

# **Deriving a Climate-Stabilizing Solution Set of *Fleet-Efficiency and Driving-Level* Requirements, for Light-Duty Vehicles in California**

**Paper #796315**

**Mike R. Bullock**

Retired Satellite Systems Engineer, 1800 Bayberry Drive, Oceanside, CA 92054

## **ABSTRACT**

An Introduction is provided, including the importance of light-duty vehicles (LDVs: cars and light duty trucks) and the top-level LDV requirements to limit their carbon dioxide (“CO<sub>2</sub>”) emissions.

Climate crisis fundamentals are presented, including its cause, its potential for harm, California mandates, and a greenhouse gas (GHG) reduction road map to avoid disaster.

A 2030 climate-stabilizing GHG reduction target value is calculated, using statements by climate experts. The formula for GHG emissions, as a function of per-capita driving, population, fleet CO<sub>2</sub> emissions per mile, and the applicable low-carbon fuel standard is given. The ratio of the 2015 value of car-emission-per-mile to the 2005 value of car-emission-per-mile is obtained.

Internal Combustion Engine (ICE) mileage values from 2000 to 2030 are identified, as either mandates or new requirements. A table is presented that estimates 2015 LDV fleet mileage.

Zero Emission Vehicle (ZEV) parameters are given. Methods are derived to compute equivalent 2030 mileage. Four cases are defined and overall equivalent mileage is computed for each. Those equivalent fleet mileage values are used to compute their corresponding required per-capita driving reductions, with respect to 2005. Measures to achieve the most reasonable per-capita driving reduction are described, with reductions allocated to each measure.

A conclusion is presented.

## **INTRODUCTION**

Humanity’s top-level requirement is to stabilize our climate at a livable level. This top-level requirement must flow down to cars and light-duty trucks, also known as Light-Duty Vehicles (LDVs), due to the significant size of their emissions. As an example, LDVs emit 41% of the GHG in San Diego County<sup>1</sup>.

From a systems engineering perspective, the needed top-level LDV requirements are an upper bound on greenhouse gas (GHG) emissions per mile driven, applicable to all of the vehicles on the road, in the year of interest, and an upper bound on per-capita driving, given population growth. These two upper bounds must achieve the climate-stabilizing GHG emission target level. This paper will do a calculation of required driving levels, based on calculations of how clean our cars and fuels could be, predicted population growth, and the latest, science-based, climate-

stabilizing target, or requirement. All three categories of LDV emission-reduction strategies will be used: cleaner cars, cleaner fuels, and less driving. Four cases will be considered.

## **BACKGROUND: OUR CLIMATE PREDICAMENT**

### **Basic Cause**

Our climate crisis exists primarily because of these two facts<sup>2</sup>: First, our combustion of fossil fuels puts “great quantities” of CO<sub>2</sub> into our atmosphere; second, atmospheric CO<sub>2</sub> traps heat.

### **California’s Primary CO<sub>2</sub>\_e Emission-Reduction Mandates**

California’s Governor’s Executive Order S-3-05<sup>3</sup> is based on the greenhouse gas (GHG) reduction limits that were recommended by climate scientists, for industrialized nations, in 2005. In 2005, climate scientists believed that if the industrialized nations of the world achieved the reduction-targets of S-3-05 (and other nations did something less), the Earth’s climate could be stabilized at a livable level, with a reasonably high level of certainty. More specifically, this executive order aims for an average, over-the-year, atmospheric, temperature rise of “only” 2 degree Celsius, above the preindustrial temperature. It attempts to do this by limiting atmospheric CO<sub>2</sub>\_e to 450 PPM by 2050 and then reducing emissions further, so that atmospheric levels would come down to more tolerable levels in subsequent years. The S-3-05 emission targets are the 2000 emission level by 2010, the 1990 level by 2020, and 80% below the 1990 level by 2050.

It was thought that if the industrialized world achieved S-3-05 (and the non-industrialized world achieved an easier task), there would be a 50% chance that the maximum temperature rise will be less than 2 degrees Celsius, thus leaving a 50% chance that it would be larger than 2 degrees Celsius. A 2 degree increase would put over a billion people on the planet into a position described as “water stress” and it would mean a loss of 97% of our coral reefs.

There would also be a 30% chance that the temperature increase would be greater than 3 degrees Celsius. A temperature change of 3 degree Celsius is described in Reference 3 as being “exponentially worse” than a 2 degree Celsius increase.

The second California climate mandate is AB 32, the *Global Warming Solutions Act of 2006*. It includes provisions for a cap and trade program, to ensure meeting S-3-05’s 2020 target, which is to be emitting at no more than the 1990 level of emissions. AB 32 was to continue after 2020. AB 32 required CARB to always implement measures that achieved the maximum *technologically feasible and cost-effective* (words taken from AB 32) greenhouse-gas-emission reductions.

In 2015 Governor Brown signed B-30-15. This Executive Order established a mandate for 40% below 2020 emissions by 2030, as can be seen by a Google search. If S-3-05 is interpreted as a straight line between its 2020 and its 2050 targets, then the B-30-15 target of 2030 is the same as the S-3-05 implied target of 2035, because 2035 is halfway between 2020 and 2050 and 40% is halfway to 80%. More recently, California adopted SB 32, which made achieving B-30-15 legally binding. Finally, in 2018, the Governors Executive Order B-55-18 established a mandate of zero net emissions by the year 2045.

California achieved the second GHG emission target of S-3-05 (to emit at the 1990 level by 2020) in 2018, which is two years early. However, the world emission levels have, for most years, been increasing, contrary to the S-3-05 trajectory. Because the world has been consistently failing to follow S-3-05's 2010-to-2020 trajectory, if California, still wants to lead the way to human survival, it must do far better than S-3-05, going forward, as will be shown.

## **Failing to Achieve these Climate Mandates**

What could happen if we fail to achieve S-3-05, AB 32, and B-30-15 or if we achieve them but they turn out to be too little too late and other states and countries follow our example or do less?

It has been written<sup>4</sup> that, "A recent string of reports from impeccable mainstream institutions - the International Energy Agency, the World Bank, the accounting firm of PricewaterhouseCoopers - have warned that the Earth is on a trajectory to warm by at least 4 Degrees Celsius and this would be incompatible with continued human survival."

It has also been written<sup>5</sup> that, "Lags in the replacement of fossil-fuel use by clean energy use have put the world on a pace for 6 degree Celsius by the end of this century. Such a large temperature rise occurred 250 million years ago and extinguished 90 percent of the life on Earth. The current rise is of the same magnitude but is occurring faster."

## **Pictures That Are Worth a Thousand Words**

Figure 1 shows (1) atmospheric CO<sub>2</sub> (in blue) and (2) averaged-over-a-year-then-averaged-over-the-surface-of-the-earth, atmospheric temperature (in red). This temperature is with respect to a recent preindustrial revolution value. The data starts 800,000 years ago. It shows that the current value of atmospheric CO<sub>2</sub>, which is over 410 PPM, far exceeds the values of the last 800,000 years. It also shows that we might expect the corresponding temperature to eventually be over 12 degrees above preindustrial temperatures. This would bring about a human disaster<sup>3, 4, 5</sup>.

Figure 2 shows the average yearly temperature (in blue) with respect to the 1960-to-1990 baseline temperature. It also shows atmospheric levels of CO<sub>2</sub> (in red). The CO<sub>2</sub> spike of Figure 1 is seen on Figure 2 to be an accelerating ramp up, starting at the time of our industrial revolution. The S-3-05 goal of 450 PPM is literally "off the chart", in Figure 2. Figure 2 shows that, as expected, temperatures are starting to rise along with the rising levels of CO<sub>2</sub>. The large variations in temperature that are observed are primarily due to the random nature of the amount of solar energy being received by the earth.

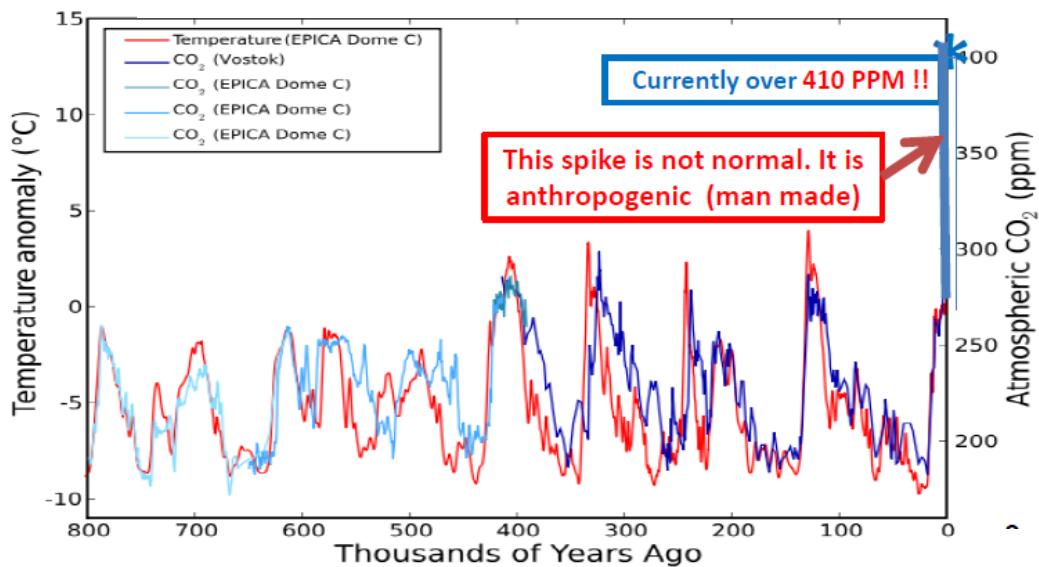
## **FURTHER BACKGROUND: CALIFORNIA'S SB 375 AND AN IMPORTANT DATA SET**

As shown in the Introduction, LDVs emit significant amounts of CO<sub>2</sub>. The question arises: will driving need to be reduced or can cleaner cars and cleaner fuels arrive in time to avoid such behavioral change? Steve Winkelman, of the Center for Clean Air Policy (CCAP), worked on this problem and his results may probably inspired California's SB 375.

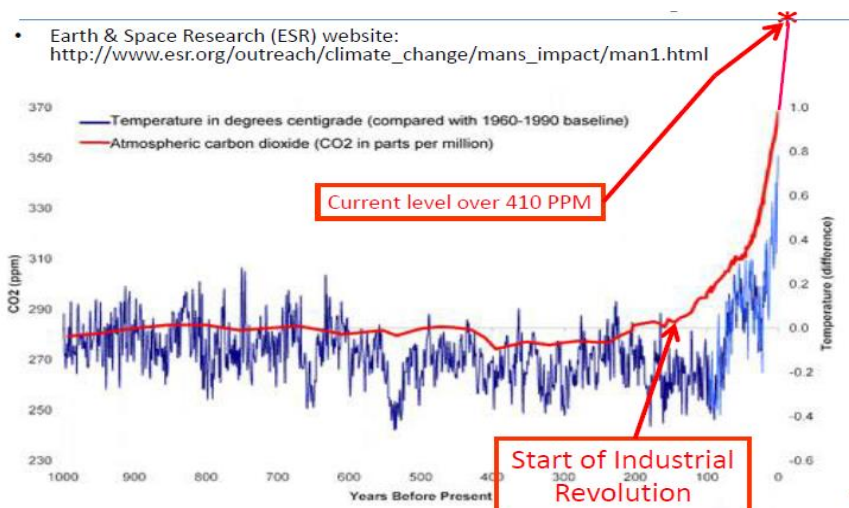
## SB 375, the Sustainable Communities and Climate Protection Act of 2008

Under SB 375, the California Air Resources Board (CARB) has given each Metropolitan Planning Organization (MPO) in California driving-reduction targets, for the years 2020 and 2035. “Driving” means yearly, per capita, vehicle miles travelled (VMT), by LDVs, with respect to 2005. The CARB-provided values are shown at this Wikipedia link, [http://en.wikipedia.org/wiki/SB\\_375](http://en.wikipedia.org/wiki/SB_375). It is important to note that although this link and many other sources show the targets to be “GHG” and not “VMT”, SB 375 clearly states that the reductions are to be the result of the MPO’s Regional Transportation Plan (RTP), or, more specifically, the Sustainable Communities Strategy (SCS) portion of the RTP. Nothing in the SCS will improve average mileage. That will be done by the state and federal governments by their Corporate Average Fleet Efficiency (CAFÉ) standards and any other laws or regulations that they might adopt. The SCS can only reduce GHG by reducing VMT.

**Figure 1 Atmospheric CO<sub>2</sub> and Mean Temperature from 800,000 Years Ago**



**Figure 2. Atmospheric CO<sub>2</sub> and Mean Temperature, Over the Last 1,000 Years**



Under SB 375, every Regional Transportation Plan (RTP) must include a section called a Sustainable Communities Strategy (SCS). The SCS must include driving reduction predictions corresponding to the CARB targets. Each SCS must include only *feasible* transportation, land use, and transportation-related policy data. If the SCS driving-reduction predictions fail to meet the CARB-provided targets, the MPO must prepare an Alternative Planning Strategy (APS). An APS uses *infeasible* transportation, land use, and transportation-related policy assumptions. The total reductions, resulting from both the SCS and the APS, must at least meet the CARB-provided targets.

### Useful Factors from Steve Winkelman’s Data

Figure 3<sup>6</sup> shows 5 variables as a percent of their 2005 value and also the 1990 emission value (turquoise) related to the 2005 O2 emission value (the blue line). All of the variables are for LDVs. The year 2005 is the baseline year of SB 375. The red line is the Caltrans prediction of VMT. The purple line is California’s current mandate for a Low Carbon Fuel Standard (LCFS). The LCFS also can be used to get the equivalent mileage from the actual mileage by dividing the actual mileage by the LCFS. The LCFS can be used to get the equivalent CO2 per mile driven by multiplying the actual CO2 per mile driven by the LCFS. As shown, by 2020, fuel in California must emit 10% less per gallon than in 2005. As written above, the turquoise line is the 1990 GHG emission in California. As shown, it is 12% below the 2005 level. This is important because S-3-05 specifies that in 2020, state GHG emission levels must be at the 1990 level. The green line is the CO2 emitted per mile, as specified by AB 1493, also known as “Pavley 1 and 2” named after Senator Fran Pavley. The values shown do not account for the LCFS. The yellow (or gold) line is the S-3-05 mandate, referenced to 2005 emission levels. The blue line is the product of the red (miles), the green (CO2 per mile), and the purple line (LCFS, which reduces emission per mile) and is the percentage of GHG emissions compared to 2005. Since VMT is not being adequately controlled, the blue line is not achieving the S-3-05 line. Figure 3 shows that driving must be reduced. For this reason, Steve Winkelman can be thought of as the true father of SB 375.

**Figure 3** The S-3-05 Trajectory (the Gold Line) AND the CO2 Emitted from Personal Driving (the Blue Line), where that CO2 is a Function (the Product) of the California-Fleet-Average CO2 per Mile (the Green Line), The Predicted Driving (VMT, the Red Line), and the Low-Carbon Fuel Standard (the Purple Line)

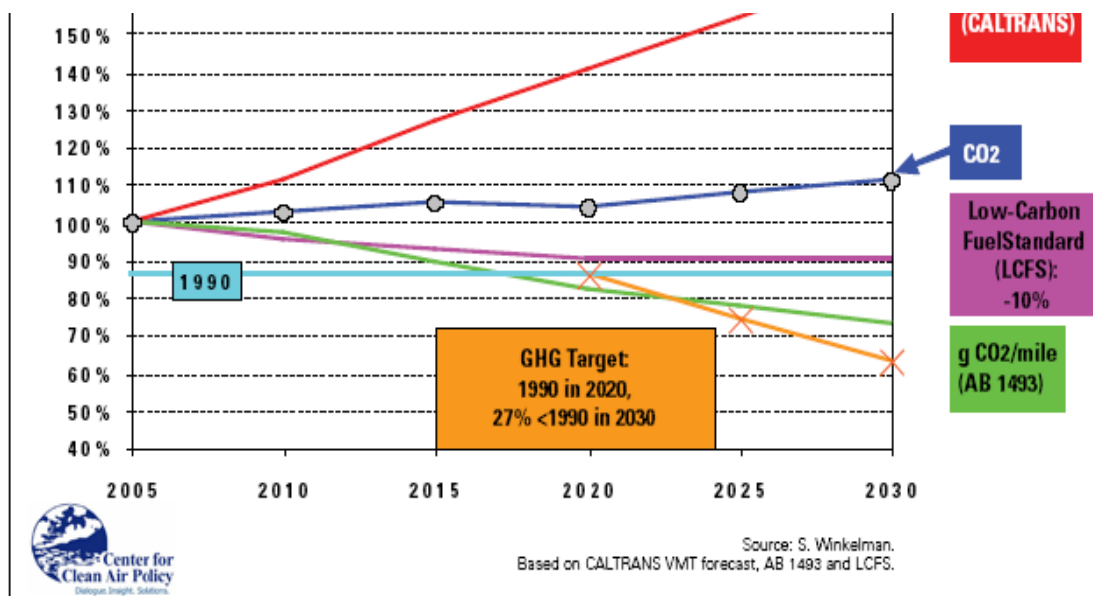


Figure 3 provides inspiration for a road map to climate success for LDVs. Climate-stabilization targets must be identified (from the climate scientists) and achieved by a set of requirements that will increase fleet efficiency and another set that will reduce per-capita driving.

## **THE DERIVATION OF CALIFORNIA'S TOP-LEVEL LDV REQUIREMENTS TO SUPPORT CLIMATE STABILIZATION**

It is clear that more efficient (less CO<sub>2</sub> emitted per mile) LDVs will be needed and this can be achieved with appropriate requirements. Significant improvements in efficiency will be needed if driving reductions are going to remain within what many people would consider politically achievable. Mileage and equivalent mileage will need to be specified. A significant fleet-fraction of Zero-Emission Vehicles (ZEVs, either Battery-Electric LDVs or Hydrogen Fuel Cell LDVs) will be needed. Since mileage and equivalent mileage are more heuristic than CO<sub>2</sub> emissions per mile, they will be used in the derivations. CO<sub>2</sub> per mile driven will not appear in the final equations.

Since the SB-375 work used 2005 as the reference year, that convention will be used. It will be assumed that cars last 15 years.

### **GHG Emission Target to Support Climate Stabilization**

The primary problem with S-3-05 is that California's resolve and actions have been largely ignored by other states, our federal government, and many countries. Therefore, rather than achieving 2000 levels by 2010 (the first target of S-3-05) and 1990 levels by 2020 (the 2<sup>nd</sup> target of S-3-05), world emission has been increasing for nearly all of the years since 2010. (California, on the other hand achieved its 1990 emission level in 2018. This is two years sooner than the 2<sup>nd</sup> target of the S-3-05 requirement.) Reference 7 states on Page 14 that the required rate of reduction, if commenced in 2020, would be 15%. That rate means that the factor of 0.85 must be achieved, year after year. If this were done for 10 years, the factor would be  $(0.85)^{10} = 0.2$ , by 2030. This reduction of 80% down from the 2020 value matches the 2050 target requirement of S-3-5, which is 80% below the 1990 value. According to S-3-05, the 2020 emission value should be the same as the 1990 emission value. As noted above, the S-3-05 emission of 2050 was designed to support capping atmospheric CO<sub>2</sub> at 450 PPM<sup>3</sup>. "Capping" means that the sum of all emissions (anthropogenic and natural) equals the sum of all sequestration (mostly photosynthesis.) Therefore, the author of the Reference 7 statement wanted the world to achieve the third target of S-3-05 to get the atmospheric CO<sub>2</sub> to stop going up 20 years sooner than what S-3-05 was written to achieve. This shows the urgent nature of our climate crisis. Therefore, if California wants to do its part by setting an example for the world, the correct requirement for California is to achieve emissions that are reduced to 80% below California's 1990 value by 2030. The world's reduction rate is not anywhere near the needed 15% as we move towards the end of 2020. Therefore, the target, of 80% below 1990 levels by 2030 is considered to be correct for California. Reference 7 also calls into question the advisability of aiming for a 2 degree Celsius increase, given the possibilities of positive feedbacks that would increase warming. This concern for positive feedbacks is another reason that this paper will work towards identifying LDV requirement sets that will support LDVs achieving 80% below 1990 value by 2030. Thinking

that LDVs can, for some reason, fail to achieve this target is dangerous thinking. As stated above, LDVs emit, by far, the most CO<sub>2</sub> of all categories.

## Notes on Methods

The base year is 2005. An intermediate year of 2015 is used. The car efficiency factor of 2015 with respect to 2005 is taken directly from Figure 3. The car efficiency factor of 2030 with respect to 2015 is derived herein, resulting in a set of car-efficiency requirements.

It is assumed that cars last 15 years. This is equivalent to assuming that the effect of the cars that last more than 15 years, thus increasing emissions, will be offset by the effect of the older cars that don't last as long as 15 years, thus reducing old-car emissions. As will be seen, there will also have to be some sort of an additional action to remove many of the older Internal Combustion Engine cars that are 15, through just 8 years old. Natural attrition will take care of some of this since as cars get older the probability that they will be taken out of service increases. However, some sort of "cash for gas guzzlers" program will be needed. How this is done is not covered in this paper. This is not unique. As another example, the car manufacturers will have to figure out how to produce the needed cars and batteries.

## Primary Variables Used

Table 1 defines the primary variables that are used.

## Fundamental Equations

The emissions are equal to the CO<sub>2</sub> per mile driven multiplied by the per-capita driving multiplied by the population, since per-capita driving multiplied by the population is total driving. This is true for any given year.

$$\text{Future Year } k: \quad e_k = c_k * d_k * p_k \quad (\text{Eq. 1})$$

$$\text{Base Year } i: \quad e_i = c_i * d_i * p_i \quad (\text{Eq. 2})$$

Dividing both sides of Equation 1 by equal values results in an equality. The terms on the right side of the equation can be associated as shown here:

$$\frac{e_k}{e_i} = \frac{c_k}{c_i} * \frac{d_k}{d_i} * \frac{p_k}{p_i} \quad (\text{Eq. 3})$$

**Table 1 Variable Definitions**

<b>Variable Definitions</b>	
$e_k$	<b>LDV Emitted CO<sub>2</sub>, in Year "k"</b>
$L_k$	<b>Low Carbon Fuel Standard (LCFS) Factor that reduces the Per-Gallon CO<sub>2</sub> emissions, in Year "k"</b>
$C_k$	<b>LDV CO<sub>2</sub> emitted per mile driven, average, in Year "k", not accounting for the Low Carbon Fuel Standard (LCFS) Factor</b>
$c_k$	<b>LDV CO<sub>2</sub> emitted per mile driven, average, in Year "k", accounting for the Low Carbon Fuel Standard (LCFS) Factor</b>

$p_k$	Population, in Year “k”
$d_k$	Per-capita LDV driving, in Year “k”
$D_k$	LDV Driving, in Year “k”
$M_k$	LDV Mileage, miles per gallon, in Year “k”
$m_k$	LDV Equivalent Mileage, miles per gallon, in Year “k” accounting for Low Carbon Fuel Standard (LCFS) Factor, so this is $M_k/L_k$
N	Number of pounds of CO2 per gallon of fuel but not accounting for the Low Carbon Fuel Standard (LCFS) Factor

Since CO2 per mile (“c”) is a constant (use “A”, noting that it is equal to about 20 pounds per gallon) multiplied by the number of Gallons (“G”) and since number of gallons is distance (use “D”) divided by mileage (use “m”), then  $c = A*D/m$ . this shows that the ratio of the “c” values in different years is going to be equal to the reciprocal of the “m” values in those different years because the other variables will cancel out. Therefore:

$$\text{To work with mileage: } \frac{m_i}{m_k} = \frac{c_k}{c_i} \quad (\text{Eq. 4})$$

Putting Equation 4 into Equation 5 results in the following equation:

$$\frac{e_k}{e_i} = \frac{m_i}{m_k} * \frac{d_k}{d_i} * \frac{p_k}{p_i} \quad (\text{Eq. 5})$$

Showing the base year of 2005, the future year of 2030, introducing the intermediate year of 2015 and the year of 1990 (since emissions in 2030 are with respect to the 1990 value) results in Equation 6.

$$\frac{e_{2030}}{e_{1990}} * \frac{e_{1990}}{e_{2005}} = \frac{c_{2030}}{c_{2015}} * \frac{c_{2015}}{c_{2005}} * \frac{d_{2030}}{d_{2005}} * \frac{p_{2030}}{p_{2005}} \quad (\text{Eq. 6})$$

The ratio on the far left is the climate-stabilizing target, which is the factor of the 2030 emission to the 1990 emission. It has been shown that this is 0.20 or 80% less. The next ratio is the emission of 1990 compared to 2005. It is the turquoise line of Figure 3, which is 0.87. The first ratio on the right side of the equation is the fleet emission per mile in 2030 compared to the value in 2015. This ratio will be derived in this report and it will result in a set of car-efficiency requirements. Moving to the right, the next ratio is the car efficiency in 2015 compared to 2005. It can be obtained by multiplying the purple line 2015 value times the green line 2015 value, which is  $0.90 * 0.93$ . The next term, still going from right to left, is the independent variable. It is the per-capita driving reduction required, with respect to the 2005 level of driving. The final term on the far right is the ratio of the population in 2030 to the population in 2005. Reference 8 shows that California’s population in 2005 was 35,985,582. Reference 9 shows that California’s population in 2030 is predicted to be 42,263,654. Therefore,

$$P_{2030}/P_{2005} = 42263654 \div 35985582 = 1.17446076 \quad (\text{Eq. 7})$$

Putting in the known values results in Equation 8:



$$0.20 * 0.87 = \frac{c_{2030}}{c_{2015}} * 0.90 * 0.93 * \frac{d_{2030}}{d_{2005}} * 1.17446076 \quad (\text{Eq. 8})$$

Combining the values, solving for the independent variable (the per-capita driving ratio), and changing from emission-per-mile to equivalent-miles-per-gallon results in the following:

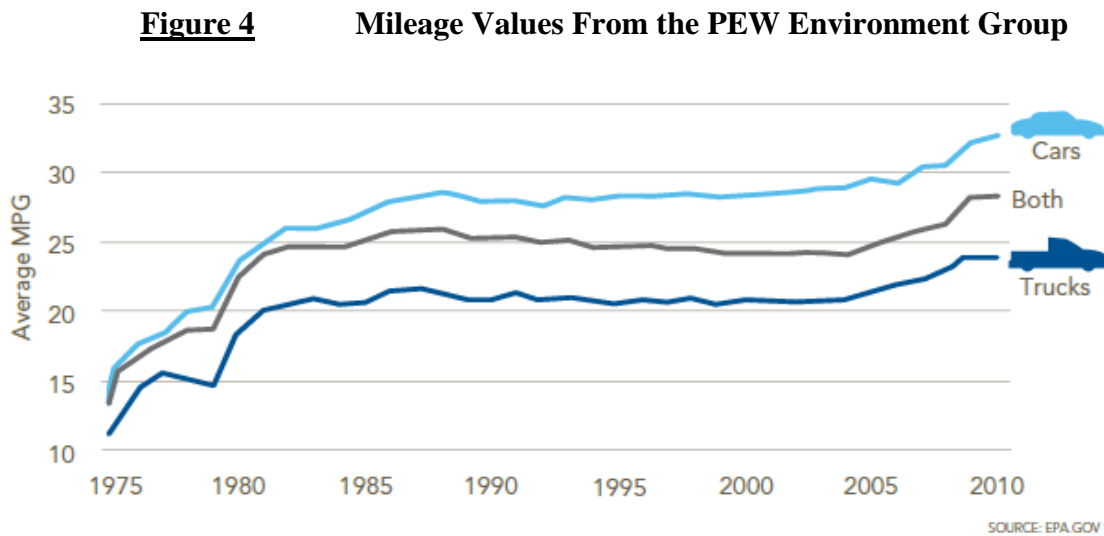
$$\frac{d_{2030}}{d_{2005}} = 0.177004896 * \frac{m_{2030}}{m_{2015}} \quad (\text{Eq. 9})$$

With the coefficient being so small, it is doubtful that we can get the equivalent mileage in 2030 to be high enough to keep the driving ratio from falling below one. The mileage of the 2005 fleet will be based on the best data we can get and by assuming cars last 15 years. The equivalent mileage in 2030 will need to be as high as possible to keep the driving-reduction factor from going too far below 1, because it is difficult to reduce driving too much. The equivalent mileage will be dependent on the fleet-efficiency requirements in the near future and going out to 2030. Those requirements are among the primary results of this report.

### Internal Combustion Engine (ICE) Mileage, from Year 2000 to Year 2030

The years from 2000 to 2011 are taken from a plot produced by the PEW Environment Group, [http://www.pewenvironment.org/uploadedFiles/PEG/Publications/Fact\\_Sheet/History%20of%20Fuel%20Economy%20Clean%20Energy%20Factsheet.pdf](http://www.pewenvironment.org/uploadedFiles/PEG/Publications/Fact_Sheet/History%20of%20Fuel%20Economy%20Clean%20Energy%20Factsheet.pdf)

The plot is shown here as Figure 6. The “Both” values are used.



The values from 2012 to 2025 are taken from the US Energy Information Agency (EIA) as shown on their website, <http://www.eia.org/energy/factsheets/summary.cfm?id=113>. They are the LDV Corporate Average Fleet Efficiency (CAFE) values enacted into law in the first term of President Obama. From 2025 to 2030, it is assumed that the yearly ICE improvement in CAFE will be 2.5 MPG.

## Overall Mileage of California’s LDV Fleet in 2015

Table 2 uses these values of the Internal Combustion Engine (ICE) LDV mileage to compute the mileage of the LDV fleet in 2015. It assumes that the fraction of ZEVs being used over these years is small enough to be ignored. The 100 miles driven, nominally, by each set of cars, is an arbitrary value and inconsequential in the final calculation, because it will divide out. It is never-the-less used, so that it is possible to compare the gallons of fuel used for the different years. The “f” factor could be used to account for a set of cars being driven less. It was decided to not use this option by setting all of the values to 1. The Low Carbon Fuel Standard (LCFS) values are taken from Figure 3. The gallons of fuel are computed as shown in Equation 10, using the definition for  $L_k$  that is shown in Table 2.

$$\text{Gallons Used per } f * 100 \text{ miles} = \frac{f \times 100}{(\text{CAFE MPG})/L_k} \quad (\text{Eq. 10})$$

As shown in Table 2, using the definitions in Eq. 9:

$$m_{2015} = 27.63$$

If it is deemed acceptable to have per-capita driving in 2030 be reduced 32% with respect to 2005 driving, then the left side of Eq. 9 becomes 0.68 and it is possible to use Eq. 9 to solve for the 2030 mileage as:

$$m_{2030} = (27.63) * 0.68 * \left( \frac{1}{0.177004896} \right) = 106.1462 \quad (\text{Eq. 11})$$

Likewise if it is decided that the per-capita driving in 2030 should equal the per-capita driving in 2005 then:

$$m_{2030} = (27.63) * 1.00 * \left( \frac{1}{0.177004896} \right) = 156.0974 \quad (\text{Eq. 12})$$

These values will provide the targets for the tables that compute the mileage values for 2030.

## How ICE Mileage Values Will Be Used with ZEV Equivalent Mileage Values

To have LDVs achieve our climate-stabilizing target, after 2015, the net (computed using both ICE and ZEV vehicles) mileage values for each year will need to greatly improve by having a significant fraction of ZEVs. The ICE CAFÉ standards are used in this report as just the ICE contribution to fleet MPG. The ICE MPG values are inadequate by themselves and will therefore need to become less important; the ZEVs sales will need to overtake the ICE sales.

Federal requirements will need to change significantly. Currently, federally-mandated corporate average fuel efficiency (CAFÉ) standards have been implemented, from 2000 to 2025. These standards require that each corporation produce and sell their fleet of cars and light-duty trucks in the needed proportions, so that the combined mileage of all of the cars they sell (total miles driven in all cars sold in the year of interest divided by the total gallons used by all those cars, for any arbitrary distance) at least meets the specified mileage.

**Table 2 Calculation of the Fleet MPG for 2015**

<b>LDV Set</b>	<b>Years Old</b>	<b>Model Year</b>	<b>CAFE MPG</b>	<b>LCFS Factor L<sub>Year</sub></b>	<b>Factor Driven f</b>	<b>Gallons Used Per f*100 Miles</b>
1	14-15	2001	24.0	1.0	1.0	4.17
2	13-14	2002	24.0	1.0	1.0	4.17
3	12-13	2003	24.0	1.0	1.0	4.17
4	11-12	2004	24.0	1.0	1.0	4.17
5	10-11	2005	25.0	1.0	1.0	4.00
6	9-10	2006	25.7	.9933	1.0	3.87
7	8-9	2007	26.3	.9867	1.0	3.75
8	7-8	2008	27.0	.9800	1.0	3.63
9	6-7	2009	28.0	.9733	1.0	3.48
10	5-6	2010	28.0	.9667	1.0	3.45
11	4-5	2011	29.1	.9600	1.0	3.30
12	3-4	2012	29.8	.9533	1.0	3.20
13	2-3	2013	30.6	.9467	1.0	3.09
14	1-2	2014	31.4	.9400	1.0	2.99
15	0-1	2015	32.6	.9333	1.0	2.86
<b>Sum of Gallons:</b>						<b>54.29</b>
<b>Miles = 100*Sum(f's):</b>						<b>1500</b>
<b>MPG = Miles/(Sum of Gallons):</b>						<b>27.63</b>

The car companies want to maximize their profits while achieving the required CAFÉ standard. In California, the car companies are already be required to sell a specified number of electric vehicles, which have a particularly-high, equivalent-value of miles-per-gallon. If the laws are not changed, this situation will allow companies to take advantage of their ZEV vehicles to sell more low-mileage, high-profit cars and light-duty trucks, and still achieve the federal CAFÉ standard.

It will be better to apply the CAFÉ standards to only the ICEs and then require, in addition to the CAFÉ standards, that the fleet of LDVs sold achieve some mandated fraction of ZEVs. The ZEVs will get ever-improving equivalent mileage, as our electrical grid is powered by a larger percent of renewable energy. In other words, their equivalent mileage is not fixed, but will improve over the years. Requirements developed here are for 2030. Therefore a high percentage of all the electricity generated in the state, including both the “in front of the meter” (known as the “Renewable Portfolio Standard” or “RPS”) portion and the “behind the meter” portion is assumed to come from sources that do not emit CO<sub>2</sub>. The values of 85% and 90% are assumed. The values become one of the important fleet-efficiency requirements for cases that are considered. Hopefully these assumptions are reasonable. San Diego’s Climate Action Plan (CAP) was the first to specify 100% renewable energy by 2035. Many other cities have followed San Diego’s lead in this regard.

## How to Compute the ZEV Equivalent Mileage Values

To calculate the equivalent mileage of the 2030 fleet of LDVs, it is necessary to derive a formula to compute the equivalent mileage of ZEVs, as a function of the percent of electricity that is generated without emitting CO<sub>2</sub> (the mixed case), the equivalent ZEV mileage if the electricity is from 100% fossil fuel (the “West Virginia” case), and the equivalent ZEV mileage if the electricity is from 100% renewable sources (the ideal case), which is not infinity because it is assumed that the manufacturing of the car emits CO<sub>2</sub>. The variable definitions in Table 3 are used.

**Table 3 Variables Used in the Calculation of ZEV Equivalent Mileage**

Variable	Definition
$m_z$	ZEV Equivalent mileage
$m_{zr}$	ZEV Equivalent mileage if the electricity is from renewables
$m_{zf}$	ZEV Equivalent mileage if the electricity is from fossil fuels
$r$	fraction of electricity generated from renewable sources
$G$	Gallons of equivalent fuel used
$D$	Arbitrary distance travelled
$Num$	$m_{zr} * m_{zf}$
$Den$	$r * m_{zf} + (1 - r) * m_{zr}$

The derivation of the equation for equivalent ZEV mileage is based on the notion that the ZEV can be imagined to travel “r” fraction of the time on electricity generated from renewables and “(1-r)” fraction of the time on fossil fuel. If the vehicle travels “D” miles, then, using the definitions shown in Table 4, the following equation can be written.

$$G = \frac{r*D}{m_{zr}} + \frac{(1-r)*D}{m_{zf}} \quad (\text{Eq. 13})$$

$$m_z = D/G = D / \left( \frac{r*D}{m_{zr}} + \frac{(1-r)*D}{m_{zf}} \right) \quad (\text{Eq. 14})$$

Dividing the numerator and the denominator by D and multiplying the numerator and the denominator by the product of the two equivalent mileage values ( $m_{zr}$  and  $m_{zf}$ ) results in Equations 31.

$$m_z = m_{zr} * m_{zf} / (r * m_{zf} + (1 - r) * m_{zr}) \quad (\text{Eq. 15})$$

Using the definitions in Table 3:

$$m_z = Num / (Den) \quad (\text{Eq. 16})$$

Table 4 shows 3 assignments of assumed values in which the fraction of electricity generated from renewables is varied and the results, using Equations 15 and 16, results in the three values of ZEV equivalent mileage. This shows the urgent need to move towards cleaner electricity.

**Table 4 Variable Assignment and the Resulting ZEV Mileages**

$m_{zr}$	$m_{zf}$	r	1-r	Num	Den	$m_z$
5000	70	0.80	0.20	350000.00	1056.00	331.44
5000	70	0.85	0.15	350000.00	809.50	432.37
5000	70	0.90	0.10	350000.00	563.00	621.67

### Additional Variables Needed to Compute the Overall Equivalent Mileage in 2030, Taking Into Account Both ICEs and ZEVs

Table 5 shows the additional definitions that will be used in the calculation of 2030 overall mileage.

**Table 5 Additional Variables Used in the Calculation of 2030 LDV Mileage**

Variable	Definition
$D_i$	Distance travelled by ICE vehicles
$D_z$	Distance travelled by ZEV vehicles
$G_i$	Gallons of equivalent fuel used by ICE vehicles
$G_z$	Gallons of equivalent fuel used by ZEVs

### Computing an LDV Overall Equivalent Fleet Mileage, for the *Balanced\_1* Case

Table 6 shows the calculation for the overall equivalent mileage for all the cars on the road, in the year of 2030, for the *Balanced\_1* case.

The name, *Balanced\_1*, comes from the attempt to *balance* the difficulty of achieving the fleet efficiency-related requirements with the difficulty of achieving the driving-reduction related requirements. The *Balanced\_1* case assumes that electricity is 85% renewable, which is also difficult.

There will also be a *Balanced\_2* case that assumes that electricity is 90% renewable. Both the *Balanced\_1* and the *Balanced\_2* cases assume that it is reasonable to have per-capita driving in 2030 reduced 32%, with respect to 2005 per-capita driving. That assumption, along with the 85% renewable electricity assumption, was used to select the  $z$  values of Table 6 to result in the Equation 11 value of overall 2030 mileage, which is 106.1263 Miles Per Gallon (MPG). From Table 4, 85% renewable electricity results in a ZEV equivalent mileage of 432.37 MPG. That value of equivalent ZEV mileage in 2030, when electricity is 85% renewable, is used for all of the ZEV model years, for

this case. Note that this is overlooking the fact that not all BEVs are equally efficient. In order to simplify this analysis, the Table 4 values of  $m_{zr}$  and  $m_{zf}$  are considered to be applicable to all the ZEV models. Therefore, the 432.37 MPG value can be divided into each  $D_z$  value to compute the corresponding  $G_z$  value, in all of the model years being considered.

To reduce the miles driven in poor-mileage ICE's, the "f" factor is used. For example, if "f" is set to 0.30, as it is in 2016, then the miles driven is reduced by 70%. Achieving the required "f" values may require some type of "cash-for-gas-guzzlers" program. However, it could also be noted that when older cars are second or third cars in multi-car families in which family members have the luxury of choosing which car to drive, family members will usually choose the car that is cheaper to operate, thus making the "f" factors easier to achieve. Finally, the Low Carbon Fuel Standard (LCFS) is assumed to continue to improve from the currently mandated value of 0.9 by the end of 2019. This is another method of reducing the CO2 emissions of the ICE vehicles.

For the ICE vehicles, the  $G_i$  values are computed as the  $D_i$  value divided by the equivalent MPG value. The equivalent MPG is the CAFÉ MPG divided by the LCFS factor.

It is arbitrarily assumed that the cars, for each year being considered (the models for that year, both ZEVs and ICEs), go a total of 100 miles. Although this is an extremely small fraction of the actual miles that will be driven, it doesn't change the result because the number of gallons of equivalent gasoline is always proportional to miles. The fraction of cars that are ZEVs ( $z$ ) is used to divide up this value of 100 Miles. However, the factor "f" reduces the miles driven by the ICE vehicles and this brings down the total miles driven for the years in which the "f" term is less than 1. For each year, the total miles per gallon (MPG) is computed as the total miles driven divided by the total gallons used. However, this value is not used in the calculation of the entire fleet equivalent mileage. The overall equivalent mileage is computed as the total miles driven divided by the total gallons used, where these quantities are summed over all of the 15 categories (years) of LDVs.

The following formulas are used to compute the overall equivalent mileage in 2030, of all of the LDVs on the road.

For the ICE calculations, for 2016, where

- " $L_k$ " is defined in Table 1 (LCFS factor for year "k") and is the value in the "LCFS" column of Table 6 and
- " $z$ " is from the "z" column and is the fraction of cars sold in the year that are ZEVs and
- " $m_i$ " is the value from the CAFÉ MPG column:

$$D_i = 100 * f * (1 - z) \quad (\text{Eq. 17})$$

$$G_i = D_i / (m_i / L_{2016}) \quad (\text{Eq. 18})$$

For the ZEV calculations:

$$D_z = 100 * z \quad (\text{Eq. 17})$$

$$G_z = D_z / (432.37) \quad (\text{Eq. 18})$$

In updating this report from its 2015 version, the fleet fraction of ZEVs (" $z$ "), from 2015 to 2019, had to be reduced to approximate the low values that actually occurred from 2015 to 2019. However,

in 2020, it is assumed that the fraction will be at least as large as 8%, which is not such a trivial value. If it is actually larger than 8%, then there will be some margin built into the requirements derived in this report.

**Table 6 Calculation of 2030 LDV Mileage Assuming the *Balanced\_1* Case**

Year	ICE Parameters and Calculations						ZEVs			Yearly Totals		
	CAFÉ MPG	LCFS	Eq. MPG	f	$D_i$	$G_i$	$z$	$D_z$	$G_z$	Total Miles	Total Gallons	2030 MPG
2016	34.3	.9267	37.01	.3	29.4	0.7943	.02	2	.005	31.40	0.7989	39.30
2017	35.1	.9200	38.15	.4	39.2	1.0275	.02	2	.005	41.20	1.0321	39.92
2018	36.1	.9133	39.53	.5	48.5	1.2271	.03	3	.007	51.50	1.2340	41.73
2019	37.1	.9067	40.92	.6	57.6	1.4077	.04	4	.009	61.60	1.4169	43.47
2020	38.3	.9000	42.56	.7	64.4	1.5133	.08	8	.019	72.40	1.5318	47.26
2021	40.3	.8500	47.41	.8	64.0	1.3499	.20	20	.046	84.00	1.3961	60.17
2022	42.3	.8000	52.88	.9	58.5	1.1064	.35	35	.081	93.50	1.1873	78.75
2023	44.3	.8000	55.38	1.0	45.0	0.8126	.55	55	.127	100.00	0.9398	106.40
2024	46.5	.8000	58.13	1.0	20.0	0.3441	.80	80	.185	100.00	0.5291	188.99
2025	48.7	.8000	60.88	1.0	6.0	0.0986	.94	94	.217	100.00	0.3160	316.48
2026	51.2	.8000	64.00	1.0	3.0	0.0469	.97	97	.224	100.00	0.2712	368.70
2027	53.7	.8000	67.13	1.0	2.0	0.0298	.98	98	.227	100.00	0.2565	389.93
2028	56.2	.8000	70.25	1.0	1.0	0.0142	.99	99	.229	100.00	0.2432	411.17
2029	58.7	.8000	73.38	1.0	1.0	0.0136	.99	99	.229	100.00	0.2426	412.20
2030	61.2	.8000	76.50	1.0	1.0	0.0131	.99	99	.229	100.00	0.2420	413.15
<b>Sum of Miles and then Gallons of Equivalent Fuel:</b>										<b>1235.60</b>	<b>11.64</b>	
<b>Equivalent MPG of LDV Fleet in 2030:</b>										<b>106.17</b>		
<b>Sum of ZEV Miles = 795. Fraction of Miles Driven by ZEVs = 64.3%</b>												

There is probably some margin from the 2016 to 2019 values as well. The difficult values are for 2022, 2023, and 2024, with 2024 requiring that ZEV sales are 80% of all the cars purchased in California. The purple color of the  $z$  values denotes difficulty. This shows that the government will need to require that the car companies achieve the  $z$  values or buy credits from a company such as Tesla, which sells 100% ZEVs.

The Table 6  $z$  values were put into an EXCEL spread sheet that looks like Table 6. It produced the values shown in Table 6. The values were selected to try to get to the 106.1462 value that was computed in Eq. 11.

Using the result of 106.17 MPG into Equation 9, gives the following result:

$$\frac{d_{2030}}{d_{2005}} = 0.17700 * \frac{m_{2030}}{m_{2015}} = 0.17700 * \frac{106.17}{27.63} = 0.68016 \quad (\text{Eq. 19})$$

This is the 32% reduction desired. It will be difficult to achieve. However, the required schedule of ZEV adoption is also difficult. The values of  $z$  from the years 2021 to 2025 will be at least as difficult as achieving the 32% reduction. This situation motivates the next case. If electricity could be made cleaner sooner, the years from 2021 to 2025 could be less difficult.

## Computing an LDV Overall Equivalent Fleet Mileage, for the *Balanced\_2* Case

The *Balanced\_2* case is shown in Table 7.

The *Balanced\_2* case is the same as the *Balanced\_1* case except it includes an assumption that electricity is 90% renewable in 2030 instead of 85%. Table 7 shows the results using that assumption, which becomes a requirement for this case. For the *Balanced\_2* case, the values of  $z$  are once again assigned to achieve the desired driving-reduction value of 32%.

From the second line of Table 4, this means that the equivalent mileage of the ZEV vehicles is 621.67 MPG.

Eq. 18 becomes:

$$G_z = D_z / (621.67) \quad (\text{Eq. 20})$$

This is used to compute the gallons of equivalent fuel from the distance, for the ZEV vehicles in Table 7.

The Table 7  $z$  values were put into an EXCEL spread sheet that looks like Table 7. It produced the values shown in Table 7. The  $z$  values were selected to try to get to the 106.1462 value that was computed in Eq. 11.

Using the Table 7 result of 106.22 MPG into Equation 9, gives the following result:



$$\frac{d_{2030}}{d_{2005}} = 0.17700 * \frac{m_{2030}}{m_{2015}} = 0.17700 * \frac{106.22}{27.63} = 0.68045 \quad (\text{Eq. 21})$$

**Table 7** Calculation of 2030 LDV Mileage Assuming the *Balanced\_2* Case

Year	ICE Parameters and Calculations						ZEVs			Yearly Totals		
	CAFÉ MPG	LCFS	Eq. MPG	f	$D_i$	$G_i$	$z$	$D_z$	$G_z$	Total Miles	Total Gallons	2030 MPG
2016	34.3	.927	37.01	.3	29.4	0.7943	.02	2	.003	31.40	.7975	39.37
2017	35.1	.920	38.15	.4	39.2	1.0275	.02	2	.003	41.20	1.0307	39.97
2018	36.1	.913	39.53	.5	48.5	1.2271	.03	3	.005	51.50	1.2319	41.81
2019	37.1	.907	40.92	.6	57.6	1.4077	.04	4	.006	61.60	1.4141	43.56
2020	38.3	.900	42.56	.7	64.4	1.5133	.08	8	.013	72.40	1.5262	47.44
2021	40.3	.850	47.41	.8	68.0	1.4342	.15	15	.024	83.00	1.4584	56.91
2022	42.3	.800	52.88	.9	67.5	1.2766	.25	25	.040	92.50	1.3168	70.25
2023	44.3	.800	55.38	1.0	55.0	0.9932	.45	45	.072	100.00	1.0656	93.84
2024	46.5	.800	58.13	1.0	30.0	0.5161	.70	70	.113	100.00	.6287	159.05
2025	48.7	.800	60.88	1.0	5.0	0.0821	.95	95	.153	100.00	.2349	425.62
2026	51.2	.800	64.00	1.0	3.0	0.0469	.97	97	.156	100.00	.2029	492.84
2027	53.7	.800	67.13	1.0	2.0	0.0298	.98	98	.158	100.00	.1874	533.52
2028	56.2	.800	70.25	1.0	1.0	0.0142	.99	99	.159	100.00	.1735	576.42
2029	58.7	.800	73.38	1.0	1.0	0.0136	.99	99	.159	100.00	.1729	578.45
2030	61.2	.800	76.50	1.0	1.0	0.0131	.99	99	.159	100.00	.1723	580.31
Sum of Miles and then Gallons of Equivalent Fuel:										1233.60	11.61	
Equivalent MPG of LDV Fleet in 2030:										106.22		
Sum of ZEV Miles = 761. Fraction of Miles Driven by ZEVs = 61.7%												

This is the 32% reduction desired. It will be difficult to achieve. However, the required schedule of ZEV adoption is also difficult. The values of  $z$  from the years 2021 to 2025 will be at least as difficult as achieving the 32% reduction. However, they are easier to achieve than the values needed in the *Balanced\_1* Case. This quantifies the benefit of increasing the renewable fraction of electricity from 85% to 90%.

### **Computing an LDV Overall Equivalent Fleet Mileage, for the *2005\_Driving* Case**

When climate change and transportation policies are discussed, the opinion that we should simply electrify our fleet as soon as possible is often expressed. The idea is that the per-capita driving level does not have to be reduced, if we electrify our fleet fast enough. The relationships developed in this paper enable an analysis to see how this would work. This gives rise to the *2005\_Driving* Case. For this case, it is assumed that electricity is 90% renewable.

From the third line of Table 4, this means that the equivalent mileage of the ZEV vehicles is 621.67 MPG. Therefore, the relationship shown in Eq. 20 is used.

The *2005\_Driving* case is shown in Table 8.

For the *2005\_Driving* case, the values of  $z$  are assigned to achieve the overall equivalent mileage (MPG) value computed in Eq. 12, which is 156.0974, because that value was computed for there being no change in the per-capita driving from the 2005 value.

Using the result of 155.99 MPG into Equation 9, gives the following result:

$$\frac{d_{2030}}{d_{2005}} = 0.17700 * \frac{m_{2030}}{m_{2015}} = 0.17700 * \frac{155.99}{27.63} = 0.99930 \quad (\text{Eq. 22})$$

This is the 0% reduction desired. However, the required schedule of ZEV adoption is not possible. Jumping from 8% in 2020 to 82% in 2021 defies reason. It appears that our best bet, to do our part to avoid human extinction, is to proceed with the assumption (and thus requirement) that we are going to have to reduce per-capita driving, as shown in either the *Balanced\_1* or the *Balance\_2* case.

### **Computing an LDV Overall Equivalent Fleet Mileage, for the *Mary\_Nichols* Case**

Mary Nichols was first appointed to the California Air Resource Board (CARB) in 1975 and became Chair in 1979. After leaving CARB, she founded the Los Angeles Chapter of the Natural Resources Defense Council (NRDC) in 1989. She was reappointed to the position of Chair of

CARB in 2007 by Governor Arnold Schwarzenegger and she is still serving in that position today.

**Table 8 Calculation of 2030 LDV Mileage Assuming the 2005\_Driving Case**

Year	ICE Parameters and Calculations						ZEVs			Yearly Totals		
	CAFÉ MPG	LCFS	Eq. MPG	f	$D_i$	$G_i$	z	$D_z$	$G_z$	Total Miles	Total Gallons	2030 MPG
2016	34.3	.9267	37.01	.3	29.4	.7943	.02	2.0	.003	31.40	0.7975	39.37
2017	35.1	.9200	38.15	.4	39.2	1.0275	.02	2.0	.003	41.20	1.0307	39.97
2018	36.1	.9133	39.53	.5	48.5	1.2271	.03	3.0	.005	51.50	1.2319	41.81
2019	37.1	.9067	40.92	.6	57.6	1.4077	.04	4.0	.006	61.60	1.4141	43.56
2020	38.3	.9000	42.56	.7	64.4	1.5133	.08	8.0	.013	72.40	1.5262	47.44
2021	40.3	.8500	47.41	.8	14.4	.3037	<u>.82</u>	82.0	.132	96.40	0.4356	221.29
2022	42.3	.8000	52.88	.9	2.7	.0511	.97	97.0	.156	99.70	0.2071	481.42
2023	44.3	.8000	55.38	1.0	1.0	.0181	.99	99.0	.159	100.00	0.1773	563.99
2024	46.5	.8000	58.13	1.0	1.0	.0172	.99	99.0	.159	100.00	0.1765	566.72
2025	48.7	.8000	60.88	1.0	1.0	.0164	.99	99.0	.159	100.00	0.1757	569.23
2026	51.2	.8000	64.00	1.0	1.0	.0156	.99	99.0	.159	100.00	0.1749	571.84
2027	53.7	.8000	67.13	1.0	1.0	.0149	.99	99.0	.159	100.00	0.1741	574.23
2028	56.2	.8000	70.25	1.0	1.0	.0142	.99	99.0	.159	100.00	0.1735	576.42
2029	58.7	.8000	73.38	1.0	1.0	.0136	.99	99.0	.159	100.00	0.1729	578.45
2030	61.2	.8000	76.50	1.0	1.0	.0131	.99	99.0	.159	100.00	0.1723	580.31
<b>Sum of Miles and then Gallons of Equivalent Fuel:</b>										<b>1254.20</b>	<b>8.04</b>	
<b>Equivalent MPG of LDV Fleet in 2030:</b>										<b>155.99</b>		
<b>Sum of ZEV Miles = 990.0 Fraction of Miles Driven by ZEVs = 78.9%</b>												

The following quote<sup>13</sup> inspires the *Mary\_Nichols* Case:

*Regulations on the books in California, set in 2012, require that 2.7 percent of new cars sold in the state this year be, in the regulatory jargon, ZEVs. These are defined as battery-only or fuel-cell cars, and plug-in hybrids. The quota rises every year starting in 2018 and reaches 22 percent in 2025. Nichols wants 100 percent of the new vehicles sold to be zero- or almost-zero-emissions by 2030*

The mathematical relationships developed in this paper make it possible to determine the driving reduction that would be required if it is desired to stabilize the climate at a livable level, assuming the schedule of fleet electrification implied by the above quote. Electricity is required to be 90% renewable. The results of the *Mary\_Nichols* Case are shown in Table 9.

The corresponding driving reduction is computed using Eq. 9.

$$\frac{d_{2030}}{d_{2005}} = 0.177005 * \frac{m_{2030}}{m_{2015}} = 0.177055 * \frac{77.24}{27.63} = 0.495 \text{ (Eq. 14)}$$

This means that the per-capita driving will need to be about 50% less in 2030 than in year 2005. It is not known if CARB understands this.

The official policy of the California Democratic Party (CDP) is expressed in its Platform. A statement that applies to this report and to CARB can be viewed by looking at the California Democratic Party (CDP) website, then select “About Us”, “Standing Committees”, “Platform Committee”, “2020 Platform”, and finally “Energy and Environment Plank”. In that Plank, the following statement is found

- *Demand a state plan specifying how cars and light-duty trucks can meet climate-stabilizing targets by defining enforceable measures to achieve necessary fleet efficiency and per-capita driving limits;*

However, your author’s efforts to get CARB to do such a “state plan”, or to convince a state legislator to write legislation to direct CARB to do such a plan, have not been successful.

If CARB would do such a plan or would consider the results of this report, they would perhaps decide to push for a more ambitious fleet electrification schedule and would also push for state legislation and regulation to enact measures to reduce VMT.

## **Preliminary Conclusions Drawn from the Results of the Four Cases Run**

Table 10 is a summary showing the most important results of the four cases considered. The purple-colored entries denote difficult requirements; red denotes nearly impossible.

Considering the *Balance\_1* and the *Balanced\_2* cases and the fleet electrification schedules for each, it is first concluded that California needs to work to get its electricity to be at least 85% renewable by 2030 and furthermore that getting it to be 90% from renewables by 2030 would make the electrification schedule much easier.

**Table 9 Calculation of 2030 LDV Mileage Assuming the *Mary\_Nichols* Case**

Year	ICE Parameters and Calculations						ZEVs			Yearly Totals		
	CAFÉ MPG	LCFS	Eq. MPG	f	$D_i$	$G_i$	z	$D_z$	$G_z$	Total Miles	Total Gallons	2030 MPG
2016	34.3	.9267	37.01	.3	29.2	.7886	.027	2.7	.004	31.89	0.7930	40.22
2017	35.1	.9200	38.15	.4	38.9	1.0201	.027	2.7	.004	41.62	1.0245	40.63
2018	36.1	.9133	39.53	.5	47.4	1.2003	.051	5.1	.008	52.56	1.2086	43.49
2019	37.1	.9067	40.92	.6	55.5	1.3560	.075	7.5	.012	63.01	1.3681	46.06
2020	38.3	.9000	42.56	.7	63.0	1.4814	.099	9.9	.016	72.98	1.4974	48.74
2021	40.3	.8500	47.41	.8	70.1	1.4790	.124	12.4	.020	82.47	1.4988	55.02
2022	42.3	.8000	52.88	.9	76.7	1.4509	.148	14.8	.024	91.48	1.4746	62.03
2023	44.3	.8000	55.38	1.0	82.8	1.4957	.172	17.2	.028	100.00	1.5233	65.65
2024	46.5	.8000	58.13	1.0	80.4	1.3834	.196	19.6	.032	100.00	1.4149	70.67
2025	48.7	.8000	60.88	1.0	78.0	1.2813	.220	22.0	.035	100.00	1.3167	75.95
2026	51.2	.8000	64.00	1.0	62.4	0.9750	.376	37.6	.060	100.00	1.0355	96.57
2027	53.7	.8000	67.13	1.0	46.8	0.6972	.532	53.2	.086	100.00	0.7828	127.75
2028	56.2	.8000	70.25	1.0	31.2	0.4441	.688	68.8	.111	100.00	0.5548	180.25
2029	58.7	.8000	73.38	1.0	15.6	0.2126	.844	84.4	.136	100.00	0.3484	287.05
2030	61.2	.8000	76.50	1.0	0.0	0.0000	1.000	100.0	.161	100.00	0.1609	621.67
<b>Sum of Miles and then Gallons of Equivalent Fuel:</b>										<b>1236.00</b>	<b>16.00</b>	
<b>Equivalent MPG of LDV Fleet in 2030:</b>										<b>77.24</b>		
<b>Sum of ZEV Miles = 457.9. Fraction of Miles Driven by ZEVs = 37.0%</b>												

Certainly, achieving a 32% reduction in driving in 2030 compared to the 2005 level will be difficult. However, increasing the rate of fleet electrification, from what is shown in the *Balanced\_1* and *Balanced\_2* cases (z, in Tables 6 and 7) would be even more difficult.

Table 10

## Four-Case Summary of Requirements

	Case Designations			
	Balanced_1	Balanced_1	2005 Driving	Mary Nichols
<b>% Renewable Electricity</b>	<b>85.0%</b>	<b>90.0%</b>	<b>90.0%</b>	<b>90.00%</b>
<b>% ZEVs, Year 2016</b>	2.0%	2.0%	2.0%	2.70%
<b>% ZEVs, Year 2017</b>	2.0%	2.0%	2.0%	2.70%
<b>% ZEVs, Year 2018</b>	3.0%	3.0%	3.0%	5.11%
<b>% ZEVs, Year 2019</b>	4.0%	4.0%	4.0%	7.53%
<b>% ZEVs, Year 2020</b>	8.0%	8.0%	8.0%	9.94%
<b>% ZEVs, Year 2021</b>	<b>20.0%</b>	15.0%	<b>82.0%</b>	12.35%
<b>% ZEVs, Year 2022</b>	<b>35.0%</b>	25.0%	<b>97.0%</b>	14.76%
<b>% ZEVs, Year 2023</b>	<b>55.0%</b>	<b>45.0%</b>	99.0%	17.18%
<b>% ZEVs, Year 2024</b>	<b>80.0%</b>	<b>70.0%</b>	99.0%	19.59%
<b>% ZEVs, Year 2025</b>	94.0%	95.0%	99.0%	22.00%
<b>% ZEVs, Year 2026</b>	97.0%	97.0%	99.0%	37.60%
<b>% ZEVs, Year 2027</b>	98.0%	98.0%	99.0%	53.20%
<b>% ZEVs, Year 2028</b>	99.0%	99.0%	99.0%	68.80%
<b>% ZEVs, Year 2029</b>	99.0%	99.0%	99.0%	84.40%
<b>% ZEVs, Year 2030</b>	99.0%	99.0%	99.0%	100.00%
<b>% Reduction in Per-Capita Driving With Respect to Year 2005</b>	<b>32.0%</b>	<b>32.0%</b>	<b>0.1%</b>	<b>50.5%</b>

Besides that, it should be recognized that California alone cannot stabilize our earth's climate. California's best hope is to set an example for other states and other countries. Taking too many of the world's production of electric vehicles will not work. For a more specific example, lithium batteries may be in short supply and so it may be counterproductive for California to have more than its fair share, thus preventing other states and countries from electrifying their fleet at the required rate. The rates of electrification shown for the *Balanced\_1* and the *Balanced\_2* cases are aggressive enough, as shown by the purple-colored entries.

California needs to adopt a set of requirements to achieve the 32% reduction. If CARB wants to work to have California legislate requirements to achieve the *Mary Nichol's* case of a 50% reduction in driving, that would also work and allow more electric cars to go to other states and countries. However the 50% reduction in per-capita driving might be politically impossible at this time.

Since the 32% reduction seems prudent, it begs the question as to what this means in terms of roadway congestion.

The net (as opposed to the per-capita) driving change, going from 2005 to 2030 can be computed by multiplying the per-capita driving factor corresponding to the 32% reduction, which is 0.68, by the population factor of 1.1744, computed in Equation 7. The product of these two values is 0.7986. This means that, even with the 17% increase in California's population, the net driving will have to drop by the factor of about 0.80, or by 20%. If this LDV-driving-reduction requirement (of 0.68) is selected, all of California's transportation money can be used to improve transit, improve active transportation (mainly walking and biking), and maintain, but not expand, roads. There can be little or no congestion because California highway capacity now is larger than it was in 2005 while the state's net driving must drop by 20%.

## **ACHIEVING THE REQUIRED DRIVING REDUCTION OF THE *BALANCED\_1* AND THE *BALANCED\_2* CASES**

As shown in Equation 19, for the *Balanced\_1* case, and in Equation 21 for the *Balanced\_2* Case, in 2030, the per-capita driving will need to be 32% below the 2005 value. As shown in this link, [https://en.wikipedia.org/wiki/Sustainable\\_Communities\\_and\\_Climate\\_Protection\\_Act\\_of\\_2008](https://en.wikipedia.org/wiki/Sustainable_Communities_and_Climate_Protection_Act_of_2008), California's Metropolitan Planning Organizations (MPOs) are adopting Region Transportation Plans (RTPs) that will achieve reductions in year 2020 and 2035. The convention adopted in this report for these reductions, specifically the per-capita driving reduction with respect to the per-capita driving in 2005, matches the SB 375 convention. As shown in the link, the targets, for year 2035, range from 0% for the Shasta MPO to 16% for Sacramento Area Council of Governments. However, it may be true that some of the 2035 requirements have been revised upwards, to be as large as 19% for some MPOs. Since the climate stabilization target year here is 2030 instead of 2035, and to be reasonably conservative, it is assumed here that the state (this is for all MPOs) will achieve a 12% reduction in per-capita driving, in 2030, compared to 2005. This leaves approximately 20% to be achieved by new requirements.

The title of each of the following subsections contains the estimated per-capita driving reduction each strategy will achieve, by 2030.

## **Reallocate Funds Earmarked for Highway Expansion to Transit and Consider Transit-Design Upgrades (2%)**

San Diego County has a sales tax measure called “TransNet”, which allocates approximately one-third for highway expansion, one-third for transit, and one-third for road maintenance. It has a provision that allows for a reallocation of funds, if supported by at least two-thirds of SANDAG Board members, including a so-called weighted vote, where governments are given a portion of 100 votes, proportional to their population. This requirement would be to reallocate the TransNet amount, earmarked for highway expansion, to transit and to do similar reallocations throughout California.

This money could be used to fund additional transit systems; improve transit operations; and/or fund the redesign and implementation of the redesign of existing transit systems. The redesign could include electrification and automation (including automation of fare collection and such features as screening passengers to prevent them from boarding if they have a fever) or even upgrading to a different transit technology.

## **A Comprehensive Road-Use Charge (RUC) Pricing and Payout System to Unbundle the Cost of Operating Roads (10%)**

*Comprehensive* means that pricing would be set to cover all costs (including road maintenance and externalities such as harm to the environment and health); that privacy and the interests of low-income drivers doing necessary driving would be protected; that the incentive to drive fuel-efficient cars would be at least as large as it is under the current fuels excise tax; and finally, as good technology becomes available, congestion pricing is used to protect critical driving from congestion.

The words *payout* and *unbundle* mean that some of the money collected would go to people that are losing money under the current system.

User fees (gas taxes and tolls) are not enough to cover road costs<sup>10</sup> and California is not properly maintaining its roads. Reference 10 shows that in California user fees amount to only 24.1% of what is spent on roads. Besides this, the improved mileage of the ICEs and the large number of ZEVs mean that gas tax revenues will drop precipitously.

This RUC system could be used to help reduce the ICE LDV miles driven in 2016 to 2022, as shown in the “f” column of Tables 6 through 9. This system could probably be implemented in less than 2 years if the urgency of our climate crisis is recognized..

## **Unbundling the Cost of Car Parking (8%)**

Unbundling the cost of car parking<sup>11</sup> throughout California is conservatively estimated to decrease driving by 8%, based on Table 1 of Reference 11. That table shows driving reductions that occur in response to introducing a price, for 10 cases. Its average reduction in driving is 25% and its smallest reduction is 15%. However, these numbers are for individual cases whereas the 8% is the decrease in driving in California, due to introducing value pricing where there is zero price today, or where the price is below its value price. These concepts are explained in Reference 11.

The first such systems should be installed by a (RFP is Request for Proposal) RFP-process-identified, third-party vendor, such as Google, Qualcomm, or Lime Bicycle, for municipal government employees, as part of the government’s Climate Action Plan. The system would be operated for the financial gain of the employees, with a hard requirement in the RFP that even



employees that continue to drive every day would at least break even. The winning third-party vendor would be skilled at monetizing parking whenever it is not being used by the employees and skilled at monetizing data. The parking system would be fully automated, like Uber, except with a more useful phone app that would find the best parking at the user-specified price and walk-distance. The parking would be available to all drivers driving a car registered in the system. Briefly stated, the system is value priced, shared, automated, and provides earnings to all the people that are effectively losing wages or paying higher costs because the parking is being provided. The vendor would also be good at expanding the system both geographically and over all types of uses, in an economically disruptive way; as Uber and Lyft did to the taxi cab industry. The system would be as easy to use as “free” parking, once the car is registered. It would utilize congestion pricing to protect the desired maximum-occupancy rate.

## **Good Bicycle Projects**

The best criterion for spending money for bicycle transportation is the estimated reduction in driving per the amount spent. The following strategies may come close to maximizing this parameter.

### ***Projects to Improve Bicycle Access (1%)***

All of the smart-growth neighborhoods, central business districts, and other high trip destinations or origins, both existing and planned, should be checked to see if bicycle access could be substantially improved with either a traffic calming project, a “complete streets” project, more shoulder width, or a project to overcome some natural or made-made obstacle. For example, in some cases, long stretches of freeways cut off bicycle passage on surface streets that are perpendicular to the freeway. In some of these cases, a bicycle bridge over the freeway would be cost effective.

### ***League-of-American-Bicyclist-Certified (LCI) Instruction of “Traffic Skills 101” (1%)***

Most serious injuries to bike riders occur in accidents that do not involve a motor vehicle<sup>12</sup>. Most car-bike accidents are caused by wrong-way riding and errors in intersections; the clear-cut-hit-from-behind accident is rare<sup>12</sup>.

After attending *Traffic Skills 101*, students that pass a rigorous written test and demonstrate proficiency in riding in traffic and other challenging conditions in passing an on-road-riding test would be paid for their time and effort.

As an example of what could be done in San Diego County, if the average class size was 3 riders per instructor and each rider passes both tests and earns \$100 and if the instructor, with overhead, costs \$500 dollars, for a total of \$800 for each 3 students, that would mean that \$160M could teach  $\$160M/\$800 = 200,000$  classes of 3 students, for a total of 600,000 students. The population of San Diego County is around 3 million.

## **Eliminate or Greatly Increase the Maximum Height and Density Limits Close to Transit Stops that Meet Appropriate Service Standards (2%)**

As sprawl is reduced, more compact, transit-oriented development (TOD) will need to be built. This strategy will incentivize a consideration of what level of transit service will be needed, how it can be achieved, and what levels of maximum height and density are appropriate. Having no limits at all is reasonable if models show that the development can function without harming the existing adjacent

neighborhoods, given the level of transit service and other supporting transportation policies (such as car parking that unbundles the cost and supports the full sharing of parking<sup>12</sup>) that can be assumed.

### **Complete Streets (Streets designed for all users), “Road Diets”, and “Traffic Calming”, Such as Replacing Signalized Intersections with Roundabouts (1%)**

These projects will encourage active transportation, such as bicycling and walking. These projects also fit well with the addition of TOD and increasing density. They will reduce speeds and therefore reduce noise. The noise reduction and increased safety will encourage people to want to live on and around the redesigned arterials where they would not want to have lived before. People will also be more inclined to shop and to work in such surroundings.

### **Net Driving Reduction from All Identified Strategies**

By 2030, the sum of these strategies should be realized as shown in Table 11.

## **CONCLUSION**

The urgency of our climate crisis dictates that California should develop plans such as the cases considered in this paper for a climate-stabilizing target year of 2030. The state needs to select a case and move forward with legislation and implementation. The cases considered in this paper indicate that California should achieve electricity that is at least 85% from renewable sources and a per-capita driving reduction of at least 32% with respect to 2005 driving levels. The ten driving-reducing requirements described in this paper are an example of how this could be done.

**Table 11 Requirements to Achieve a 32% Reduction in 2030 Per-Capita Driving, with Respect to 2005**

<b>Driving Reduction Requirements</b>	<b>Percent Reduction</b>	<b>Factor</b>
Legislated (SB 375) Plans to Reduce Driving	12%	0.88
Value-Priced Road Use Charge (RUC)	10%	0.90
Value-Priced Parking (Unbundling the Cost)	8%	0.92
Transfer Highway Expansion Funds to Transit	2%	0.98
Increase Height & Density by Transit Stations	2%	0.98
"Complete Streets", "Road Diet" (walk/bike)	1%	0.99
<i>Pay-to-Graduate</i> Bicycle Traffic-Skills Class	1%	0.99
Bicycle Projects to Improve Access	1%	0.99
<b>Product of Factors</b>		<b>0.68</b>
<b>% Reduction</b>		<b>32%</b>

**ABBREVIATIONS AND ACRONYMS**

<b>AB 1493</b>	California’s Assembly Bill 1493	<b>ICE</b>	Internal Combustion Engine LDV
<b>AB 32</b>	California’s Assembly Bill 32	<b>kW-h</b>	Kilo Watt-hour
<b>APS</b>	Alternative Planning Strategy	<b>LCFS</b>	Low Carbon Fuel Standard
<b>CAFE</b>	Corporate Average Fleet Efficiency	<b>LDV</b>	Light-Duty Vehicle
<b>CARB</b>	California Air Resources Board	<b>MPO</b>	Metropolitan Planning Organization
<b>CBD</b>	Center for Biological Diversity	<b>Pavley</b>	Senator Pavley’s AB 1493
<b>CEQA</b>	California Environmental Quality Act	<b>PPM</b>	Parts per Million
<b>CCAP</b>	Center for Clean Air Policy	<b>RPS</b>	Renewable Portfolio Standard
<b>CNFF</b>	Cleveland National Forest Foundation	<b>RTP</b>	Regional Transportation Plan
<b>SB 375</b>	California’s Senate Bill 375	<b>S-3-05</b>	Governor’s Executive Order S-3-05
<b>CO<sub>2</sub></b>	Carbon Dioxide	<b>SANDAG</b>	San Diego Association of Governments
<b>CO<sub>2</sub>_e</b>	Carbon Dioxide Equivalent GHG	<b>SCS</b>	Sustainable Community Strategy
<b>EHM</b>	“Extra Heroic Measures” LDV Case	<b>TransNet</b>	San Diego County sales tax
<b>GEO</b>	Governor’s Executive Order		

<b>GHG</b>	Greenhouse gas	<b>URL</b>	Universal Resource Locator
<b>GW-h</b>	Giga Watt-Hours	<b>VMT</b>	Vehicle Miles Travelled
<b>HM</b>	“Heroic Measures” LDV Case	<b>ZEV</b>	Zero Emission Vehicle LDV

## ACKNOWLEDGEMENTS

Darrell Clarke, Lead Volunteer for the Sierra Club’s “Beyond Oil Campaign”; Dr. Dennis Martinek, Oceanside Planning Commissioner; Sandra Goldberg, formerly California Deputy Attorney General; Dr. Nilmini Silva-Send, Senior Policy Analyst of the Energy Policy Initiative Center; Diane Nygaard, Director of Preserve Calavera and founder of *Nelson Nygaard Consulting Associates*; Jack Shu, CNFF President; Joan Bullock; San Diego Sierra Club Executive Committee Chairs: Caroline Chase, John Stump, and (former Assembly Member) Lori Saldaña; Malinda Dickenson, *Law Offices of Malinda R. Dickenson*; Conservation Committee Chair Mollie Biggers; Ed Mainland and Jim Stewart, Co-Chairs, Energy-Climate Committee, Sierra Club California; Bern Grush, Chief Scientist, *Skymeter Corporation*; and SANDAG Staff: Susan Baldwin, Senior Regional Planner; Charles Stoll, Director of Land Use and Transportation Planning; and Stephan Vance, Senior Regional Planner.

## REFERENCES

- 1 Anders, S. J.; De Haan, D. O.; Silva-Send, N.; Tanaka, S.T.; Tyner, L.; *San Diego County Greenhouse Gas Inventory*, September 2008, <http://www.sandiego.edu/epic/ghginventory/>
- 2 Tarbuck, E.; Lutgens, F.; *Earth Science*; Tenth Edition, published by Prentice Hall, 2003, page 539
- 3 Vespa, M.; *Comments on Survey of CEQA Documents on Greenhouse Gas Emissions Draft Work Plan and Development of GHG Threshold of Significance for Residential and Commercial Projects*, Letter from Center for Biological Diversity to Elaine Chang, Deputy Executive Officer of Planning, Rule Development, and Area Sources of the South Coast Air Quality Management District; dated April 15, 2009. <http://www.aqmd.gov/ceqa/handbook/GHG/2009/april22mtg/CBDcomments.pdf>
- 4 Hertsgaard, M; *Latino Climate Solution, the Nation*, Dec. 24/31, 2012.
- 5 Whitney E.; *How to Meet the Climate Crisis, UU World*, Volume XXVI No. 4, Winter 2012.
- 6 Adams, T.; Eaken, A.; Notthoff, A.; *Communities Tackle Global Warming, A Guide to California’s SB 375*, June 2009, NRDC; <http://www.nrdc.org/globalWarming/sb375/files/sb375.pdf>
- 7 Hansen, James, Brief of Amicus Curiae, Exhibit A, Case3:11-cv-o22o3-EMC Document108 Filed 11/14/11. from <http://ourchildrenstrust.org/sites/default/files/Hansen%20Amicus%20.pdf>
- 8 State of California, Department of Finance, California County Population Estimates and Components of Change by Year, July 1, 2000-2010. Sacramento, California, December 2011, from <http://www.dof.ca.gov/research/demographic/reports/estimates/e-2/2000-10/>, the “[E-2. California County Population Estimates and Components of Change by Year — July 1, 2000–2010](http://www.dof.ca.gov/research/demographic/reports/estimates/e-2/2000-10/)”
- 9 State of California Department of Finance, from <http://www.dof.ca.gov/Forecasting/Demographics/Projections/> then select the EXCEL file from “Total Population by County”

- 10 Henschman, Joseph; *Gasoline Taxes and Tolls Pay for Only a Third of State & Local Road Spending*; January 17, 2013; <http://taxfoundation.org/article/gasoline-taxes-and-tolls-pay-only-third-state-local-road-spending>
- 11 Bullock, M.; Stewart, J.; *A Plan to Efficiently and Conveniently Unbundle Car Parking Costs*; Paper 2010-A-554-AWMA, from the Air and Waste Management Association's 103<sup>rd</sup> Annual Conference and Exhibition; Calgary, Canada, June 21-24, 2010. <http://sierraclub.typepad.com/files/mike-bullock-parking-paper.pdf>
- 12 Forester, J. *Effective Cycling*, MIT Press, 6<sup>th</sup> Edition, 1993.
- 13 Lippert, John; Bloomberg News August 2, 2015; *California Has a Plan to End the Auto Industry as We Know It*; <http://www.bloomberg.com/news/articles/2015-08-03/california-regulator-mary-nichols-may-transform-the-auto-industry>

## **KEYWORDS**

Driving, climate, mandates, S-3-05, SB 375, RTP, CEQA, Unbundled, GHG, CAFÉ, ZEVs