State of California
AIR RESOURCES BOARD

Appendix B

Emissions Modeling

Cool Car Standards and Test Procedures

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This Appendix discusses how staff determined the emission benefit from the proposed regulation.

Table of Contents

List of Tables

List of Figures

List of Acronyms

AB	Assembly Bill
ADVISOR	ADvanced VehIcle SimulatOR model, developed by NREL
ARB	California Air Resources Board
B-Pillar	The roof support between a car's front door window and rear side window
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EMFAC	EMission FACtors model, developed by ARB
LBNL	Lawrence Berkeley National Laboratory
MMT	Million Metric Tons
mpg	Miles per gallon
NOx	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
PPD	Predicted Percent Dissatisfied; a measure of the percentage of people likely to feel too hot or too cold in a given environment
SC03	Air conditioner test cycle
SFTP	Supplemental Federal Test Procedure
SUV	Sport Utility Vehicle
Tts	Total Solar Transmission
VMT	Vehicle Miles Traveled

I. DETERMINING THE PROJECTED BASELINE INVENTORY

A. ARB's EMFAC Model

Projected inventories for the Air Resources Board (ARB) are typically generated using EMFAC (ARB's EMission FACtors model). EMFAC provides activity data for vehicle miles traveled (VMT), including distribution of VMT throughout the day, mileage accrual rates, cumulative mileage, vehicle retirement/relocation rates, and other pertinent information such as vehicle population and age distribution. Activity and other inputs are extrapolated into the future; current projections extend until 2040.

Although the focus of the model is assessment of tailpipe emissions, EMFAC incorporates some assumptions regarding air conditioner use and impacts. EMFAC includes an air conditioner use rate of 10 percent for California. This figure is substantially lower than projections by the National Renewable Energy Laboratory[1] (NREL) and others[2] of air conditioner use in California. Staff believes this is largely due to the temperature averaging process within EMFAC, which results in temperatures that are milder than actual conditions. Further, the estimated effect of air conditioner use on fuel consumption is substantially lower in EMFAC than elsewhere in the literature. These issues are discussed in more detail in subsequent sections. The result of these issues is that the projected baseline emissions from mobile air conditioner use in California appear to be underestimated by EMFAC. Therefore, staff examined other ways to determine the anticipated effect of this proposal on mobile air conditioner-related emissions.

B. Thermal Comfort Model

The air conditioner in a vehicle is typically activated because the vehicle occupant(s) is uncomfortably warm. There are a variety of thermal comfort models in use today to translate the measured or modeled perceived level of discomfort into likely air conditioner use rates. NREL has developed a thermal comfort model which estimates a vehicle occupant's comfort level during winter warm-up or summer cool-down. Like most thermal comfort models, NREL's model is based on Fanger's heat balance equations.

The underlying premise of thermal comfort modeling is that if a person is thermally uncomfortable, he or she will take action to become more comfortable (i.e., turn on the heat or the air conditioner). A person's sense of thermal comfort is primarily related to their thermal balance. Physical activity, clothing, air temperature, mean

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[1] The U.S. Department of Energy's National Renewable Energy Laboratory is the nation's primary laboratory for renewable energy and energy efficiency research and development. NREL's mission and strategy are focused on advancing our nation's energy goals. For more information about this national laboratory, visit http://www.nrel.gov

[2] For example, see the Intergovernmental Panel on Climate Change and the Technology & Economic Assessment Panel's Special Report: Safeguarding the Ozone Layer and the Global Climate System, Chapter 6, Mobile Air Conditioning. Available at http://www.ipcc.ch/ipccreports/sroc.htm.

radiant temperature,[3] air velocity, and humidity all influence the body's thermal balance. Given these factors, thermal comfort can be modeled, and presented as the "predicted percent dissatisfied", or "PPD". The PPD is a measure of the percentage of people likely to feel too hot or too cold in a given environment. In the "too hot" environment, PPD equals the percentage of people who would turn on the air conditioner (For a discussion of NREL's thermal comfort model, see Johnson, 2002, or Chaney et al., 2007).

NREL's thermal comfort model predicts that mobile air conditioners are used for 28 percent of the VMT nationwide.[4] Not surprisingly, states like Arizona (58 percent) and Florida (57 percent) have much higher use rates than states like Alaska (6 percent) and Wyoming (15 percent). California is near the national average, with an air conditioner use estimate of 29 percent (Rugh et al., 2004). This estimate takes into account variations in trip behavior by time of day and year, and the VMT for each of the seven major cities in California that were analyzed by NREL. Results from each city were weighted by population figures. Staff believes the NREL air conditioner use rate is more appropriate than the use rate currently incorporated into EMFAC because of the way the temperature data is treated within EMFAC, which results in the incorporation of more mild temperatures than are actually seen in California, especially during the summer. Therefore, staff utilized NREL's California air conditioner use rate when determining baseline air conditioner-related emissions as well as anticipated benefits ensuing from the proposed regulation.

C. The Effect of Air Conditioners on Emissions

Use of the air conditioner can substantially increase exhaust emissions. This is primarily due to the increased fuel consumed from the extra load on the engine caused by the air conditioner compressor. The load effect increases as vehicle fuel efficiency increases. A vehicle that achieves 25 mpg without the air conditioner might see fuel consumption increase by 20 percent when the air conditioner is in use, while fuel consumption increases of 50 to 100 percent have been estimated for an 80 mpg vehicle (see, for example, Farrington et al., 2000). Large trucks generally have a smaller impact due to the higher power engines used, and relatively lower baseline fuel efficiency.

[3] Mean radiant temperature (MRT) is a term used to account for the fact that temperatures are not uniform. For example, if a person is sitting in a hot vehicle, the temperature is generally hotter at the instrument panel than in the foot well. The MRT is the uniform black body surrounding temperature to which a person would exchange the same amount of heat as they do in the actual non-uniform thermal environment. The MRT inside a vehicle may be considerably above ambient if the vehicle were sitting in the sun for hours.

[4] NREL's published literature is by state. Some references suggest a 34 percent nationwide figure, derived from NREL's state-by-state rates, but in its estimate of national air conditioner use, the United States Environmental Protection Agency (EPA) reports that NREL provided a national air conditioner use rate of 28% of the VMT, compared to EPA's estimate of around 24% of the VMT. See EPA, 2006.

D. The Baseline Inventory

Staff's estimate for California's indirect mobile air conditioner related emissions is based on a simple model incorporating work done by Lawrence Berkeley National Laboratory (LBNL) and the NREL work effort described above. The model utilizes typical California air conditioner use rates as established by NREL, adjusted for the detailed VMT and fleet operations inherent in EMFAC, the impact of air conditioner use on fuel use, and the relationship between changes in soak temperature and air conditioner fuel use developed by NREL. The air conditioner on-time depends on factors such as temperature, humidity, vehicle orientation, parking conditions, and vehicle color mix. After adjusting for the potential indirect air conditioner credits available under AB 1493, the adjusted baseline level of CO_2 emissions from mobile air conditioner use was calculated. The model framework was developed by LBNL, and is shown in Table B-1 for 2040.

Model inputs include the number of vehicles and VMT projected for 2040. EMFAC projects that slightly over half of the projected 2040 VMT for affected vehicles is from passenger cars, while the balance (49.6 percent) is from light-duty trucks and medium-duty vehicles. Baseline vehicle fuel consumption for 2040 was set at 41 miles per gallon (mpg) average for the affected vehicles.[5] Indications are that these more fuel efficient vehicles will have a larger greenhouse gas emissions impact from air conditioner use. Therefore, staff assumed that the typical current impact of 19 percent increased fuel consumption with air conditioner use[6] would increase to 26 percent by 2040.

E. Baseline Inventory Adjustment

Using vehicle population and VMT from EMFAC, air conditioner use rate estimated above, and the effect of that air conditioner use on fuel consumption and CO_2 emissions discussed above, staff projected a baseline fuel consumption estimate for 2040, shown in Table B-1, of 0.80 billion gallons of fuel per year. However, an adjustment to this projected baseline inventory is necessary, due to the credit system that was included in regulations developed in response to Assembly Bill (AB) 1493, and adopted in 2004. That regulation includes carbon dioxide (CO_2) credits for reducing indirect air conditioner emissions.[7] One way to obtain credits is to upgrade a typical current system using a pneumatically controlled fixed displacement compressor to one using an externally controlled variable displacement compressor. A fixed compressor operates in an on/off mode. With significant cooling demand,

[5] This figure is based on staff's population-weighted average fuel economy estimates ranging from 45 mpg for passenger cars to 30 mpg for medium-duty vehicles.

[6] This figure is based on testing performed for the Supplemental Federal Test Procedure (SFTP, 1996) and Clean Air Vehicle Technology Center (CAVTC, 1999). In the SFTP tests, small cars had 34 percent higher emissions with the air conditioner on, while midsize cars had a 24 percent increase, and larger vehicles such as large trucks and sport utility vehicles (SUVs) had more modest emission increases of around 11 percent.

[7] Indirect emissions are tailpipe emissions and are the result of the load of the air conditioner on the engine; using the air conditioner increases the load, and the fuel consumption, of the vehicle, compared to operation of the vehicle with the air conditioner off.

such as occurs with high interior conditions or with very hot ambient conditions, the compressor works constantly. But as cooling demand is reduced, the fixed compressor adjusts to achieve the desired temperature by cycling on and off and/or by adding heat back into the cooled air. Fuel consumption under these conditions is significantly increased. A variable compressor compresses only the amount of coolant needed to achieve the needed temperature reduction; these compressors are able to operate at higher efficiencies under steady state conditions than are the fixed compressors. However, when cooling demand is high, performance is similar to that of a traditional fixed compressor.

A study completed for the AB 1493 regulation estimated the effect of advances in air conditioning systems, including a move to externally controlled variable displacement compressors from pneumatically controlled fixed displacement compressors (NSCCAF, 2004). As reported in the Staff Report for AB 1493,[8] such a change in compressor type, coupled with improved air recirculation and a change in refrigerant to HFC-152a, would reduce the fuel used for air conditioning by around 2.3 percent for cars and minivans, and just over two percent for trucks and sport utility vehicles (ARB, 2004). To estimate the benefits of this proposal, staff conservatively assumed that all manufacturers would choose to generate these credits. This assumption ensures that the benefit from switching to better air conditioners is not inappropriately double counted in the projected benefit from this regulation. Based on EMFAC's projected VMT split between cars and trucks in the inventory, staff reduced the estimated fuel used for air conditioning in the projected baseline inventories by 2.2 percent. The effect of staff's proposal was layered onto this adjusted projected baseline inventory.

Using the inputs discussed above, as summarized in Table B-1, 0.78 billion gallons of fuel per year are projected to be consumed for mobile air conditioner operations in 2040. This level of fuel use is associated with 6.92 million metric ton (MMT) CO_2.

Table B- 1. Baseline Model Inputs.

	Input			**Source/Calculation**
F4	2040 registrations for 2012+MY	36.98	million vehicles	EMFAC
F5	2040 VMT per day, 2012+MY	1251.58	million miles/day	EMFAC
F6	VMT per year	434.30	billion miles/yr	F5*347/1000; 347 is the weekday-equivalent days/year
F7	Annual fuel use	10.59	billion gal/yr	F6/41 mpg estimate
F8	Increased fuel consumption from a/c use	26%		Conservative increase from current 19% average
F9	% time a/c is on	29%		Rugh et al., 2004
	Output			
F13	a/c contribution to fuel use	0.799	billion gal/yr	F7*F8*F9
F14	Adjusted for AB 1493	0.781	billion gal/yr	F13*.978
F15	a/c contribution to CO_2 emissions	6.92	$MMTCO_2$/yr	F14*8.857 MMT CO_2/Billion gal. gasoline

[8] Staff directs the reader to the Staff Report for the AB 1493 regulation (ARB, 2004), specifically the discussion surrounding Table 5.1-12 (page 75).

II. MODELING THE EMISSION BENEFIT

Staff's proposal will reduce the interior temperature of vehicles parked in the sun. A cooler interior means less energy must be removed from the vehicle to make it comfortable. If less energy is needed, the air conditioner will operate at lower load and/or can be made smaller. A smaller air conditioner compressor will reduce the fuel used and emissions generated for air conditioning, and is lower in weight (requiring less fuel and emissions to move the vehicle). These fuel benefits are associated with reduced CO_2 emissions.

AB 32 requires a reduction in greenhouse gas emissions of around 25 percent in 2020. Further reduction goals for 2050 have been specified by Executive Order. Using the approach discussed below, the benefits for the proposed regulation were determined for 2020 and 2040, which is as far in the future as EMFAC projects VMT and other data at present. The mileage from remaining pre-2012 model year vehicles is low by 2040, so the projections for 2040 should be close to those at full implementation.

A. Anticipated Reductions in Soak Temperature

To determine the expected reduction in soak temperatures, staff made some simplifications and assumptions, based on data presented in the Staff Report and in Appendix C.

- 50 percent of total solar heat gain through glazing passes through the windshield, 30 percent through the sidelites, and 20 percent through the backlite(s). By 2040, 50 percent of vehicles in these classes are expected to have a rooflite(s) (Peter, 2004). A similar heat gain is obtained through a rooflite as through a windshield.
- One-third of sidelite surface area is estimated to be forward of the B-pillar; two-thirds are rear of the B-pillar. This likely underestimates forward glazing for pick-up trucks, and overestimates it for SUVs.
- All-around solar management glazing with a total solar transmission (Tts) of 60 percent reduces the interior soak temperature by 6^oC compared to clear or light green tint.
- All-around solar management glazing with a total solar transmission of 50 percent (as typically would be achieved for laminated glass using glazing with a direct solar reflectance of around 30 percent) reduces the interior soak temperature by 8^oC compared to clear or light green tint.
- All-around solar management glazing with a total solar transmission of 40 percent (as typically would be achieved for laminated glass using glazing with a direct solar reflectance of 40 to 43 percent) reduces the interior soak temperature by at least 9^oC compared to clear or light green tint.

- Current rooflites are estimated to have a total solar transmittance of 40 percent. Reducing the transmittance to 30 percent is estimated to reduce interior soak temperatures by at least 1^{o}C.
- Some vehicle glazing already incorporates solar control. Staff estimates that 40 percent of sidelites forward of the B-pillar already achieve a total solar transmission near the proposed 60% level. Therefore, projected soak temperature reductions are limited to the 60% that do not.
- Staff estimates that 25% of glass rear of the B-pillar in passenger vehicles already achieves a total solar transmission near the proposed 60% level. Therefore, projected soak temperature reductions are limited to the 75% that do not.
- For SUVs and pick-up trucks, adjustments are made for the current use of privacy glazing. Staff estimates that 65 percent of SUVs and pick-up trucks use privacy glazing where allowed in the vehicle.[9]

When fully implemented, the proposed regulation requires the use of windshields meeting a 40 percent total solar transmission. This corresponds to 4.5^{o}C anticipated soak temperature reduction. This applies to all vehicles. In addition to this, additional soak temperature reductions are expected from the proposed requirements for sidelites, backlite(s), and rooflite(s). These vary by vehicle type. A total temperature reduction of 7.7^{o}C, is estimated for typical sedans, and 6.7^{o}C for SUVs and pick-up trucks. The calculations are presented in Table B-2, and show the temperature reduction, glazing position corrections, and corrections for current technology use. For example, for car sidelites rear of the B-pillar, 6^{o}C (anticipated temperature reduction with all-around glazing meeting a 60% Tts requirement) times 30% (portion of solar heat gain through sidelites) times 67% (portion of sidelites rear of the B-pillar) times 75% (portion of those sidelites not currently using solar management glazing that limits total solar transmission to around 60%) results in a 0.9^{o}C anticipated soak temperature reduction.

Table B- 2. Soak Temperature Reductions.

	Cars		SUVs/Pick-ups	
Windshield-all vehicles	9^{o}C*50%	4.5 ^{o}C	9^{o}C*50%	4.5 ^{o}C
Rooflite(s)-all vehicles	1^{o}C	1 ^{o}C	1^{o}C	1 ^{o}C
Sidelites-cars, front	6^{o}C*30%*33%*60%	0.4 ^{o}C	-	
Sidelites-cars, rear of B-pillar	6^{o}C*30%*67%*75%	0.9 ^{o}C	-	
Backlite(s)- cars	6^{o}C*20%*75%	0.9 ^{o}C	-	
Sidelites-SUVs, P/Us, Front	-		6^{o}C*30%*33%*60%	0.36 ^{o}C
Sidelites-SUVs, P/Us, Rear	-		6^{o}C*30%*67%*35%	0.42 ^{o}C
Backlite(s)-SUVs, P/Us	-		6^{o}C*20%*35%	0.42 ^{o}C
Total		**7.7^{o}C**		**6.7^{o}C**

[9] Benefit from the solar control requirements for privacy glazing cannot be estimated because staff lacks sufficient data as to current average solar management performance for privacy glazing at this time.

B. Converting Soak Temperature Reductions to Reduced Fuel Use

To translate reduced soak temperatures into a potential reduction in air conditioner compressor size, NREL developed a transient air conditioner model.[10] Vehicles were equipped with technologies to reduce net solar load, and interior temperatures were measured and compared to baseline vehicles. Maintaining existing compressor power, the cabin cools more quickly in the solar control vehicle than in the baseline vehicle. The model then reduces compressor power to decrease the cooling capacity of the system until it matches the baseline condition. In an assessment of a Cadillac STS, meeting the temperature goal required a 5.7 kilowatt air conditioning system for the baseline vehicle. For the experimental vehicle, which had a lower starting temperature, a 4.0 kilowatt system was adequate to meet the goal. This is a 30 percent reduction in cooling load (Rugh et al., 2007).

After the potential reduction in air conditioner compressor size was estimated, NREL modeled fuel use for the smaller compressor using their ADVISOR (ADvanced VehIcle SimulatOR) model, which is designed to assess the performance and fuel economy of conventional, electric, and hybrid vehicles. Reducing the air conditioner load by 30 percent resulted in a 26 percent reduction in air conditioner fuel use, or 1.2 percent reduced air conditioner fuel use per degree F reduction in interior temperature (Rugh et al., 2007).

Staff's modeling approach uses this relationship between reduced soak temperatures and air conditioner fuel use. Although the Cadillac is a single vehicle, it is approximately midway in size between smaller cars and SUVs, so the figure seems reasonable. It is also more conservative than earlier figures for a Ford Explorer developed by NREL of 2.2 percent reduced fuel use per degree F (Rugh et al., 2001).

While staff believes that the air conditioner use factor should account for variable inputs such as the orientation of parked cars and the insolation rate, the calculated benefit reflects a 20 percent downward adjustment to ensure that the benefits are not overstated. This adjustment will accommodate non-included variables, such as the fraction of vehicles without a properly functioning air conditioner.[11]

Staff applied the reduced interior temperatures to the work demand for an externally controlled variable compressor. Because the variable compressor works only as hard as is needed to achieve comfort, the reduced interior temperatures will result in lower compressor demand, and reduced associated emissions. A similar benefit would be expected if a fixed compressor were downsized to more properly fit the new

[10] For an in-depth discussion on how expected reductions in interior soak temperature are related to anticipated reductions in air conditioner use or downsizing of air conditioner capacity, and estimates of reduced fuel consumption and therefore reduced CO_2 emissions, staff refers the reader to Rugh and Farrington (2008) and the documents referenced therein.

[11] Cooling in a vehicle without air conditioning generally relies on the windows. Aerodynamics, and therefore fuel consumption, suffers when the windows are down. To the extent that a cooler interior leads to the windows remaining up at freeway speeds, staff expects some benefit to accrue with the proposed regulation even from vehicles without functional air conditioners.

lower demand.[12] Since an air conditioner that is larger than needed is inefficient and has higher cost, staff anticipates that over time, manufacturers will re-size the air conditioner to account for the lower solar load; this would be done automatically with new models, typically introduced every five years.

C. Emission Benefit

Table B-3 reiterates model inputs presented in Table B-1. In addition, the model outputs in terms of reduced fuel consumption and reduced CO_2 emissions are presented.

1. Reduced Compressor Power Needs

According to this model, with nearly full implementation, the anticipated reductions in soak temperature would result in adjusted reduced CO_2 emissions of 0.86 MMT per year when considering only the reduced compressor power needs for cool cars.

As a check of staff's methodology, one glass manufacturer who has developed a thermal simulation model to assess the benefits of various solar control products offered to run simulations on the probable benefits of a variety of control scenarios.

Table B- 3. Model Inputs and Outputs.

	Input			**Source**
F4	2040 registrations for 2012+MY	36.98	Mil. vehicles	EMFAC
F5	2040 VMT per day, 2012+MY	1251.58	Mil. miles/day	EMFAC
F6	VMT per year	434.30	Bil. miles/yr	F5*347/1000
F7	Annual fuel use	10.59	Bil. gal/yr	F6/41 mpg estimate
F8	increased fuel consumption due to a/c use	26%		Conservative increase from current 19% average
F9	% time a/c is on	29%		Rugh et al., 2004
	Output			
F13	a/c contribution to fuel use	0.799	Bil. gal/yr	F7*F8*F9
F14	Adjusted for AB 1493	0.781	Bil. gal/yr	F13*0.978
F15	a/c contribution to CO_2 emissions	6.918	$MMTCO_2$/yr	F14* 8.857 conversion to $MMTCO_2$
F17	**Effect of cool cars proposal (reduce 7.7°C (13.8 °F) or PCs and 6.7°C (12.1 °F) for LDT/MDVs)**			
F18	Reduction in a/c fuel use PC	16.6%		1.2% per °F * 13.8 °F
F19	Reduction in a/c fuel use LDT MDV	14.5%		1.2% per °F * 12.1 °F
F20	Adjusted a/c contribution to fuel use	0.660	Bil. gal/yr	(.504*F14-(F18*F14))+(.496*F14-(F19*F14))
F21	Reduced CO_2 emissions	1.076	$MMTCO_2$/yr	(F14-F20)*8.857 $MMTCO_2$/Bgal
F22	Adjusted Reduced CO_2 emissions	0.861	$MMTCO_2$/yr	adjust 20% downward for uncertainties

[12] Air conditioner systems for vehicles are typically sized to achieve a cool-down of a black vehicle parked in the Phoenix summer sun to a comfortable temperature in a set amount of time, so if the interior is less hot, the desired temperature goal will be achieved more quickly. Therefore, to attain the same overall air conditioner performance, a smaller (lower kilowatt) air conditioner can be used.

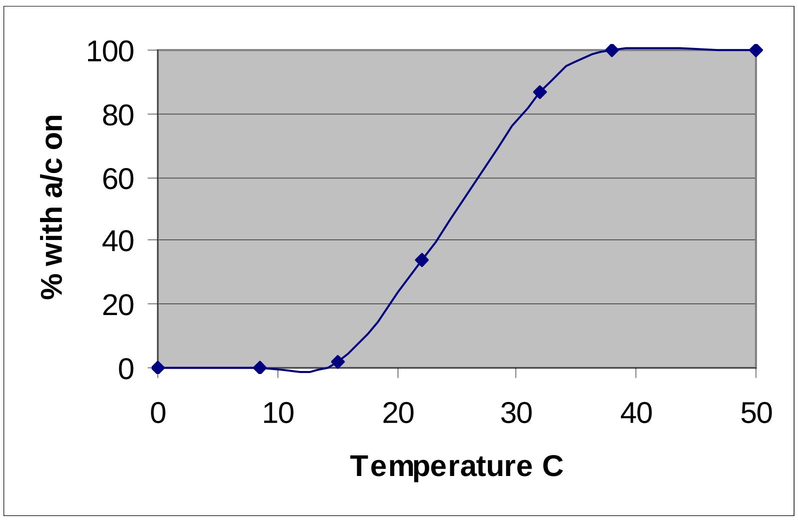
The model results indicated that the use of an infrared reflective windshield can reduce the CO_2 emissions by 2.76 MMT per year. This is higher than staff's modeled results, but seems consistent.

2. Reduced Air Conditioner Use

In addition to the benefits to be obtained through reduced load on the air conditioner, the cooler interior temperature will result in reduced use of the air conditioner during periods of mild-to-moderate temperatures and/or short soak times. During these periods, a person might use the air conditioner under current conditions, but with new solar controls in place, the air conditioner might not be necessary for thermal comfort. These times, termed "shoulder months" by staff, would be associated with additional benefits. To quantify these benefits, staff assumed that shoulder months occur in relatively mild temperatures where some but fewer than half of people are currently expected to activate the air conditioner. Figure B-1 shows a typical air conditioner usage curve developed for Phoenix, AZ.[13]

The figure shows the percent of people dissatisfied with the thermal environment. A person will have the air conditioner button in the car switched to the on position based on the following factors: the ambient temperature in Phoenix, average temperature of the surrounding surfaces, air velocity in the car, summer clothing, and a driving metabolic rate. These data do not include the effect of increased interior temperatures relative to ambient temperatures. Updated figures are available that offer a conservative assumption that the interior temperature is 10^{o}C warmer than ambient. Staff opted not to use the updated figures because the air conditioner use rates incorporated in the model are based on figures such as this one. Updating to the newer figure would result in expected increases in air conditioner use, which have not yet been estimated by NREL.

Figure B- 1. Typical Air Conditioner Usage in Phoenix, AZ.



[13] Data to generate curve provided by John Rugh, NREL.

To determine when mild-to-moderate conditions might occur in California, staff turned to EMFAC's hourly temperature data by hour, averaged for California. These data are presented in Table B-9, located at the end of this document. Perceptions of heat are also influenced by humidity. The combination of temperature and humidity is referred to as the "heat index". EMFAC contains humidity data by hour, averaged for California. The humidity in California is moderate, so the heat index is generally within 2 degrees of the temperature. Since the effect is small, staff did not adjust the temperatures for humidity. Doing so would have resulted in the addition of one more shoulder month designation for rush hour. The heat index is shown in Table B-4.

Using Figure B-1 above, staff defined a "shoulder month" as one with temperatures between 18°C (64°F) and 24°C (75°F). Peak temperatures typically occur around 2 p.m., and "shoulder month" peak temperatures occur from February through May, and in November. If the evening rush is examined, four months would be considered shoulder months (April through June and October). During the morning rush, shoulder month conditions are met between April and October. Recall that the averaging process included in EMFAC makes California's temperatures seem more mild than they are in actuality. However, for the purpose of determining shoulder

Table B- 4. California Heat Index.

Time	Temperature (F)	Relative Humidity	Heat Index	Correction
0	55.2	76.7	53	-2
100	54.5	77.7	53	-2
200	54.0	78.2	52	-2
300	53.4	78.3	51	-2
400	53.1	79.6	50	-3
500	53.0	79.9	50	-3
600	54.1	78.5	52	-2
700	56.7	74.2	55	-2
800	60.3	67.8	58	-2
900	63.9	61.1	62	-2
1000	66.6	55.8	65	-1.5
1100	68.7	52.1	68	-1
1200	70.2	49.7	69	-1
1300	71.0	48.1	70	-1
1400	71.4	47.8	70	-1
1500	70.9	48.6	70	-1
1600	69.2	51.2	68	-1
1700	66.4	56.1	64	-2.5
1800	63.4	61.9	61	-2
1900	60.8	66.9	59	-2
2000	59.1	70.2	57	-2
2100	57.9	72.7	56	-2
2200	56.8	74.6	55	-2
2300	56.0	75.9	54	-2.5

months, relative temperatures should be adequate, and the months that are identified using this process are the same ones that would be logically identified by readers familiar with California's weather patterns.

Reduced air conditioner use during shoulder months results in an additional benefit available beyond that calculated for reduced compressor power needs.[14] Staff used temperatures during the evening rush hour (5 to 6 pm) to determine that, for California as a whole, four of twelve months are shoulder months. This fraction was multiplied by the calculated benefits from Table B-3 (.33 x 0.86 MMT CO_2) to arrive at an additional 0.29 MMT CO_2 per year during these shoulder months. Adding this number to the 0.86 MMT estimated previously results in a total of 1.15 MMT CO_2 per year benefit in 2040. In addition, the improved solar control may result in very short soaks that may not heat up the vehicle sufficiently to require the use of the air conditioner. These potential benefits have not been quantified.

3. Out-Migration

There are further benefits that can be quantified. EMFAC includes attrition rates for the vehicle fleet. Some attrition is due to vehicle scrappage, and some to vehicles relocating to other states. The CO_2 emissions benefit for those migrating vehicles will continue to accrue even though the vehicle has relocated out of state. EMFAC does not provide a break-out of scrappage versus attrition. However, approximately 300,000 people leave the state each year (CDOF, 2007). Staff estimates that these people took 200,000 vehicles with them. By 2040, it would be expected that all the departing vehicles will comply with the proposed standards. Therefore, staff has estimated the CO_2 benefit for the remaining useful life of these vehicles. Median vehicle age is 9 years, with an expected useful life of 12 years for the air conditioner system. Assuming that older vehicles are sold, and newer vehicles are retained, staff estimates that the average age of a vehicle migrating to another state is 5 years; based on EMFAC projections, a 5 year old vehicle would have approximately 48,000 miles on the odometer. Assuming an air conditioner useful life of 120,000 miles, benefits will accrue for an additional 72,000 miles. These additional benefits are not included in California projections as the vehicles have been removed from the California inventory. Staff estimates that the 200,000 vehicles estimated to migrate annually would provide an additional annual benefit of 0.03 MMT CO_2. This figure was derived by multiplying the annual number of migrating vehicles times the remaining mileage and entering the resulting vehicle miles per year into the model previously presented in Table B-3.

4. Nationwide Benefits

There are additional potential benefits that can be estimated. When faced with California regulations, manufacturers can choose to make California cars, or, if the costs are less than the cost of doing that, make all US vehicles comply with the California requirements. In this case, estimated direct costs for tier 1 (2012)

[14] An air conditioner with a smaller compressor is smaller and more efficient, but if it is not used at all, the benefit is even greater.

requirements to the manufacturer are $35 for the solar reflective windshield, and up to $25 per carset (average $11) for the sidelites and backlite. Manufacturers have told staff that it costs $2-3 per piece to put destination-specific components into a vehicle. This means that for a typical vehicle, it may be more cost-effective for the manufacturer to use the same sidelites and backlite for the vehicle regardless of its final U.S. destination. Therefore, benefits that accrue from these glazing positions will accrue in other states as well. Using the aforementioned model, including AB 1493 and uncertainty adjustments, and assuming the same fleet mix as in California, as well as national average air conditioner use rates of 28 percent and national vehicle population and VMT estimates, projected benefits for the rest of the nation are estimated at 1.96 MMT CO_2 nationwide. If manufacturers chose to market a 50-state car, projected benefits are increased to 8.30 MMT CO_2.

These benefits are summarized in Table B-5. Summing all the quantified CO_2 benefits from this proposed regulation could result in up to 9.5 MMT CO_2 reduced annually nationwide, although a benefit at the lower end of the range is more likely.

Table B- 5. Overall CO_2 Benefits, 2040.

	MMT CO_2 per year
Reduced Compressor Need	0.86
Shoulder Months	0.29
Out-Migration	0.03
Nationwide	1.96 to 8.30
Total – California Only	1.18
Total - Nationwide	3.14 to 9.48

III. Alternate Regulatory Scenarios

Staff assessed a variety of regulatory options, including requirements for solar reflective windshield only, all-around solar reflective glazing, all-around solar management glazing, and the specific phase-in proposal for solar management glazing proposed by the Alliance of Automobile Manufacturers (the Alliance). Assuming full implementation, the comparisons can be made using the same modeling approach as discussed above. All that needs to change is the estimated soak temperature reductions. However, phase-in schedules will significantly affect the benefits that accrue in 2020. This section will describe the method used to assess a sample of the regulatory options investigated by staff. It includes the benefits available from reduced compressor requirements, as well as from reduced air conditioner use during shoulder months, but does not include the benefits from vehicles that have migrated out of California nor the available benefits from the potential use of solar management glazing nationwide. Therefore, the benefits presented in the tables in this section should be considered on a relative basis only, rather than as actual benefits under any given scenario.

As mentioned above, the scenarios examined may have different phase-in schedules, as well as different final goals. To determine the emission benefit from each scenario, staff obtained EMFAC-projected VMT and vehicle registration data for 2012 through 2040 model-year vehicles less than or equal to 10,000 pounds gross vehicle weight rating. The benefits were calculated relative to the 1.15 MMT CO_2 per year expected in 2040 from implementation of the proposed regulation in California (excluding out-migration). The same assumptions were used as indicated in section A above (see pages B-5 and B-6), adjusted for the scenario – all-around glazing with a total solar transmission of 50 percent reduces the interior soak temperature by 8^{o}C; all-around glazing with a total solar transmission of 60 percent reduces the interior soak temperature by 6^{o}C; and so on. As an example of the process, if the alternate proposal was for all-around glazing with a total solar transmission of 50 percent, with the windshield in 2012 and the balance in 2013, the 2012 emission benefit would be calculated from the VMT of 2012 model year affected vehicles at 50 percent (windshield only) of the total 8^{o}C benefit from using this product in all glazing positions. In 2013, the benefit would be calculated from the VMT from the remaining 2012 model year vehicles at that control level (some would have been retired or left the state), plus the VMT of 2013 model year affected vehicles at 100 percent of the total 8^{o}C benefit from using this product in all glazing positions. In 2014, the 2014 VMT from 2012 model year vehicles at 50 percent control are added to the 2014 VMT from 2013 and 2014 model year vehicles at 100 percent control. This process continues through 2020, the year for which AB 32 has a specified emission reduction goal, and then through 2040, the last year to which EMFAC projections currently extend.

For lengthy phase-in alternatives, 2040 projections may fall substantially short of full implementation. For instance, the Alliance proposal phase-in continues through the 2017 model year. There is still a significant portion of the 2040 fleet with functioning air conditioners that does not have full solar control. The projections in the Staff Report for an all-around total solar transmission of 60 percent, as proposed by the Alliance, will be close to full implementation.

Staff reports the anticipated benefits for the six proposals which are presented in Table B-6. The anticipated relative benefits for these proposals are presented in Table B-7. The difference in the benefit seen for staff's proposal in 2040 in this table compared to that in Table B-5 results from the fact that full implementation is not actually achieved by 2040. The benefits in 2040 presented previously assume that full implementation occurred by that time. In addition, these relative benefits do not include benefits from vehicles that have left the state.

Staff's proposal is similar to the Alliance proposal in that both call for a total solar transmission limit of 60% for most of the vehicle glazing. Staff's proposal, however, has a significantly shorter phase-in period, requires the use of better performing glazing on the rooflite, and on the windshield. Improved windshield performance is readily achievable because the laminated windshield can use solar reflective materials to improve solar performance. The improved windshield, together with the increased level of solar control for the rooflites in Staff's proposal, results in over forty

Table B- 6. Alternate Scenarios.

		Windshield	Sidelites	Backlite	Rooflite
A	Regulatory Proposal	75% 2012 @ Tts 50%	100% 2012 @ Tts 60%	100% 2012 @ Tts 60%	100% 2012 @ Tts 30%
	(phase-in for 2012 rqmt)	100% 2013 @ Tts 50%			
		100% 2014 @ Tts 40%			
B	Reg. Proposal w/o phase-in	100% 2012 @ Tts 50%	100% 2012 @ Tts 60%	100% 2012 @ Tts 60%	100% 2012 @ Tts 30%
		100% 2014 @ Tts 40%			
C	All-Around 40%	100% 2012 @ Tts 40%	100% 2012 @ Tts 40%	100% 2012 @ Tts 40%	100% 2012 @ Tts 30%
D	All-Around 50%	100% 2012 @ Tts 50%	100% 2012 @ Tts 50%	100% 2012 @ Tts 50%	100% 2012 @ Tts 40%
E	All-Around 60%	100% 2012 @ Tts 60%	100% 2012 @ Tts 50%	100% 2012 @ Tts 50%	100% 2012 @ Tts 40%
F	Alliance Proposal	25% 2012 @ Tts 60%	-	25% 2012 @ Tts 60%	
		50% 2013 @ Tts 60%	-	50% 2013@ Tts 60%	
		75% 2013 @ Tts 60%	25% 2012 @ Tts 60%	75% 2013@ Tts 60%	25% 2012 @ Tts 60%
		100% 2013 @ Tts 60%	50% 2013 @ Tts 60%	100% 2013@ Tts 60%	50% 2013@ Tts 60%
			75% 2013 @ Tts 60%		75% 2013@ Tts 60%
			100% 2013 @ Tts 60%		100% 2013@ Tts 60%

Table B- 7. Benefits of Regulatory Alternatives in 2020 and 2040 (MMT CO_2).

		Emissions Reduction	
	Alternative	2020	2040
B	Staff's Proposal w/o phase-in	0.685	1.12
C	Tts $\leq$ 40%	0.783	1.28
D	Tts $\leq$ 50%	0.623	1.01
E	Tts $\leq$ 60% w/o phase-in	0.556	0.90
F	Alliance Proposal	0.386	0.75
	Staff's Proposal		
A	Tts $\leq$ 40%, $\leq$ 60%	0.678	1.12

percent greater emission reductions in 2020, and over 30 percent greater benefit by 2040.

IV. Reductions in Criteria Pollutants

Reducing the fuel used for air conditioning will also result in reductions in emissions of criteria pollutants such as oxides of nitrogen, reactive organic gases, and carbon monoxide. Table B-8 presents staff's estimates of the associated reductions. The estimates are based on EMFAC output of the effect of air conditioner use on criteria pollutants, adjusted for the air conditioner use rate, effect on fuel efficiency and greenhouse gas emissions as presented herein, and by the ratio of baseline air conditioner–related fuel use to adjusted fuel use. EMFAC's air conditioner-related emissions were multiplied by (0.29/0.10) to adjust for the air conditioner use rate, by (0.26/0.11) to adjust for the effect on fuel efficiency to provide baseline air conditioner-related emissions, which are then multiplied by the estimated 16% reduction in air conditioner related fuel use resulting from this proposal. Results are presented in Table B-8.

Table B- 8. Associated Reductions in Criteria Pollutants, 2040

Criteria Pollutant	Tons per year
Reactive Organic Gases	106
Carbon Monoxide	12,696
Oxides of Nitrogen	297

Carbon monoxide is also a greenhouse gas, with a greenhouse warming potential of around 1.9. Staff converted the projected reductions in carbon monoxide to an equivalent 0.02 MMT CO_2 per year. This can be added to the projected CO_2 benefits.

V. References

ARB (California Air Resources Board). 2004. Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Public Hearing to Consider Adoption of Regulations to Control Greenhouse Gas Emissions from Motor Vehicles. August 6, 2004. Page 75, Table 5.2-12.

CAVTC (Clean Air Vehicle Technology Center). 1999. Final Report, CRC Project E-37. Effect of Air Conditioning on Regulated Emissions for In-Use Vehicles. Phase I.

CDOF (State of California, Department of Finance). 2007. They Moved and Went Where: California's Migration Flow, 1995-2000: Sacramento, California. June 2007.

Chaney, L, K Thundiyil, S Chidambaram, 2007. Fuel Savings and Emission Reductions from Next-Generation Mobile Air Conditioning Technology in India.

Presented at the Vehicle Thermal Management Systems Conference & Exhibition (VTMS-8), Nottingham, England. May 20–24, 2007. NREL/CP-540-41154.
EPA, Office of Transportation and Air Quality. 2006. Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates. Final Technical Support Document. EPA420-R-06-017. December 2006.
Farrington, R, J Rugh, G Barber. 2000. Effect of Solar-Reflective Glazing on Fuel Economy, Tailpipe Emissions, and Thermal Comfort. SAE Paper No. 2000-01-2694.
Gravel, R, R Farrington. 2001. Innovative climate control technologies boost vehicle economy, decrease emissions. http://www1.eere.energy.gov/vehiclesandfuels/pdfs/success/val3_23_01.pdf
Johnson, V. 2002. Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach. SAE Paper No. 2002-01-1957.
NSCCAF (Northeast States Center for a Clean Air Future). Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles. September 2004. Appendix D is an analysis by Meszler Engineering Services to determine the benefits from a variety of air conditioner systems.
Peter, J. 2004. The Sky's the Limit. *Automotive Industries*. July 2004.
Rugh, J. 2008. Personal communication.
Rugh, J, V Hovland, S Anderson. 2004. Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioners. 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit, Washington DC. April 14-15, 2004.
Rugh, JP, L Chaney, J Lustbader, 2007. Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and a New Solar-Reflective Glazing. SAE Paper No. 2007-01-1194.
Rugh, JP, T Hendricks, K Koram. 2001. Effect of solar reflective glazing on Ford Explorer climate control, fuel economy, and emissions. SAE Paper No. 2001-01-3077.
SFTP (Supplemental Federal Test Procedure), 1996. Data generated to support California Air Resources Board's Public Hearing to Consider Adoption of New Certification Tests and Standards to Control Exhaust Emissions from Aggressive Driving and Air-Conditioner Usage for Passenger Cars, Light-Duty Trucks and Medium Duty Vehicles under 8,501 Pounds Gross Vehicle Weight Rating.

Table B- 9. Average Temperature Profiles for California

Time	January	February	March	April	May	June	July	August	September	October	November	December
	Temperatures (^oF)											
0000	46.6	48.6	50.7	54.2	57.0	60.7	63.7	64.3	62.3	58.8	51.2	45.3
0100	45.6	48.0	50.0	53.6	56.4	59.8	63.1	63.4	61.6	58.2	50.4	44.6
0200	44.8	47.8	49.3	53.0	55.7	59.2	62.7	63.0	61.2	57.5	49.6	43.8
0300	43.4	46.8	48.7	52.4	55.4	58.9	62.7	63.0	60.9	56.8	48.5	42.6
0400	43.5	47.2	48.7	52.1	54.9	58.3	61.8	62.1	60.0	56.8	48.9	43.1
0500	43.7	46.8	48.4	51.9	55.1	58.9	62.0	61.8	60.0	56.6	48.6	42.9
0600	43.7	46.9	48.9	54.0	57.9	61.9	64.1	63.5	60.9	57.3	48.8	43.1
0700	44.0	47.9	51.3	58.0	61.2	65.4	67.3	67.3	65.0	60.2	50.6	44.0
0800	47.0	51.3	54.7	62.0	64.3	68.5	70.5	71.0	69.4	64.7	55.0	47.0
0900	50.6	54.9	57.7	65.0	66.9	71.4	73.6	74.5	73.2	68.7	59.5	51.1
1000	53.3	57.2	59.9	67.3	69.0	73.7	76.2	77.3	76.3	71.5	62.9	54.4
1100	55.9	59.2	61.4	68.9	70.9	75.8	78.2	79.5	78.6	74.0	65.4	56.8
1200	57.0	60.7	62.6	70.2	72.3	77.1	79.9	81.2	80.5	75.4	67.0	58.4
1300	57.6	61.1	63.1	70.9	73.0	78.1	81.0	82.5	81.6	76.1	67.5	59.1
1400	57.7	63.0	63.4	71.3	73.1	78.2	81.5	82.8	81.8	76.0	67.5	59.2
1500	57.4	62.7	63.1	70.9	72.7	77.9	81.1	82.4	81.3	75.0	66.5	58.5
1600	56.8	60.3	62.1	69.5	71.2	76.6	80.0	80.7	79.6	72.4	63.6	55.9
1700	53.8	57.7	60.0	67.2	69.2	74.8	78.0	78.2	76.2	68.7	59.5	52.3
1800	51.6	55.1	57.2	63.8	66.3	71.9	74.8	74.5	71.7	65.3	56.8	50.3
1900	50.1	53.4	55.1	60.7	63.2	68.2	70.9	70.7	68.5	63.3	55.4	49.2
2000	49.3	52.3	53.9	58.9	61.2	65.5	68.3	68.6	66.6	62.0	54.2	48.1
2100	48.6	51.6	53.0	57.6	59.8	63.8	66.5	67.0	65.2	60.9	53.3	47.4
2200	47.9	50.5	52.2	56.3	58.7	62.4	65.2	65.7	63.9	60.0	52.6	46.7
2300	47.8	49.4	51.4	55.3	57.9	61.4	64.3	64.8	63.2	59.2	51.9	46.1