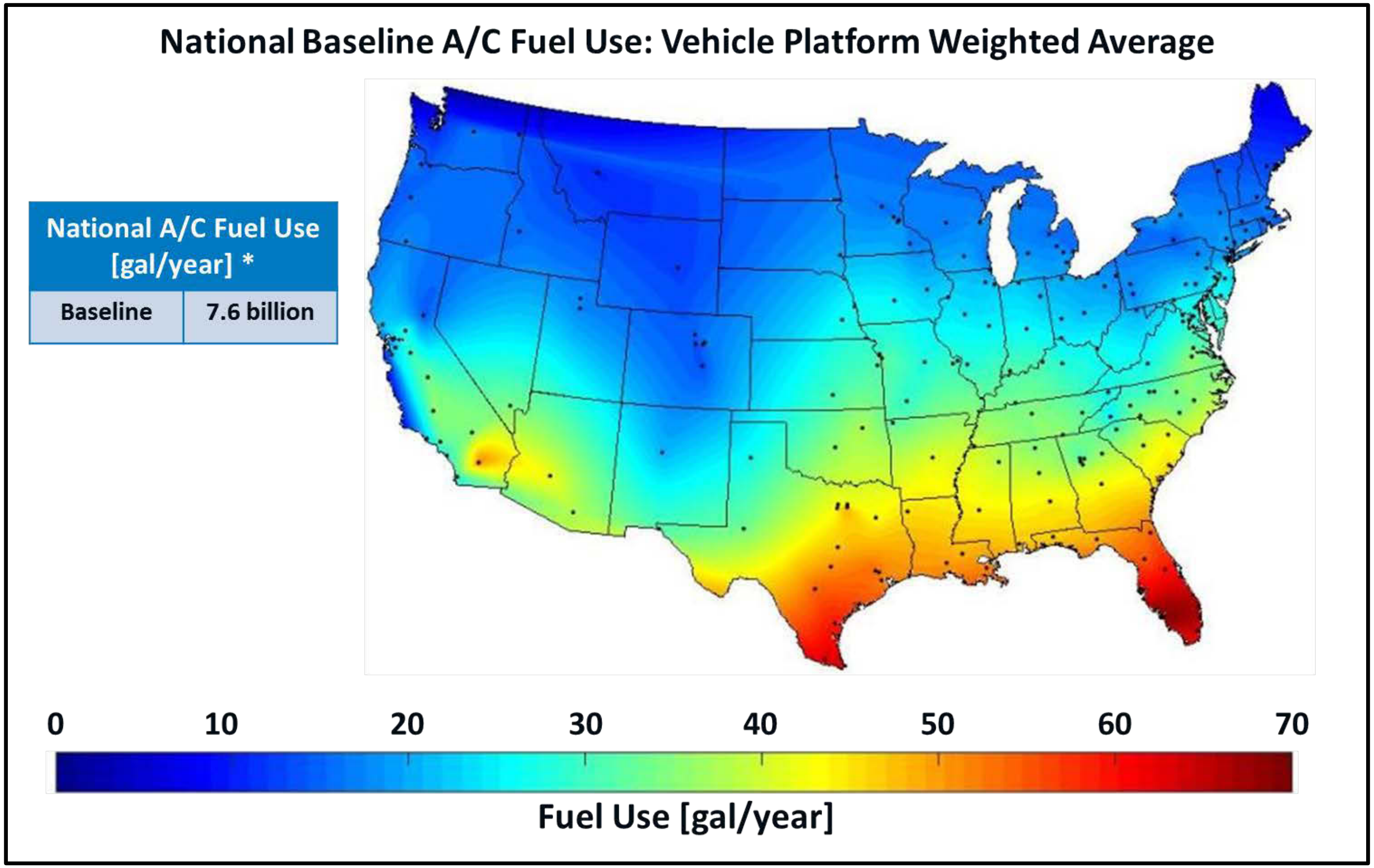
Results – National Level Analysis

- Average Baseline A/C Fuel Use Estimated at 30.0 gal/year per vehicle
- Equivalent to 23.5 g/mi (compared to 13.8 and 17.2 for 2017 and Later Final Ruling)

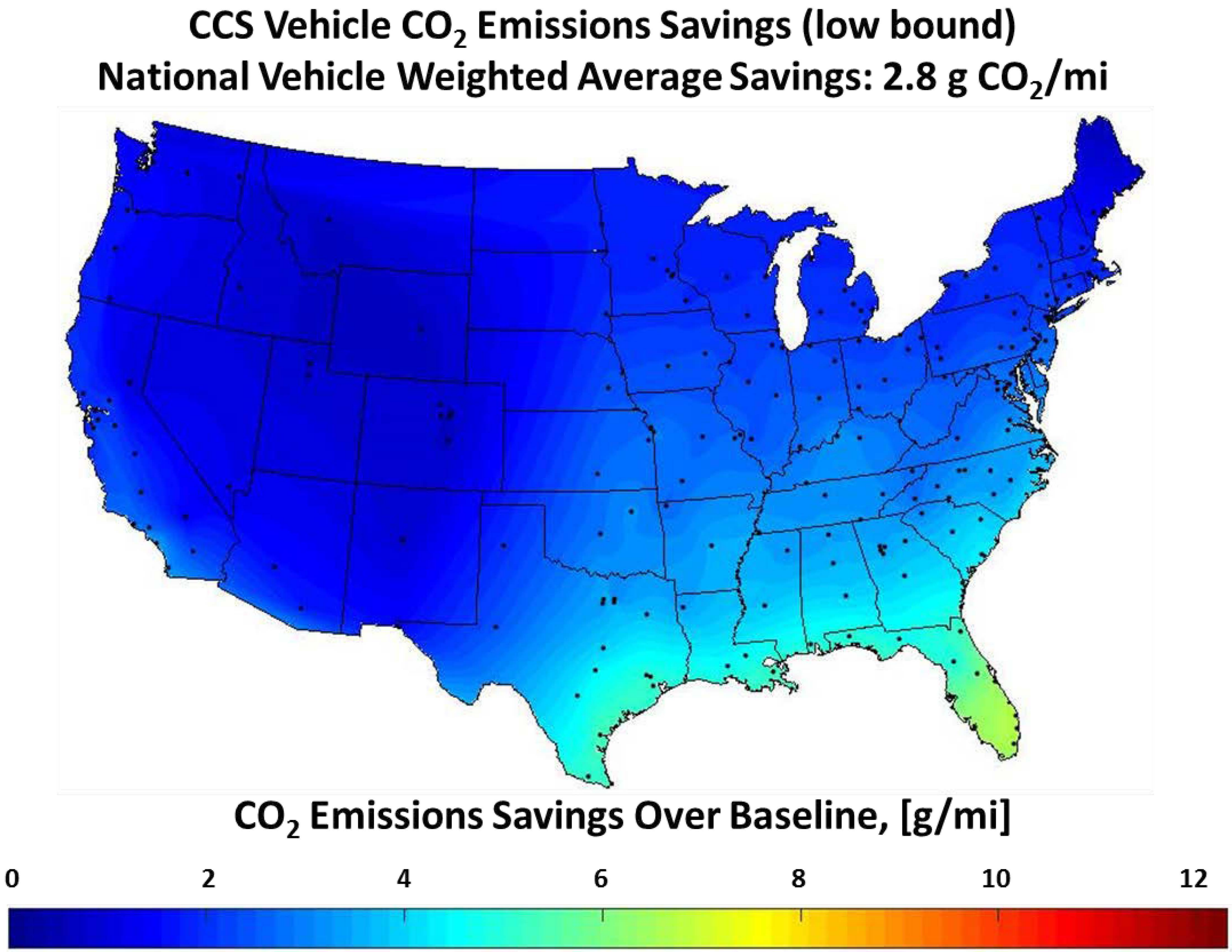


Results – National Level Analysis

Vehicle Configuration	Individual Vehicle A/C Fuel Use [Gal/year]	U.S. Light-Duty Fleet A/C Fuel Use [Gal/year] *	U.S. A/C Carbon Dioxide Emissions [Tons/year] **
National Baseline Vehicle	30.0	7. 59 billion	74.3 million
CCS Vehicle +2.0°C cabin offset (low bound confidence)	26.5	6.69 billion (100% adoption)	65.5 million (100% adoption)
CCS Vehicle +2.6°C cabin offset (average)	24.9	6.29 billion (100% adoption)	61.6 million (100% adoption)
CCS Vehicle +3.2°C cabin offset (high bound confidence)	23.4	5.91 billion (100% adoption)	57.9 million (100% adoption)
Savings With Climate Seat (Low bound, 90% Confidence)	**3.5**	**0.9 billion (100% adoption)**	**8.8 million (100% adoption)**
Savings With Climate Seat (average)	**5.1**	**1.30 billion (100% adoption)**	**12.7 million (100% adoption)**
Savings With Climate Seat (High bound, 90% Confidence)	**6.6**	**1.67 billion (100% adoption)**	**16.4 million (100% adoption)**

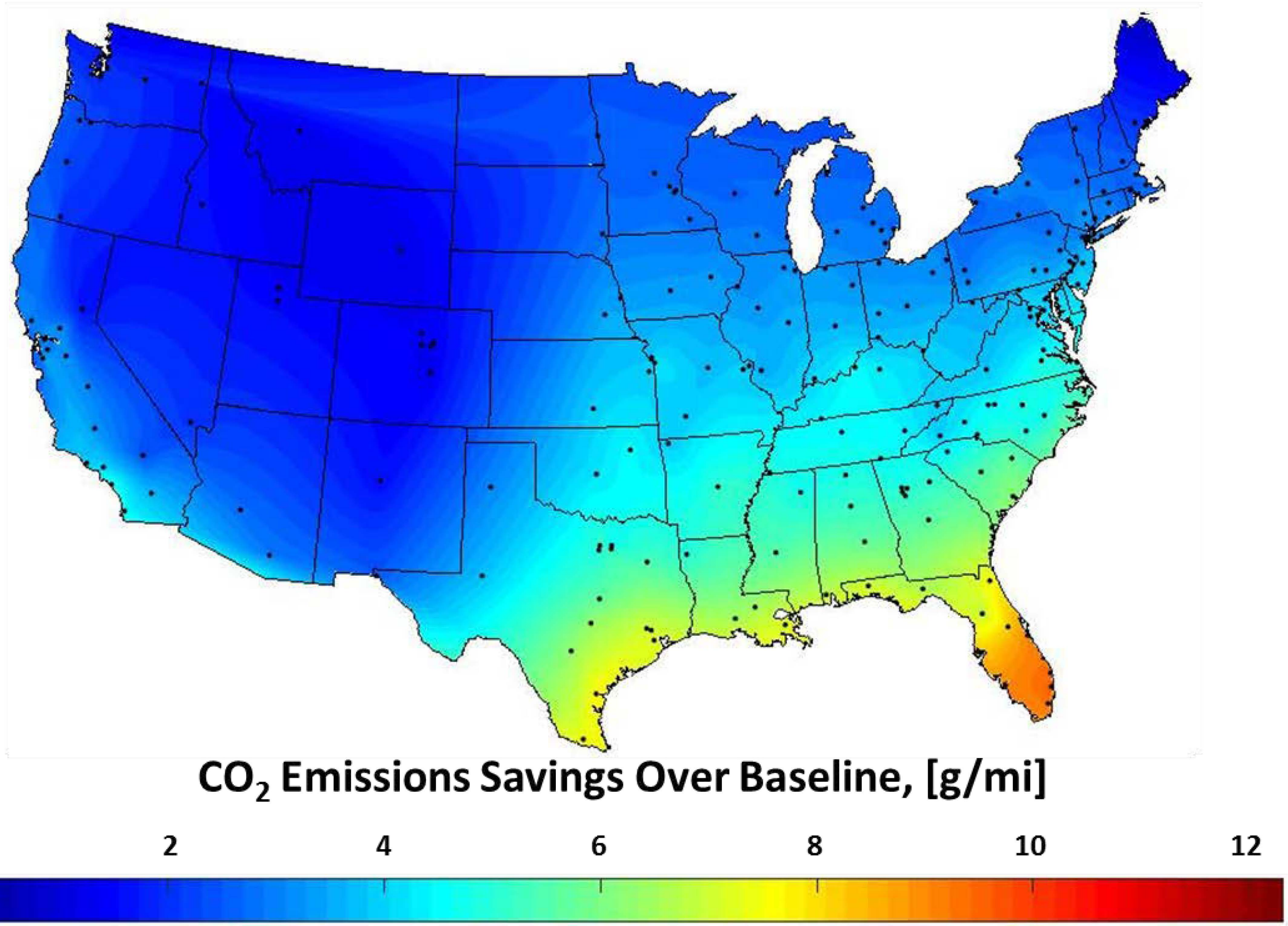
* Based on U.S. light-duty vehicle fleet size of 252,714,871 vehicles [2], individual vehicles traveling 11346 miles/year [3] ** Based on 8887 grams of CO_2 per gallon of gasoline [4]

Results – National Level Analysis



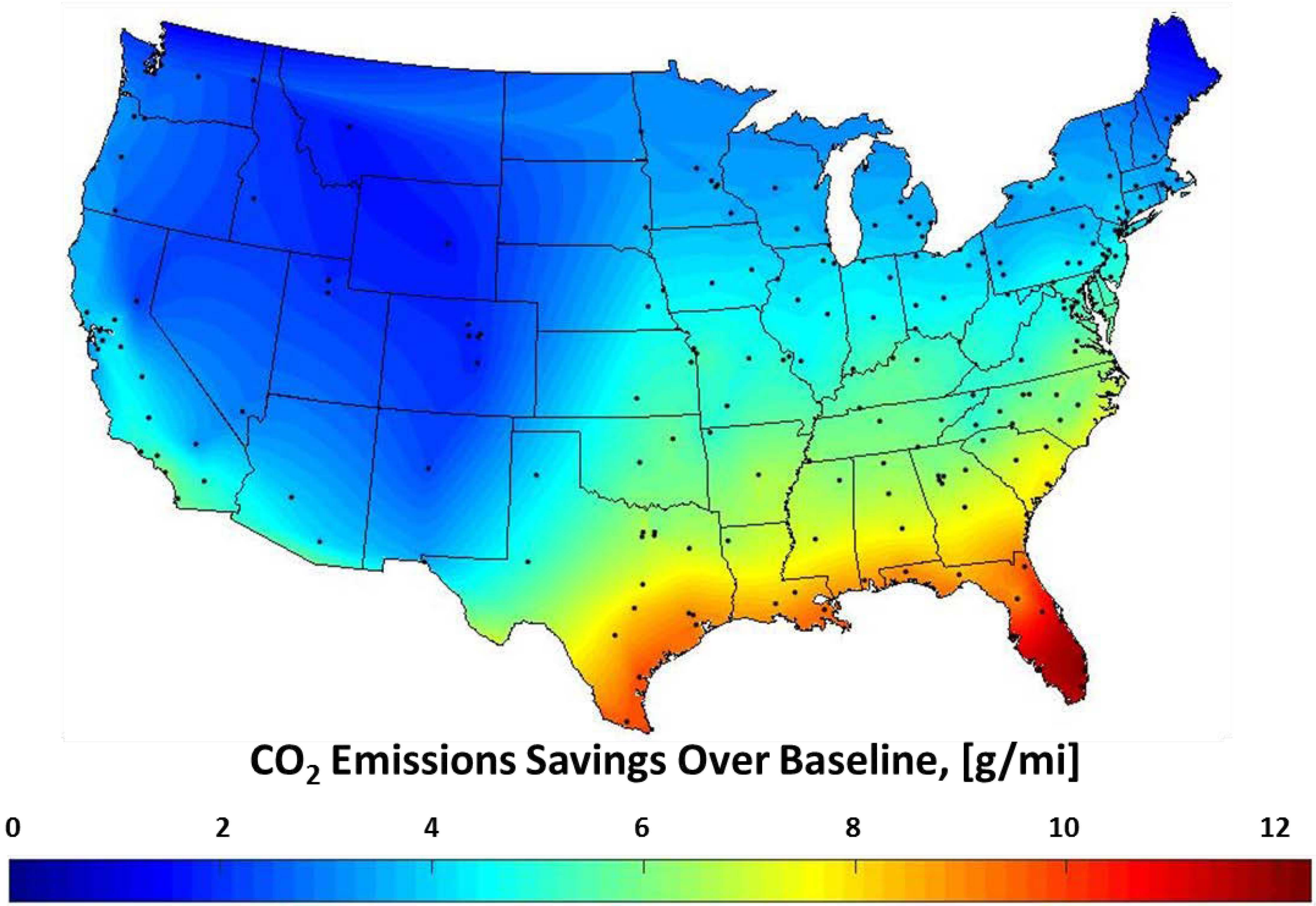
Results – National Level Analysis

CCS Vehicle CO_2 Emissions Savings (average)
National Vehicle Weighted Average Savings: 4.0 g CO_2/mi



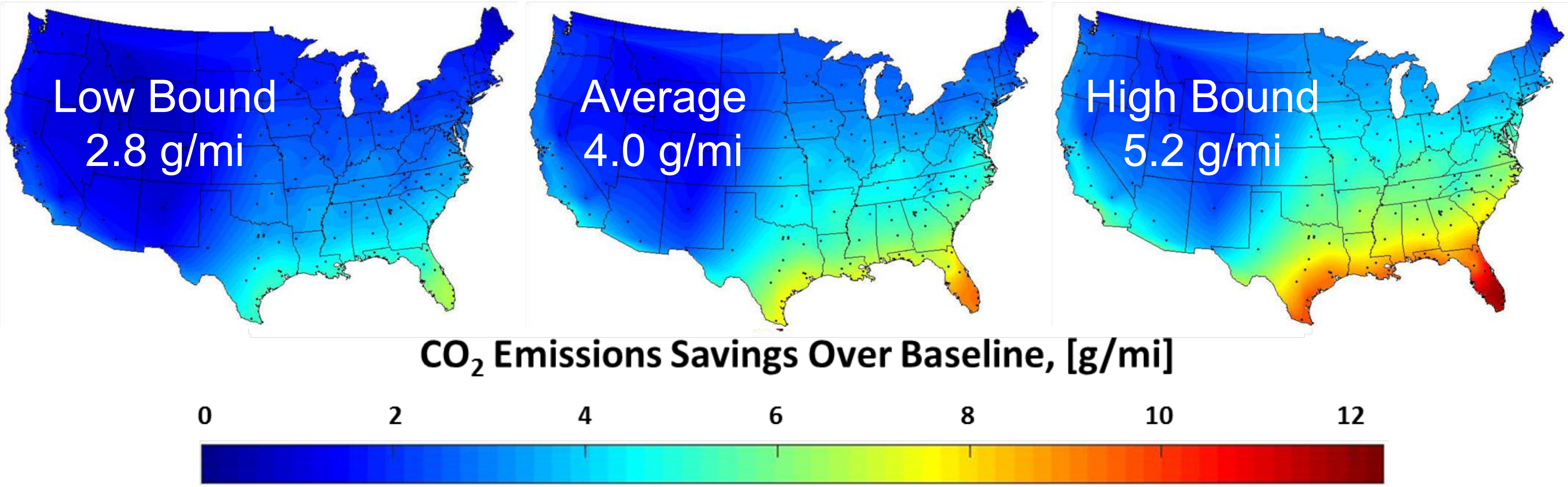
Results – National Level Analysis

CCS Vehicle CO_2 Emissions Savings (high bound)
National Vehicle Weighted Average Savings: 5.2 g CO_2/mi



Results – National Level Analysis

Vehicle Configuration	Individual Vehicle A/C CO_2 Emissions [g/mi]	Individual Vehicle CO_2 Emissions Savings [g/mi]	U.S. Location with Lowest Emissions Anchorage, AK	U.S. Location with Highest Emissions Honolulu, HI
National Baseline Vehicle	23.5		3.5 g/mi	55.4 g/mi
CCS Vehicle +2.0°C offset (low bound)	20.7	2.8	0.7 g/mi savings	7.2 g/mi savings
CCS Vehicle +2.6°C offset (average)	19.5	4.0	1.1 g/mi savings	10.2 g/mi savings
CCS Vehicle +3.2°C offset (high bound)	18.3	5.2	1.3 g/mi savings	13.1 g/mi savings



Results – National Level Analysis
Comparison of CCS Performance to Current Ventilated Seat Credit

1. NREL determined registrations for Car (48%) and Truck/SUV (52%)
2. EPA Baseline A/C Emissions Impact = 13.8*0.48 + 17.2*0.52 = 15.6 g/mi
3. Split NREL results into car/truck based on EPA ratios:

$$Car: \frac{13.8}{15.6} * 23.5 = 20.8 \qquad Truck: \frac{17.2}{15.6} * 23.5 = 26.0$$

4. Scaled up existing seat ventilation credit (1.0 and 1.3 g/mi)

$$Car: \frac{20.8}{13.8} * 1.0g/mi = 1.5g/mi \qquad Truck: \frac{26.0}{17.2} * 1.3g/mi = 2.0$$

		Car			Truck		
Vehicle Configuration	**Cabin Offset (°C)**	**A/C CO2 Emissions (g/mi)**	**CO2 Savings (g/mi)**	**CCS Improvement over ventilated seat (g/mi)**	**A/C CO2 Emissions (g/mile)**	**CO2 Savings (g/mi)**	**CCS improvement over ventilated seat (g/mi)**
Current Off-Cycle Ventilated Seat Menu Credit (Adjusted)			1.5			2.0	
National Baseline Vehicle		20.8			26.0		
CCS Vehicle: Low bound	**2.0**	**18.3**	**2.5**	**1.0**	**22.9**	**3.1**	**1.1**
CCS Vehicle: Average	**2.6**	**17.3**	**3.5**	**2.0**	**21.5**	**4.5**	**2.5**
CCS Vehicle: High bound	**3.2**	**16.2**	**4.6**	**3.1**	**20.2**	**5.8**	**3.8**

Summary

Process

- **Developed method for evaluating the performance of actively cooled seats**
- **Demonstrated method with Gentherm CCS™**

Results

- **Experimental results showed Gentherm CCS provided 2.6°C avg. elevation in cabin air temperature for equivalent comfort**
- **National analysis estimated actively cooled seat average savings of 4.0g CO_2/mi (3.5 g/mi car and 4.4 g/mi truck)**
  - Baseline national analysis light-duty A/C emissions impact is 23.5g CO2/mi
  - Existing ventilated seat credit scaled up to allow comparison
- **Actively cooled seat savings of 2.0 – 2.5g CO_2/mi over existing ventilated seat credit (adjusted for NREL baseline)**

Acknowledgements and Contacts

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