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SUMMARY OF THE OZONE AIR QUALITY FORUM AND TECHNICAL ROUNDTABLE

HELD OCTOBER 31, 2006, IN DIAMOND BAR, CA

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TABLE OF CONTENTS

1. INTRODUCTION

The South Coast Air Quality Management District (SCAQMD or District) convened a panel of experts on October 31, 2006, for an "Ozone Air Quality Forum and Technical Roundtable". The presentations and discussion focused on ozone air quality issues relevant to California's South Coast Air Basin (SoCAB). Specifically, the forum and technical roundtable were convened to discuss ozone air quality trends and future planning efforts. Although the long-term ozone air quality trend in the SoCAB showed steady improvement during the 1980s and 1990s, the more recent trend has flattened out, showing only marginal gains since the end of the last decade. The slower rate of improvement occurred despite continued implementation of emission control measures in the current Air Quality Management Plan (AQMP). As the District proceeds with efforts to revise the AQMP in 2007, it is imperative to examine the effectiveness and possible shortcomings of the current strategy to attain ozone air quality standards. This forum was established to facilitate and encourage thoughtful discussion of the issues and concerns regarding further improvements in ozone air quality in southern California.

The meeting was organized in two parts. In the morning sessions (Part I), presentations were made by technical experts to frame the issues and concerns about ozone air quality. These issues included air quality trends; atmospheric chemistry; effects of implementing various volatile organic compound (VOC) and oxide of nitrogen (NO_x) emission control strategies; growth patterns; weekday/weekend effects; greater use of ethanol fuel; and control measure achievements and their effectiveness. The afternoon session (Part II) featured a roundtable discussion by the experts focusing on three questions:

1. What are the main causes/explanations for the slow down in ozone air quality improvements over the recent years?
2. What could be done differently to more effectively reduce ozone levels given the need to attain fine particle standards?
3. What research and development should be emphasized in the near future to further air quality improvement and our understanding of the issues?

The presenters from Part I and other invited experts provided their views on the three questions, followed by comments from the public and stakeholders. The following experts participated in the roundtable discussion:

Dr. Barry Wallerstein, D.Env., Executive Officer, SCAQMD

Mr. Henry Hogo, Assistant Deputy Executive Officer, Science and Technology Advancement, SCAQMD

Dr. John Seinfeld, California Institute of Technology

Dr. Robert Harley, University of California Berkeley

Dr. Michael Benjamin, Mobile Source Analysis Branch, California Air Resources Board

Dr. Arnold Sherwood, Institute for Transportation Studies, University of California, Berkeley

Dr. Douglas Lawson, National Renewable Energy Laboratory

Mr. Michael Jackson, TIAX LLC

Mr. Paul Wuebben, Clean Fuels Officer, Science and Technology Advancement, SCAQMD

Ms. Cynthia Marvin, Planning & Technical Support Division, California Air Resources Board

Dr. Charles Blanchard, ENVAIR Consulting

Ms. Carol Bohnenkamp, U.S. Environmental Protection Agency, Region IX

Dr. William Carter, University of California, Riverside

Dr. Eric Fujita, Desert Research Institute, University of Nevada, Reno

Mr. Ralph Morris, Environ Corporation

Dr. Steven Reynolds, ENVAIR Consulting

Dr. Arthur Winer, University of California, Los Angeles

Mr. Frederick Lurmann, Sonoma Technology, Inc.

2. ISSUES AND CONCERNS REGARDING OZONE AIR QUALITY

2.1 RECENT OZONE/EXPOSURE TRENDS AND AIR QUALITY MODELING

Mr. Henry Hogo of the SCAQMD explained that the National Ambient Air Quality Standards (NAAQS) for four of the six criteria pollutants had been achieved in the SoCAB. Compliance with the ozone and $PM_{2.5}$ NAAQS was the current focus of the SCAQMD's planning efforts. While $PM_{2.5}$ and ozone control strategies are connected through their common precursor, NO_x, the focus of his presentation was ozone. Mr. Hogo described trends in ambient ozone concentrations, ozone precursor (NO_x and VOC) concentrations, and population exposure to ozone, and results from ozone air quality modeling in the SoCAB. Mr. Hogo's presentation slides are compiled in Appendix A.

Displays of the annual basin-wide maximum 1-hr and 8-hr ambient ozone concentrations, number of NAAQS exceedance days per year, and design values were presented to illustrate air quality trends. The maximum ozone data for 1990 to 2005 indicate a downward trend in the 1990s and a leveling off in the 2000s. The downward trend is more dramatic for maximum 1-hr concentrations than for 8-hr concentrations.

The number of exceedance days shows a similar trend with greater improvement in the 1990s than in recent years. The overall decrease in exceedance days is substantial—1-hr NAAQS exccedances decreased from 130 days in 1990 to 30 days in 2005, and 8-hr NAAQS exccedances decreased from 160 days in 1990 to 80 days in 2005. Maps of the three-year average exceedance frequencies also show dramatic reductions in the area affected by high concentrations between 1982 and 2004. In the 1980s, most of the inland areas between Los Angeles and San Bernardino experienced more than 100 exceedances of the 8-hr standard per year. In 2002-2004, only small areas around Santa Clarita and Lake Gregory in the San Bernardino Mountains experienced more than 50 exceedances of the 8-hr standard per year.

The design value is a statistical indicator of high concentrations that is used to assess compliance with the NAAQS. The 1-hr design value is the fourth highest concentration in three years and the 8-hr design value is the three-year average of the fourth highest 8-hr concentration per year. Trends in the design values are more stable than in individual annual data and clearly show consistent ozone decreases from 1990 to 2000 and relatively constant ozone levels from 2001 to 2005 for both 1-hr and 8-hr design values.

Ozone is formed from hydrocarbons (HCs) and NO_x in the presence of sunlight. Multi-station average precursor concentrations show 50% to 70% decreases between 1994 and 2005. HC concentrations decreased more than NO_x concentrations, and the decreases of HCs and NO_x were more rapid in the 1990s than in recent years. The morning non-methane hydrocarbon (NMHC) to NO_x ratio, which is an important indicator for the rate of ozone formation, declined from 4 in 1994 to 2.3 recent years, suggesting that control measures have, in fact, shifted the ozone chemical regime. Concerns remain that precursor trends were nearly flat, and ozone concentrations were flat, during the recent period when emission control measures were being implemented by the SCAQMD.

Differences in precursors and ozone on weekdays and weekends can provide insights into effectiveness of precursor controls. Data for the SoCAB show similar or slightly higher ozone levels on weekends than on weekdays even though HC and NO_x concentrations are lower on weekends than weekdays. Higher NMHC-to-NO_x ratios on weekends may explain some of these effects, but the weekday/weekend differences are many and quite complex. Data for Burbank, Pico Rivera, and downtown Los Angeles show qualitatively similar weekday/weekend differences in precursor concentrations.

Per capita exposure to ozone levels above the standards (in ppb-hours) and total population dosage to ozone show large reductions between 1990 and 1999 and no trend since 2000. The year-to-year relative variations in exposure and dosage are larger in recent years. The downward trend in population exposure to ozone is much strong than the trend in ozone concentration due to reduction in the areas affected by high concentrations. Per capita exposures to ozone above the standards are much higher in San Bernardino and Riverside Counties than in Los Angeles County and especially in Orange County. Reductions in population exposure to levels above the 1-hr standard are greater than those above the 8-hr standard.

Regional air quality models are tools used for attainment demonstrations. They can provide guidance on levels and directions of controls. Ozone isopleths for the basin-wide 1-hr and 8-hr maximums developed by Ralph Morris for the 1994 AQMP are shown as examples of results from these tools. They show that ozone can be reduced by lowering either NO_x or VOC emissions. These particular isopleth diagrams suggest that attainment of the 0.08-ppm 8-hr standard will require larger emission reductions than those needed to attain the 0.12-ppm 1-hr standard.

Mr. Hogo concluded this talk with three statements regarding ozone trends:

- Peak ozone concentrations appear to be leveling in recent years.
- HC concentrations are decreasing more slowly in recent years.
- Population exposure and dosage is decreasing, but the year-to-year relative variations are larger in recent years.

2.2 CHEMISTRY OF OZONE FORMATION IN THE ATMOSPHERE

Dr. John Seinfeld of California Institute of Technology presented an overview of the chemistry of ozone formation in the atmosphere (see Appendix B for presentation slides).

Dr. Seinfeld explained the basic photochemical cycle of NO_2, NO, and ozone which involves three fast reactions and results in concentrations of these species achieving a steady-state or equilibrium in the atmosphere. These fast reactions do not result in net production of ozone. HCs and/or carbon monoxide (CO) are needed to produce ozone. Ozone production can be concisely illustrated using CO as a simple example of a carbon-containing compound. HCs perform the same role as CO in the atmospheric chemistry of ozone. The addition of CO and HCs perturbs the $NO_2/NO/O_3$ steady state. CO reacts with the hydroxyl radial (OH), which is ubiquitous in the troposphere, to produce CO_2 and the hydroperoxy radical (HO_2). The HO_2 radical subsequently reacts with NO to make NO_2 and regenerate the hydroxyl radial (OH). The conversion of NO to NO_2 oxidation resulting from the oxidation of CO and HCs by OH shifts the steady-state equilibrium of the NO_2/NO/O_3 system toward ozone. Specifically, an ozone molecule is produced each time an NO molecule is converted to NO_2 via the CO oxidation pathway. In fact, net ozone production is proportional to the rate of the HO_2 + NO reaction ($P_{O3} = k_{HO2+NO}$ [HO_2][NO]).

Competing reactions can remove radical species from this system. Under low NO conditions, the HO_2 radicals react with themselves to form hydrogen peroxide (H_2O_2). Under higher NO_x conditions, the OH radical reacts with NO_2 to form nitric acid (HNO_3). These H_2O_2 and HNO_3 reactions represent important radical termination and NO_x removal processes. Under low NO_x conditions (NO < 1-5 ppb), the production of ozone is essential proportional to NO_x. Under higher NO_x conditions, the production of ozone is proportional to the ratio of [CO]/[NO_2] or [HCs]/[NO_2] and the production of ozone is inversely proportional to NO_x. It is important to recognize and understand the dual role of NO_x in ozone chemistry. Ozone production efficiency is determined by the ratio of rate of ozone production to the rate of NO_x loss from the system.

Dr. Seinfeld presented an ozone isopleth diagram generated from a photochemical box model. The diagram illustrates the maximum ozone levels achieved from various starting concentrations of VOCs and NO_x. Similar ozone levels can be produced in the high NO_x/low VOC regime and the low NO_x/high VOC regimes, but the response to changes in VOC and NO_x inputs is very different in these regimes. More reliable diagrams can be obtained from full three-dimensional regional models that include ozone chemistry and both the transport and emissions components.

Sensitivity of ozone photochemical production to VOC and NO_x is illustrated in simple box model simulations showing ozone evolution as a function of time of day. The examples simulate hypothetical air parcels containing an initial, urban-like mixture of anthropogenic VOC and NO_x under summertime conditions with 1 ppb of biogenic isoprene and varying rates of vertical mixing and free tropospheric entrainment. The base-case simulations illustrate the characteristic tendency for the system to evolve from VOC-limitation to NO_x-limitation with time and for the point of transition to be delayed as mixing decreases. Simulations with half the base-case VOC show slower ozone formation but finally produce afternoon ozone levels similar to those in the base case. Simulations with half the base-case NO_x show more rapid ozone formation, but afternoon ozone levels are lower than those in the base case. These characteristics of the ozone chemistry are important for understanding the weekday/weekend differences in ozone levels found in the SoCAB.

2.3 SENSITIVITY ANALYSIS IN AIR QUALITY MODELING

Dr. Robert Harley of the University of California, Berkeley, presented a summary of recent sensitivity analysis of air quality models (see Appendix C for slides). As background, he explained that air quality models were useful tools for analyzing and synthesizing an understanding of emissions, atmospheric chemistry, meteorology, and deposition processes. The use of regional photochemical air quality models was also mandated by the U.S. Environmental Protection Agency (EPA) for demonstration of attainment strategies for NAAQS compliance. The modeling process starts with evaluating the performance of the model against observed concentrations of ozone and ozone precursors to determine if the patterns of concentrations are reproduced accurately and whether the comparisons are statistically acceptable. Once the base-case model performance is established, the model's response to emission changes and sensitivity to changes in other model input and parameters can be explored.

To illustrate model sensitivities, Dr. Harley used simulations of the June 23-25, 1987, Southern California Air Quality Study (SCAQS) ozone episode with baseline emissions for 1987 and estimated emissions for 1997 and 2010. The regional VOC emissions estimates for 1997 and 2010 were 62% and 78% lower than those for 1987, respectively. The regional NO_x emissions estimates were 22% and 50% lower in 1997 and 2010 than in 1987, respectively. His results indicated that maximum estimated ozone levels in central Los Angeles, Azusa, and Rubidoux in 1997 were substantially lower than those in 1987 which is not unexpected given the large VOC emissions reduction; however, model estimates for 2010 were fairly similar to those for 1997 even though VOC and NO_x emissions for 2010 were lower than those for 1997. Time trends in the model results are roughly similar to observations at these locations which show downward trends through the 1990s and then a flattening of the ozone levels in the 2000s.

Dr. Harley presented results for the adjoint sensitivity analysis method where variations in about 900 model inputs or parameters were investigated. Effects of variations of boundary conditions, initial conditions, emissions, chemical kinetic reaction rate parameters (250 in the version of the SAPRC mechanism used), and dry deposition velocities on maximum ozone estimates were explored. The three most important input parameters for maximum ozone in Rubidoux in 1987 were the chemical kinetic rate parameters for NO_2 photolysis, the O_3 + NO reaction, and NO_2 + OH reaction. Anthropogenic NO_x and VOC emissions were the 8^{th} and 10^{th} most important factors in determining the peak ozone estimates for Rubidoux in 1987 (see Appendix C for other parameters). With lower emission rates in simulations for 1997, the NO_x emissions rates, NO_2 + OH reaction rate parameters, and anthropogenic VOC emission rates were the three most important factors for peak ozone production in Rubidoux. The direction of the NO_x emissions influence on ozone switched from positive in 1987 to negative in 1997, indicating a dramatic shift in the chemical regime. Likewise, with even lower emission rates in 2010, the model's ozone estimates were most sensitive to (1) anthropogenic VOC emission rates, (2) NO_x emissions rates, and (3) the NO_2 + OH reaction rate parameters. The 2010 sensitivity results showed a similar negative influence of NO_x emissions rate on peak ozone in Rubidoux.

Another example of model sensitivity involved examining the influence of VOC emission changes in a subregion around Azusa. Various percentage increases in anthropogenic and biogenic VOC emissions were investigated for this location. The results indicated that even though biogenic VOC emissions are generally much more reactive than anthropogenic VOC emissions, a 100% increase in local VOC emissions had a larger effect on peak ozone in Azusa than a 100% increase in biogenic VOC emissions. The reason for this response was believed to be that biogenic VOC emissions were primarily in the mountains around Azusa while anthropogenic VOC emissions were in the upwind, urban area.

The sensitivity analyses described above show the effects of multiplicative scaling of input parameters (e.g., scaling by 10% or 100%). It is also possible to consider additive perturbations of input parameters. For example, one can examine the effect of adding emissions to a location where they were nonexistent in the base case. Dr. Harley showed examples of adding NO_x emissions near Azusa, which decreased ozone, and adding NO_x emissions offshore, which increased ozone.

Dr. Harley offered the following conclusions:

1. The adjoint method is an efficient means to study ozone sensitivity to many model inputs and gain better understanding of the parameters important for ozone levels. It is no longer necessary to pre-select parameters for model sensitivity studies; instead all the parameters with adjoint methods can be examined.
2. Using these methods, anthropogenic emissions were found to significantly influence ozone in the SoCAB.
3. The method also allows efficient mapping of source regions that affect air quality at specific locations and facilitates subregional analysis of emission control effectiveness.
4. The 2005 emission inventory indicates that the proportion of total NO_x emissions from diesel vehicles (>50%) is larger than that indicated in previous inventories. Because of large weekday/weekend differences in diesel vehicle activity, one should be able to see greater weekday/weekend modulation of NO_x and ozone levels in the coming years that may provide insight into control strategies effectiveness.

2.4 OZONE PRECURSOR EMISSION TRENDS IN THE SOCAB 1990-2020

Dr. Michael Benjamin of the California Air Resources Board (ARB) presented information on emission trends in the SoCAB (slides are shown in Appendix D). His presentation described (1) historical ROG and NO_x emissions trends, (2) future ROG and NO_x emissions trends, (3) major ROG and NO_x sources, (4) mobile source inventory improvements, and (5) mobile source inventory research. Note, the terms ROG and VOC are used synonymously in this report even though, technically, ROG is a subset of VOC.

The estimated ROG emissions in the summer, excluding biogenic emissions and emissions from ships beyond three miles from shore, have declined from 1,950 tons per day (tpd) in 1990 to 842 tpd in 2005. The estimated NO_x emissions declined from 1,600 to 977 tpd between 1990 and 2005. The more rapid decline in ROG emission than in NO_x emissions is qualitatively consistent with the trends in ambient HC and NO_x concentrations during this period. However, quantitatively, ROG emissions trends are declining less rapidly than the ambient concentration trends shown by Henry Hogo, and NO_x emission trends are declining less rapidly than ambient concentrations during this period. Most of the reductions in emissions were due to changes in stationary and on-road mobile sources. ROG and NO_x emissions from area-wide and off-road sources changed very little during this period. Dramatic year-to-year reductions in emissions occur in years during which substantial control measures were implemented (e.g., reformulated gasoline in 1996-1997). Notable emission increases occurred in years during which reductions from implementation of new control measures were insufficient to offset the effects of the growth of population and vehicle miles traveled (VMT) on emissions (e.g., a 20-tpd increase in NO_x in 1999-2000 and ROG in 2001-2002).

The projected 2020 emissions with currently adopted control measures indicate ROG and NO_x emissions are 574 and 478 tpd, respectively. These amounts represent 32% and 51%

decreases in ROG and NO_x emissions from their 2005 levels. Note, these future emission levels do not include additional control measures that are likely to be included in the SCAQMD's AQMP and ARB's SIP to achieve compliance with the NAAQS. The largest ROG emission reductions are expected to come from light-duty passenger vehicles and recreational boats. The largest NO_x emission reductions are expected to come from heavy-duty diesel trucks, light-duty passenger vehicles, and construction and mining equipment. Because emissions in some source categories will increase while others will decrease, the relative source contributions for the 2020 inventory are quite different than those for 2005. For example, the ROG emissions from light-duty passenger vehicles will decrease from 33% of the 2005 inventory to 17% of the 2020 inventory, while the ROG emissions from consumer products will increase from 12% of the 2005 inventory to 19% of the 2020 inventory. Likewise, emissions from off-road vehicles are projected to be greater than those from on-road vehicles in 2020.

The principal improvements that have been made to the mobile source inventory are the inclusion of vehicles pending DMV registration, redistribution of on-road heavy-duty vehicle (HDV) VMT from the county of registration to the county of operation, revision of HDV emission factors based on Coordinating Research Council (CRC) studies, inclusion of ethanol permeation, and revision of recreational boat, gasoline-can, and construction equipment emissions. The on-road improvements are included in the soon-to-be-released EMFAC 2007 model.

Research is underway to improve light-duty passenger vehicle emission estimates (via the on-going ARB Surveillance), to confirm CRC HDV emission factors, and to better characterize alternate fuel (biodiesel and ethanol) vehicle emissions, gasoline can permeation, and locomotive emissions. Additional research studies have been suggested for improvements in HDV activity and emissions, off-road ethanol permeation, and off-road emissions and deterioration.

2.5 DEMOGRAPHIC TRENDS IN THE SOCAB

Dr. Arnold Sherwood of the University of California, Berkeley, presented information on the population, housing, employment, and VMT trends in the SoCAB and in specific counties. The slides are presented in Appendix E. He indicated that actual and projected demographic data are used in transportation modeling and in future area source and stationary source inventories.

The population of the region grew from 10 million in 1975 to 18 million in 2005. Population growth in the inland counties was especially high. Housing has not grown as rapidly as population and employment. VMT has grown faster than population. Dr. Sherwood's principal message is that population, housing, and employment are expected to continue growing at substantial rates in the SoCAB, with about 2.5 million residents added per decade, and that VMT is estimated to continue growing at about double the population and employment growth rates. The reason VMT is growing faster than population is that longer commutes are associated with new and more affordable housing being built farther inland. The growth in population, and especially VMT, represents a major challenge for the AQMP.

2.6 WEEKEND OZONE EFFECT – THE WEEKLY EMISSION CONTROL EXPERIMENT

Dr. Douglas Lawson of the National Renewal Energy Laboratory (NREL) presented information on the weekend ozone effect and his answers to the three questions posed by the SCAQMD. Dr. Lawson's slides are shown in Appendix F.

Dr. Lawson suggested the emissions changes between weekdays and weekends are a natural (weekly) emission control experiment that can inform scientists on ozone control strategies. The entire July 2003 issue of the *Journal of the Air and Waste Management Association* was devoted to articles on weekend ozone in southern California. He presented weekday versus weekend ozone and NO regression relationships derived from daytime ambient data in Azusa from 1999 to 2000. They showed ozone was 32% and 55% higher on Saturdays and Sundays, respectively, than on Tuesdays through Thursdays, and NO was 49% and 71% lower on Saturdays and Sundays, respectively, than on Tuesdays through Thursdays. Data from more than 20 other monitoring sites in the SoCAB show directionally similar characteristics. On average, the 0600-2000 ambient ozone concentrations are 21% and 25% higher on Saturdays and Sundays, respectively, than on Tuesdays through Thursdays while 0600-2000 ambient NO concentrations are 38% and 64% lower Saturdays and Sundays, respectively, than on Tuesdays through Thursdays. The exception is Banning, a far downwind site, where weekend NO concentrations are slightly higher than on weekdays and weekend ozone concentrations are lower than on weekdays (1 of 26 stations).

A plot of diurnal variation of average hourly NO and ozone concentrations at Azusa in 1995 shows less ozone inhibition from NO and one hour earlier NO-O_3 cross-over time on weekend days than on weekdays. Dr. Lawson indicated the shorter time to NO-O_3 crossover results in more time for photochemical production of ozone on weekends, and a greater rate of ozone formation midday on weekends.

Investigators in the ARB/ NREL weekend ozone effect studies in 1999-2003 ranked a variety of hypothesis in their importance to ozone formation and confidence level. The NO_x emissions reduction hypothesis was ranked (with high confidence) as significantly important for explaining greater ozone formation on weekends. Other hypotheses, such as NO_x timing, pollutant carryover, increased weekend VOC emissions, and increased photolysis due to decreased PM, were ranked as small or insignificant.

Dr. Lawson showed a logarithmic ozone isopleth diagram where the path from 1987 to 2000 was shown as well as potential future paths. He indicate that the 2003 weekend NO, VOC, and ozone average ambient concentrations from Azusa, Los Angeles, Pico Rivera, and Upland are similar to the projected 2010 weekday concentrations. NO_x and VOC emission reductions planned by 2010 appear to lead down an isopleth of constant ozone, rather than one with decreasing ozone. He suggested major changes in the control strategy are needed to achieve ozone reductions.

Regarding the main causes/explanations for the slowdown in ozone air quality improvements over the recent years (Question 1), Dr. Lawson suggested examining the main effects of the two new programs adopted since 1998, the RECLAIM and Carl Moyer programs.

Both programs have primarily been responsible for reducing NO_x emissions rather than HC emissions. He indicated that the weekend ozone studies suggest an increased emphasis on NO_x reductions rather than on VOC reductions has slowed ozone improvements (i.e., similar to what currently occurs on weekends relative to weekdays in the SoCAB and remainder of United States).

Dr. Lawson suggested focusing on high-emitting HC (and CO) light-duty vehicles (LDVs) in order to more effectively reduce ozone levels (Question 2). These high-emitting vehicles are not being identified or repaired through the current Smog Check program. These few vehicles (~5% of the on-road fleet) produce disproportionately high amounts of HC, particulate matter (PM), and air toxics. PM emissions are likely to be reduced when the high HC/CO emitters are repaired or removed from the fleet. He noted that Dr. Blanchard found no statistically significant difference between weekday and weekend PM nitrate in Southern California, despite large weekend NO reductions.

The principal research and development effort needed to further air quality improvement (Question 3) is implementation of the AQMP recommendation for Smog Check enhancement to identify, repair, and verify repairs (or scrap) high-emitting HC (and CO vehicles). Implementation of a comprehensive high-emitting vehicle Smog Check program would produce an immediate benefit in air quality. The difficult task is identifying the high-emitting vehicles and forcing them into the testing program. Tightening Smog Check failure cut points and more frequent testing will do little to improve air quality because the failure of the Smog Check program is a human behavior problem, not a technological problem.

Another important research and development effort is to understand why current ambient VOC speciation does not match existing inventory. The 55 organic species measured in the Photochemical Assessment Monitoring Stations (PAMS) are primarily mobile-source/gasoline-related. The species contained in solvents, coatings, and other sources are either not measured or below detection. A top-down study is needed to understand if current ambient data match current inventory. The mismatch between ambient and emissions inventory VOC speciation undermines the credibility of virtually all previous air quality simulation modeling. The simulations have been flawed because inventories have greatly underestimated mobile source emissions. Dr. Lawson provide graphs and excerpts from documents dating between 1971 and 2007 indicating a history (and pattern) of underestimating emissions from LDVs and projecting substantial reductions in their emission in the near future.

The presentation concluded with a quote from Daniel J. Boorstin (1914-2004), Librarian of Congress from 1975-1987: "*We easily forget that smog is the price of freedom of our streets from manure, and from the flies and diseases it brought.*"

2.7 IN-USE EMISSIONS PERFORMANCE OF ON- AND OFF-ROAD VEHICLE AAPPLICATIONS

Michael Jackson of TIAX LLC presented information on regional emissions inventories and both in-use LDV and HDV emissions. The slides from his presentation are shown In Appendix G.

Mr. Jackson reviewed the relative source contributions of mobile and stationary sources to current regional emission inventories and highlighted the importance of mobile sources for VOC and NO_x emissions. He compared the SCAQMD's 2003 and 2007 AQMP inventories which showed substantial increase in estimated ROG emissions in 2007 compared to 2003. The differences in baseline and future-year on-road mobile inventories in the AQMP are mostly due to changes in the EMFAC model between the 2002 and 2007 versions. Future-year off-road vehicle emissions are also substantially higher in the 2007 AQMP inventory.

On-road LDV NO_x and ROG emissions have been reduced dramatically with cleaner fuels and advanced catalyst technology. Dynamometer testing of in-use ULEV and PZEV vehicles at U.C. Riverside (by Dr. Joe Norbeck's group) showed most HC emissions rates were very low, well below the 0.01 g/mi SULEV standard. Similarly, NO_x emissions from the same in-use fleet of vehicles were far below the 0.20 g/mi ULEV I standard and generally near the 0.05 g/mi ULEV II standard. These newer vehicles had odometer readings of 1,500 to 101,000 miles at the time of testing, and the results suggest the newer emission control technologies deteriorate less than older technologies. The effects of the new technologies are reflected in EMFAC model estimates. Estimates from the 2007 AQMP indicate large decreases (55% to 68%) in the 2010 fleet average LDV emission rates are likely to occur by 2020. Most LDVs are very clean. Most LDV emissions come from high-emitting vehicles: 5% of the fleet emits about 50% of the emissions and 20% of the fleet emits about 90% of the emissions. There is a need to investigate whether the newer technologies will be robust or will deteriorate and perpetuate the high-emitter problem.

Emissions from heavy-duty diesel vehicles dominate the NO_x emission inventory, with 23% and 20% of total NO_x emissions coming from on-road and off-road HDVs in the SoCAB, respectively. Diesel engines are favored for HDV applications because they provide high efficiency, fuel economy, torque/hp, reliability, durability, and low overall life-cycle costs. The new 2007 and 2010 heavy-duty diesel engine certification standards are far more stringent than previous standards, decreasing allowable PM and NO_x emissions by more than 90% from 1998 levels. Engines can meet these 2010 standards with ultra-low sulfur fuel, exhaust gas recirculation, and after-treatment of both NO_x and PM using selective catalytic reduction and PM traps. Whether in-use emissions from these new technologies remain similar to zero-mileage emissions standards remains a concern. The EMFAC2007 model estimates large (60% to 66%) reductions in HDV emissions from 2010 to 2020.

Engine certification standards for construction vehicles and other off-road vehicles are becoming tighter between now and 2014. For example, PM and NMHC+NO_x standards for 175- to 750-hp engines are about 90% lower in 2014 than in 2000. Estimating emissions for these vehicles is difficult because of the uncertainty in the activities and duty-cycles. Whether trends in the in-use vehicle emissions will track the trends in the new standards is an open question.

In summary, control of in-use emissions from engines and vehicles is clearly needed. Attainment of $PM_{2.5}$ and ozone standards will require substantial emission reductions from mobile sources. Cleaner fuels and advanced technologies may provide needed reductions for attainment, but engine and vehicle standards will have to be achieved in-use and over their useful lives. Emissions from LDVs have been dramatically reduced and deterioration may be less of a problem because the new ultra-low emission technology is appearing more robust than earlier technologies. Gross polluters are an on-going problem. It is still hard to find and reduce missions from gross polluters, but the Smog Check Program, On-Board Diagnostics (OBD), and fleet turnover may reduce their impact.

New emissions standards for heavy-duty, on-and off-road vehicles will considerably reduced NO_x and $PM_{2.5}$ emissions. Confirmation that the reductions occur in-use and over vehicle and equipment useful life is needed. Not-to-exceed (NTE) emission testing requirements, road-side testing, and OBD may reduce in-use emissions from heavy-duty and off-road vehicles.

Dr. Wallerstein asked Mr. Jackson to comment on the potential for manufacturers to use the microprocessor to design for achieving standards on the test cycle but allowing something very different in use. Mr. Jackson indicated that the test cycle may be very different from in-use duty cycles, so the in-use emissions may be quite different regardless of the microprocessor design. NTE testing procedures may help with this problem by constraining what the manufacturers can do, especially during periods of transient emission. Dr. Wallerstein also asked about the implications of differences in the fuels used for vehicle certification and fuel for routine in-use driving. Mr. Jackson said there will likely be differences in emissions from vehicles using the indolene test fuel and California reformulated gasoline that contains 5.7% ethanol.

2.8 AIR QUALITY IMPACTS FROM ETHANOL USE

Paul Wuebben of the SCAQMD presented information on current and future air quality impacts of ethanol use. He first described concerns about emissions and ozone air quality in 2003, in which the highest ozone concentrations were observed since the mid-1990s. 2003 was an exceptionally warm year and evaporative emissions were estimated to be high not only because of the high temperatures but also because of the commingling of ethanol and MTBE in fuels and ethanol permeation. Commingling of ethanol in non-ethanol blends may result in Reid Vapor Pressure increases and higher evaporative emissions. Modeling analyses suggest the evaporative emission enhancement from co-mingling ethanol and MTBE in fuels and ethanol permeation could increase 1-hr maximum ozone concentrations by 10 to 20 ppb.

Different blends of ethanol and gasoline (E6, E10, and E85) have been suggested for future use in the SoCAB and concerns remain regarding their potential impact on ozone levels. A key chemistry question is whether the combination of reduced CO emissions and increased VOC emissions with E6 and E10 will lead to increases or decreases in future ozone levels. This question needs to be evaluated for the high temperature conditions associated with high ozone days. The absence of the federal oxygenate mandate means neighboring gas stations may have different blends that could result in enhanced permeation. Nominal increases in VOC emissions in future years may lead to ozone exceedances.

A number of ethanol blend issues were addressed at the June 15, 2006, AQMD Ethanol Forum. Estimates of excess permeation emissions from ethanol use in on-road and off-road vehicles in the SoCAB were 20 and 40 tons per day at 87°F and 97°F, respectively, in 2010. The accuracy and robustness of predictive models for evaporative emissions from various fuel blends are questionable because they are based on data for older fuels and vehicles, and new data on ULEV and SULEV show complicated interactions between gasoline volatility and ethanol. There is also evidence of NO_x emissions increases from 10% ethanol blends. ARB is evaluating mitigation measures to ensure that control measures do not increase emissions. An improved predictive model may provide a new reformulated fuel strategy. A zero summertime ethanol policy might work but would be unpopular with refiners and ethanol producers. Fuel offset requirements may be considered, but may not be sufficient. The issue of CO offsets of VOC emission increases remains, and the ethanol industry suggests that the effect is fully offset when the CO reactivity is properly adjusted. ARB does not expect CO reactivity to significantly offset permeation increases. The benefits of E85 use, such as reduction in toxic and evaporative HC emissions compared to gasoline, were noted. Plug-in hybrid flexible-fueled vehicles operating on renewable E-100 might be a more attractive long-term strategy.

Mr. Weubben concluded his presentation by emphasizing that (1) low level blends of ethanol create excess emissions and air impacts which could be mitigated by not allowing oxygenate gasoline in summer months, (2) the effects of ethanol blends should be evaluated for off-road as well as on-road vehicles, and (3) the role of renewable E-85 fuel ethanol is expected to grow, but probably will depend on development of cellulosic conversion technology (i.e., better enzymes).

2.9 ARB PERSPECTIVE ON OZONE AND GOODS MOVEMENT

Ms. Cynthia Marvin, ARB, addressed ozone air quality concerns in general and specific concerns related to goods movement. She began her presentation with the following "bottom line" conclusions.

The long-term decrease in ozone that occurred in California was due to a strategy that reduced both VOC and NO_x emissions. The recent data show a flattening of the ozone trends. ARB staff compared the severity of the meteorology since 2000 with earlier years and found a higher frequency of adverse meteorological conditions since 2000 which may partially explain the flattening trend. Meteorological conditions in 2003 were the worst since before 1980. Because NO_x emissions contribute to both ozone and fine particles, looking at the ozone problem in isolation does not make sense. $PM_{2.5}$ levels have been decreasing in this same time period, and ARB believes this trend is a result of decreases in NO_x emissions, diesel PM, and other direct PM emissions. ARB continues to believe that a dual pollutant strategy, reducing both NO_x and VOC emissions, is most effective for addressing the ozone problem.

Goods movement is a huge concern in Southern California and in Northern California as well around the port of Oakland. The projected increase in trade will shift the direction from which emissions come. The new SIP goods movement-oriented emission control measures focus on diesel PM, NO_x, and SO_x emission reductions in order to reduce $PM_{2.5}$ levels and the associated health risks; they do not specifically address VOC emissions. Therefore, it will be important to ensure that VOC controls keep pace with controls for other pollutants to ensure the success of the ozone plan.

Looking back on what we have learned over the past 15 years, we see large improvements. There a surprising number of days when ozone levels in the western SoCAB were below the state standard, which is the most protective standard. In downtown Los Angeles, ozone levels were below the state standard on 170 days (or more) of 184 days in the ozone season every year since 1997, except 2003. There has been a dramatic reduction between 1995 and 2005 in the population living in areas that exceed the federal ozone standard. Now, over half the population, or 9 million people, live in areas that meet the federal 8-hr ozone standard; however, almost half still live in inland areas that do not meet the standard. The population is highly mobile and people are exposed to higher levels when they move around the SoCAB.

There have been widespread decreases in the annual $PM_{2.5}$ levels in the SoCAB in recent years. Data for Riverside, Pasadena, and Lynwood are representative of the SoCAB and indicate decreases of 15-20% since 2001. The maximum daily $PM_{2.5}$ levels at Riverside have dropped by about 10% during this same period. With the recent promulgation of the lower 24-hr $PM_{2.5}$ NAAQS, efforts to reduce $PM_{2.5}$ levels will ramp up; those efforts will be a high priority for all the agencies. Examination of trends in the chemical components of $PM_{2.5}$ at Riverside shows that two-thirds of the reductions in annual $PM_{2.5}$ mass are due to the reductions in ammonium nitrate concentrations.

Looking ahead, the growth in goods movement projected for 2001 to 2020 is significant. Cargo volume through the ports of Los Angeles, Long Beach, and Oakland is expected to triple. California's population is expected to increase by 25%. Truck travel is expected to increase by 50% and rail cargo is expected to grow by 110%. There is a need to gear up to control existing emissions from the port-related activities and to add infrastructure to mitigate the expected future increases in emissions. Without new control measures, emissions from goods movement (HDVs, trains, ships, and harbor craft) in 2020 are expected to contribute 70% of the regional diesel PM and SO_x emissions and 38% of the regional NO_x emissions in the SoCAB.

Estimates of the health impacts suggest that port-related activities cause 1,200 deaths per year. Diesel PM, ammonium nitrate, and ozone are estimated to cause 50%, 40%, and 10% of the deaths. These estimates are useful when tradeoffs between different strategies and for setting priorities are considered.

The ARB goal for goods movement is to reverse growth in emissions. The hope is to reduce emissions as much as possible by 2010, at least to 2001 levels, to rapidly reduce diesel PM risk in the community, to reduce risk statewide by 85% by 2020, and to attain federal $PM_{2.5}$ and ozone standards by 2020. Goods movement strategies rely on known technology, including cleaner engines and fuels, fleet modernization (by retrofit or replacement), speed reduction and idling limits, and shore-based power for ships and tugs. The ARB strategy included in the latest AQMP is projected to reduce basin-wide NO_x and VOC emission by 50% and 10%, respectively, in 2020.

Ms. Marvin noted that two research projects are important to enhance the understanding of the ozone problem. First, upper air (2000 feet agl) measurements of ozone, and especially ozone precursors, are needed in order to characterize conditions where the bulk of the ozone is formed. Second, there is a need to assess the effectiveness of a control strategy over an entire ozone season. SCAQMD and ARB staff are working on season-long model simulations and will continue making improvement in this area.

In conclusion, she suggested that agencies continue to seek maximum feasible, cost-effective reductions of VOC and NO_x, and prioritize controls for community health benefits.

Dr. Lawson noted that the 2007 PM after-treatment for HDVs increases the NO_2/NO_x ratio in emissions and asked Ms. Marvin what the likely effect would be on ozone. Ms. Marvin and Dr. Benjamin did not know what the effects would be.

Dr. Sherwood asked what the possible effects would be in California of new light-duty diesel vehicles that are popular in Europe. Ms. Marvin explained that the California and national exhaust standards are fuel-neutral; diesel vehicles must comply with the same standards as gasoline vehicles. Some difference may exist in diagnostic requirements. Manufacturers are still having difficulty achieving compliance for diesel vehicles. The likely effects are small. Dr. Wallerstein commented that the in-use emissions from diesel vehicles could be higher than those from gasoline vehicles, and requiring manufacturers to focus on cleaner diesels may divert resources away from more promising clean-vehicle technologies, such as plug-in hybrids.

2.10 QUESTIONS FROM THE PUBLIC

Ms. Diane Forte of Environment Now asked two questions. The ARB and the SCAQMD indicated that their rules are fully effective: How effective are the rules in practice? Second, what are the likely effects of climate change on ozone?

Ms. Marvin indicated that the ARB accounts for rule effectiveness in its strategies, based on what is learned from in-use compliance data and deterioration rates. Ms. Elaine Chang explained that the SCAQMD has compliance inspectors in the field and has a system of actual emission reporting for stationary sources which provides information on rule effectiveness. The SCAQMD periodically revises the stationary source rule effectiveness assumptions based on these data. Dr. Wallerstein commented that the SCAQMD has real-time NO_x emission monitoring data for the largest stationary sources which allows it to track compliance.

Mr. Joe Cassmassi of the SCAQMD indicated climate change is a concern. In the SoCAB, summers are becoming warmer. Meteorological trends are being monitored because the anticipated changes, such as more sunlight and higher temperatures, tend to enhance ozone.

3. ROUNDTABLE DISCUSSION OF KEY QUESTIONS

The afternoon session (Part II) consisted of a roundtable discussion by the experts focusing on three questions:

1. What are the main causes/explanations for the slowdown in ozone air quality improvements over the recent years?
2. What could be done differently to more effectively reduce ozone levels given the need to attain fine particles standards?
3. What research and development should be emphasized in the near future to further air quality improvement and our understanding of the issues?

The presenters from Part I and other invited experts provided their views on the three questions, followed by comments from the experts, public, and stakeholders.

3.1 DR. CHARLES BLANCHARD, ENVAIR CONSULTING

Dr. Blanchard explained that there is competition between the rate of ozone formation from chemistry and the rate dispersion and transport due to the meteorology. Ozone levels in Southern California and especially in the central part of the SoCAB have been reduced by reductions in VOC emissions that reduced the rate of ozone formation. However, as the rate of VOC emission reductions slows down, so does the rate of decrease in ozone levels. Dr. Blanchard believes the ambient data show flattening in VOC trends in recent years which contributes to the lack of trends in ozone. Although he has not studied it in detail, a second factor influencing the ozone trends is meteorology. There is a general belief that meteorological conditions were less adverse in the 1990s and more adverse in the 2000s, resulting in little apparent improvement in ozone levels in recent years.

Dr. Blanchard also suggested examining trends in far downwind areas during this period. He indicated the ozone trends in Barstow, Death Valley, and upwind of Las Vegas are very similar to those in the SoCAB. These similarities may be due to the similarities in the regional meteorology and meteorological adversity, and/or transport of ozone from central and southern California. The important point is that the ozone trend in the SoCAB may be part of a regional phenomenon.

Lastly, Dr. Blanchard reminded the audience of Dr. Seinfeld’s slide from the morning session showing ozone formation under conditions with half VOC and half NO_x inputs. The simulation with VOC inputs reduced to half of those in the baseline case showed slower ozone formation, but the ultimate amount of ozone formed was the same as in the baseline case. The simulation with NO_x inputs reduced to half of those in baseline case showed faster ozone formation but substantial reduction in the ultimate amount of ozone formed. This slide is an important reminder of the ultimate importance of NO_x reductions in ozone strategies, especially for far downwind areas.

3.2 MS. CAROL BOHNENKAMP, U.S. ENVIRONMENTAL PROTECTION AGENCY

Ms. Bohnenkamp indicated her agency was currently looking for "weight-of-evidence" arguments to support the SCAQMD's SIP control strategy and possibly a "mid-course correction" if one could be justified. She reiterated the concern for ozone at downwind and far downwind sites, and the importance of NO_x controls in those locations. She indicated others had provided plausible reasons for trends or lack of trends. She thought the sensitivity analysis methods presented by Dr. Harley should be used to identify the source regions where emission reductions will be most effective, such as offshore NO_x emissions. For research and development, she thought it was time for a new field study in Southern California.

3.3 DR. WILLIAM CARTER, UNIVERSITY OF CALIFORNIA, RIVERSIDE

The ambient data presented by Henry Hogo indicates ozone formation in most of the SoCAB is VOC-limited. The VOC-limited region extends out to Rubidoux. The benefits of NO_x reductions are not seen in this regime and explains why the SCAQMD is not seeing the expected reductions in ozone in these areas. Based on the ozone isopleth diagram presented by Dr. Lawson, it appears that the control strategy is roughly following a constant ozone isopleth where the benefits of VOC reductions are offset by the disbenefits of NO_x reductions. NO_x reductions are a necessity given the need to control PM.

In the short-term, the SCAQMD may want to implement additional VOC control measures to reduce ozone more rapidly. Reactivity-based controls may provide additional options for VOC control. Measurement of additional ambient VOC species, not just the 55 PAMS species, would help identify species and sources that could be subject to further controls. In the long run, NO_x controls are essential. "The ultimate cause of the [ozone] disease is NO_x", and NO_x will have to be controlled to low levels to solve the ozone problem. Suggestions for research include

1. investigation of methods for large NO_x emissions reductions in the SoCAB;
2. investigation of the quality of the emission inventory to address the relative importance of mobile sources compared to other sources, such as coatings which may not be contributing much at this point; and
3. continued research on pollution prevention.

3.4 DR. ERIC FUJITA, DESERT RESEARCH INSTITUTE

Dr. Fujita presented a table of early morning summer weekday VOC/NO_x ratios (see Appendix J). In 1987, the average VOC/NO_x ratio in ambient concentration data collected at Azusa, Los Angeles, Pico Rivera, and Upland was 8.8. The ratio in the 1987 emissions inventory was about 2.2 times lower, indicating a major discrepancy. Ambient data from the same locations had ratios of 3.9 in 1997 and 4.0 in 1999-2000, indicating that a major reduction in VOCs relative to NO_x occurred in the 1990s. Ratios in the 1997 emission inventory and the CAMx/MM5 regional model simulations compare much more favorably with ambient ratios.

Photochemical air quality models used for control strategy evaluation perform better after this bias and the discrepancy in the emission inventory was eliminated.

Dr. Fujita showed the ozone isopleth diagram presented by Dr. Lawson. He reiterated Dr. Carter's views that the SoCAB experienced a period during which VOC controls have been beneficial for ozone levels and further VOC control will help. However, he expressed concern that if further VOC controls are not achieved while NO_x emissions are being reduced, then the isopleth diagram indicates that very large (90%) NO_x emission reductions will be required to achieve the standards.

To maintain ozone levels in the mid-SoCAB, keeping VOC/NO_x ratios low will be important. They cannot be allowed to return to historical levels where ozone production is much more efficient. The issue becomes, what VOCs are left to control. To assist in identifying VOCs that could be controlled, he recommends expanding the list of measured VOC species beyond the 55 species measured in the PAMS and expanding the measurement locations to include regionally representative non-mobile source-dominated areas. PAMS species and station locations are heavily mobile source-oriented.

Dr. Fujita showed the ratio of acetylene to the sum of 55 PAMS VOC species in vehicle exhaust for new low-mileage vehicles and older high-mileage vehicles. He used acetylene because it is enriched in high-emitting vehicles that run rich and/or have poor catalytic converters. The dynamometer exhaust data for the warm test mode showed ratios of 0.04 to 0.08 for high-emitters, compared to 0.01 to 0.02 for newer, low-mileage vehicles. On-road data collected from freeways around the SoCAB show ratios of 0.05 to 0.07 which suggest VOCs in the roadways have the same characteristics as the high-emitters.

Going forward, it is important to ensure that VOC control measures are implemented as planned and that VOC/NO_x ratios in the mid-SoCAB do not increase. Because the stations that control compliance with the 8-hr standard are located far downwind, it is very important to understand the competition between ozone formation rates and transport and dispersion. Further research is needed to improve the understanding of the effects of control in both mid-SoCAB and downwind locations.

3.5 MR. RALPH MORRIS, ENVIRON CORPORATION

Mr. Ralph Morris presented model-generated 1-hr maximum ozone isopleth diagrams to illustrate several lessons learned since the 1994 AQMP. By plotting the observed fourth highest 1-hr peaks on the diagram, Mr. Morris showed that the combination of VOC and NO_x controls (27% and 12%) in 2001-2005 moved ozone down a constant ozone isopleth. He believes the ozone reductions anticipated in 1994 were not achieved because the 1994 modeling system was overly optimistic about the relationship between transport and SoCAB emission reductions, and VOC emission reductions were not fully implemented. The modeling system was overly optimistic because (1) future boundary conditions were low and did not reflect the fact that polluted air entering the SoCAB from outside is now more likely to increase rather than decrease and (2) the biogenic emission inventory was understated. The 1994 AQMP also did not anticipate the growth of goods movement-related emissions, including offshore NO_x emissions, and continuing problems with emissions from high-emitting vehicles. The 2007 AQMP modeling system represents transport, biogenic emissions, and chemistry better than the system used in 1994.

The extent of progress in reducing ozone may have been misinterpreted during the years with favorable meteorological conditions, like 2001. When conditions return to normal and include adverse conditions like those in 2003, we get more realistic views of the progress or lack there of.

Regarding future work, it is worth noting the spatial variations in control effectiveness described in Rob Harley's and John Seinfeld's presentations. It is time to abandon the concept of a single carrying-capacity for the entire basin and explore the benefits of more focused, subregional control strategies. Rob Harley's illustration of the effects of controlling offshore NO_x emissions on mid-basin ozone is a good example of this type of strategy.

In terms of control, the focus should be mobile sources. California's current Smog Check Inspection and Maintenance program is not adequately detecting high-emitting vehicles. A roadside remote sensing program similar to that under consideration in Colorado may be more effective in detecting these vehicles. Lastly, California's goal is to have 10% zero-emission vehicles by 2010. Reinstatement of the ZEV program would be beneficial for achieving the motor vehicle emission reductions.

3.6 DR. STEVEN REYNOLDS, ENVAIR CONSULTING

Dr. Reynolds explained the recent trends observed in the SoCAB are like those in some other areas with significant NO_x controls. As NO_x levels are reduced, the photochemical production of ozone becomes more efficient. The NO molecules are cycled more times through the reaction sequence producing ozone. He encouraged SCAQMD staff to take advantage of process analysis tools to gain insight into the processes most important in their area, or specific parts of the SoCAB.

He also suggested adding a more regional perspective to the analysis of control strategies. Moderately high ozone levels appear to be transported to far downwind areas, like Las Vegas. It is time to consider the impacts of the SoCAB control strategies on a larger region. Interstate ozone transport is usually considered an East Coast problem. EPA may have to provide some guidance for equitable solutions to the attainment problem for areas affecting and affected by long-range transport.

3.7 DR. ARTHUR WINER, UNIVERSITY OF CALIFORNIA, LOS ANGELES

Dr. Winer noted that other panelists had mentioned many of the important points, so he decided to take a broader perspective on the problem. He explained that he came into the air quality field when the Clean Air Act (CAA) was passed. The CAA set an attainment date of 1977. He has spent 35 years of his career watching the attainment date recede into future. The date is now 2021 and he expects to be long retired before it is achieved or revised. The idea that we are going to have magic bullet to solve this problem is naïve.

Dr. Winer read from a document that he wrote in 1996: "Whether air quality will continue to improve in southern California is open to question. It's important to recognize that almost all of the recent improvements, for example in peak ozone, are a result of policies put in place many years ago. Without a new generation of effective control measures and technology forcing policies, it is difficult to see where air pollution improvements will come from in the next decade [this decade] and beyond. Thus, there remains a danger that future growth in population and emission sources will eventually overwhelm the current generation of emission control programs and, if that happens, air quality will worsen in southern California".

He does not know whether he is the only one who can claim to have predicted the slow down that has been observed. He did indicate he would stand by his prediction for the next ten years. He made this statement in 1996 because he saw that all of the "easy, dramatic, factor of ten" control strategies were implemented and were based on policies adopted much earlier. Faced with the enormous growth in VMT and the tripling of goods movement, competition between ever more difficult control strategies and growth in the region is very problematic for achieving clean air goals.

Regarding how to address the problem, Dr. Winer made several suggestions:

1. Enhance efforts to eliminate high-emitting vehicles. These high-emitters are "low hanging fruit" and represent a floor on VOC emissions unless they are dealt with more effectively.
2. Join the National Coalition for Plug-in Hybrids (if the SCAQMD has not already done so) because these types of vehicles are an important part of the solution for clean air and the SoCAB already has the base electric capacity to charge 2 to 3 million vehicles per night.
3. Deal with the impacts of goods-movement emissions aggressively. The emissions from heavy-duty diesel vehicles and ships in the port area have an immediate health impact on the local community and a growing impact on regional air quality. Natural fleet turnover in the heavy-duty diesel truck is too long (30 years) to achieve our goals. Turnover has to be accelerated.
4. Hold multi-disciplinary forums involving air quality, land use, and transportation planners. Applying a single disciplinary approach to this problem will not succeed. Although this item is not R&D, it is nevertheless strategically important. Dr. Winer referred to an editorial he was invited to write for the most recent SCAG State of the Region report in which he discussed the intersection of air quality, land use, and transportation planning. In the editorial he indicated that air quality goals are not going to be achieved as long as we use fossil fuels and tolerate 1.3 persons per vehicle, as we have for the past 40 years. Multi-disciplinary forums with agency personnel and researchers involved in air quality, land-use, and transportation planning are essential because the current land use and transportation policies work against air quality and make it virtually impossible to achieve clean air standards.
5. The SCAQMD (and ARB) needs to be visionary, anticipatory, and proactive about the implications of reaching the end of the era of cheap oil. The large separation of people's housing from jobs is based on cheap oil. The long-term secular trend for the price of oil is clear. There may be real opportunity to change land-use and transportation policies if

we are really approaching the end of the cheap oil era. This may be an opportunity to make changes in the 10- to 20-year time frame, which is relevant for air quality planning. The end of cheap oil may provide the key to meeting air quality standards in the SoCAB.

3.8 DR. ROBERT HARLEY, UNIVERSITY OF CALIFORNIA, BERKELEY

Dr. Harley expressed concern that ozone levels could increase in the next decade given the NO_x control policies being implemented and that regulators may not be prepared for or accepting of this outcome. Regarding research needs, Dr. Harley suggested four items:

1. Obtain ambient measurements of a broader range of VOCs, including oxygenated compounds, and try to reconcile the whole emission inventory with the ambient data.
2. Improve the characterization of LDV evaporative emissions because they are becoming increasingly important relative to exhaust emissions (e.g., 50% of LDV VOC estimated in 2010 are evaporative). Try to reconcile evaporative and exhaust emissions with emissions measured in ambient air.
3. Add CO_2 to the inventory. Reconcile CO_2 emissions and fuel use as a means to evaluate the inventory.
4. Allocate resources for data analysis in future measurement campaigns. Too many data are collected but never analyzed in the air quality field.

3.9 DR. MICHAEL BENJAMIN, CALIFORNIA AIR RESOURCES BOARD

Dr. Benjamin indicated the two most pressing research needs in the area of emissions are better characterization of off-road vehicle and equipment emissions, and actual in-use data for on-road heavy-duty diesel trucks. Off-road vehicle emissions are an increasingly significant component of the inventory but are especially uncertain because of the variety of types and use. Better information is needed about their activity, duty-cycles, and spatial and temporal use patterns. Actual in-use data for heavy-duty on-road diesel vehicles are needed to evaluate deterioration rates and emission inventory assumptions.

3.10 DR. ARNOLD SHERWOOD, UNIVERSITY OF CALIFORNIA, BERKELEY

Dr. Sherwood offered three suggestions. First, he is concerned about the coincidence of increased ethanol fuel use and the flattening of ozone levels, and suggests the role of ethanol be investigated more thoroughly. Second, growth in Asia is increasing the amount of pollution transported from the east, and he suggests this transported pollution be measured and accounted for in the planning. Third, the feasibility of subregional analysis of control effectiveness should be investigated and considered in future control strategies.

3.11 DR. DOUGLAS LAWSON, NATIONAL RENEWABLE ENERGY LABORATORY

Dr. Lawson also expressed concern that unless VOC controls are pursued aggressively, he fears that ozone levels will increase in the future. He suggested four areas for further research. First, he strongly recommended using remote sensing to identify and repair high-emitting vehicles. His research since 1995 has demonstrated that this approach is feasible and potentially very effective. He reiterated that the high-emitters not only enhance ozone but also waste energy and increase exposure to air toxics. He noted the problem with LDV emissions is the vehicles (or a portion of the vehicles), not the fuel.

Second, he recommends reconciling the current emission inventory with current ambient air quality data. Previous reconciliations have provided valuable guidance for inventory improvements. The last reconciliation is out of date and the next one should be conducted with current data, not data that are four to six years old (as has been done in the past).

Third, his analysis of long range transport during the SCAQS at Spirit Mountain, Nevada, which is 300 km downwind, suggested that weekday/weekend ozone effects persist over long distances. He suggested further investigation of how NO_x affects ozone far downwind.

Fourth, he believes that the weekday and weekend emissions are significantly different, and he recommended testing the regional air quality simulation models on weekdays and weekends to evaluate their ozone response. He believes this is the ultimate test of the regional models' performance.

3.12 MR. MICHAEL JACKSON, TIAX LLC

Mr. Jackson provided comments in three areas. First, he noted the need to better understand in-use emissions and emission control system deterioration. He recommended on-board monitoring of emissions in HDVs in the future. Second, he shared Dr. Winer's concerns about the importance of land-use, emissions, and air quality planning. He recommended consideration of indirect source rules that can more fully mitigate the impacts of development. Third, he reiterated the importance of reformulated fuels. Without the very low sulfur levels in reformulated fuel, new vehicles could not meet the current standards.

3.13 MR. PAUL WUEBBEN, SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Mr. Wuebben offered several comments and recommendations. He reiterated that fuel changes may have contributed to the slowdown in ozone reductions. He indicated there was little attention paid to reformulation of gasoline after MTBE was removed. MTBE, which made up 11% of the fuel, was replaced with ethanol, aromatics, and/or olefins which have higher reactivity and volatility than MTBE. He noted vehicle speeds have increased in recent years as engine size and power have increased. Many vehicles travel 80 mph or more on the freeways. The vehicle test cycles are not representative of the in-use conditions, especially high speeds and frequent accelerations. Test fuels are also not representative of in-use conditions. Despite concerns about the disbenefits of NO_x controls for ozone, he still believes that both VOC and NO_x need to be reduced to ultimately achieve clean air. This combined strategy has benefits the reduction of air toxics, PM nitrate, NO_2, and ozone.

Mr. Wuebben recommended two changes for near-term benefits for ozone levels. First, adopt a zero-oxygen reformulated fuel standard which is feasible and would reduce 20 to 40 tpd of VOC. Second, adopt an ultrafine PM nucleation standard for HDVs to protect public health. Use this standard as justification to retrofit or replace the old trucks operating at ports and elsewhere in the SoCAB.

For the long term, a Marshall Plan for air quality is needed. It would require greater resources (~100 billion) than previously applied to make scientific and engineering advancement relevant to air pollution control. The first area would be in battery chemistry which is important in the development of plug-in hybrids. The second area of research would be hydrogen fuel cell membranes and hydrogen storage which are important for advancement of hydrogen fuel cell vehicles. The third would be enzyme conversions of C5 sugars and lignins into renewable ethanol. Overcoming the current challenges in each of these areas will require major advancements or a scientific miracle. However, faced with the reality of climate change and air quality problems, a miracle is needed. His vision of the future would be plug-in hybrid vehicles that obtained their power from the electric grid (40%), recaptured kinetic energy (30%), renewable bio-fuels (20%), and expensive gasoline (10%).

3.14 MS. CYNTHIA MARVIN, CALIFORNIA AIR RESOURCES BOARD

Ms. Marvin noted that there are profound scientific questions that can only be addressed over the long term. In the short term, ARB is in the middle of the SIP process and is counting on achieving NO_x reductions from goods-movement control measures, new heavy-duty diesel emission standards, and VOC reductions from new evaporative controls on off-road equipment. As part of this process, ARB is soliciting new ideas for cost-effective control measures.

3.15 MR. FREDERICK LURMANN, SONOMA TECHNOLOGY, INC.

Mr. Lurmann interpreted the current trends in ozone as fairly consistent with the flattening trends in ambient VOC and NO_x concentrations. He was encouraged that the 1997-2001 VOC/NO_x ratios in emission inventories are in better agreement with ambient data than they were in earlier years. The current strategy may be guiding ozone down a constant ozone isopleth line. Even though the current strategy is less effective than the previous heavily VOC-oriented strategies, it would be unwise to ignore the larger view that both NO_x and VOC controls are needed to address the ozone problem. The disbenefits of NO_x controls in the mid-SoCAB have been recognized for a long time as part of the cost of reducing ozone farther downwind. Most of the current knowledge of atmospheric chemistry indicates NO_x controls, in addition to VOC controls, are the only way to reduce ozone at the far downwind sites that determine compliance with the 8-hr ozone standard. He recommended continuing with the NO_x control strategy while doing everything feasible to further reduce VOCs. Specifically, regarding control programs, he recommended focusing on the high-emitter problem and rule compliance.

The push for further emission reductions must be strong enough to avoid, as Drs. Harley and Fujita pointed out, increasing VOC/NO_x ratios and ozone production efficiency.

Mr. Lurmann identified the need for additional ambient measurements to support tracking of trends and advancing the understanding of sources and atmospheric processes. He supports broadening the spectrum of VOC measurements from those measured in the PAMs to determine opportunities for further control and assess whether VOC reactivity is decreasing or increasing. He supports a permanent supersite monitoring program with one upwind station and one or more downwind stations to track not only VOC, NO_x, and ozone, but also PM species and air toxics. Lastly, given the importance of the emission inventory in the planning process, he recommends that SCAQMD conduct a reconciliation of the 2006 VOC and NO_x emission inventory with 2006 ambient concentration data.

3.16 DR. BARRY WALLERSTEIN. SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Dr. Wallerstein summarized the SCAQMD's ozone and PM strategies and asked whether the SCAQMD is following the best path to clean air. He explained that the SCAQMD is preparing the ozone and $PM_{2.5}$ plans, together rather than as separate plans. Given the commonality in emission sources, it makes sense to consider PM at the same time as ozone. The SCAQMD pushed up the $PM_{2.5}$ plan submittal date to be consistent with the summer 2007 ozone plan due date. This is advantageous from a planning perspective because the $PM_{2.5}$ NAAQS compliance date (2015) is six years before the ozone compliance date (2021).

The additional controls (by 2014) incorporated in the $PM_{2.5}$ plan in order of priority are (1) a 70% SO_x emission control, mostly from marine vessel fuels; (2) reductions in direct PM emissions primarily from the mobile sources; (3) a 35% NO_x emission control; and (4) additional VOC controls. In order to meet the ozone NAAQS in 2021, the NO_x and VOC control requirements would need to be increased to 50% each. The SCAQMD's engineering staff believes the technology for NO_x control measures is more easily identified than that for VOC controls at this time. These are large reductions and the technologies to reach these levels are only partially known. Dr. Wallerstein also indicated that there is an emerging view from health effects experts who support the SCAQMD's plans to prioritize $PM_{2.5}$ compliance relative to ozone compliance. He asked for assurance from the experts that this general framework for approaching ozone and $PM_{2.5}$ makes sense.

He planned to raise several issues with his staff based on the meeting. He indicated SCAQMD staff previously considered their efforts to reduce pollution levels within the SoCAB would benefit the downwind areas. He heard concerns expressed regarding long-range transport of pollution from the SoCAB, reaching as far downwind as Las Vegas. He staff will look into this issue further. Many experts commented on the need for research. He will ask his staff to develop a prioritized list of research projects that will be included as an appendix to the AQMP. Reactivity came up several times in the discussion of research and potential black box control measures. SCAQMD staff has been examining the potential for reactivity-based controls, where acetone-equivalent reactivity is used as a benchmark for low-reactivity solvents and coatings.

Dr. Wallerstein asked the panel members where they thought the SCAQMD could improve the science and "fill in the blanks" to have a better air quality plan. Several ideas were suggested:

1. Obtain new ambient VOC measurements that include oxygenated compounds and compounds present in solvents, consumer products, and gasoline vapors. Conduct a comprehensive emission inventory reconciliation to assess how well the inventory VOC speciation matches the ambient air VOC speciation.
2. Conduct comprehensive measurements at a limited number of sites over a long period in order to establish a robust data set to detect trends in the components of PM and VOC. Consider including measurement of semi-volatile VOCs, such as polycyclic aromatic hydrocarbon (PAH) compounds, which are important in health effects assessments.

Dr. Wallerstein asked the panel whether the SCAQMD was following the best path to clean air and where it should expend its political capital in the coming years. Panel members indicated the SCAQMD is correct in focusing on PM before ozone because PM mortality associations are more robust than those for ozone mortality. Panel members also thought the SCAQMD is correct in focusing its political capital on (1) remote sensing to reduce emissions from high-emitting LDVs and (2) reducing emissions from trucks, ships, and trains (federal sources) associated with goods movement and port activities.

3.17 PUBLIC COMMENTS

The public raised questions and commented on (1) the benefits of the greenhouse gas emission reduction bill (AB32) for ozone and PM attainment, (2) the need to consider reactivity-based emission control measures, (3) potential increases in ethanol permeation emissions, and (4) the benefits and acceptability of ethyl tertiary butyl ether (ETBE) as a substitute for ethanol in gasoline blends.

4. CONCLUSIONS

4.1 OZONE AIR QUALITY IMPROVEMENTS

A consensus view emerged that the slowdown in ozone air quality improvement in recent years was caused by a combination of less effective emission controls and more adverse meteorological conditions than those in the 1990s. The recent emission control program involved greater NO_x emissions reductions relative to VOC emissions reductions than in previous years, and the VOC emissions reductions may have been smaller. The year-to-year VOC emissions changes may have been zero or increasing in some recent years, especially when ethanol replaced MTBE in gasoline blends. Several isopleth analyses suggested the 2000s emissions control strategy is guiding air quality down a path of relatively constant ozone. Progress was also inhibited by the higher frequency and severity of adverse meteorological conditions in the 2000s, especially in 2003, than in the 1990s. Unusually favorable meteorological conditions in the 1990s probably enhanced ozone air quality improvements and may have generated the appearance that emission controls were more effective than they might otherwise have been.

The experts generally accepted Dr. Carter's view that "NO_x is the cause of the [ozone] disease" and that the ultimate cure is to drive down NO_x emissions and concentrations to low levels. NO_x emission reductions were recognized as essential for reducing PM levels and achieving compliance with the $PM_{2.5}$ NAAQS. Because of the disbenefits of NO_x reductions for ozone in the VOC-limited regime, which now extends inland to Rubidoux, it is important to reduce VOCs and NO_x concurrently. Many experts emphasized the importance of aggressively reducing VOCs in this phase of the strategy even though most of the easy VOC controls have already been adopted. Fears were expressed that ozone trends could stay flat or perhaps rise if VOC controls are not pursed aggressively.

One expert pointed to the weekday/weekend ozone effect as evidence of the disbenefits of NO_x control in the mid-SoCAB. He indicated similar weekday/weekend effects were observed far downwind of the SoCAB (in Nevada) in the 1987 SCAQS Study. This result was contrary to the prevailing view among the experts that NO_x controls are effective far downwind.

4.2 WHAT COULD BE DONE DIFFERENTLY?

Numerous suggestions were made for what could be done differently to more effectively reduce ozone levels given the need to attain fine particle standards. The principal suggestions follow:

1. Keep up progress on VOC reductions while NO_x emissions are being reduced.
2. Reduce emissions from high-emitting vehicles (HC, CO, and/or PM). Implement remote sensing of in-use vehicles and re-focus the Inspection and Maintenance program to identify and repair or retire early high-emitting vehicles.
3. Evaluate in-use NO_x (and PM) emissions from new HDVs and off-road equipment to determine whether they match expectations for low deterioration rates.

4. Reduce emissions from trucks, ships, and trains (federal sources) associated with goods movement and port activities.
5. Investigate the potential benefits of subregional emission control strategies.
6. Assess whether oxygenated gasoline blends have less ozone-forming potential than zero-oxygen gasoline. Consider adopting a zero-oxygen gasoline for the SoCAB.
7. Convene multi-disciplinary forums to coordinate air quality, land-use and transportation planning.

4.3 RESEARCH AND DEVELOPMENT

Many ideas for research and development to further air quality improvements and the understanding of the science were discussed. Several principal research and development topics were identified:

1. Broaden the geographic scope of the modeling analyses. Examine impacts of current emissions and future controlled emissions farther downwind. Improve the understanding of NO_x and VOC emission controls at locations farther downwind than those that currently determine compliance with the 8-hr standard. Also, consider the impacts of higher pollutant levels being transported into the SoCAB from long-range transport and offshore emissions.
2. Expand the ambient measurement program. Measure a wider spectrum of VOC species to identify opportunities for additional VOC controls and to reconcile the current VOC and NO_x emission inventory with current ambient air concentrations and VOC speciation. Implement emission inventory improvements and possibly new control measures based on the reconciliation study.
3. Develop more holistic approaches and policies for air quality, land-use, and transportation planning. Incorporate ways to make land-use and transportation planning more sensitive to air quality impacts. Take advantage of the growing public concerns for energy efficiency, greenhouse gas emissions, and cost of transportation fuels.
4. Investigate options to achieve large NO_x emissions reductions.
5. Conduct research to advance plug-in hybrid vehicles, hydrogen fuel cell vehicles, and other zero or near-zero emission vehicles.
6. Develop processes for efficient and economical conversion of cellulostic material into ethanol fuels.

APPENDIX A

MR. HENRY HOGO

Recent Ozone/Exposure Trends and Air Quality Modeling

(Presentation Updated – November 1, 2006)

Henry Hogo
South Coast Air Quality Management District

Ozone Air Quality Forum and Technical Roundtable
Diamond Bar, CA
October 31, 2006

Overview

- Ozone Air Quality Trends
- Key Primary Pollutant Trends (Hydrocarbons, Oxides of Nitrogen)
- Ozone Exposure Trends
- Ozone Air Modeling Analysis

Key Criteria Pollutants

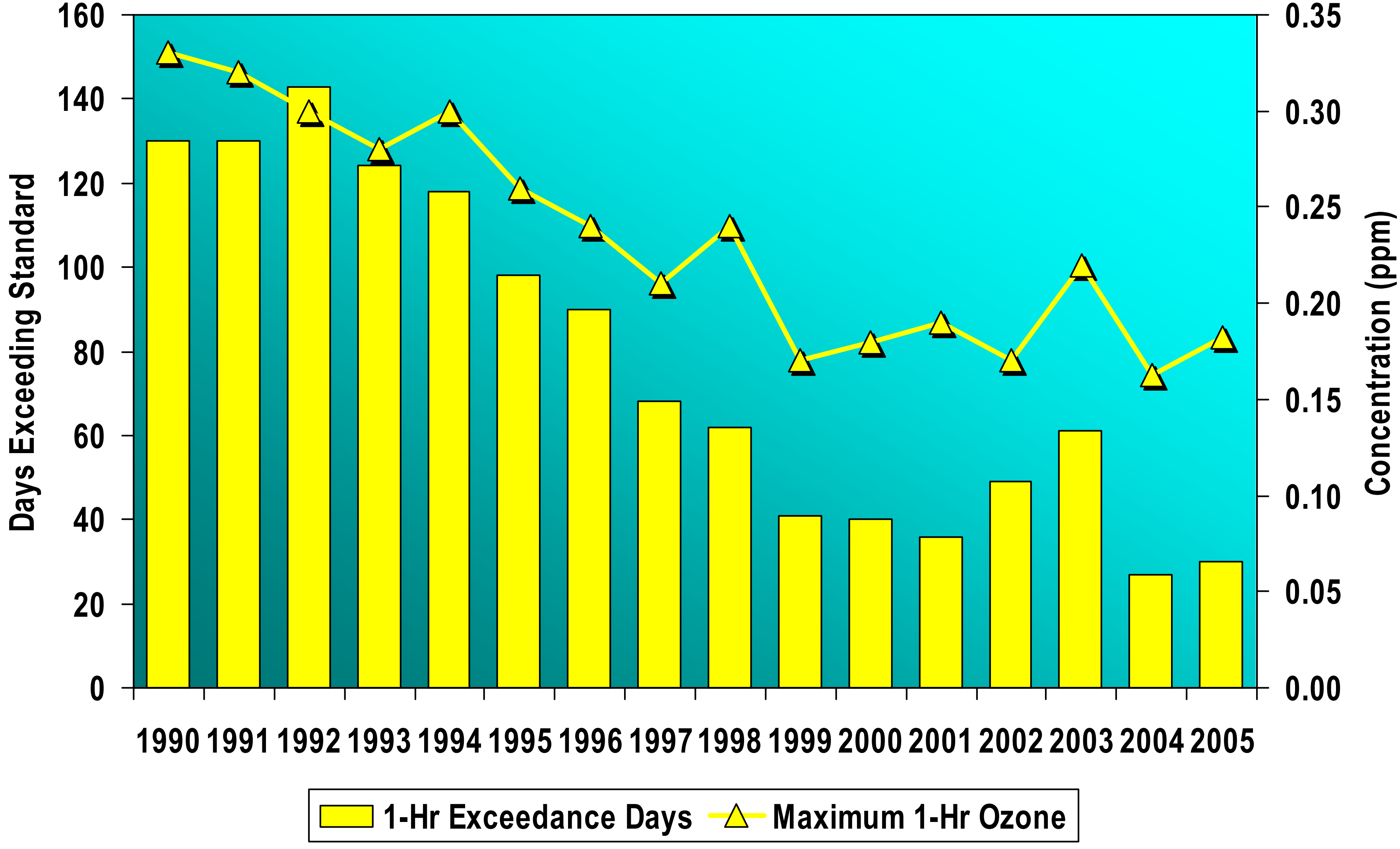
- ✓ Carbon Monoxide
- ✓ Nitrogen Dioxide
- ✓ Sulfur Dioxide
- ✓ Lead
- Ozone
- Particulate Matter (PM10, PM2.5)

Federal Ozone Air Quality Standard

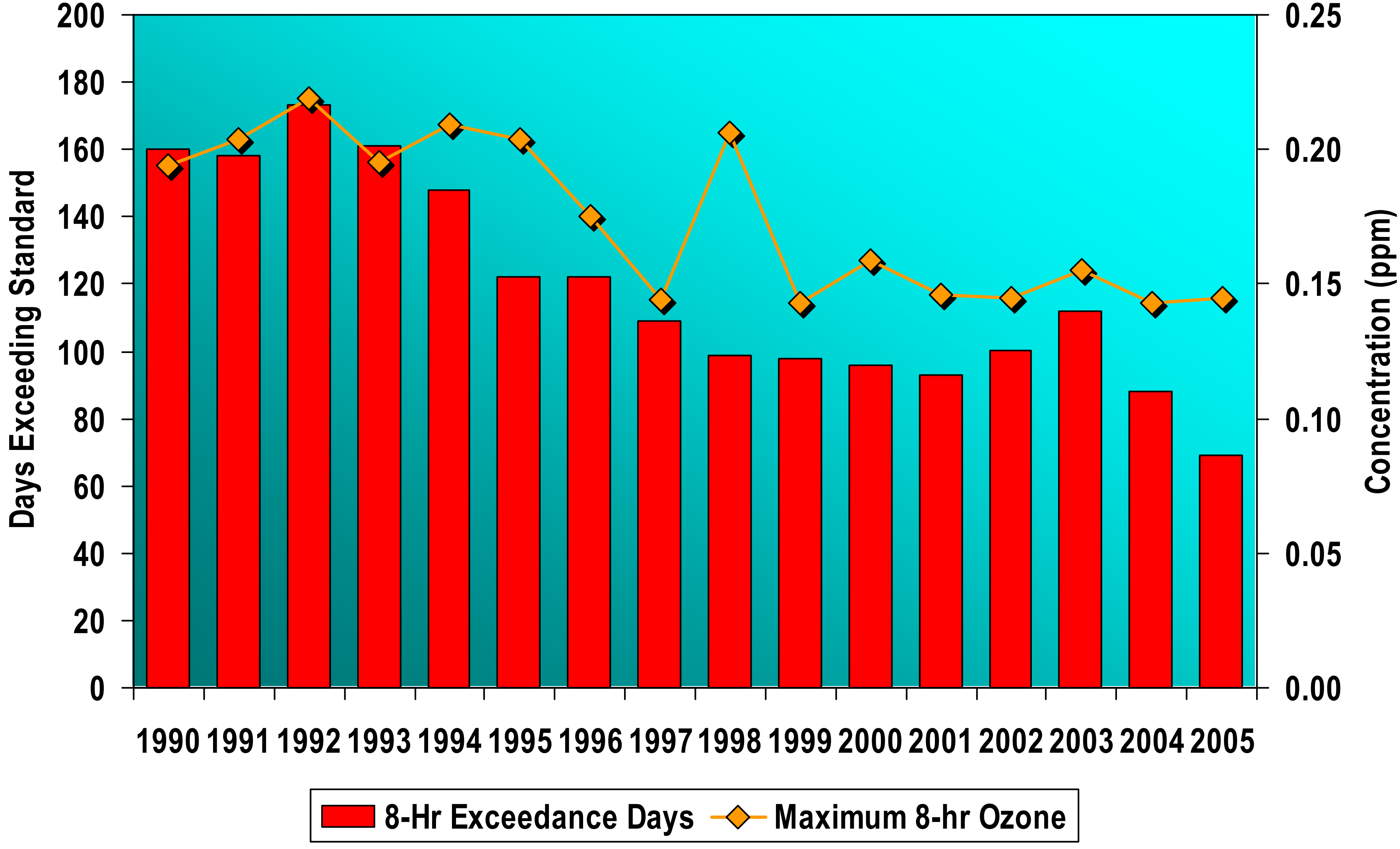
	1-hour Standard (No Longer in Effect)	8-hour Standard
Standard	0.12 ppm	0.08 ppm
Form	4th highest value over 3 years not to exceed 0.124 ppm	3-yr average of the 4th highest not to exceed 0.085 ppm
Design Value	0.33 ppm	0.131 ppm
Basin Classification	Extreme (attainment by 2010)	Severe-17 (attainment by 2021)

Ozone Air Quality Trends

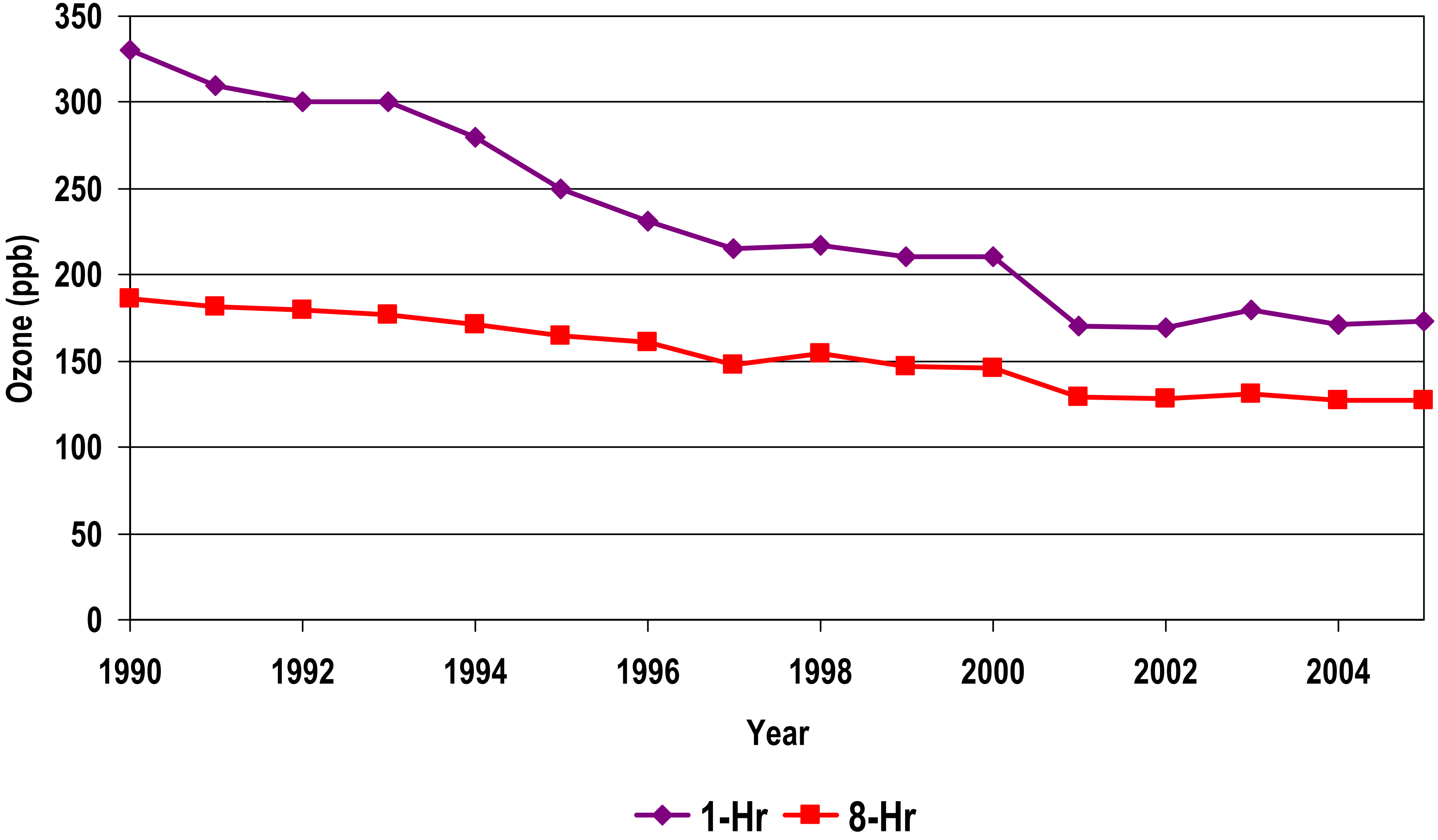
1-Hr Ozone Air Quality Trends

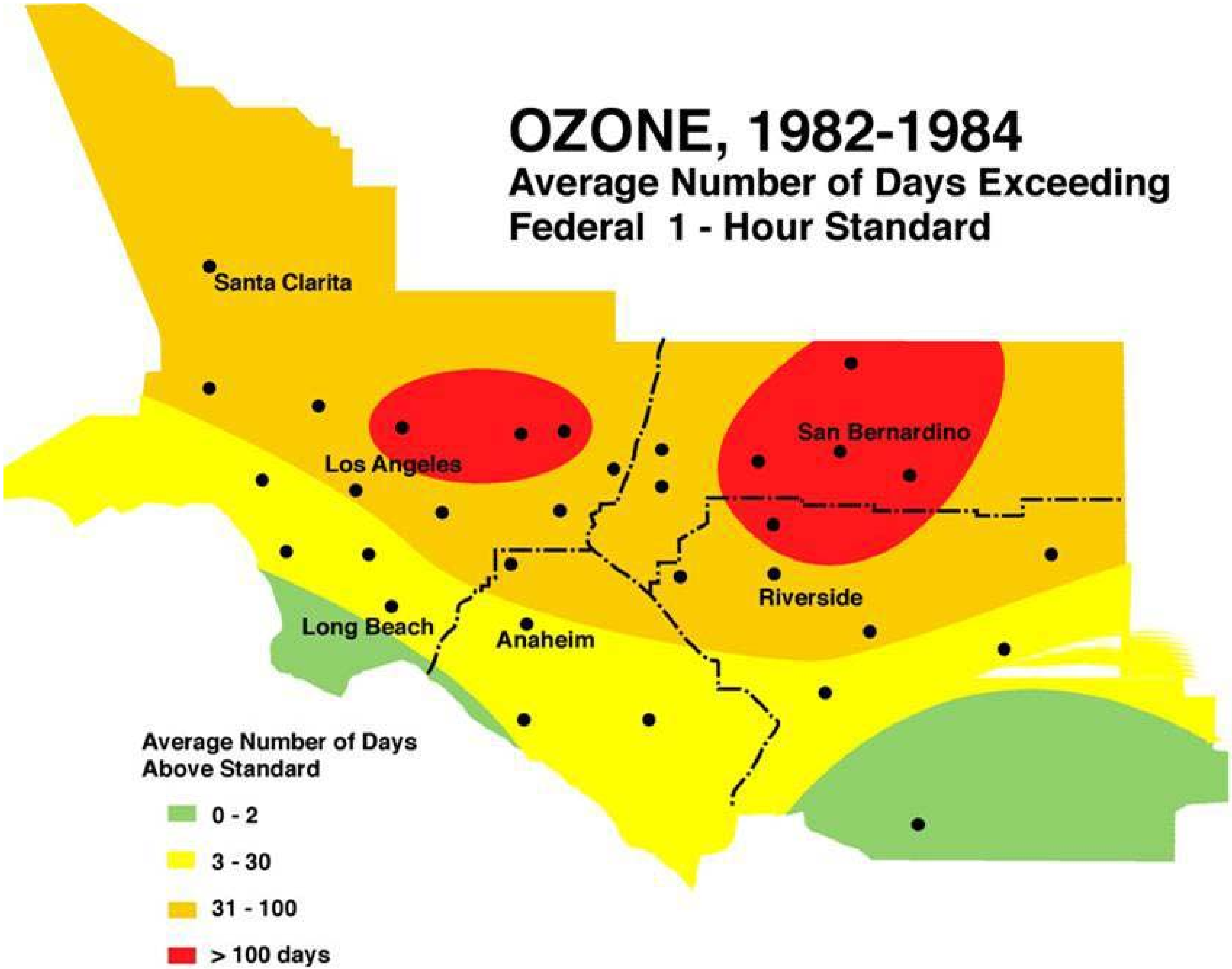


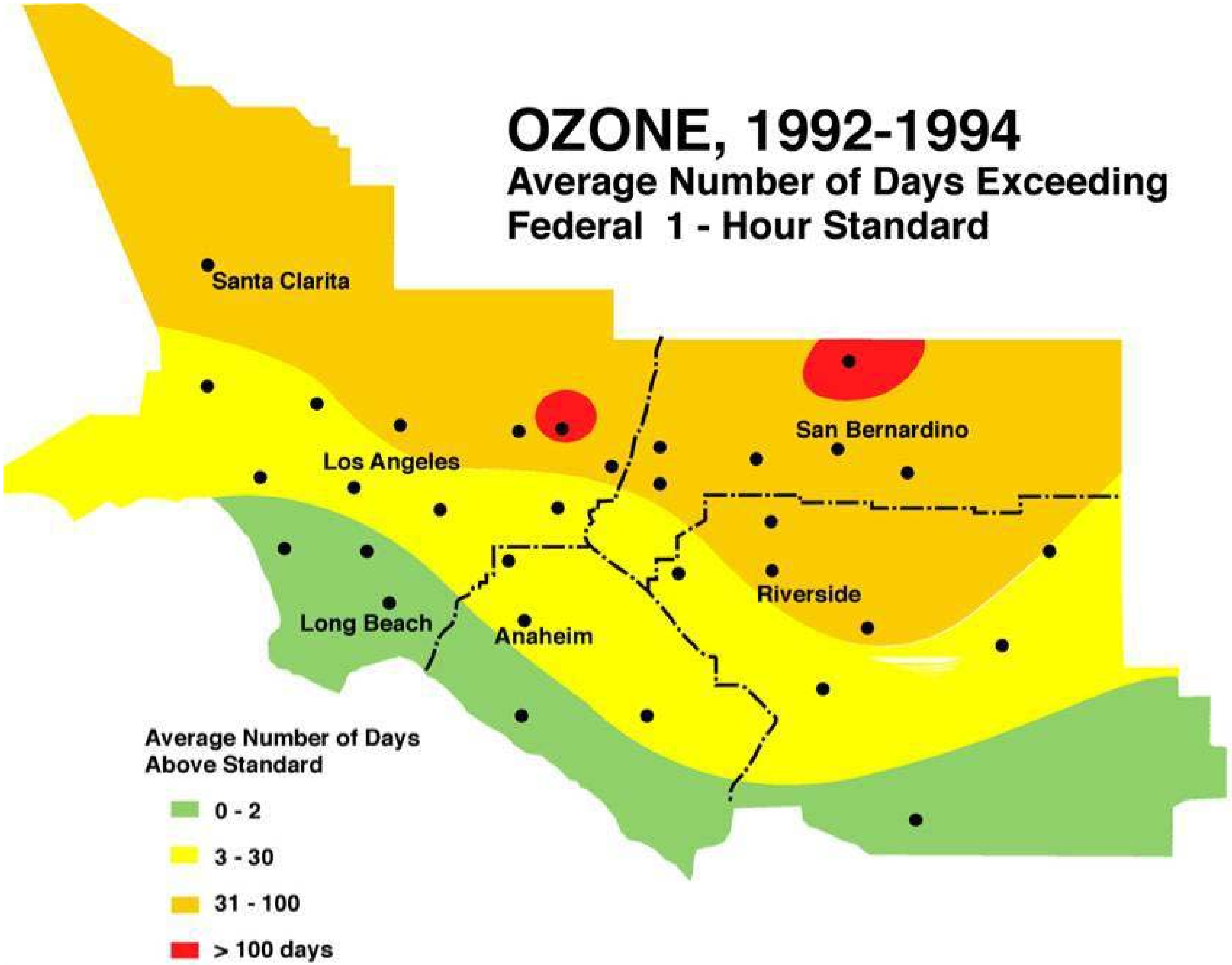
8-hr Ozone Air Quality Trends

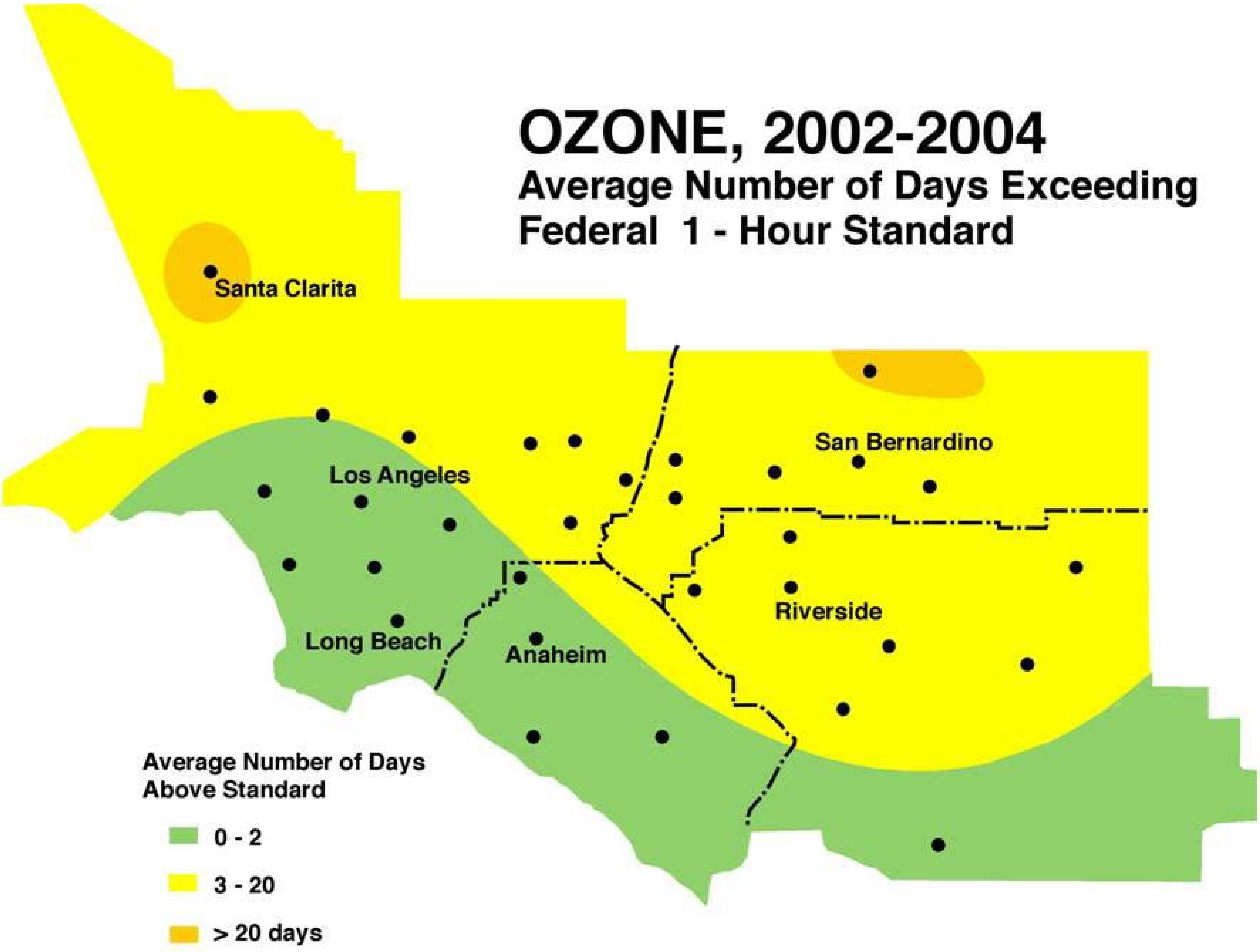


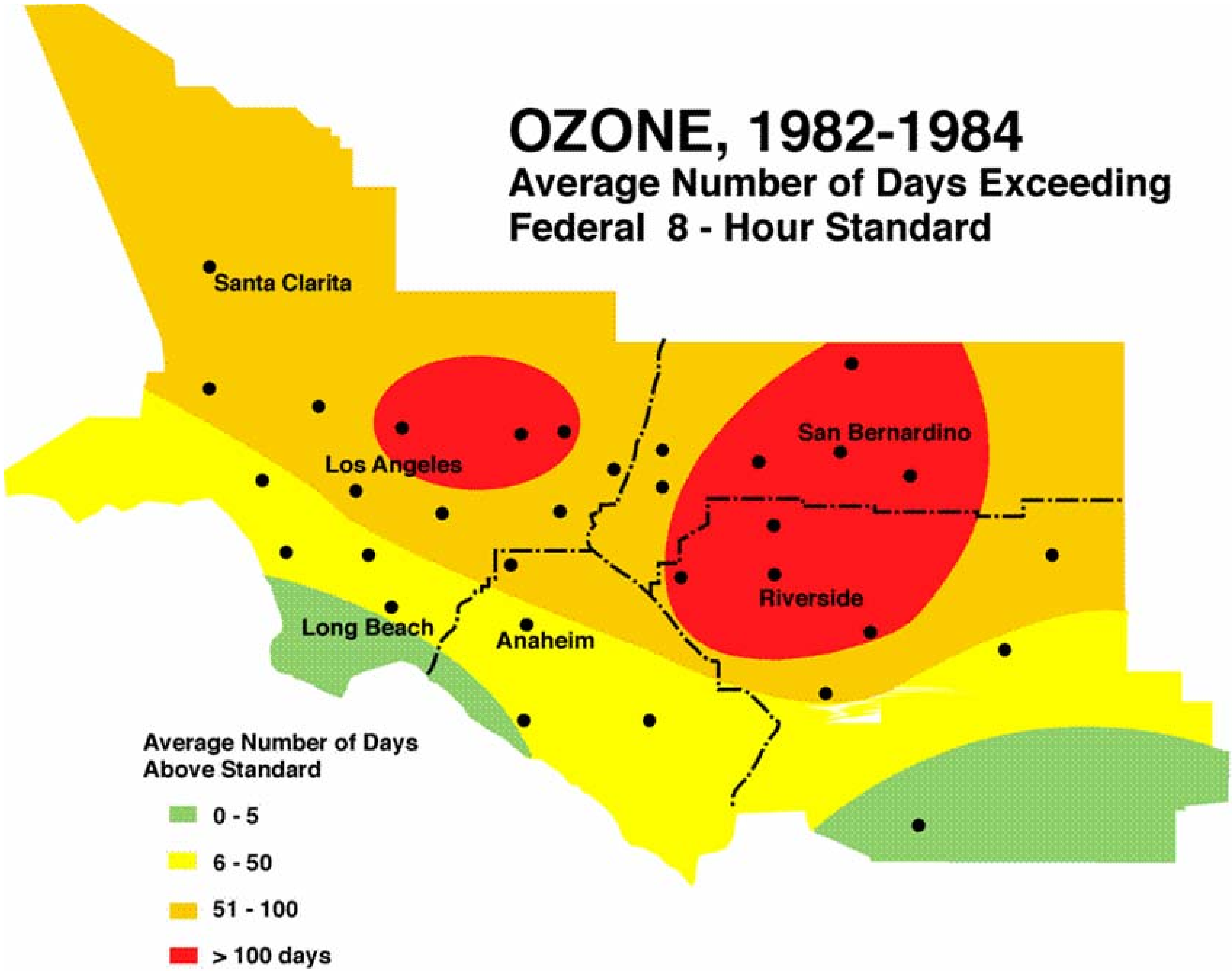
Trend in Ozone Design Values



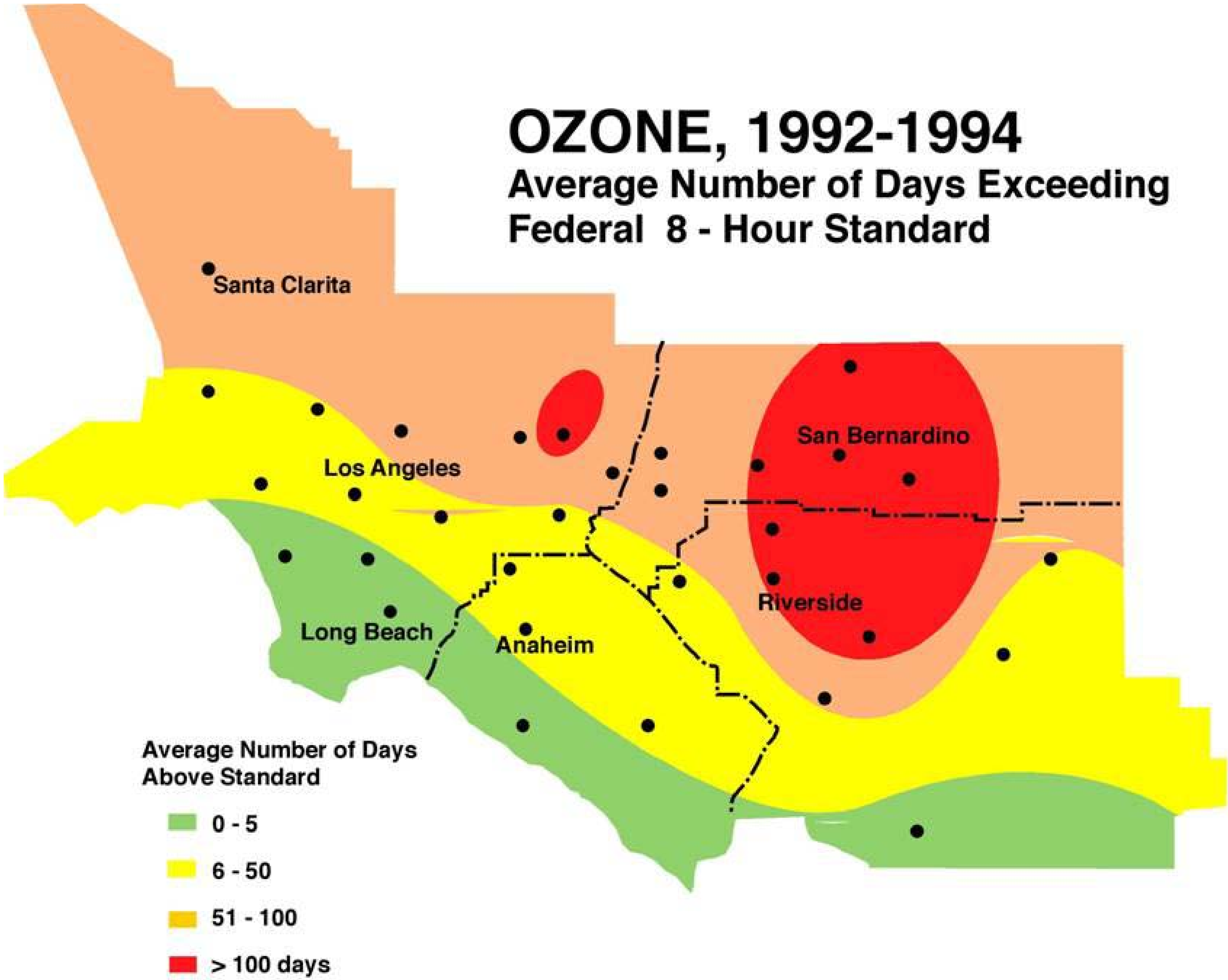

OZONE, 1982-1984
Average Number of Days Exceeding
Federal 1 - Hour Standard
Santa Clarita
Los Angeles
San Bernardino
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 2
3 - 30
31 - 100
> 100 days


OZONE, 1992-1994
Average Number of Days Exceeding
Federal 1 - Hour Standard
Santa Clarita
Los Angeles
San Bernardino
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 2
3 - 30
31 - 100
> 100 days


OZONE, 2002-2004
Average Number of Days Exceeding
Federal 1 - Hour Standard
Santa Clarita
San Bernardino
Los Angeles
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 2
3 - 20
> 20 days



OZONE, 1982-1984
Average Number of Days Exceeding
Federal 8 - Hour Standard
Santa Clarita
Los Angeles
San Bernardino
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 5
6 - 50
51 - 100
> 100 days


OZONE, 1992-1994
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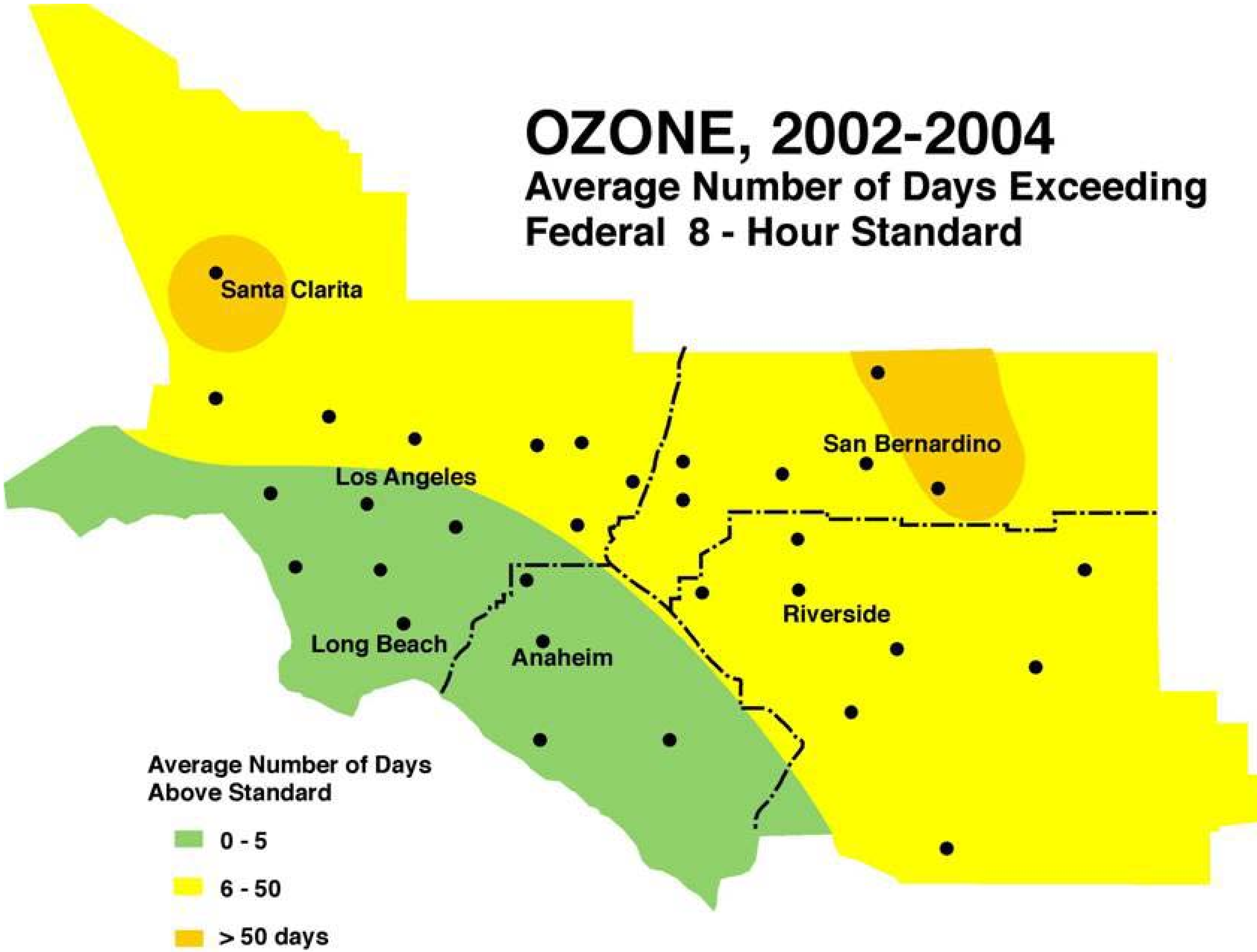
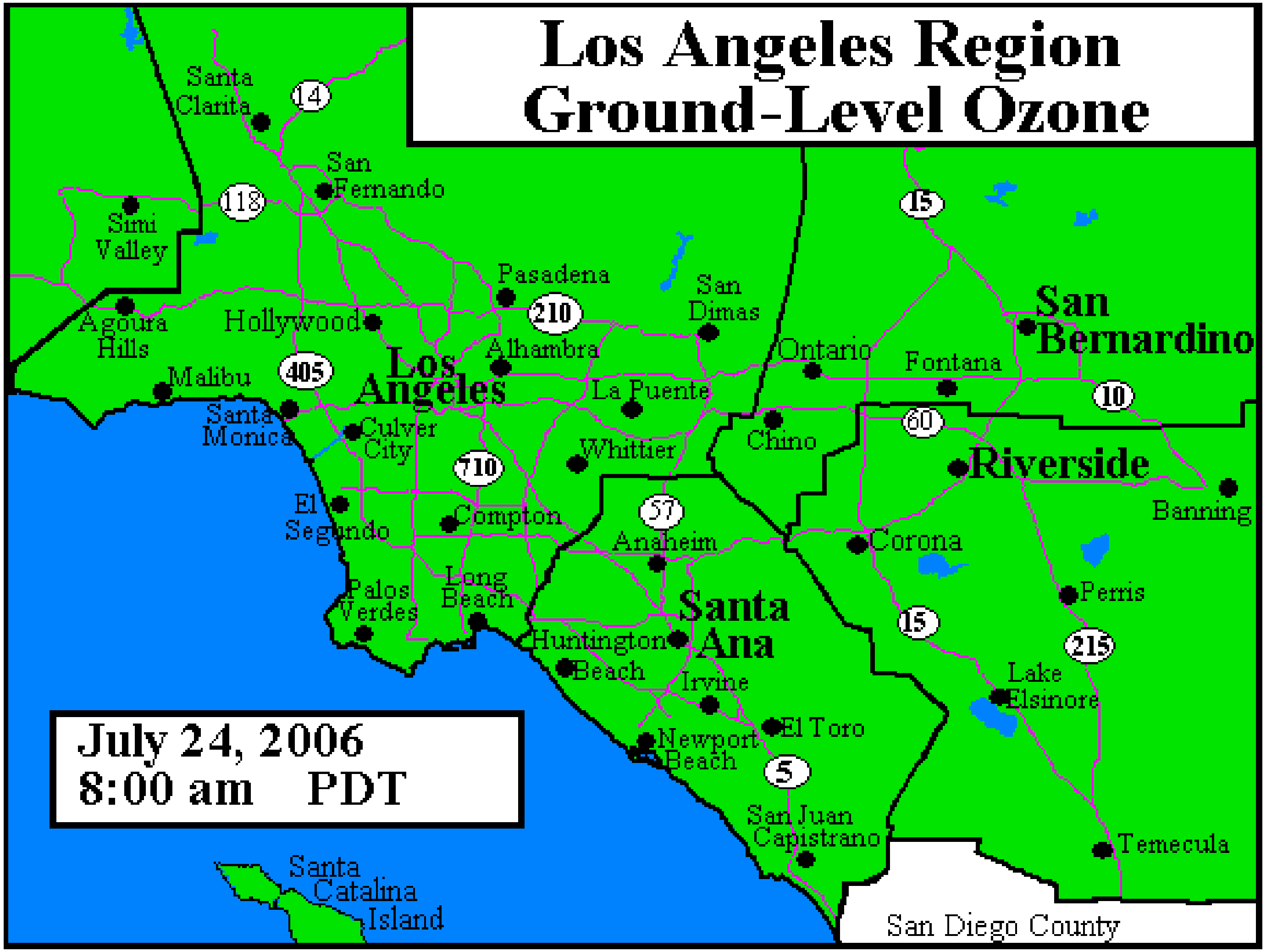
Federal 8 - Hour Standard
Santa Clarita
Los Angeles
San Bernardino
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 5
6 - 50
51 - 100
> 100 days


OZONE, 2002-2004
Average Number of Days Exceeding
Federal 8 - Hour Standard
Santa Clarita
San Bernardino
Los Angeles
Riverside
Long Beach
Anaheim
Average Number of Days
Above Standard
0 - 5
6 - 50
> 50 days

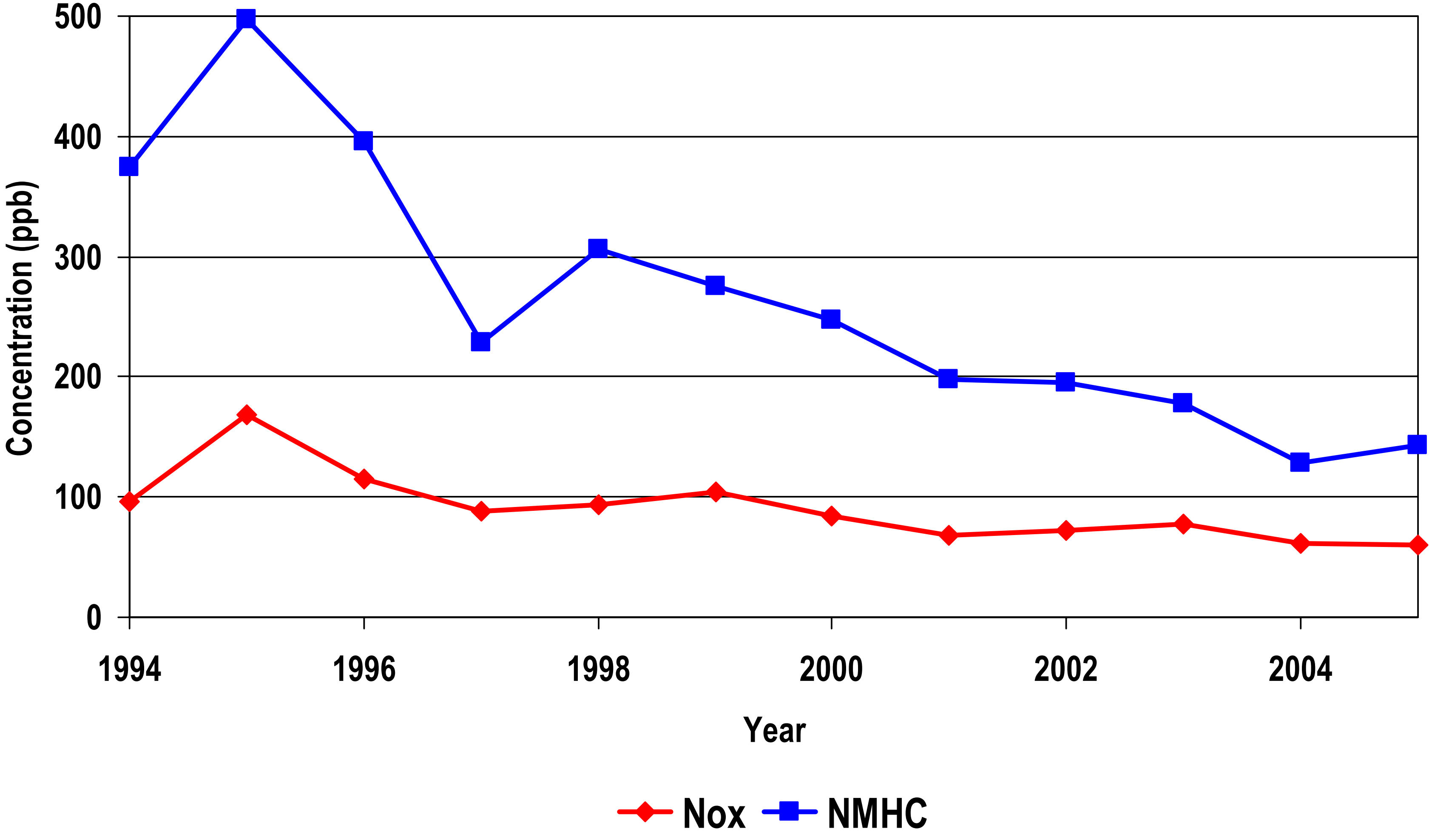
8-Hr Ozone Formation



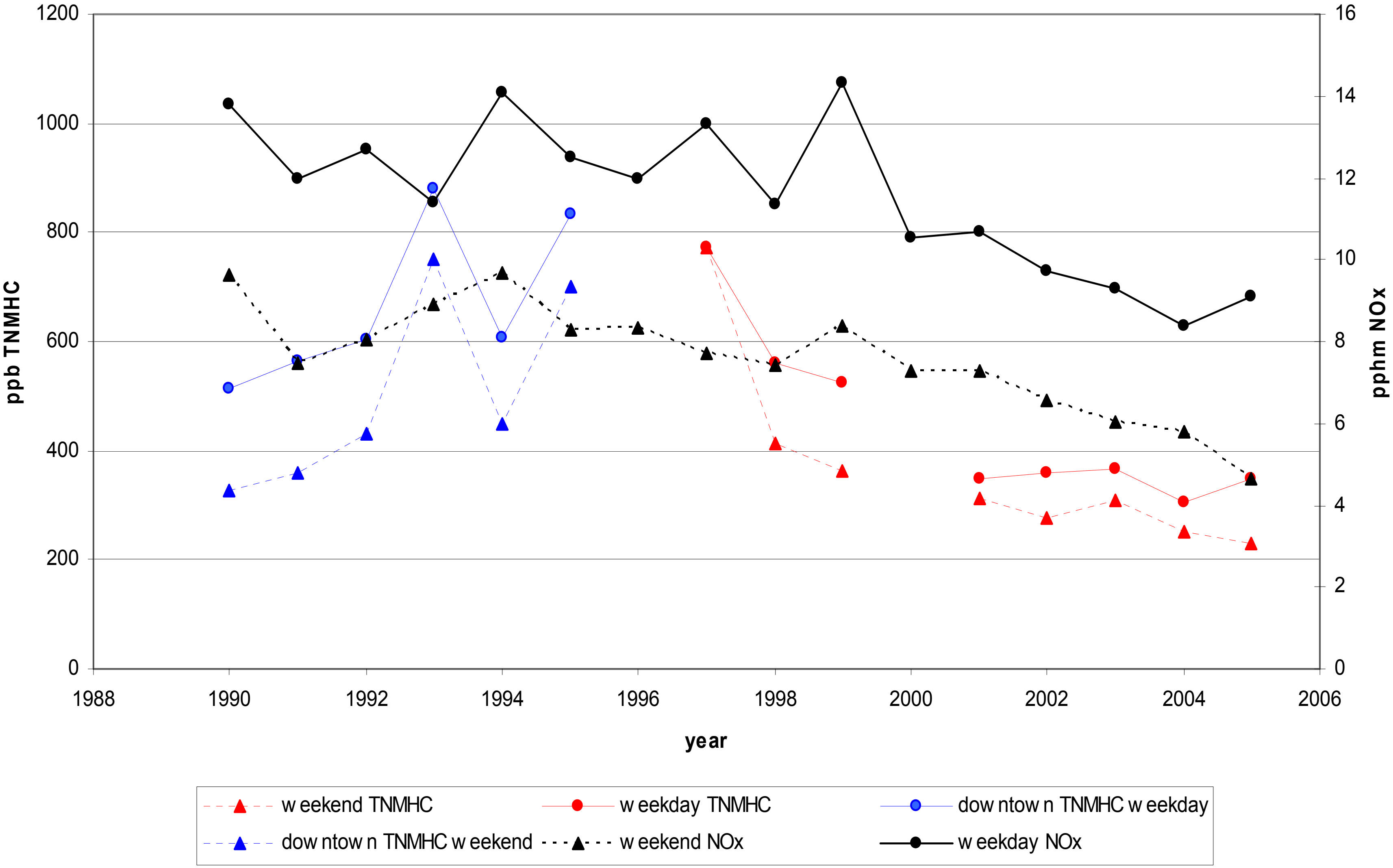
- Very Unhealthy
- Unhealthy
- Unhealthy for Sensitive Groups
- Moderate
- Good

Hydrocarbon/ Oxides of Nitrogen Trends

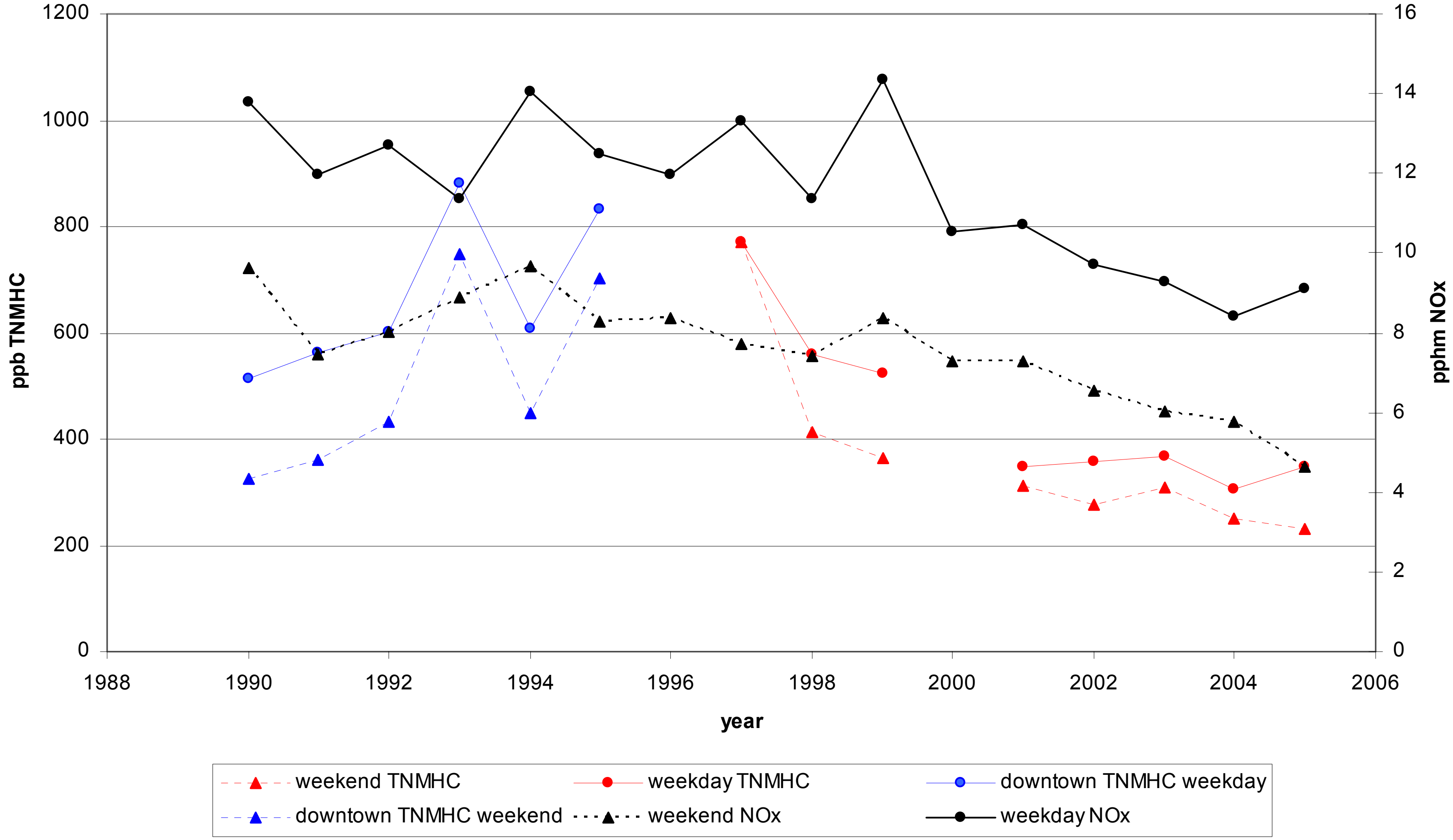
Average NMHC and NOx Concentrations



Comparison of 6-9 am NMHC and NOx Concentrations at Burbank

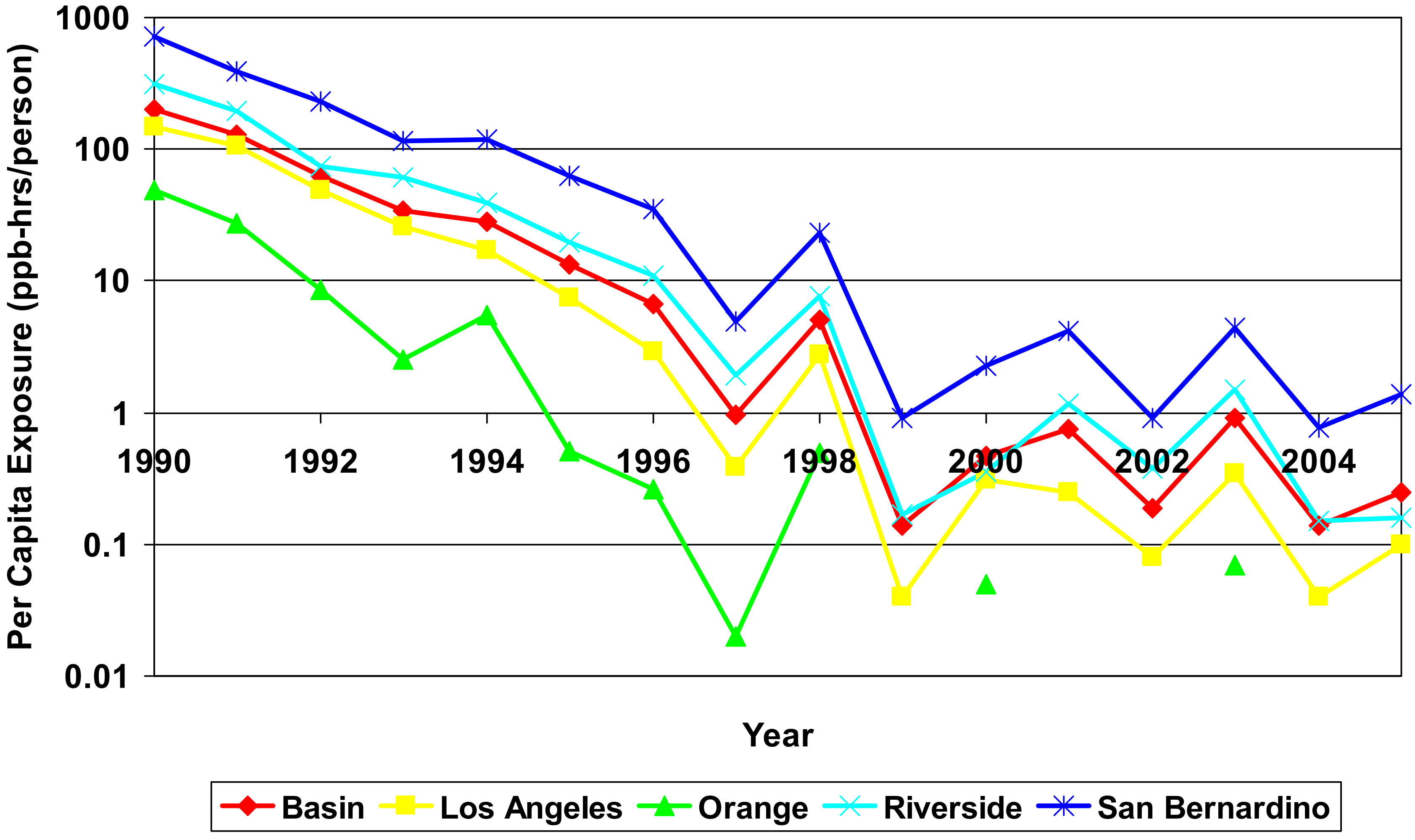


Comparison of 6-9 am NMHC and NOx Concentrations at Pico Rivera

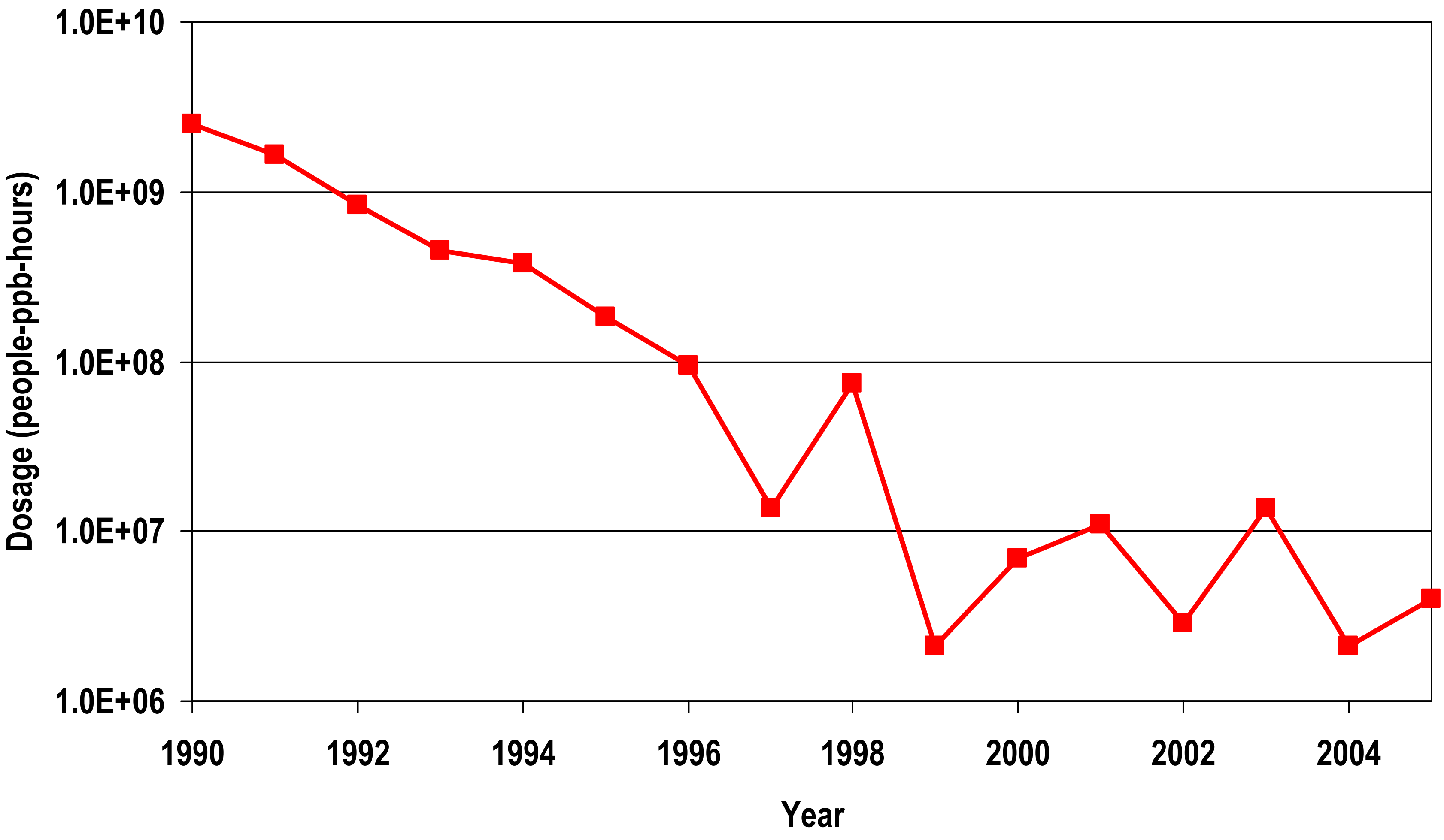


Ozone Exposure/ Dosage Trends

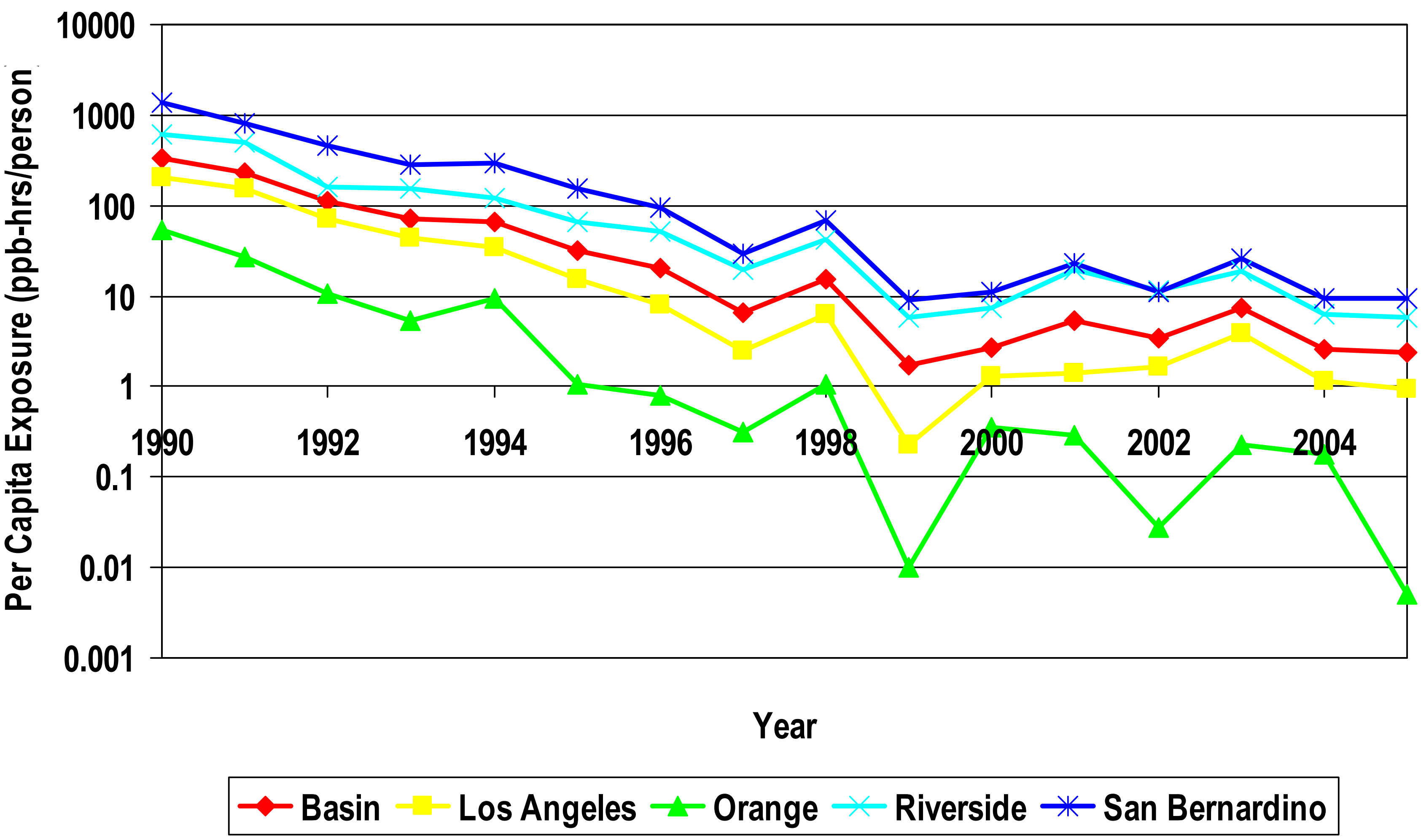
Per Capita Ozone Exposure Above the Federal 1-Hour Standard



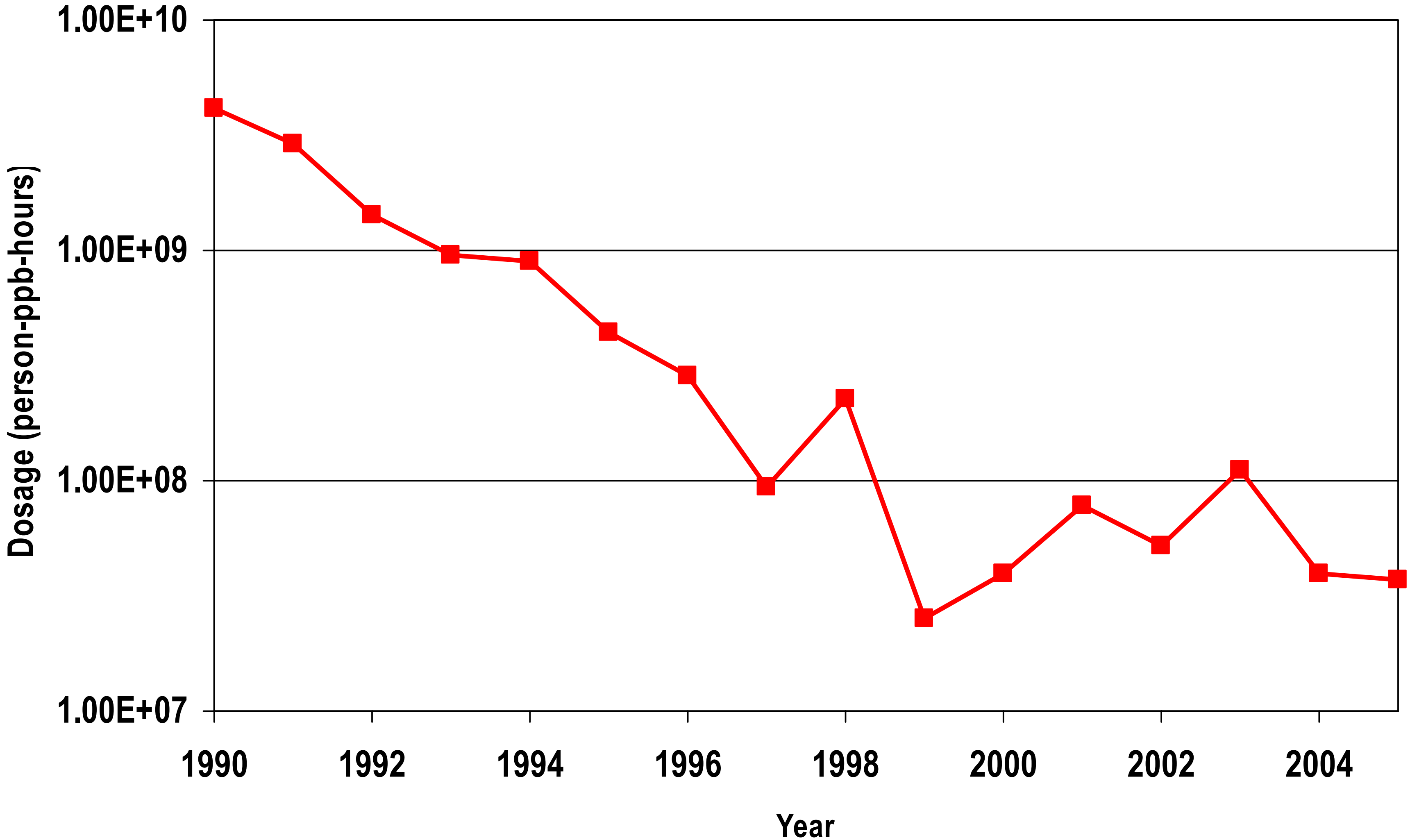
Population Dosage to 1-Hour Ozone



Per Capita Ozone Exposure Above the Federal 8-Hour Standard



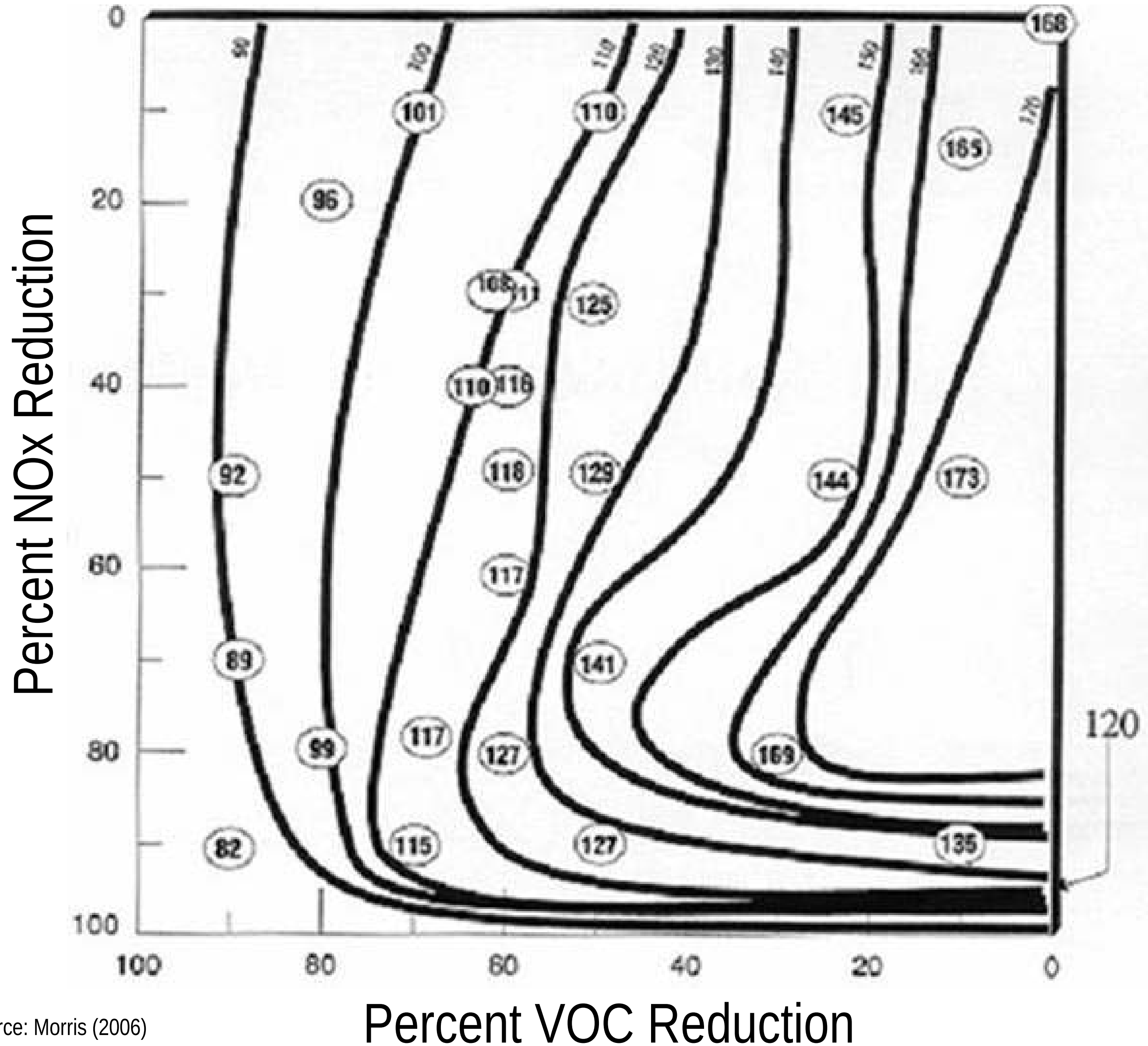
Population Dosage to 8-Hour Ozone



Ozone Air Quality Modeling

- Used for Attainment Demonstration
- Provides Guidance on Levels and Direction of Controls

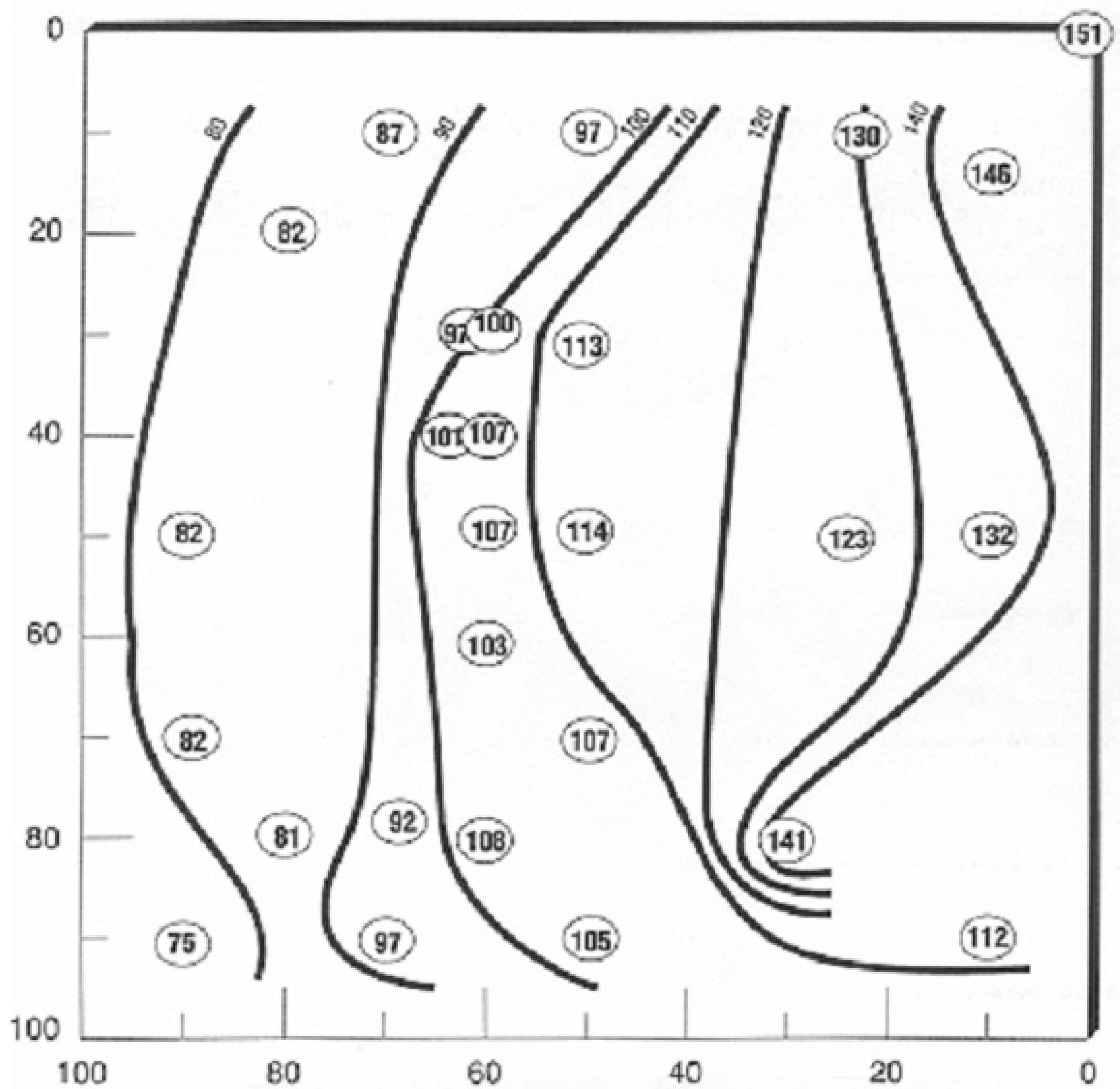
Example 1-Hr Ozone Isopleth



Source: Morris (2006)

Example 8-Hr Ozone Isopleth

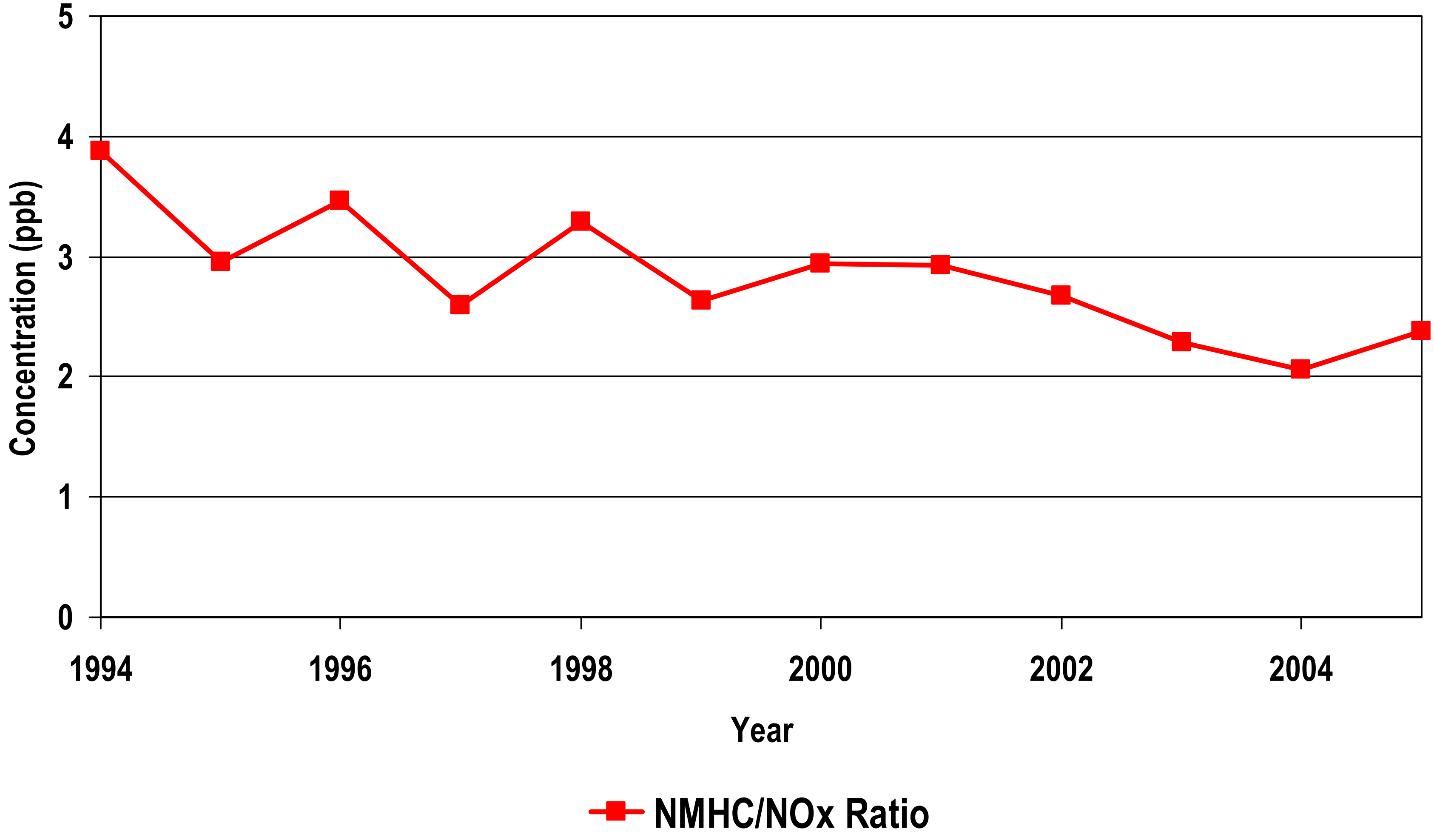
Percent NOx Reduction



Percent VOC Reduction

Source: Morris (2006)

Trend in Measured NMHC/NOx Ratios



Summary

- Peak Ozone Concentrations Appear to be Leveling in Recent Years
- Hydrocarbon Concentrations Decreasing Slower in Recent Years
- Population Exposure and Dosage Decreasing (Year-to-Year Variation Larger as Exposure/Dosage Decrease)

Parameters Influencing Ozone Levels

- Chemistry
- Meteorology
- Emissions
- Socioeconomic Growth Patterns
- Control Program Effectiveness

APPENDIX B

DR. JOHN SEINFELD

CHEMISTRY OF OZONE FORMATION IN THE ATMOSPHERE

1. Basic Photochemical Cycle of NO_2, NO, and O_3

$NO_2 + h\nu$	$\longrightarrow$	$NO + O$	(1)
$O + O_2 + M$	$\longrightarrow$	$O_3 + M$	(2)
$O_3 + NO$	$\longrightarrow$	$NO_2 + O_2$	(3)

These reactions occur relatively rapidly so that a steady state is reached, in which the ozone concentration is

$$[O_3] = \frac{j_{NO_2}[NO_2]}{k_3[NO]}$$

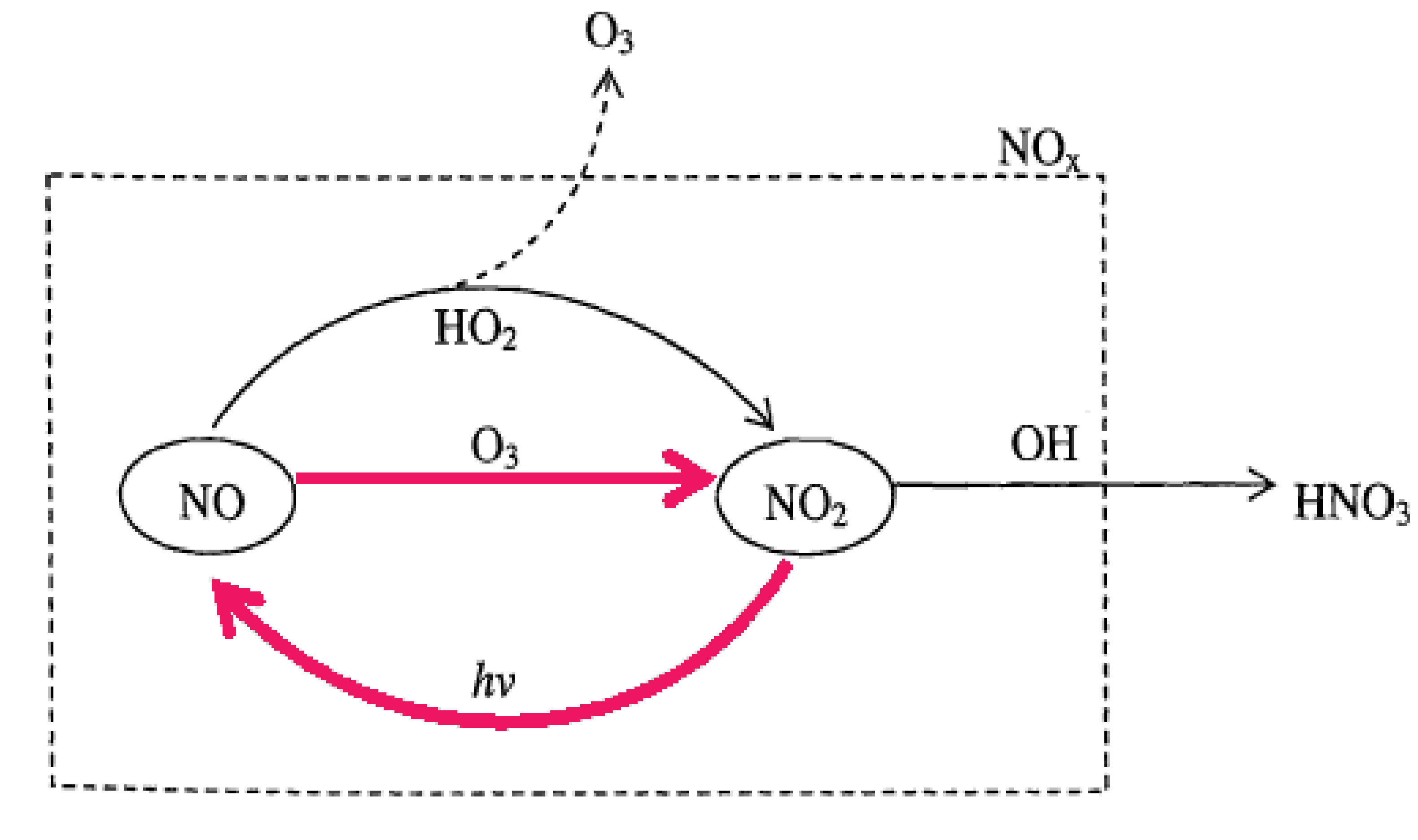
2. Atmospheric Chemistry of Carbon Monoxide

$$CO + OH \xrightarrow{O_2} CO_2 + HO_2 \quad (1)$$

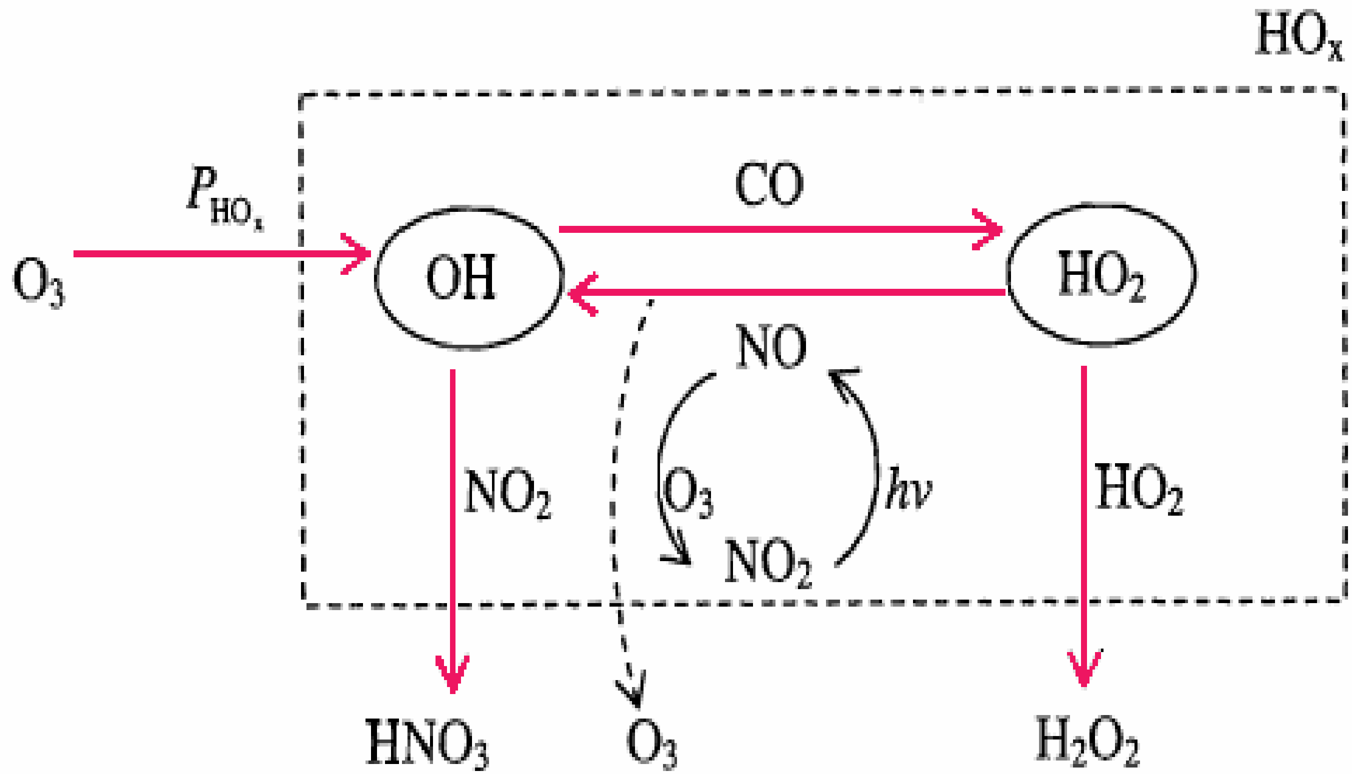
$$HO_2 + NO \longrightarrow NO_2 + OH \quad (2)$$

$$HO_2 + HO_2 \longrightarrow H_2O_2 + O_2 \quad (3)$$

$$OH + NO_2 + M \longrightarrow HNO_3 + M \quad (4)$$



$$P_{O_3} = k_{HO_2+NO}[HO_2][NO]$$



HOx
PHOx
CO
O3
OH
HO2
NO
NO2
O3
hv
HO2
NO2
HNO3
O3
H2O2

3. Dependence of O_3 Formation on NO_x

Low NO_x Limit

Principal sink of HO_x is HO_2 + HO_2

$$P_{O_3} \sim [NO] \Leftarrow \text{As } NO_x \uparrow, P_{O_3} \uparrow$$

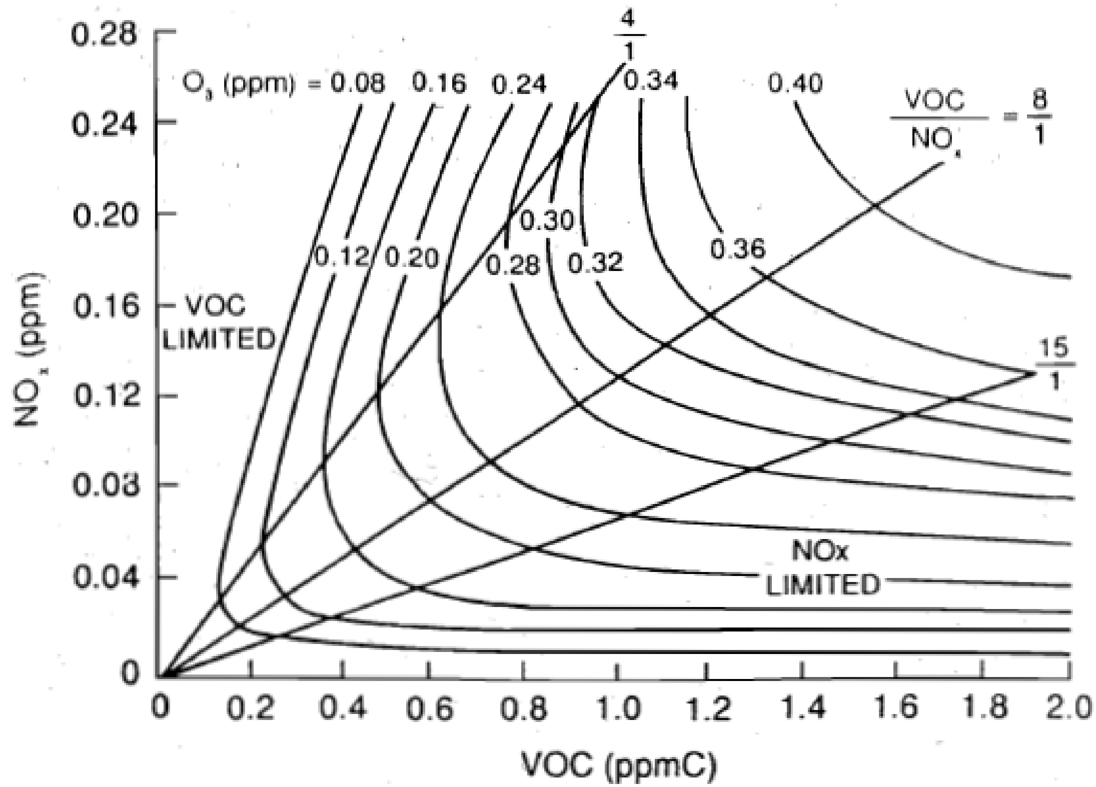
High NO_x Limit

Principal sink of HO_x is OH + NO_2

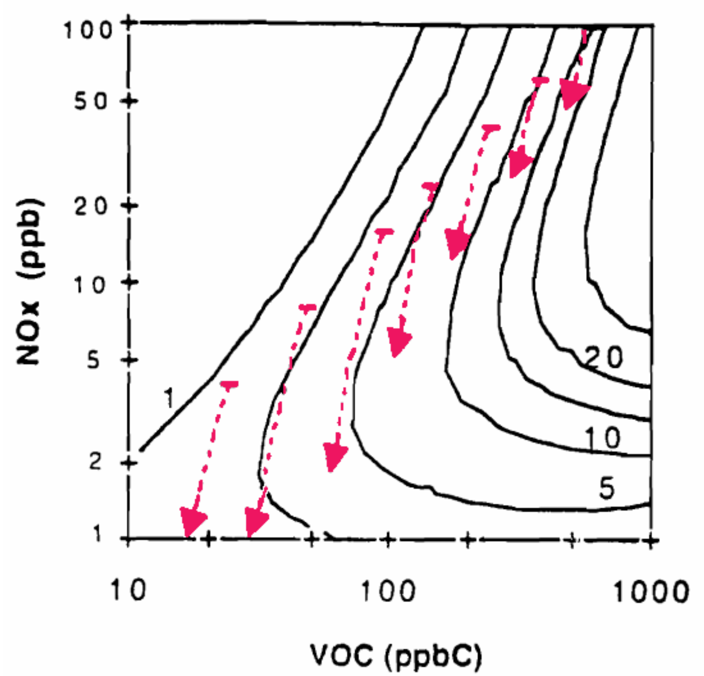
$$P_{O_3} \sim [CO]/[NO_2] \Leftarrow \text{As } NO_x \uparrow, P_{O_3} \downarrow$$

4. Ozone Production Efficiency

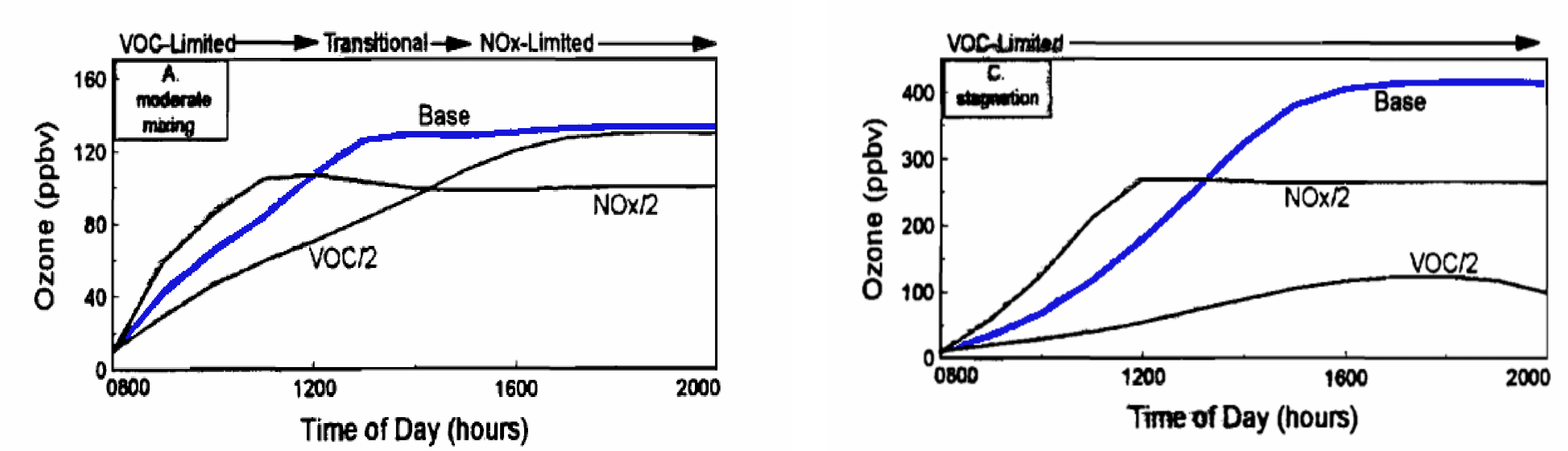
$$\text{OPE} = \frac{P_{O_3}}{L_{NO_x}}$$



Typical ozone isopleths used in EPA's EKMA. The NO_x^- limited region is typical of locations downwind of urban and suburban areas, whereas the VOC-limited region is typical of highly polluted urban areas.
Source: Adapted from Dodge, 1977.



Isopleths giving net rate of ozone production (ppb/h, solid lines) as a function of VOC (ppbC) and NOx, (ppb) for mean summer daytime meteorology and clear skies. The solid lines represent production rates of 1, 2.5, 5, 10, 15, 20 and 30 ppb/h. The dashed lines and arrows show the calculated evolution of VOC and NOx concentrations in a series of air parcels over an 8 h period (9am – 5pm), each with initial VOC/NOx = 6 and speciation typical of urban centers in the US, based on calculations shown in Milford et al. (1994)



Simple model calculations illustrating the varying sensitivity of O_3 photochemical production to VOC and NO_x. In each panel, model-calculated O_3 concentrations are plotted as a function of time of day for a hypothetical air parcel containing an initial, urban-like mixture of anthropogenic VOC and NO_x under summertime conditions with 1 ppb of biogenic isoprene and varying rates of vertical mixing and free tropospheric entrainment. For each mixing rate, simulations for three initial VOC and NO_x concentrations are presented: "Base" with initial VOC and NO_x = 1.5 and 0.25 ppm respectively; "VOC/2" with initial VOC = 0.75 and NO_x = 0.25 ppm; and "NO_x/2" with initial NO_x = 0.125 and VOC = 1.5 ppm. Note the characteristic tendency for the system to evolve from VOC-limitation to NO_x-limitation with time for the point of transition to be delayed as mixing decreases.

APPENDIX C

DR. ROBERT HARLEY

Sensitivity Analysis in Air Quality Modeling

Prof. Robert Harley

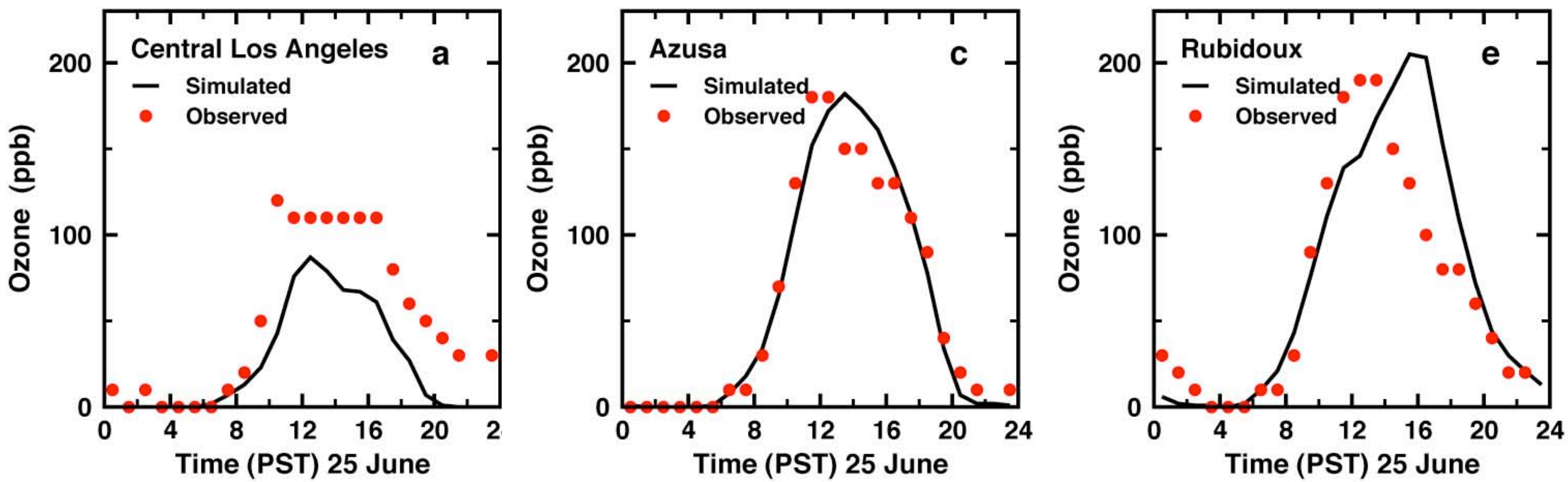
University of California, Berkeley

harley@ce.berkeley.edu

Air Quality Models

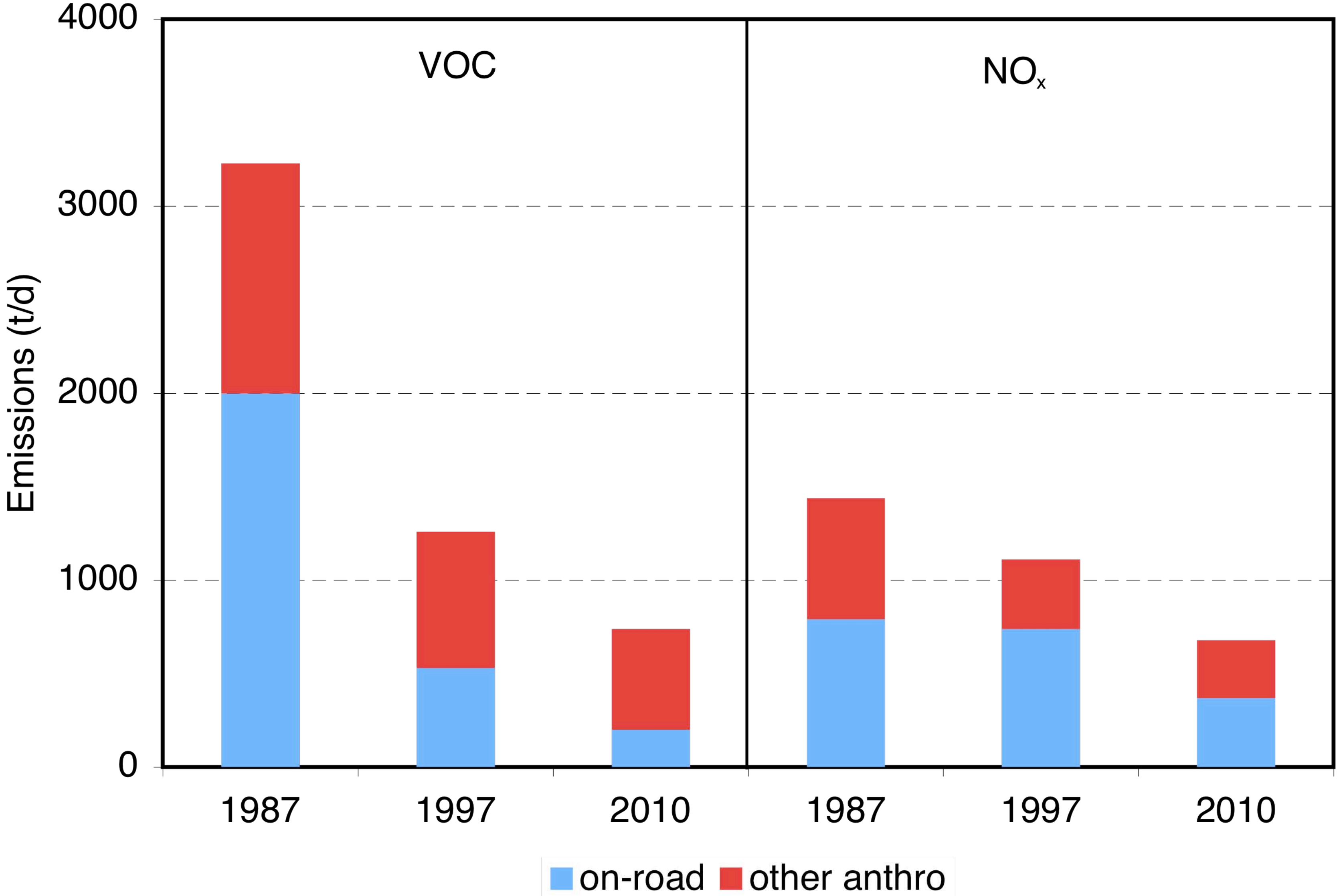
- Analyze & synthesize understanding of
  - Emissions
  - Atmospheric chemistry
  - Meteorology
  - Deposition
- Demonstrate future attainment of air quality standards

Observed and Predicted O_3



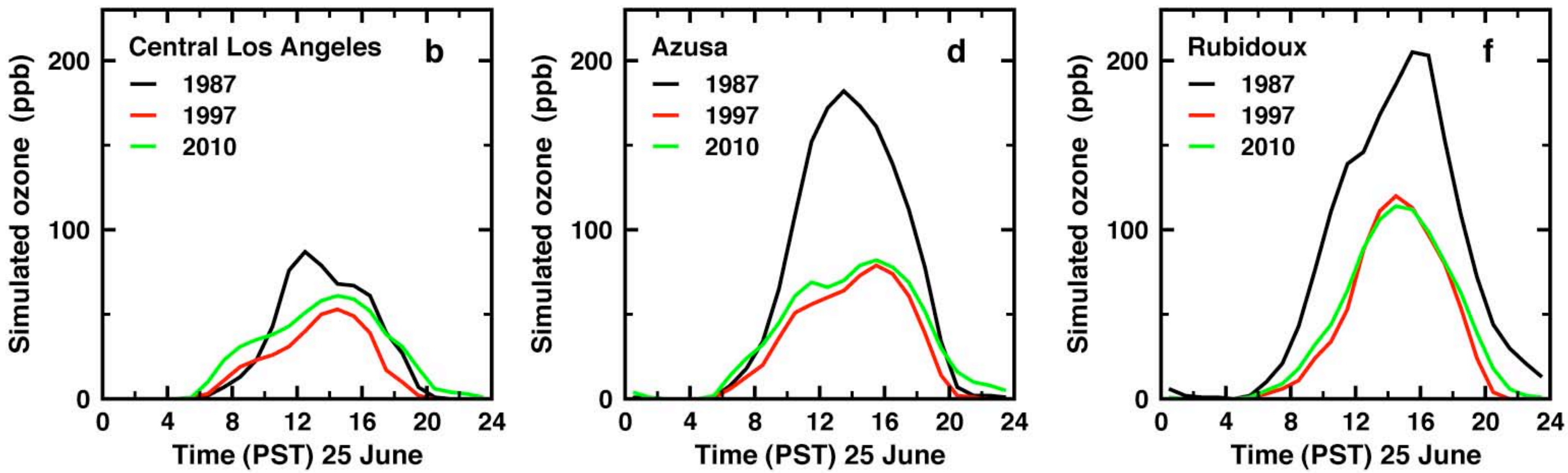
Historical 1987 O_3 episode (Martien et al. *ES&T* 2003)
Model performance (37 sites, O_3 > 60 ppb):
Bias = +6%; Gross error = 41%

Emission Scenarios



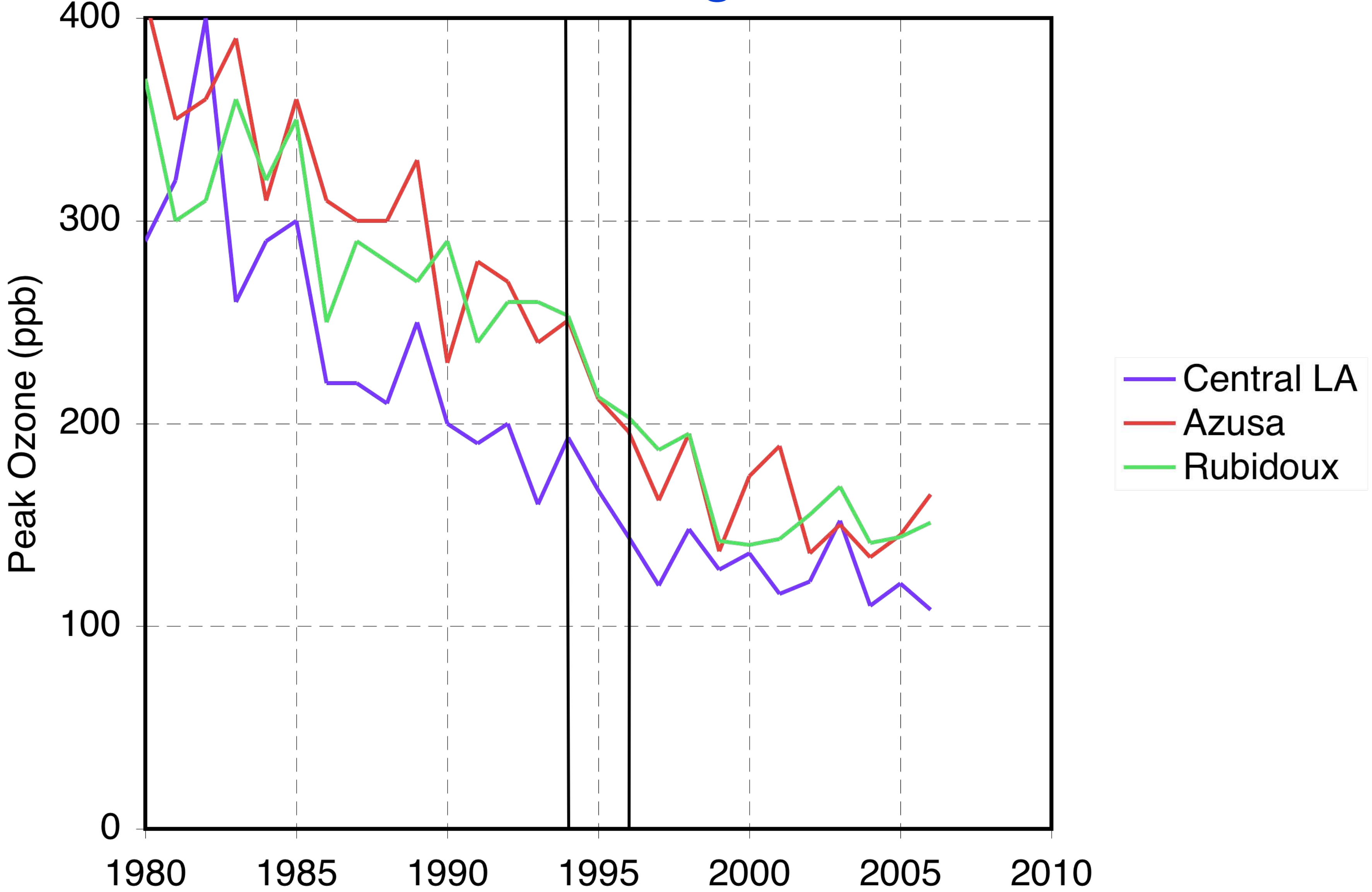
Sources: Harley et al. (*ES&T* 1997) for 1987; 2003 AQMP for 1997 & 2010

Predicted O_3 Response to Emission Changes



Martien and Harley (*ES&T* 2006)

Observed O_3 Trends



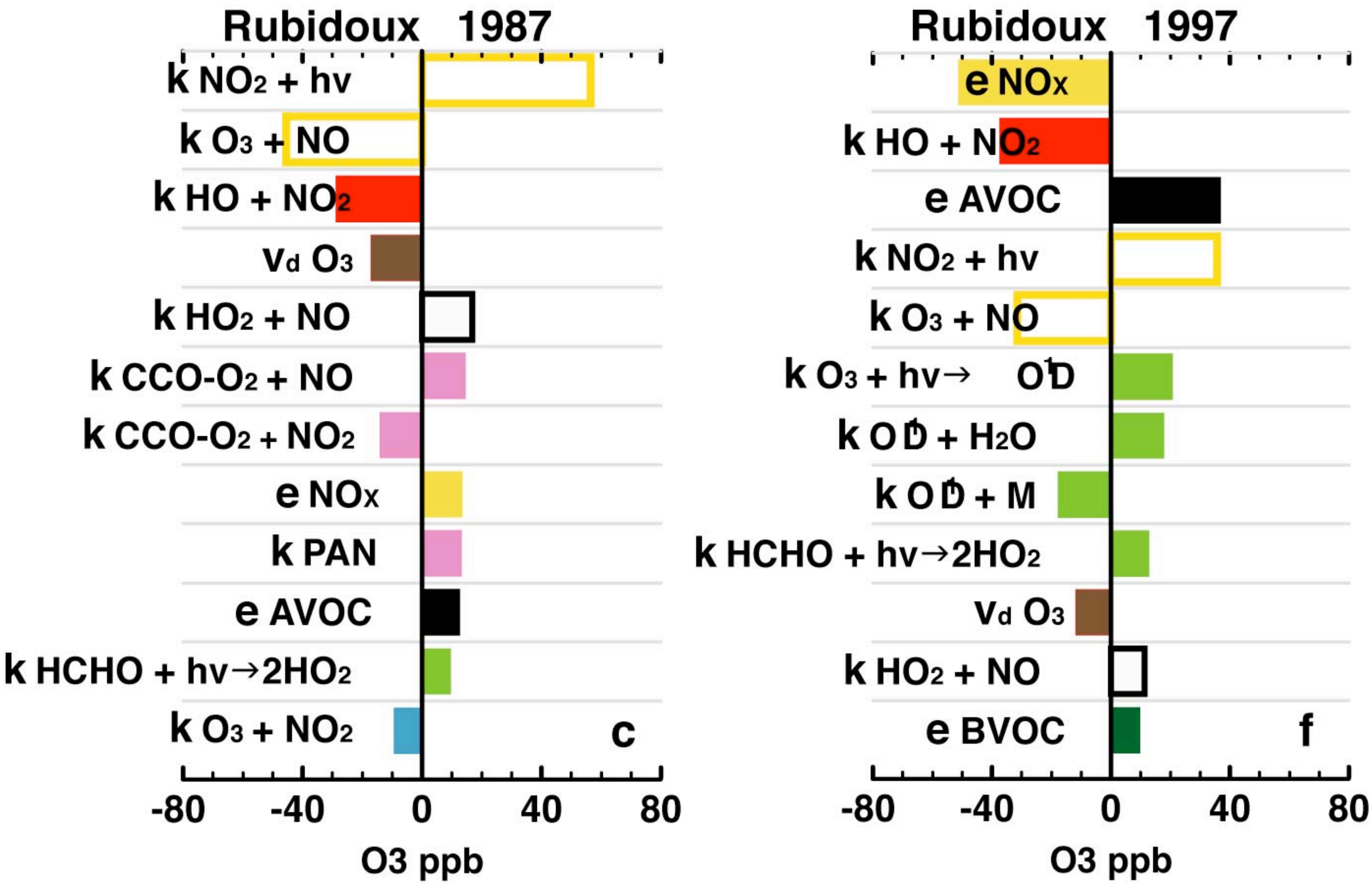
Sensitivity Analysis

- What is model response to input data?

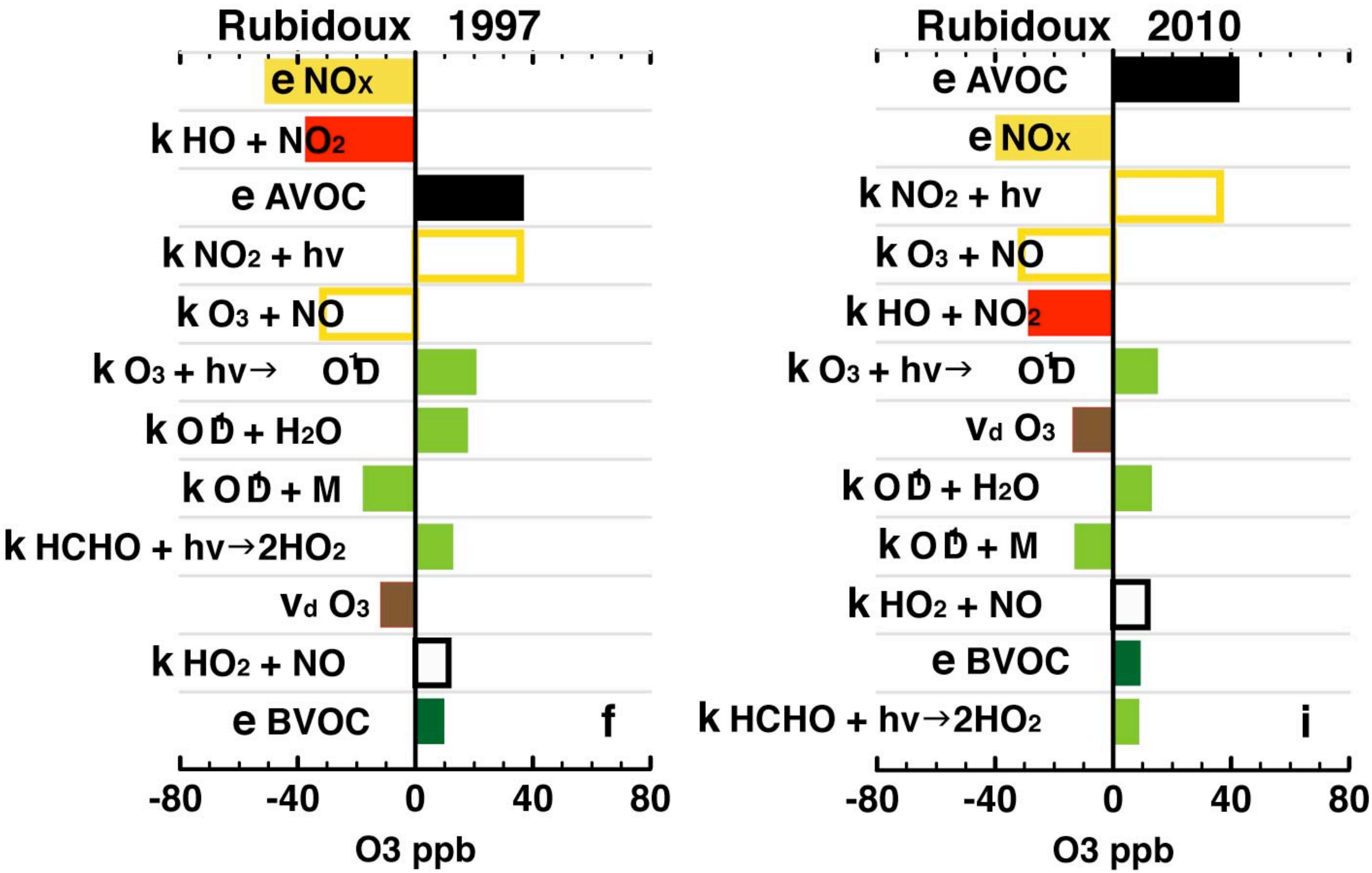
$$s_{ij} = \frac{\partial C_i}{\partial \lambda_j}$$

- Used adjoint method to calculate s_{ij} for 900 model inputs (BC, IC, *E*, *k*, v_d)
- Three emission scenarios (1987, 1997, 2010)
- See Martien and Harley (*ES&T* 2006)

O_3 Sensitivity (Ranked)



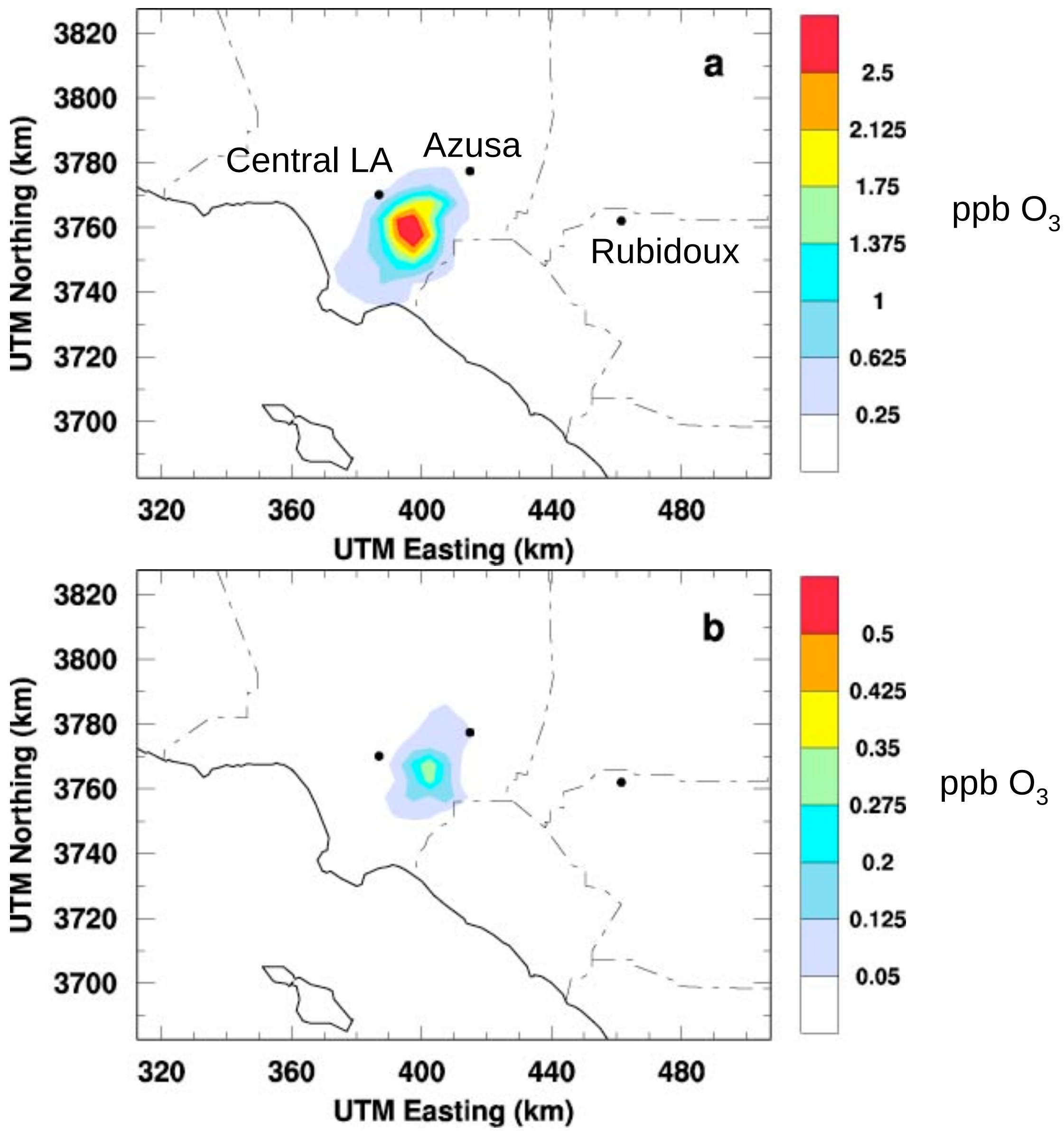
O_3 Sensitivity (Ranked)



Contributions to $\partial O_3 / \partial E_{VOC}$

Anthropogenic (AVOC)

Biogenic (BVOC)



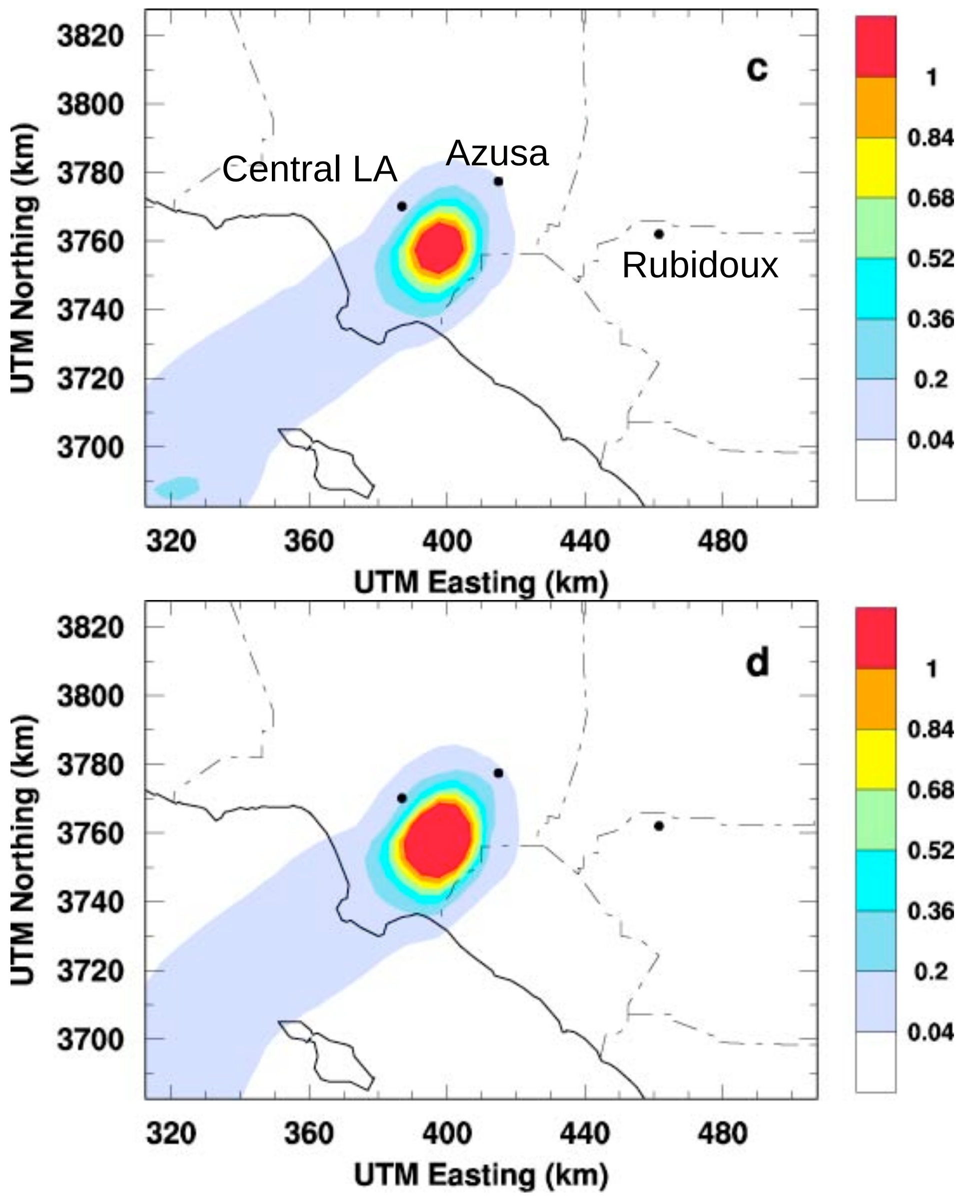
Potential Sensitivity

- Previous results show effects of <u>multiplicative</u> scaling of parameters λ_j
- Can also calculate potential sensitivity to <u>additive</u> perturbations to λ_j
- Example: effect of adding emissions where $E = 0$ in base case?

Potential Sensitivity to E_{VOC}

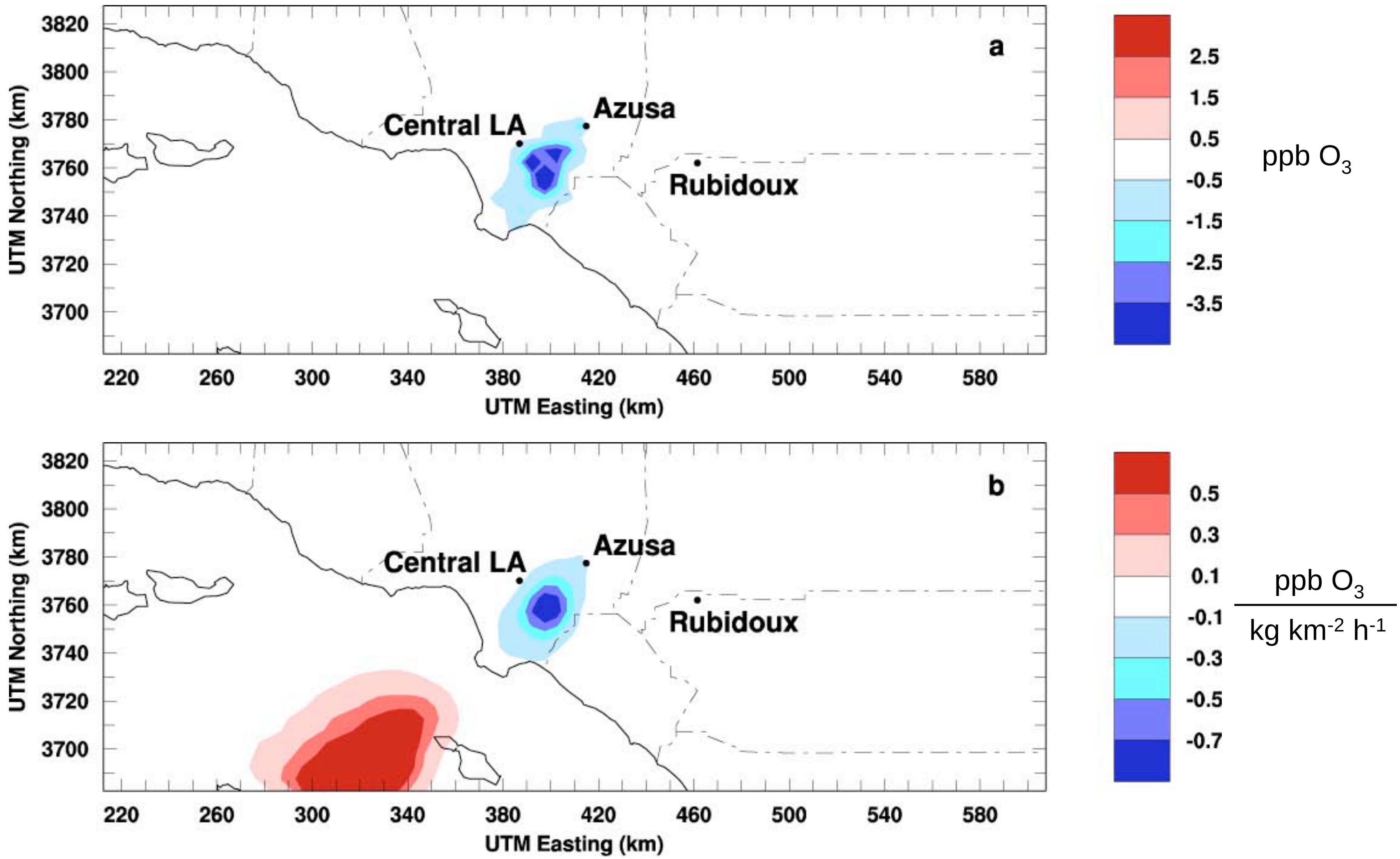
Propene

Isoprene



$\frac{\text{ppb } O_3}{\text{kg km}^{-2}\text{ h}^{-1}}$

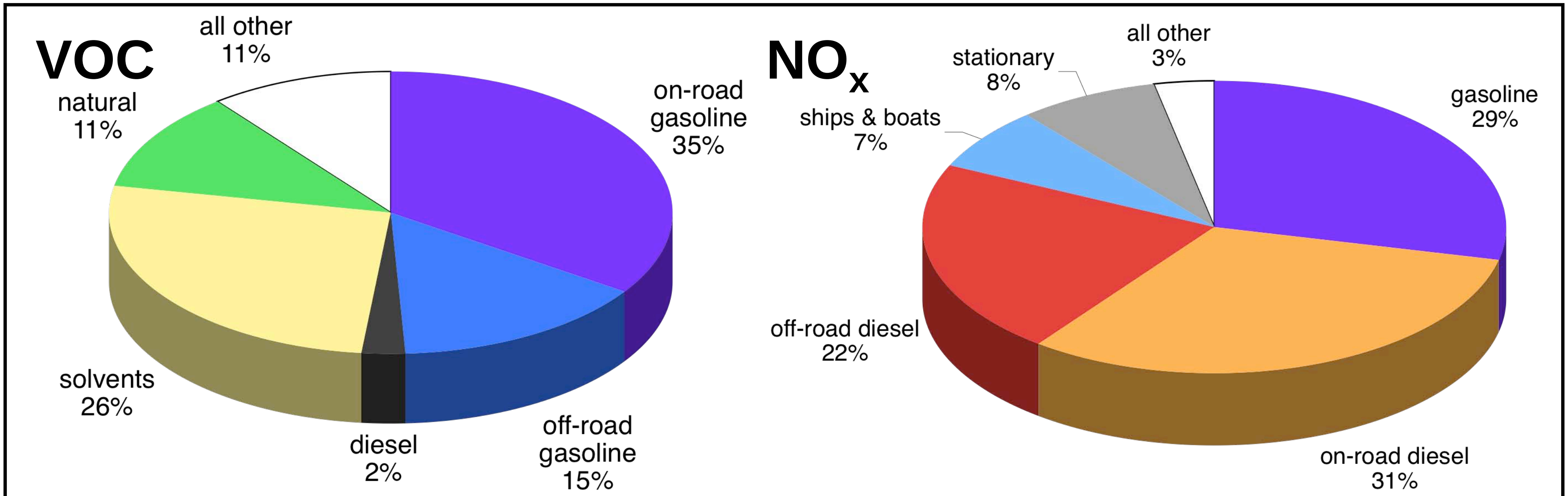
Actual vs Potential Sens to E_{NOx}



Summary

- Adjoint method used to study O_3 sensitivity to many model inputs
- Anthropogenic emissions found to be highly influential (also uncertain!)
- Mapped source regions that affect air quality at specified locations

Emission Inventory (2005)



- Annual average emissions for South Coast Air Basin
- VOC = 770 ton/day; mainly gasoline and solvents
- NO_x = 960 ton/day; mainly diesel and gasoline combustion
- Source: CARB (2006) Air Quality Almanac

APPENDIX D

DR. MICHAEL BENJAMIN

Ozone Precursor Emission Trends in the South Coast Air Basin 1990-2020

(Presentation Revised – November 1, 2006)

Michael Benjamin
California Air Resources Board

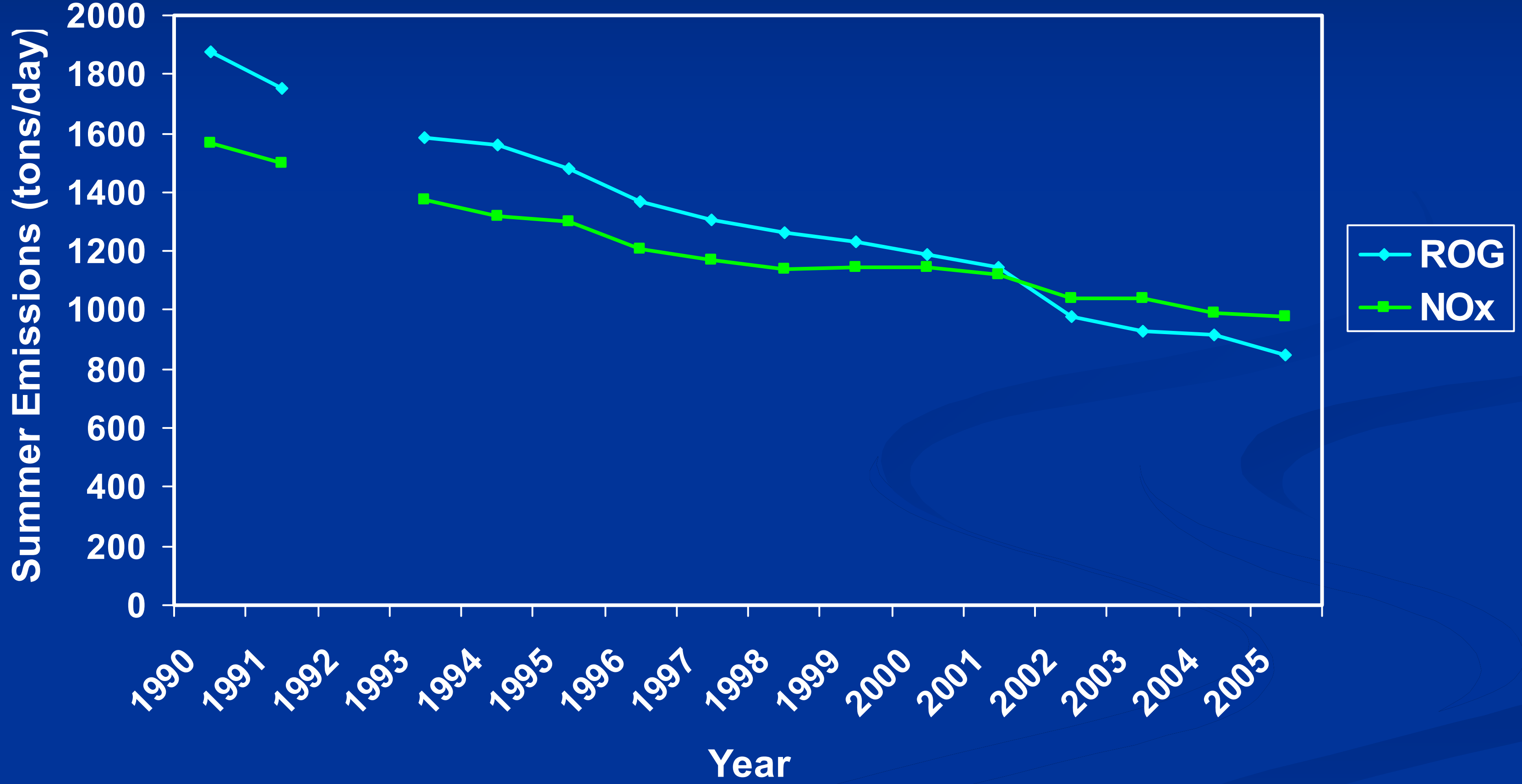
October 31, 2006
Ozone Air Quality Forum and Roundtable Discussion
Diamond Bar, California

Overview

- Historical ROG and NOx emissions trends
- Future ROG and NOx emissions trends
- Major ROG and NOx sources
- Mobile source inventory improvements
- Mobile source inventory research

Ozone Precursor Emissions

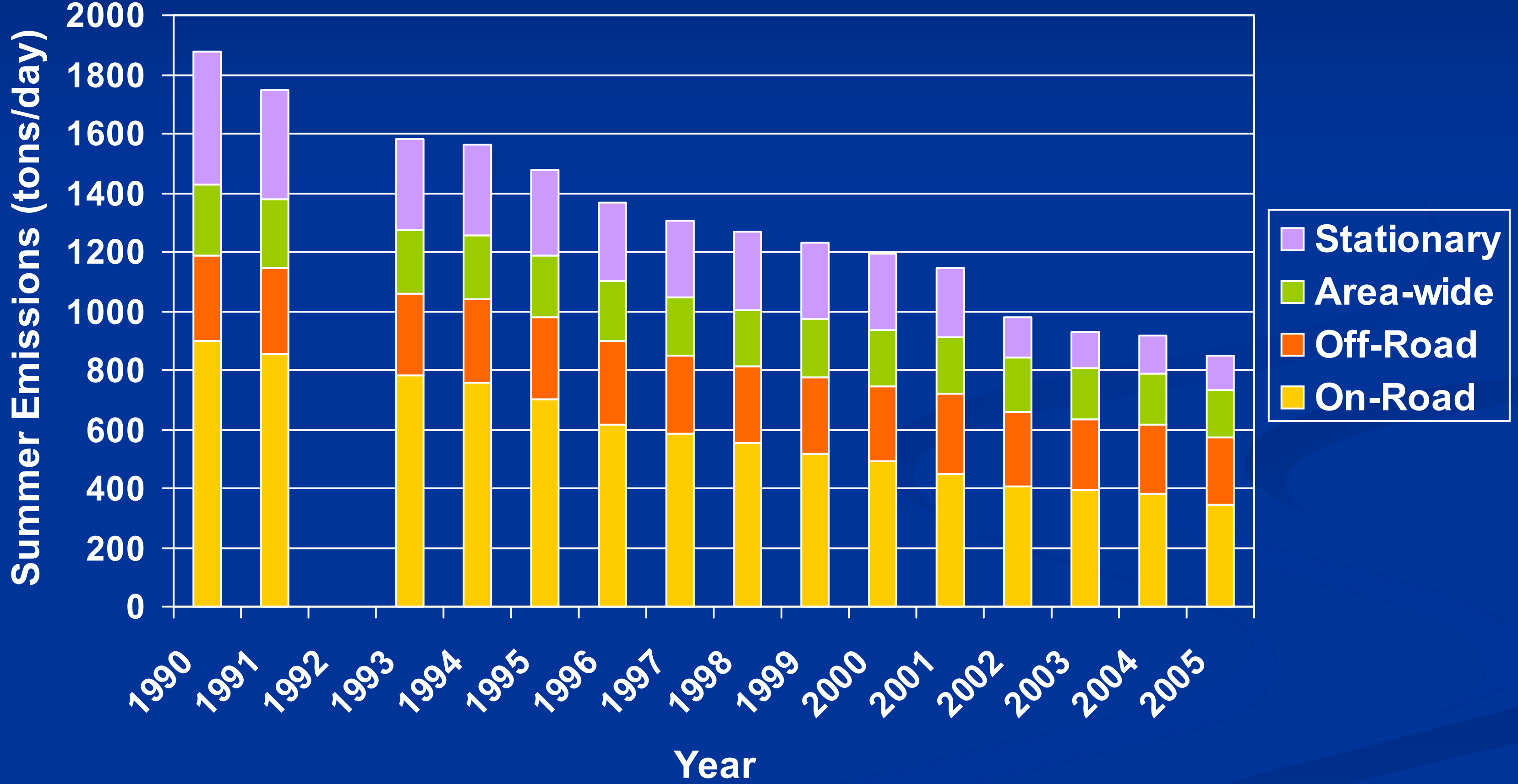
South Coast Air Basin 1990-2005 (Summer Day)



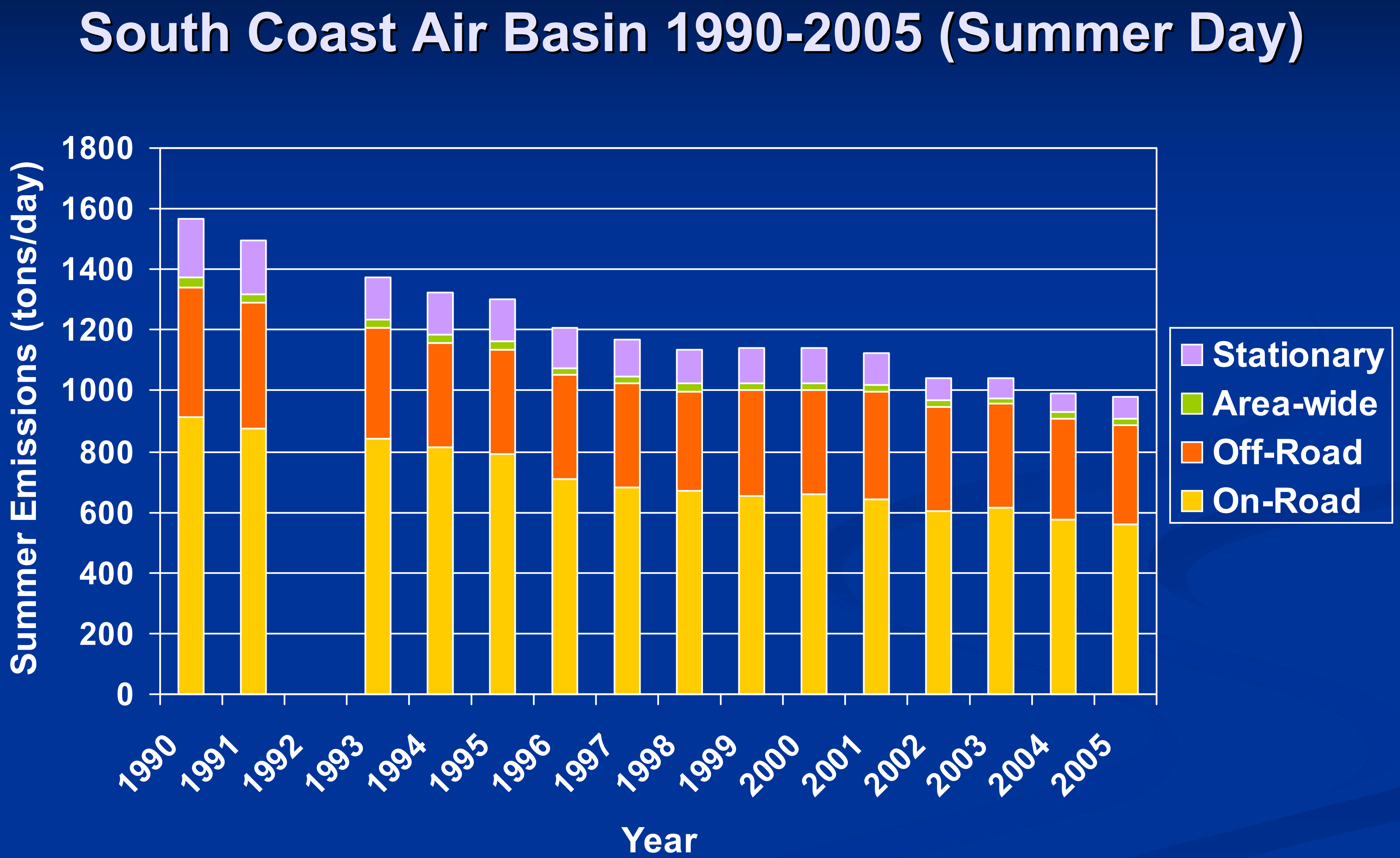
Note: Does not include biogenic emissions and ship emissions beyond 3 miles from shore

ROG Emissions Trend

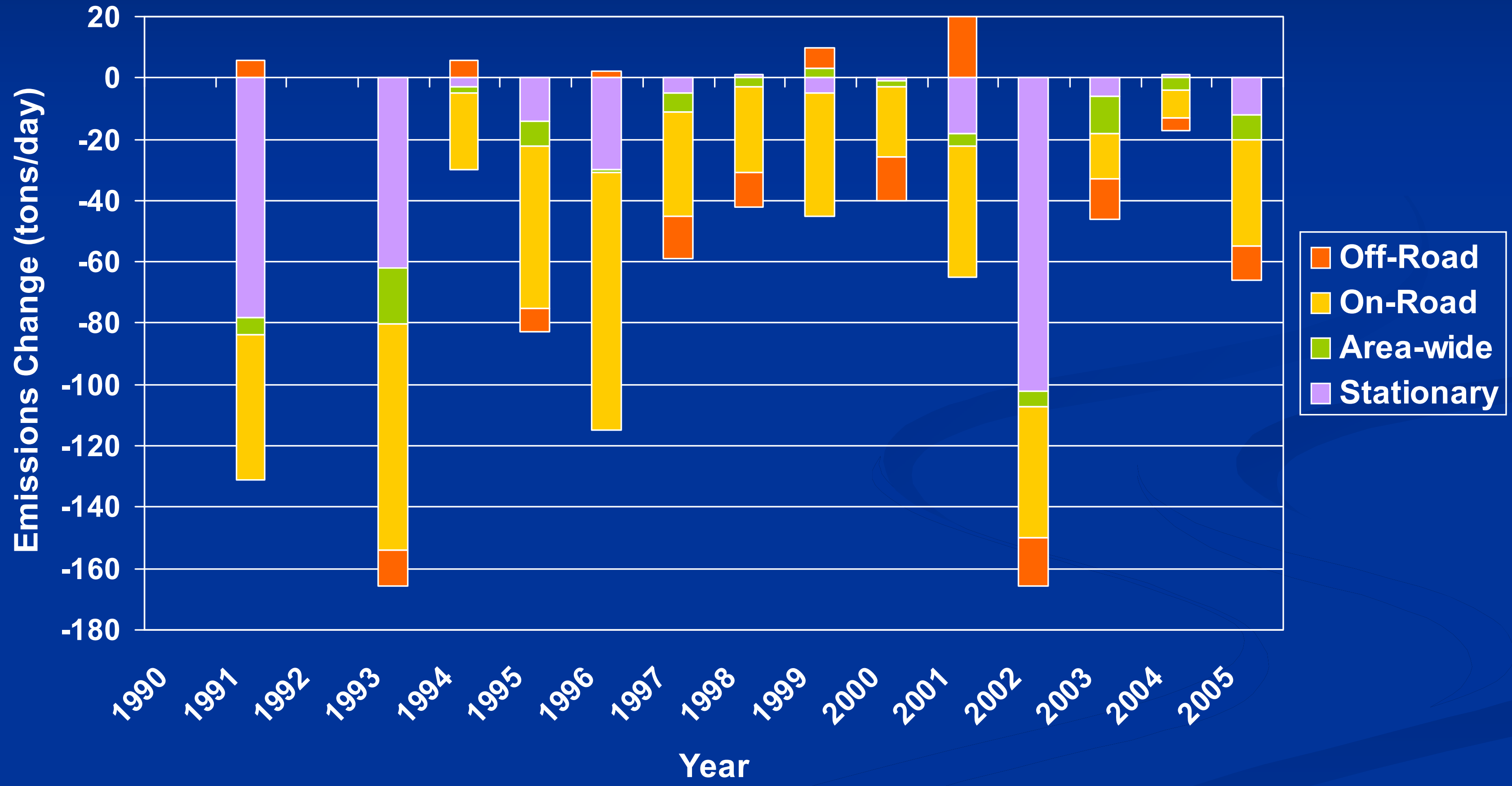
South Coast Air Basin 1990-2005 (Summer Day)



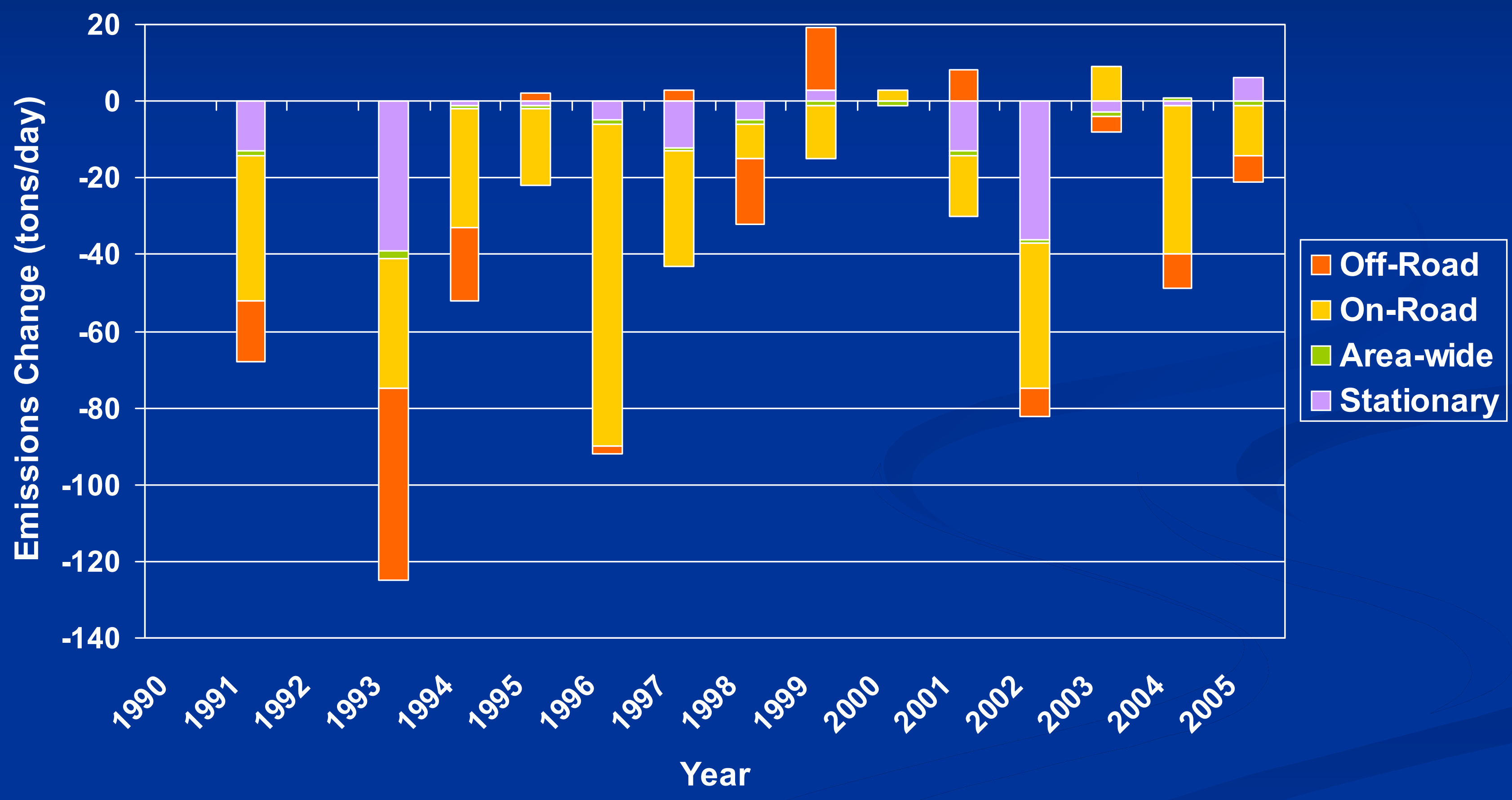
NOx Emissions Trend



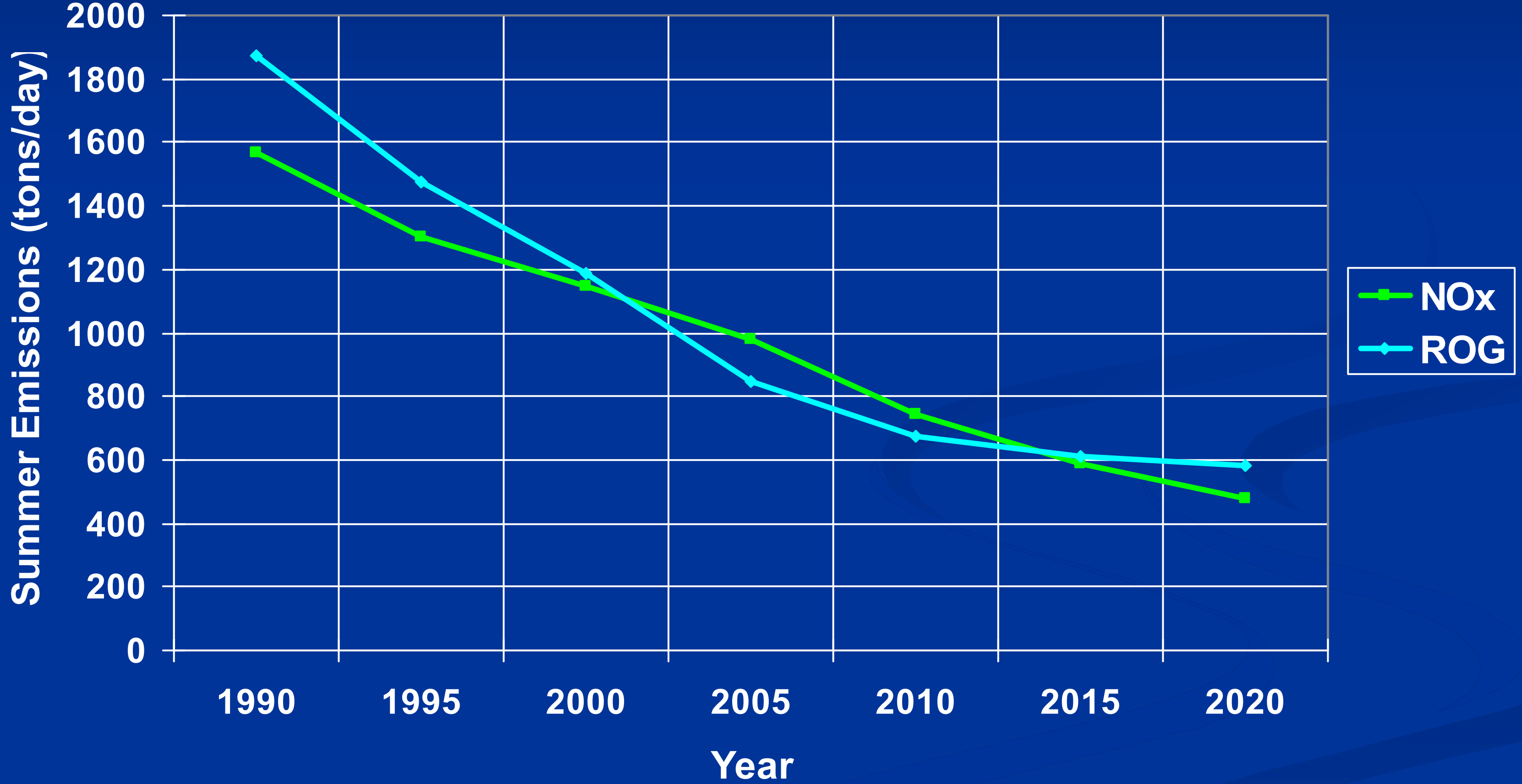
Incremental Annual ROG Emissions Reductions
(reflecting year to year impacts of growth and benefits of controls)
South Coast Air Basin 1990-2005 (Average Summer Day)



Incremental Annual NOx Emissions Reductions
(reflecting year to year impacts of growth and benefits of controls)
South Coast Air Basin 1990-2005 (Average Summer Day)



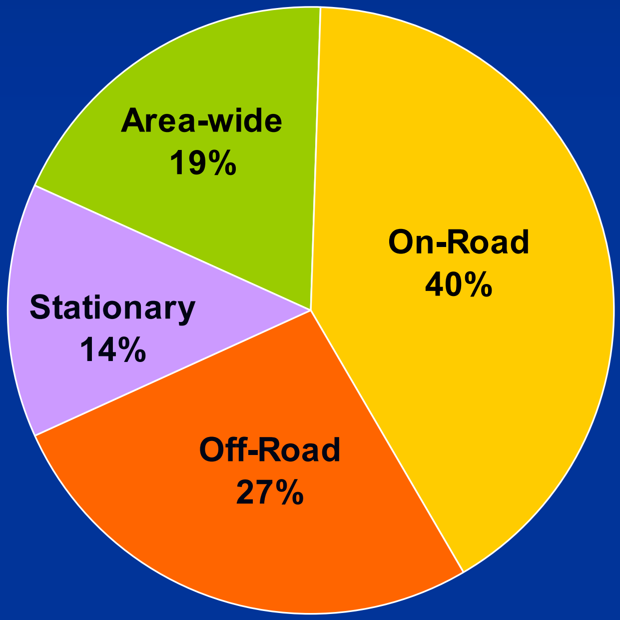
Ozone Precursor Emissions
South Coast Air Basin 1990-2020



Note: Does not include biogenic emissions and ship emissions beyond 3 miles from shore

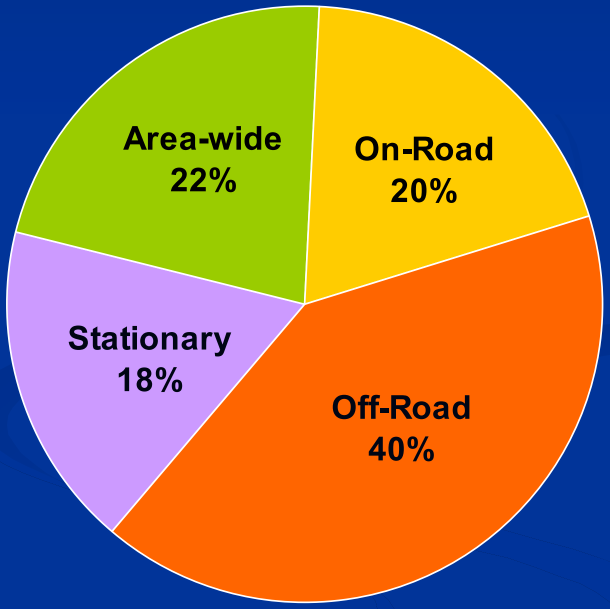
Changes in ROG Source Contributions
South Coast Air Basin 2005 and 2020 (Summer Day)

2005



842 tpd

2020



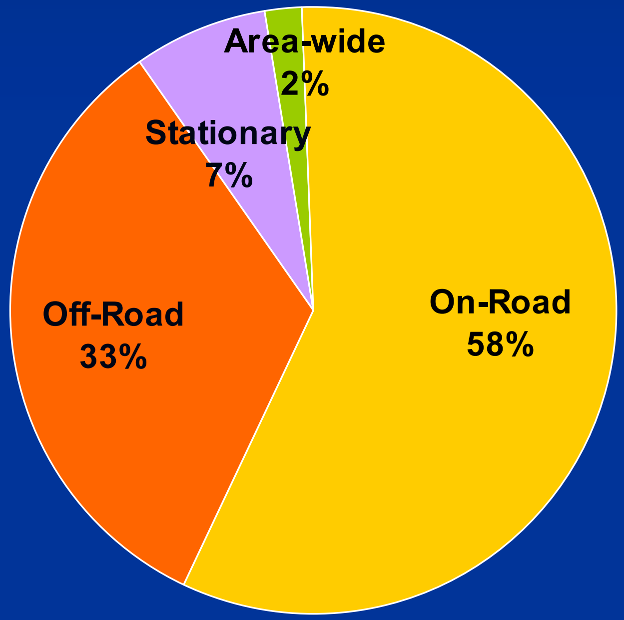
574 tpd

Top 10 ROG Sources
South Coast Air Basin 2020 (Summer Day)

			2005		2020	
2005	2020	Source Category	ROG (tpd)	% of Total	ROG (tpd)	% of Total
2	1	Consumer Products	101	12.0	112	19.5
1	2	Light Duty Passenger Cars	282	33.5	101	17.6
3	3	Recreational Boats	90	10.7	63	11.0
4	4	Lawn and Garden Equipment	50	6.0	31	5.4
5	5	Architectural Coatings (Paints)	46	5.4	30	5.3
10	6	Off-Road Recreational Vehicles	20	2.4	30	5.2
7	7	Gasoline Evaporative Losses	27	3.2	30	5.2
9	8	Non-Architectural Coatings	24	2.8	23	4.1
6	9	Heavy Duty Gas Trucks	33	3.9	16	2.7
19	10	Aircraft	*	*	*	*
		Top 10 ROG	672	79.9	436	76.0
		Other	170	20.1	138	24.0
		Total	842	100.0	574	100.0

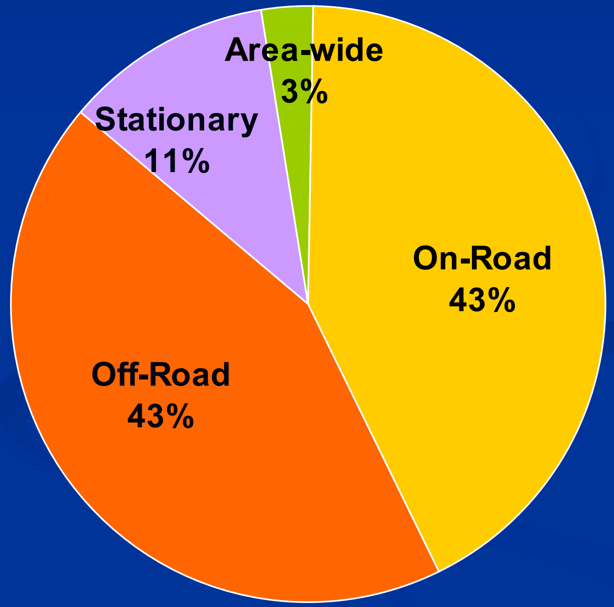
Changes in NOx Source Contributions
South Coast Air Basin 2005 and 2020 (Summer Day)

2005



977 tpd

2020



478 tpd

Top 10 NOx Sources
South Coast Air Basin 2020 (Summer Day)

			2005		2020	
2005	2020	Source Category	NOx (tpd)	% of Total	NOx (tpd)	% of Total
1	1	Heavy Duty Diesel Trucks	246	25.2	92	19.2
2	2	Light Duty Passenger Cars	243	24.9	66	13.7
6	3	Ships and Commercial Boat	40	4.1	57	12.0
4	4	GSE, TRUs, Drill Rigs, etc	98	10.0	44	9.1
3	5	Construction and Mining	104	10.7	28	5.8
12	6	Aircraft	*	*	*	*
7	7	Trains	32	3.3	26	5.4
5	8	Heavy Duty Gas Trucks	42	4.3	23	4.8
8	9	Recreational Boats	19	2.0	16	3.3
10	10	Boilers	17	1.8	14	3.0
		Top 10 NOx	842	86	366	76
		Other	134	14	113	24
		Total	977	100	478	100

Mobile Source Inventory Improvements South Coast Air Basin Impacts

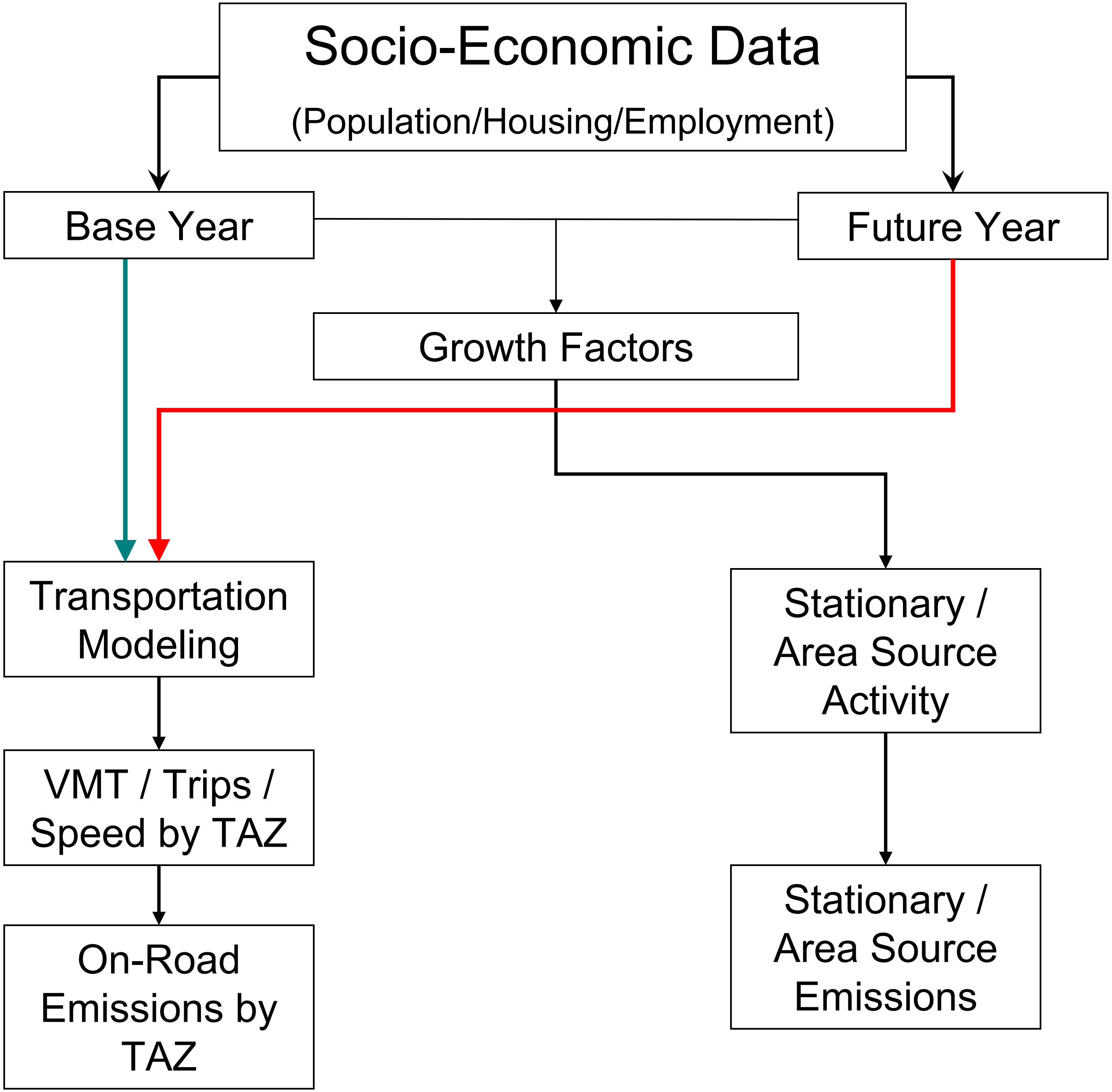
- On-Road
  - Pending vehicles (ROG ↑)
  - Heavy duty truck VMT redistribution (NOx ↓)
  - Heavy duty truck emission factors (NOx ↑)
  - Ethanol permeation (ROG ↑)
- Off-Road
  - Recreational boats (ROG ↓)
  - Construction equipment (NOx ↑)
  - Ethanol permeation (ROG ↑)
  - Gas cans (ROG ↓)

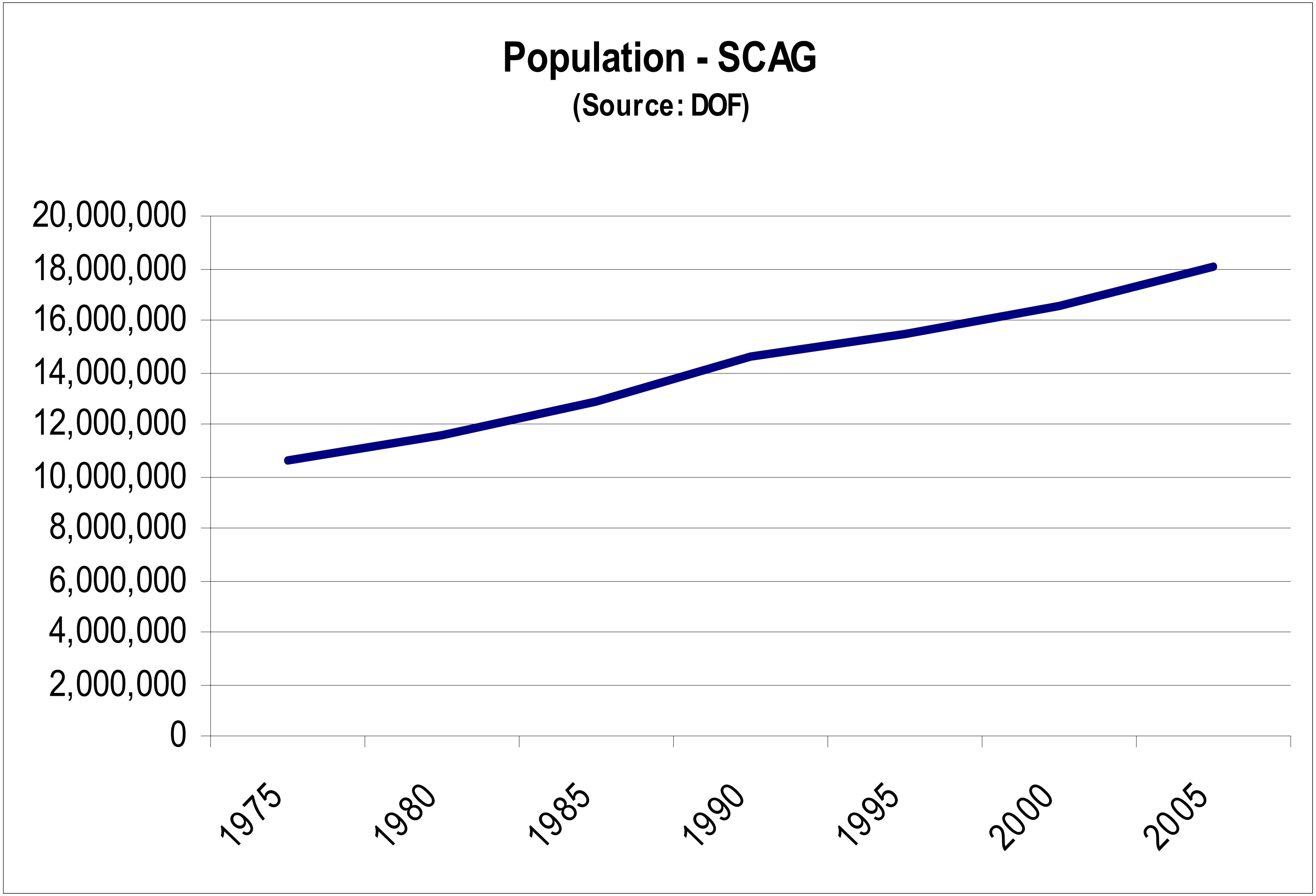
Mobile Source Inventory Research

- Current
  - Light duty passenger cars (ARB Surveillance)
  - Heavy duty trucks (South Coast)
  - Alternative fuel (ARB)
  - Gas can permeation (ARB Lab)
  - Locomotive emissions (ARB with South Coast)
- Suggested
  - Heavy duty truck activity and emissions
  - Off-road ethanol permeation
  - Off-road emissions and deterioration

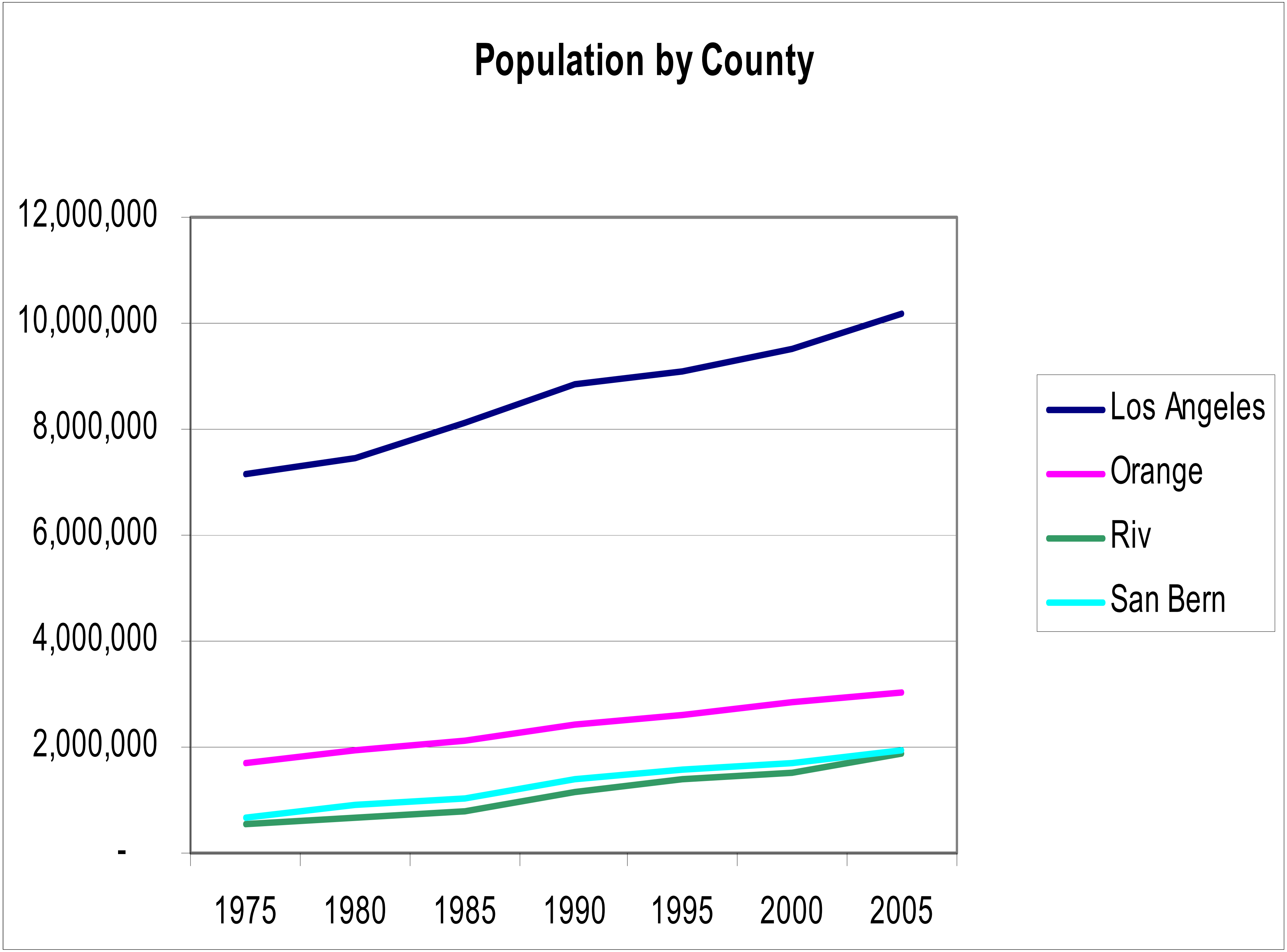
APPENDIX E

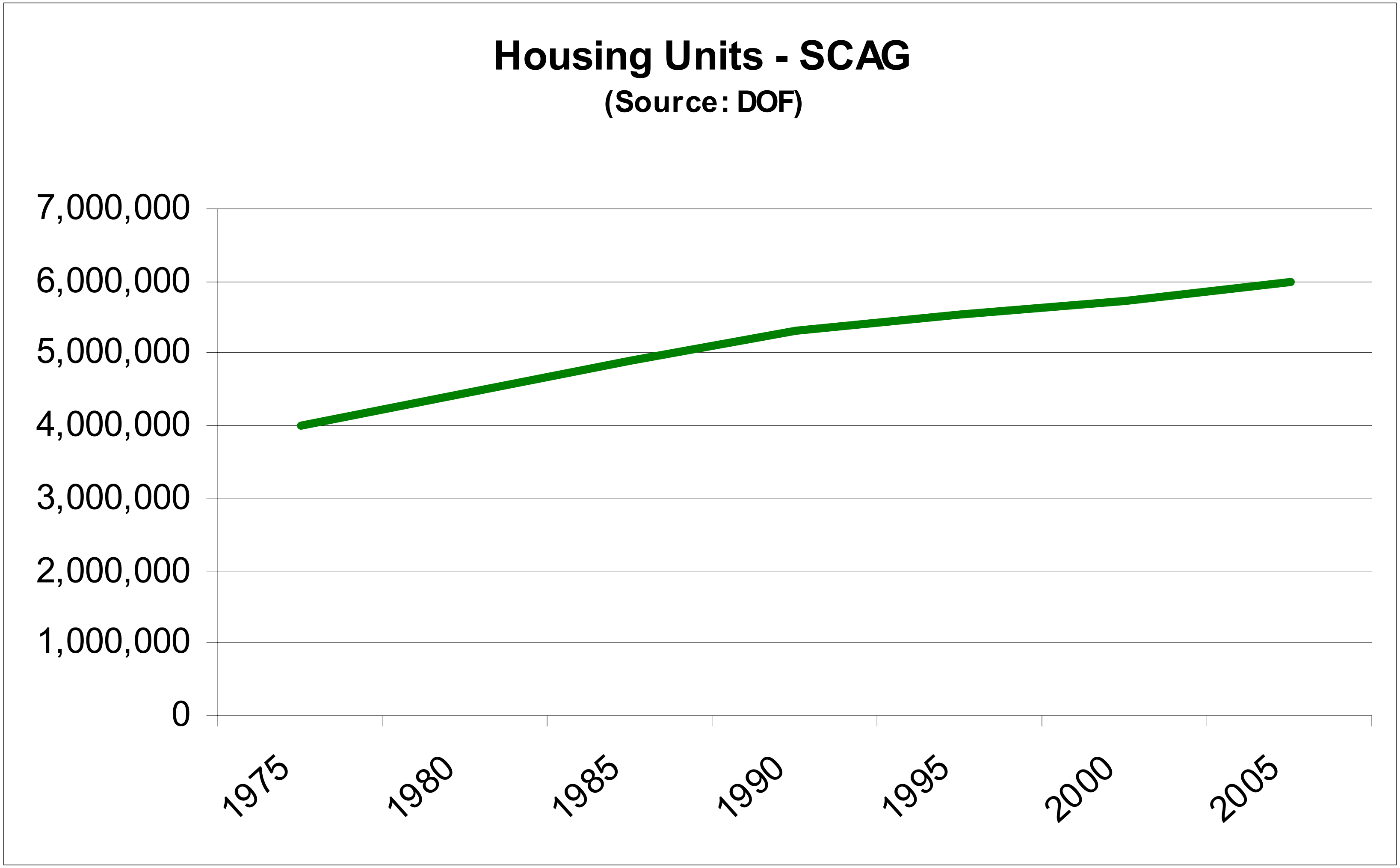
DR. ARNOLD SHERWOOD

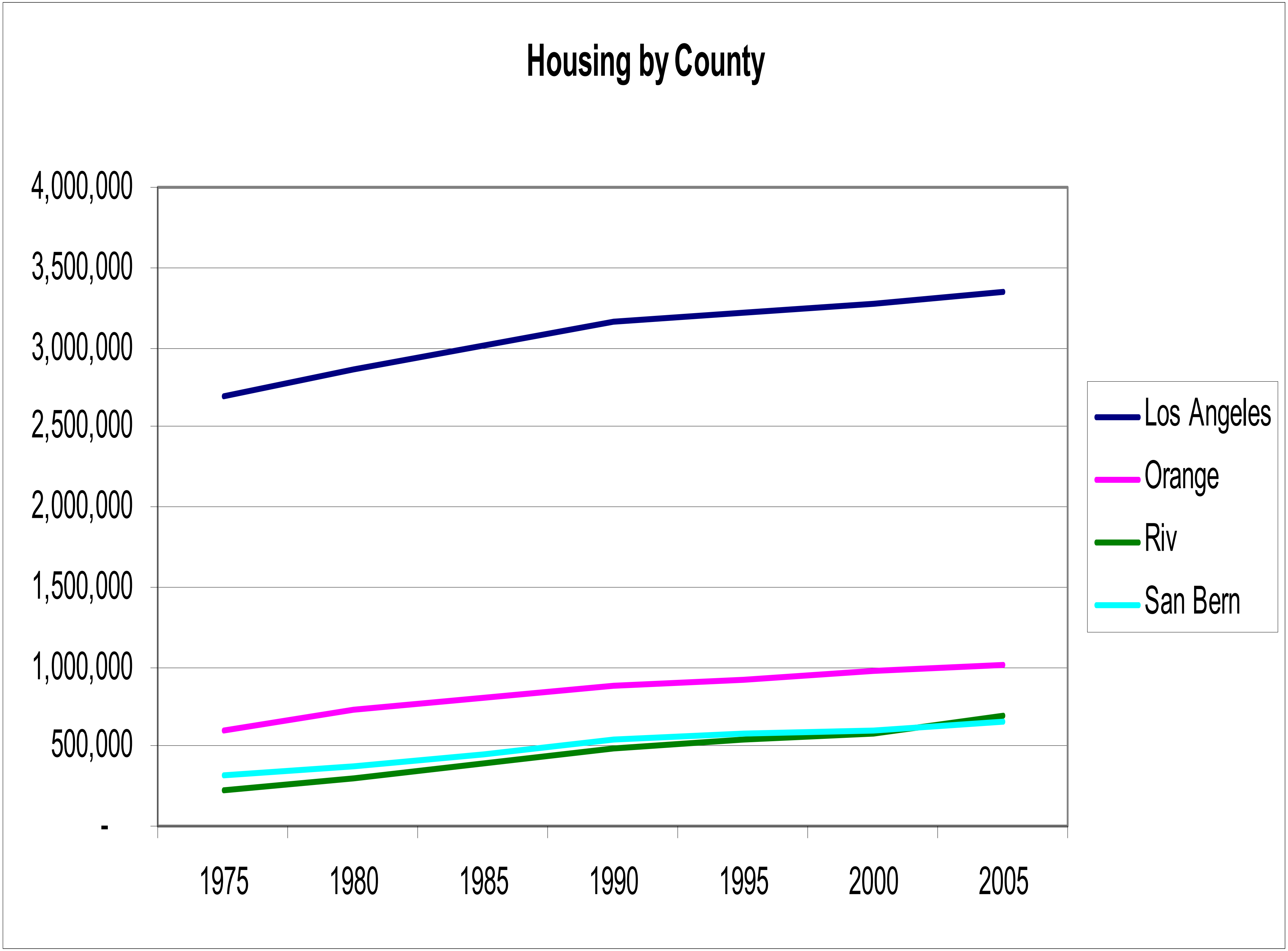

Socio-Economic Data
(Population/Housing/Employment)
Base Year
Future Year
Growth Factors
Transportation Modeling
VMT / Trips / Speed by TAZ
On-Road Emissions by TAZ
Stationary / Area Source Activity
Stationary / Area Source Emissions

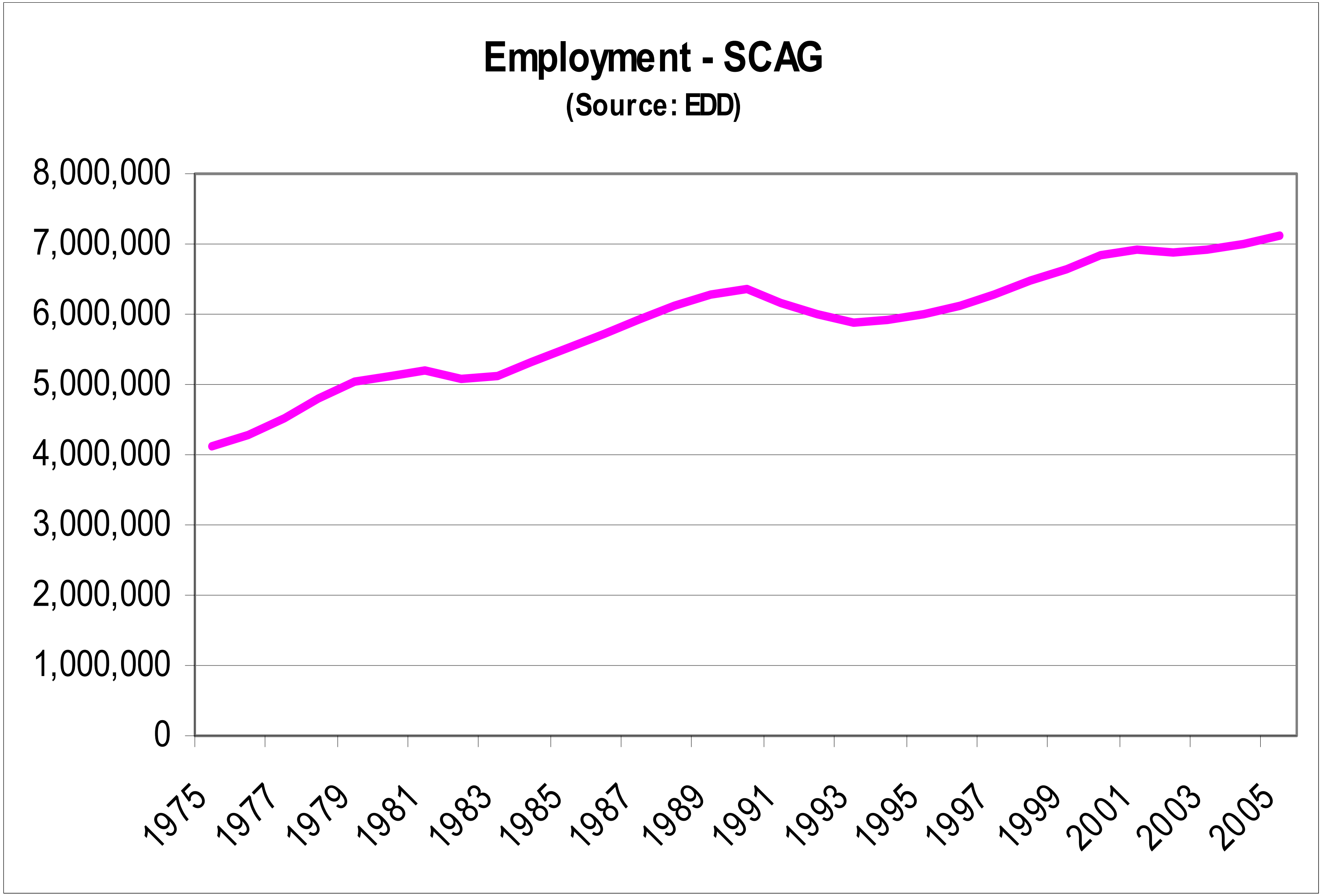


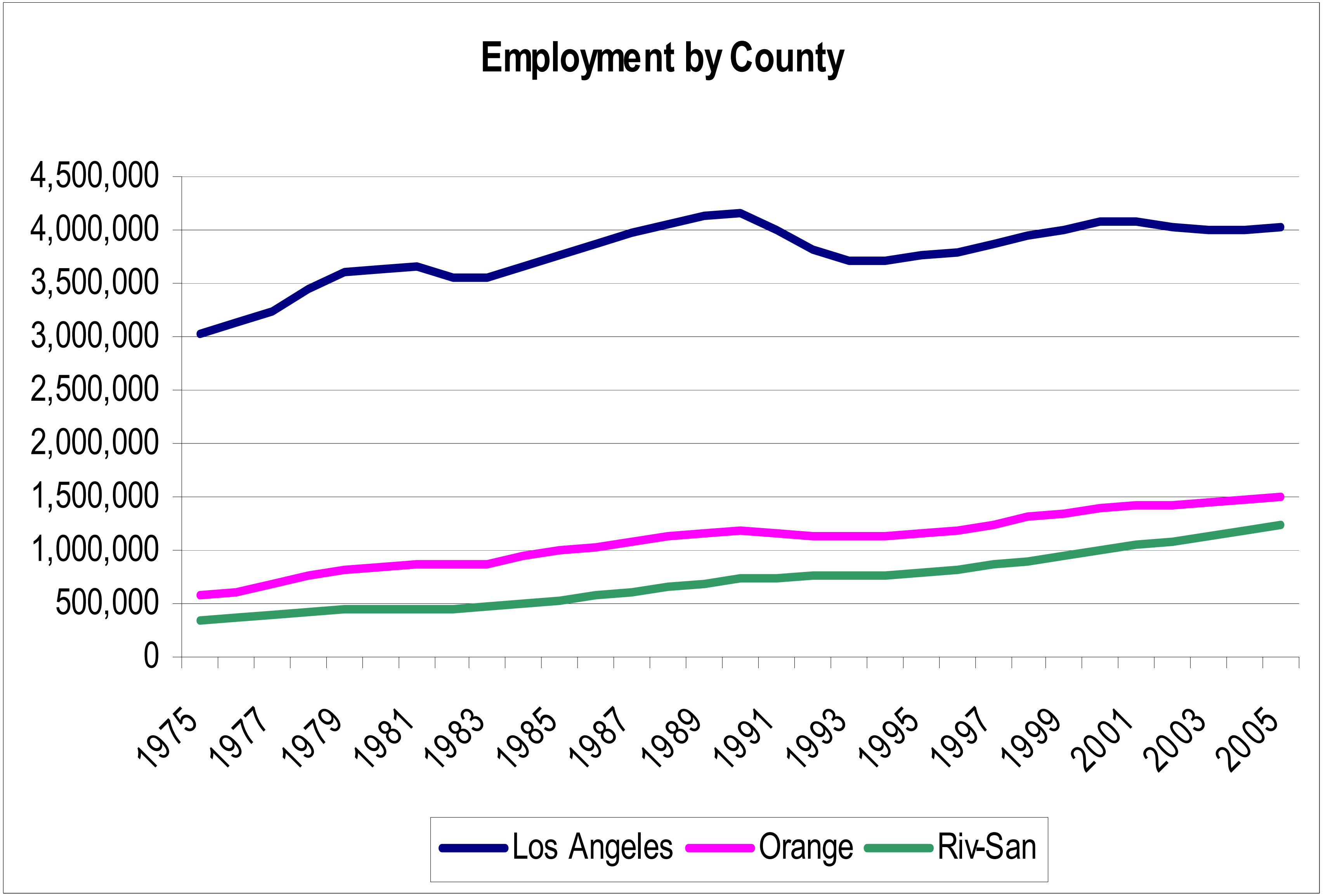
Population - SCAG
(Source: DOF)
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1975
1980
1985
1990
1995
2000
2005


Population by County
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
-
1975
1980
1985
1990
1995
2000
2005
Los Angeles
Orange
Riv
San Bern

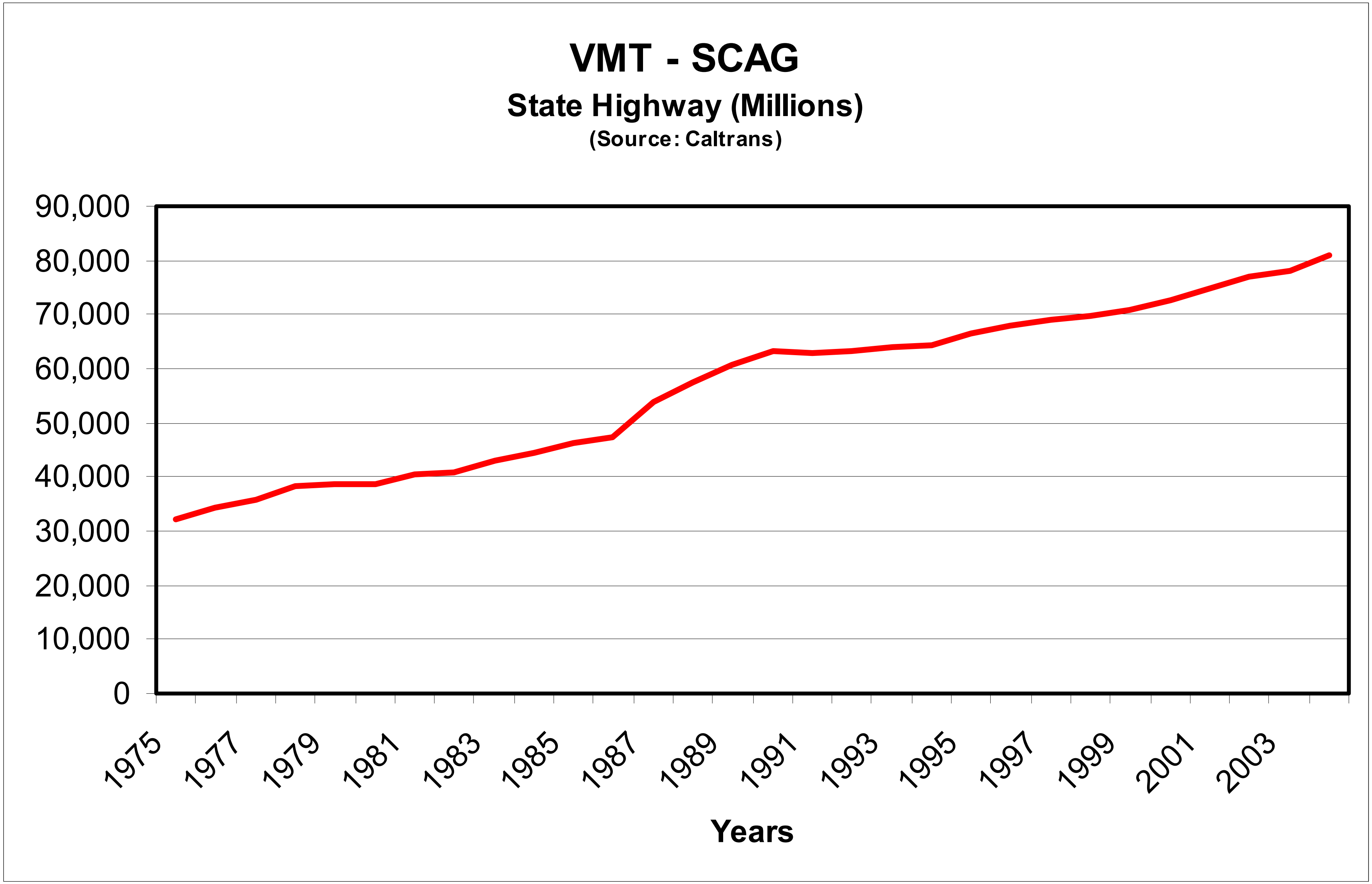

Housing Units - SCAG
(Source: DOF)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1975
1980
1985
1990
1995
2000
2005


Housing by County
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
1975
1980
1985
1990
1995
2000
2005
Los Angeles
Orange
Riv
San Bern

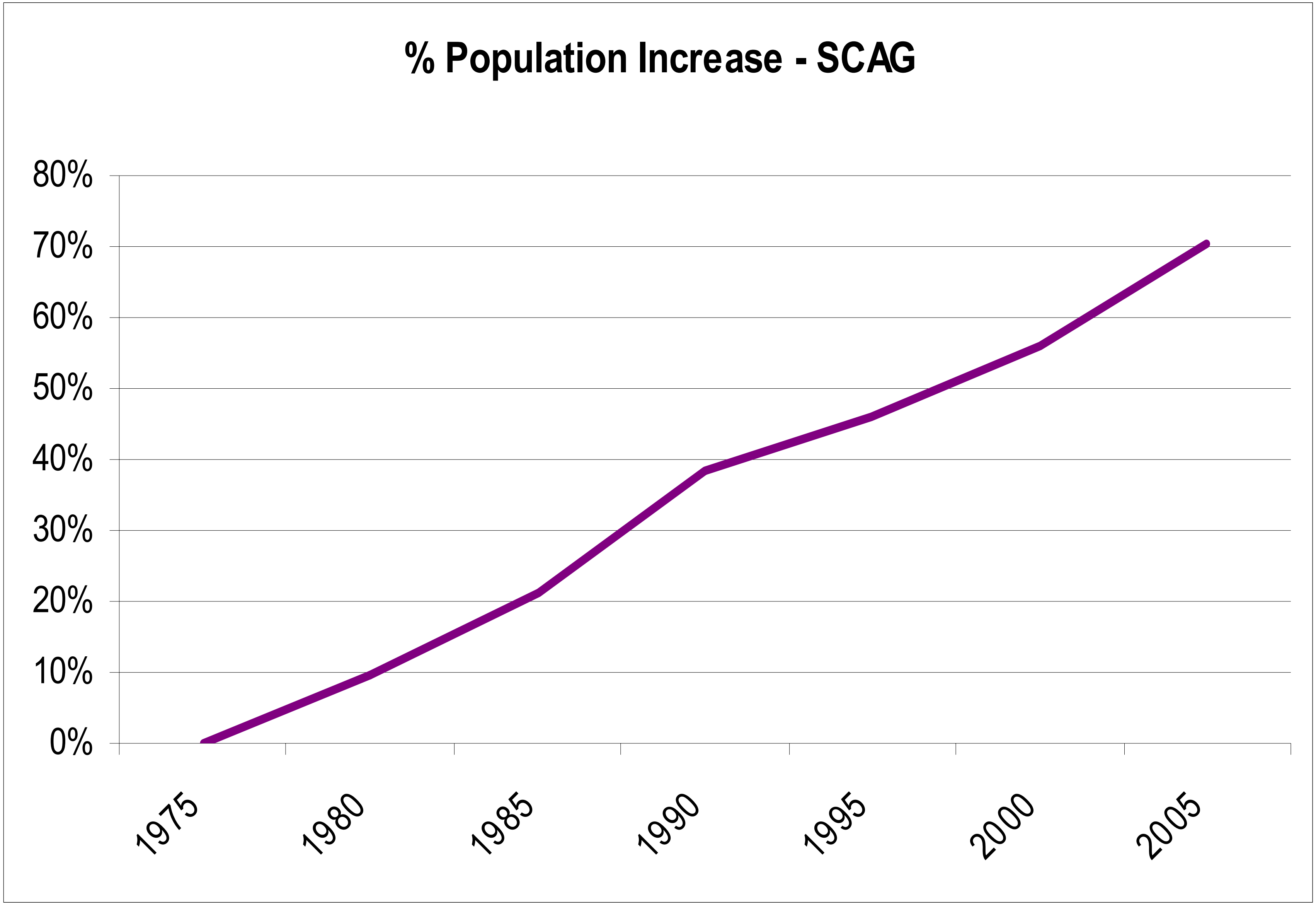

Employment - SCAG
(Source: EDD)
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005



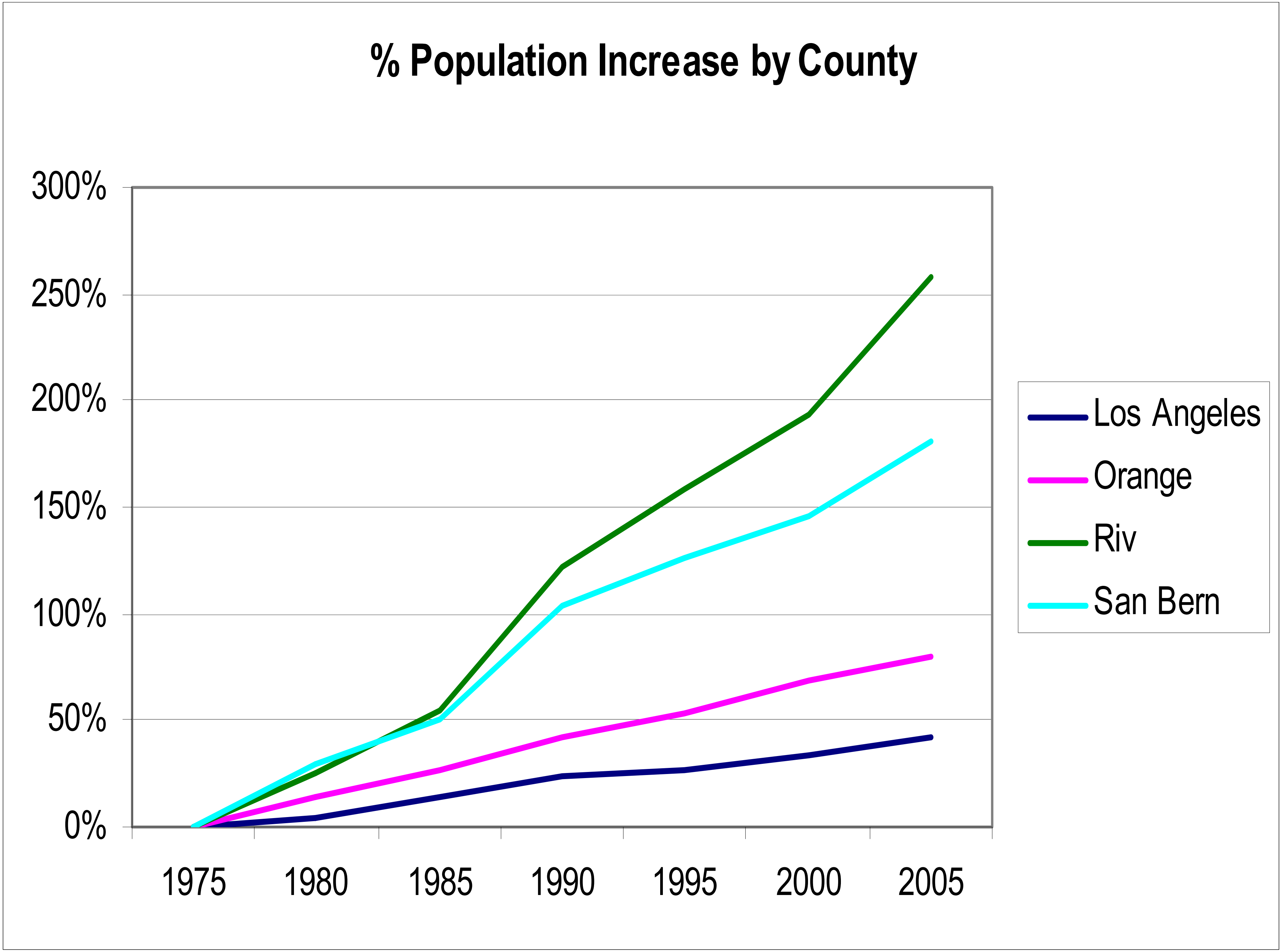
Employment by County
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
Los Angeles
Orange
Riv-San



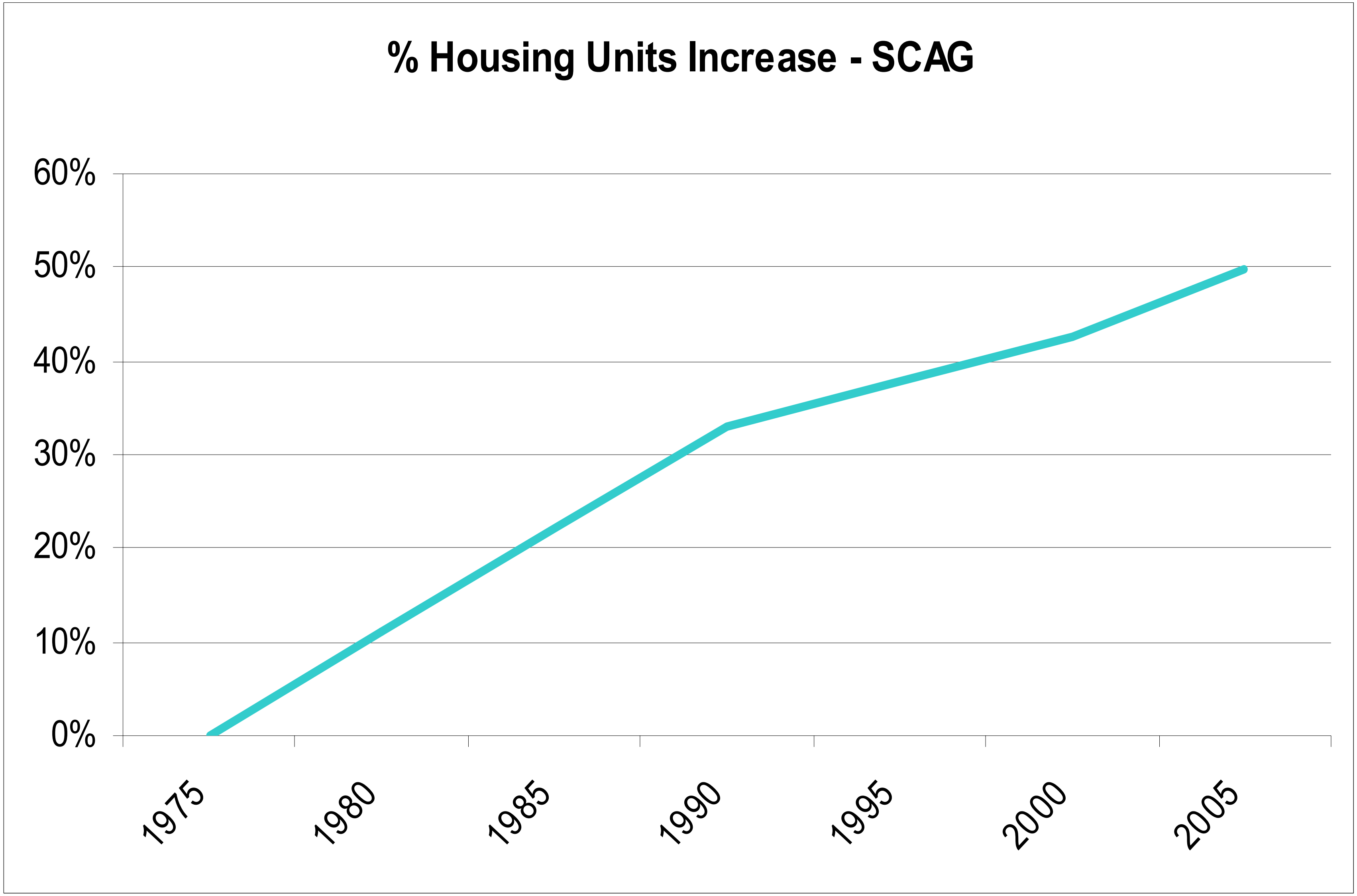
VMT - SCAG
State Highway (Millions)
(Source: Caltrans)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
Years

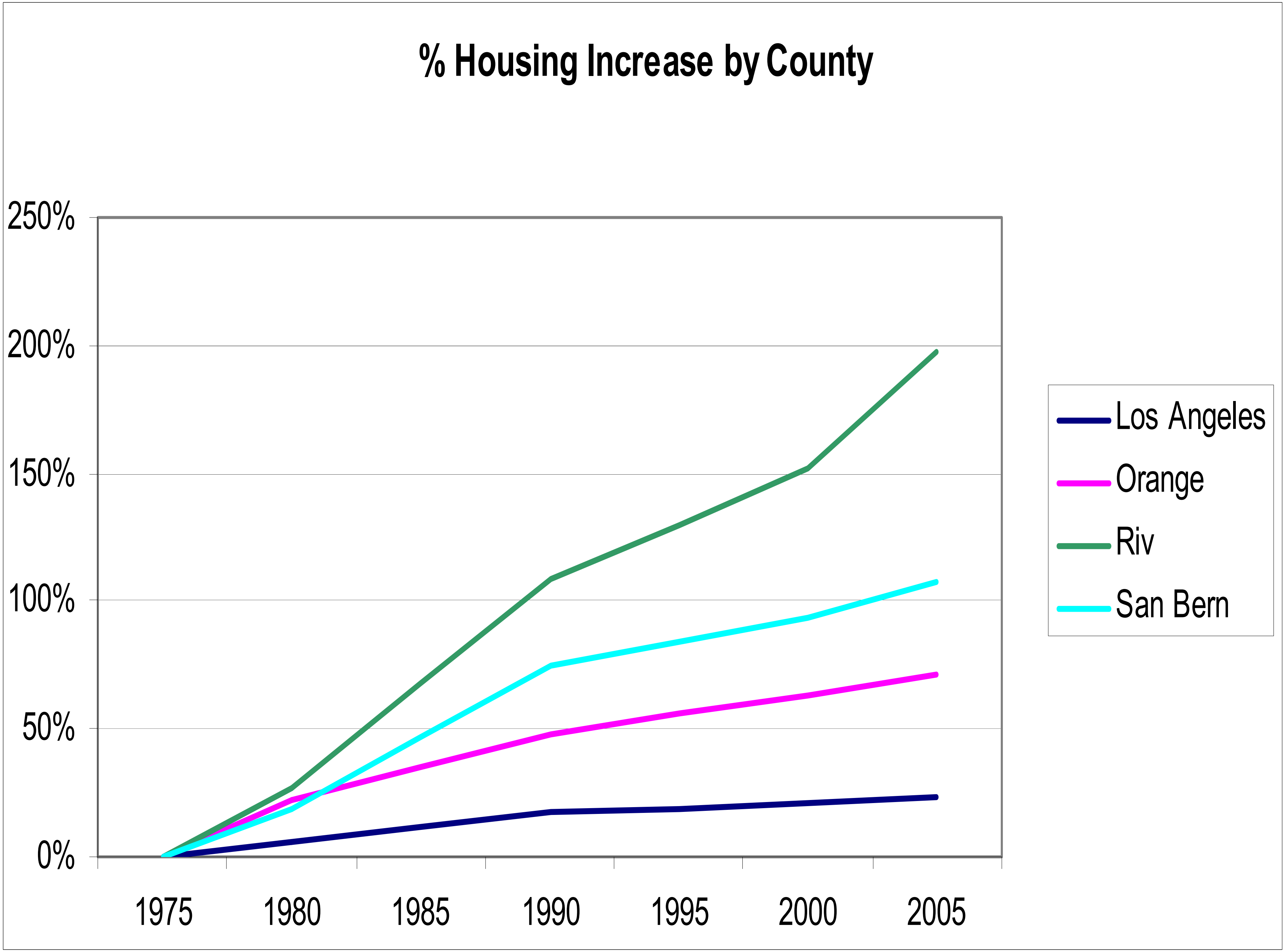


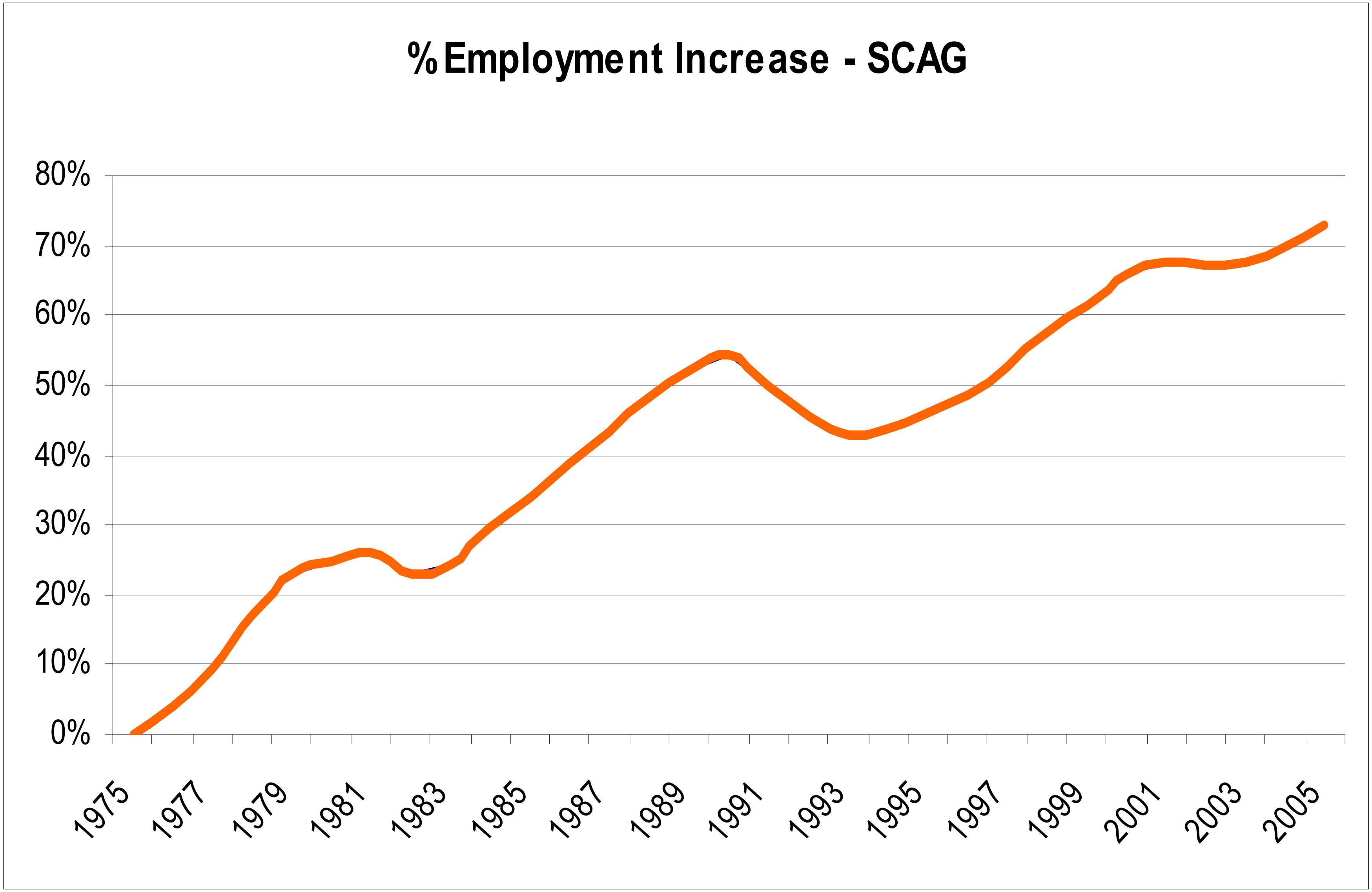
% Population Increase - SCAG
80%
70%
60%
50%
40%
30%
20%
10%
0%
1975
1980
1985
1990
1995
2000
2005



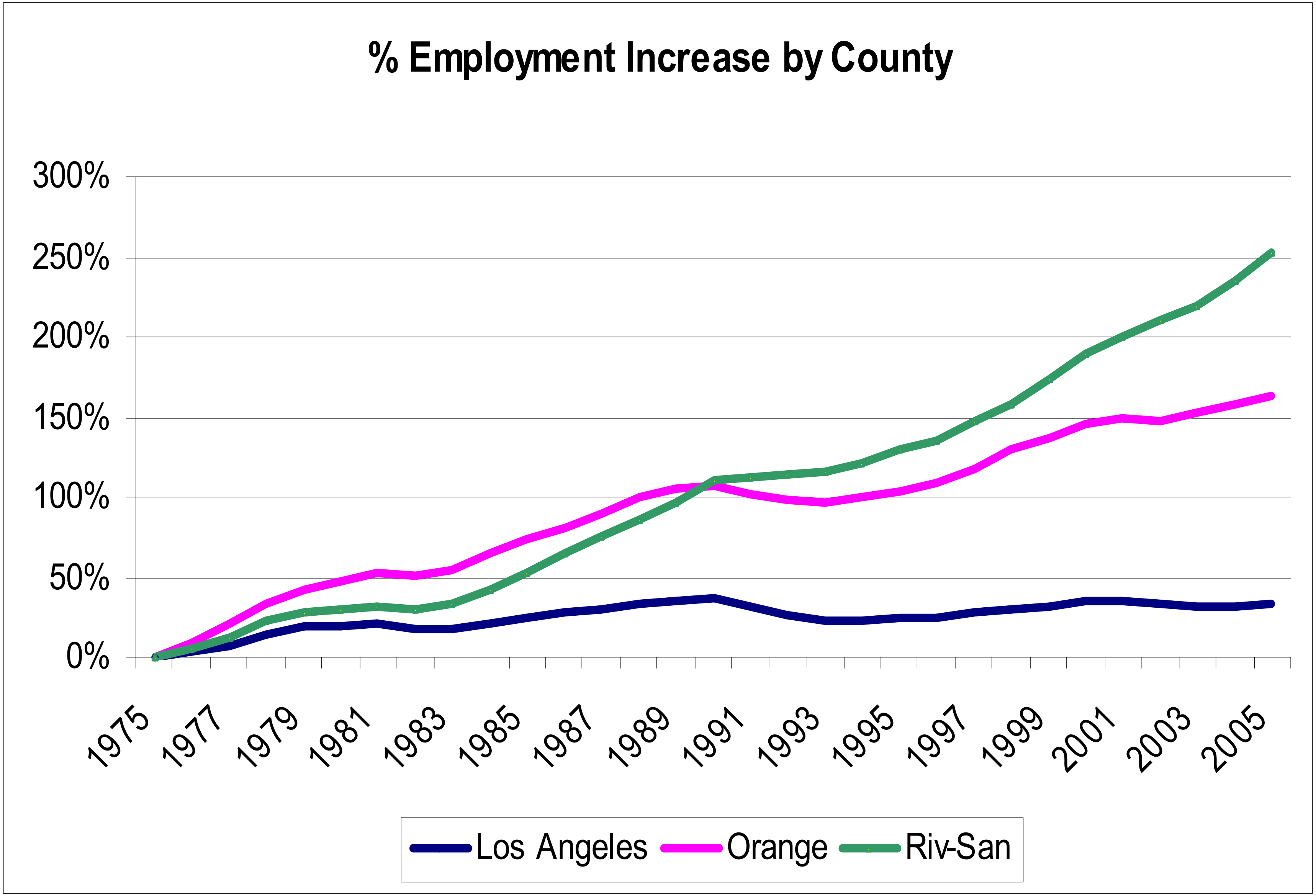
% Population Increase by County
300%
250%
200%
150%
100%
50%
0%
1975
1980
1985
1990
1995
2000
2005
Los Angeles
Orange
Riv
San Bern


% Housing Units Increase - SCAG
60%
50%
40%
30%
20%
10%
0%
1975
1980
1985
1990
1995
2000
2005

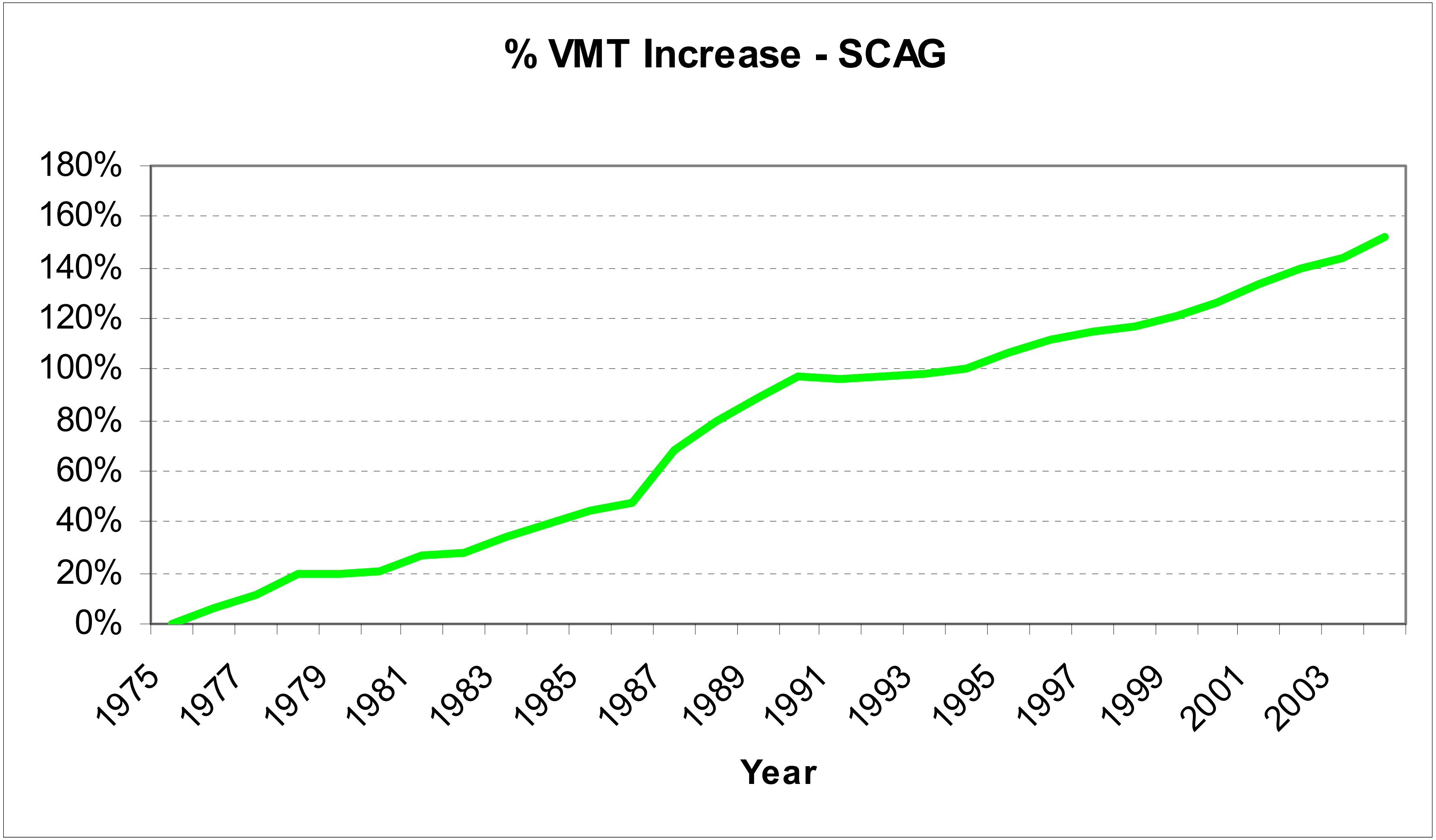

% Housing Increase by County
250%
200%
150%
100%
50%
0%
1975
1980
1985
1990
1995
2000
2005
Los Angeles
Orange
Riv
San Bern

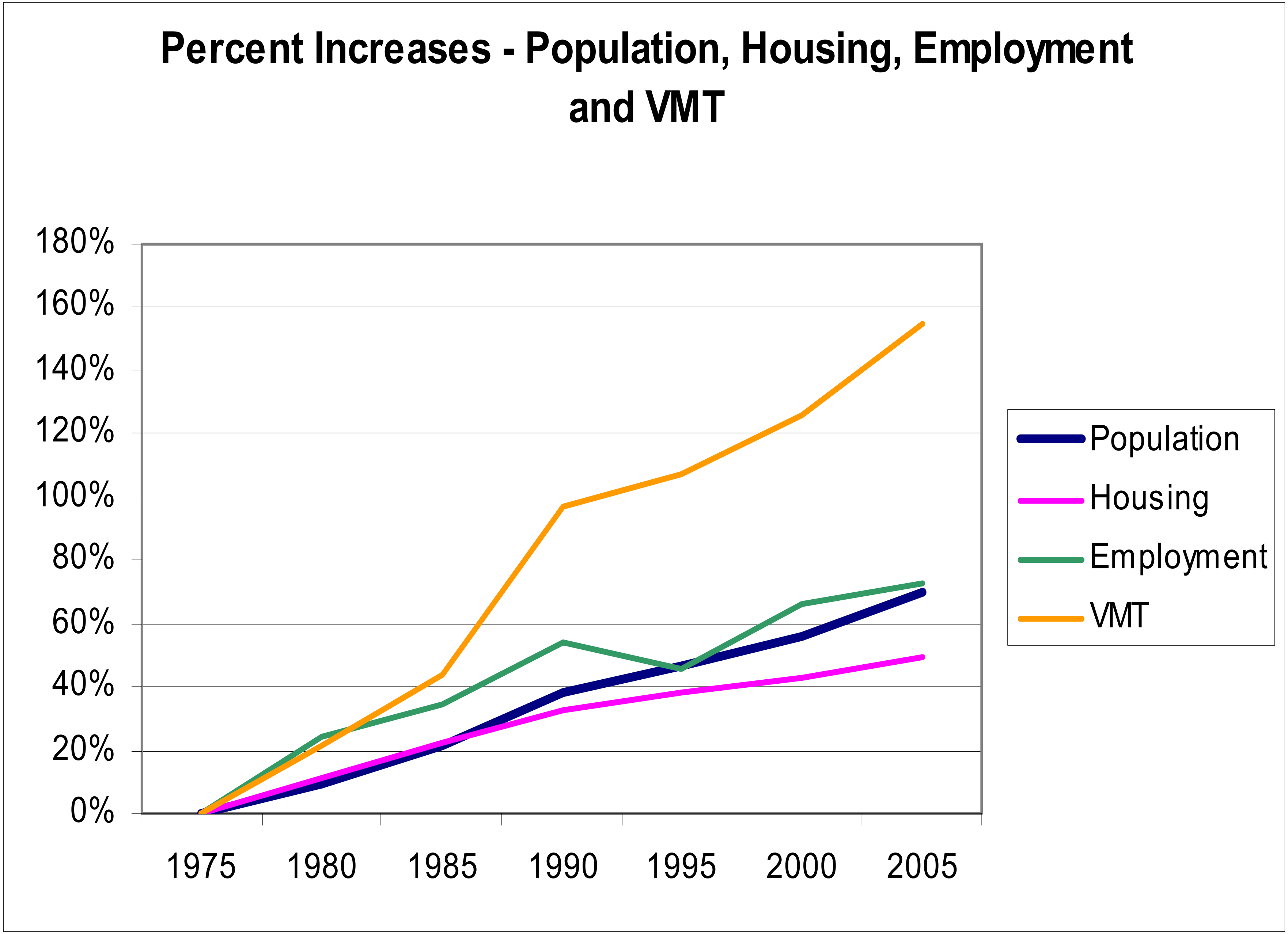


% Employment Increase - SCAG
80%
70%
60%
50%
40%
30%
20%
10%
0%
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005



% Employment Increase by County
300%
250%
200%
150%
100%
50%
0%
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
Los Angeles
Orange
Riv-San


% VMT Increase - SCAG
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
Year



Percent Increases - Population, Housing, Employment and VMT
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
1975
1980
1985
1990
1995
2000
2005
Population
Housing
Employment
VMT

APPENDIX F

DR. DOUGLAS LAWSON

Weekend Ozone Effect –

The Weekly Emission Control Experiment

Douglas R. Lawson
National Renewable Energy Laboratory
doug_lawson@nrel.gov

South Coast AQMD Ozone Air Quality Forum
Diamond Bar, CA
October 31, 2006

Special Issues on the Weekend Ozone Effect – July 2003
Studies Co-sponsored by DOE/NREL, CRC, and ARB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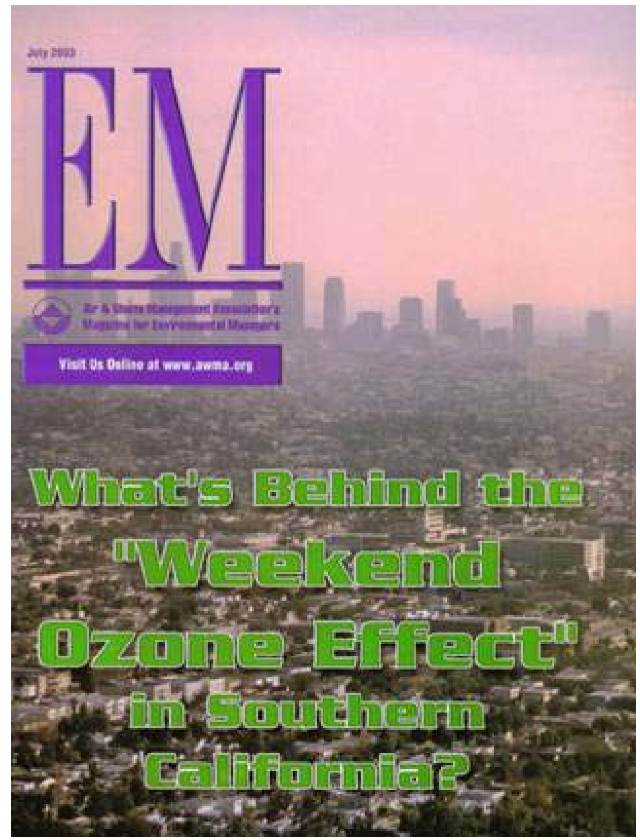
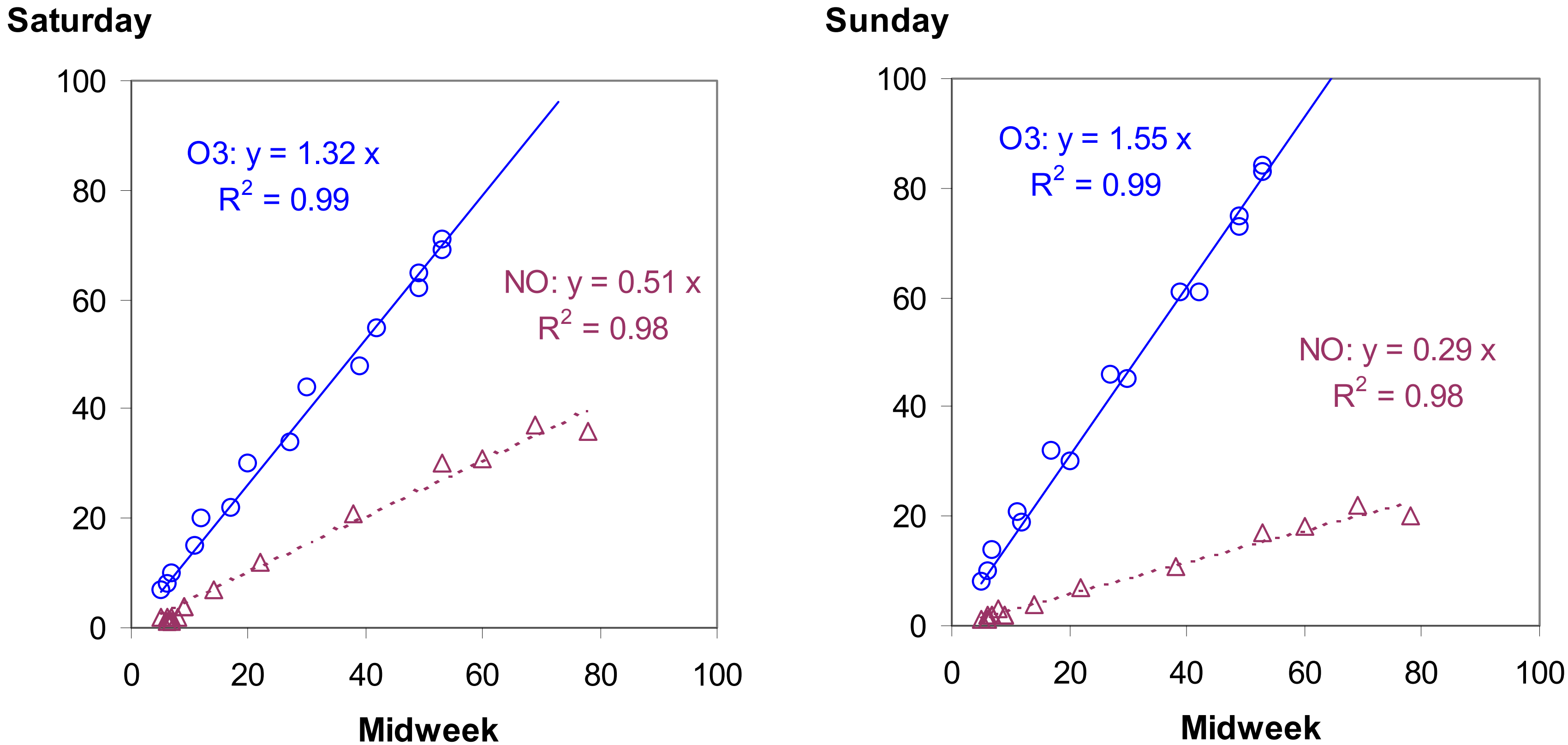
Available online at www.awma.org

Selected Papers on Weekday and Weekend Ozone Differences in Southern California



Correlations of Saturday and Sunday Versus Midweek* Hourly Daytime (0600 to 2000, PDT) O_3 and NO at Azusa, 1999-2000



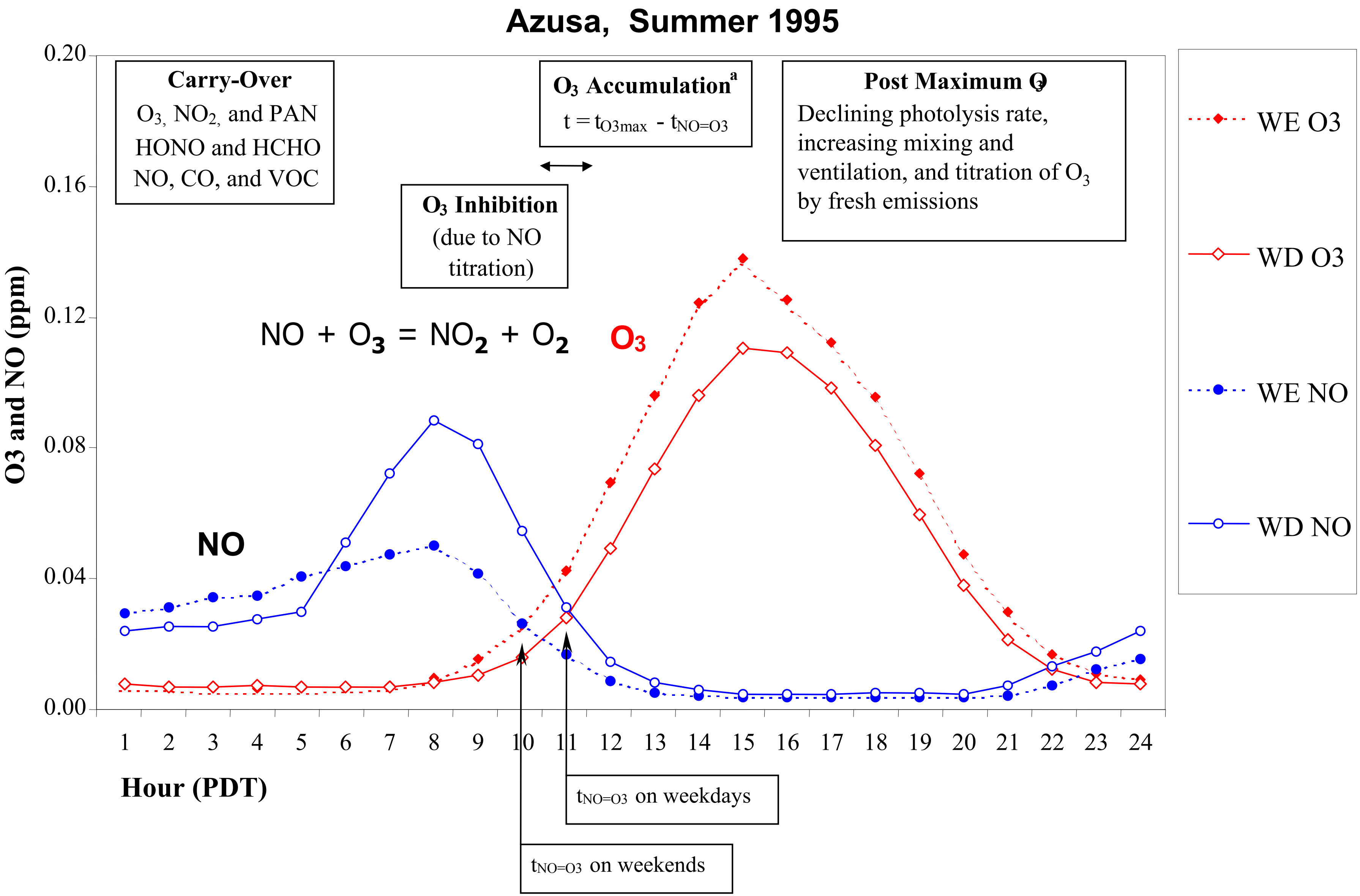
* Tuesday to Thursday

Ref: Fujita *et al*., 2003

Weekday/Weekend NO and O_3 Changes
South Coast Air Basin, 1999-2002

Site	Nitric Oxide (NO) Data 1999 – 2002		Ozone (O_3) Data 1999 – 2002	
	Sat slope	Sun slope	Sat slope	Sun slope
Anaheim	0.69	0.39	1.11	1.17
Azusa	0.69	0.37	1.35	1.46
Banning	0.47	0.34	0.98	0.80
Burbank	0.79	0.52	1.24	1.37
Costa Mesa	0.53	0.34	1.07	1.02
El Toro	No Data	No Data	1.13	1.14
Fontana	0.70	0.32	1.36	1.41
Glendora	0.69	0.41	1.32	1.39
Hawthorne	0.48	0.53	1.00	1.08
La Habra	0.41	0.17	1.32	1.44
Lake Elsinore	0.38	0.14	1.06	0.99
Lake Gregory	No Data	No Data	1.31	1.28
LA - N. Main	0.76	0.47	1.25	1.30
Lynwood	0.36	0.07	1.19	1.30
N. Long Beach	0.45	0.32	1.29	1.17
Pasadena	0.73	0.44	1.27	1.39
Perris	No Data	No Data	1.12	1.06
Pico Rivera	0.78	0.46	1.32	1.39
Pomona	0.78	0.43	1.44	1.58
Redlands	No Data	No Data	1.18	1.20
Reseda	0.75	0.47	1.10	1.13
Rubidoux	0.89	0.53	1.23	1.21
San Bernardino	0.67	0.42	1.26	1.32
Santa Clarita	0.40	0.18	1.08	1.18
Upland	0.58	0.26	1.32	1.39
W. LA-VA Hospital	0.63	0.44	1.07	1.14
Basin Average	0.62	0.36	1.21	1.25

Source: D. Campbell, DRI



"Fujita point"

Ref: Fujita *et al.*, 2003; Lawson, 2003

Conclusions by Study Investigators

Hypotheses	Importance for Ozone Formation	Confidence Level
1. NOx emissions reduction	**Significant**	**High**
2. NOx timing (NOx "boost")	Insignificant	**High**
3. Pollutant carryover near the ground	Small	**High**
4. Pollutant carryover from aloft	Insignificant	Medium
5. Increased weekend VOC emissions	Small to Insignificant	Medium
6. Increased photolysis due to decreased PM	Small to Insignificant	Medium

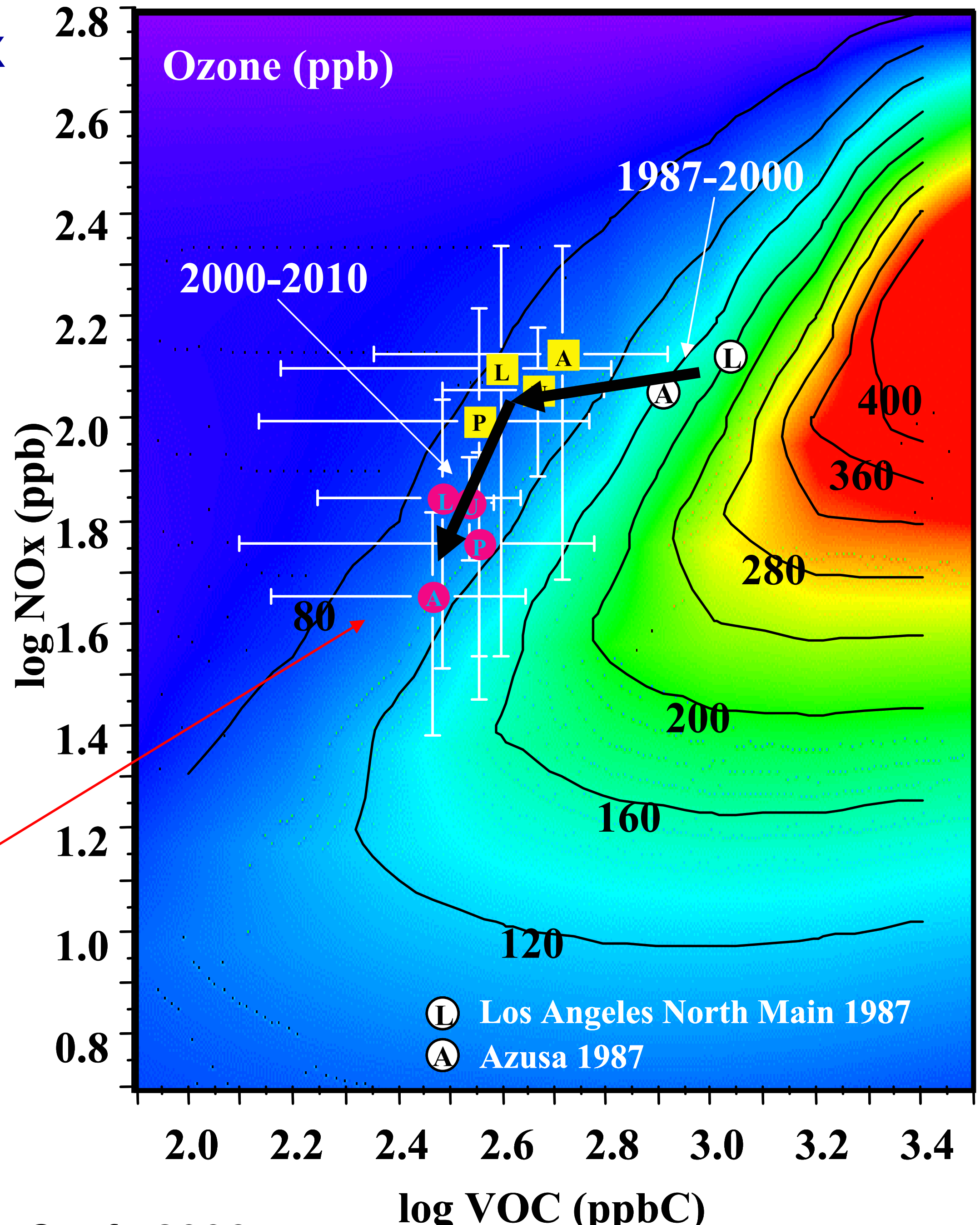
1999-2000 VOC & NOx

Mean Wednesday ± 1 sigma

Mean Sunday ± 1 sigma

<u>Monitoring Stations</u>

A – Azusa
L – Los Angeles, N. Main
P – Pico Rivera
U – Upland



Weekday VOC and NOx emissions in 2010 are projected to be similar to weekend emissions in 2000.

Ref: Fujita *et al.*, 99th AWMA Nat'l. Conf., 2006

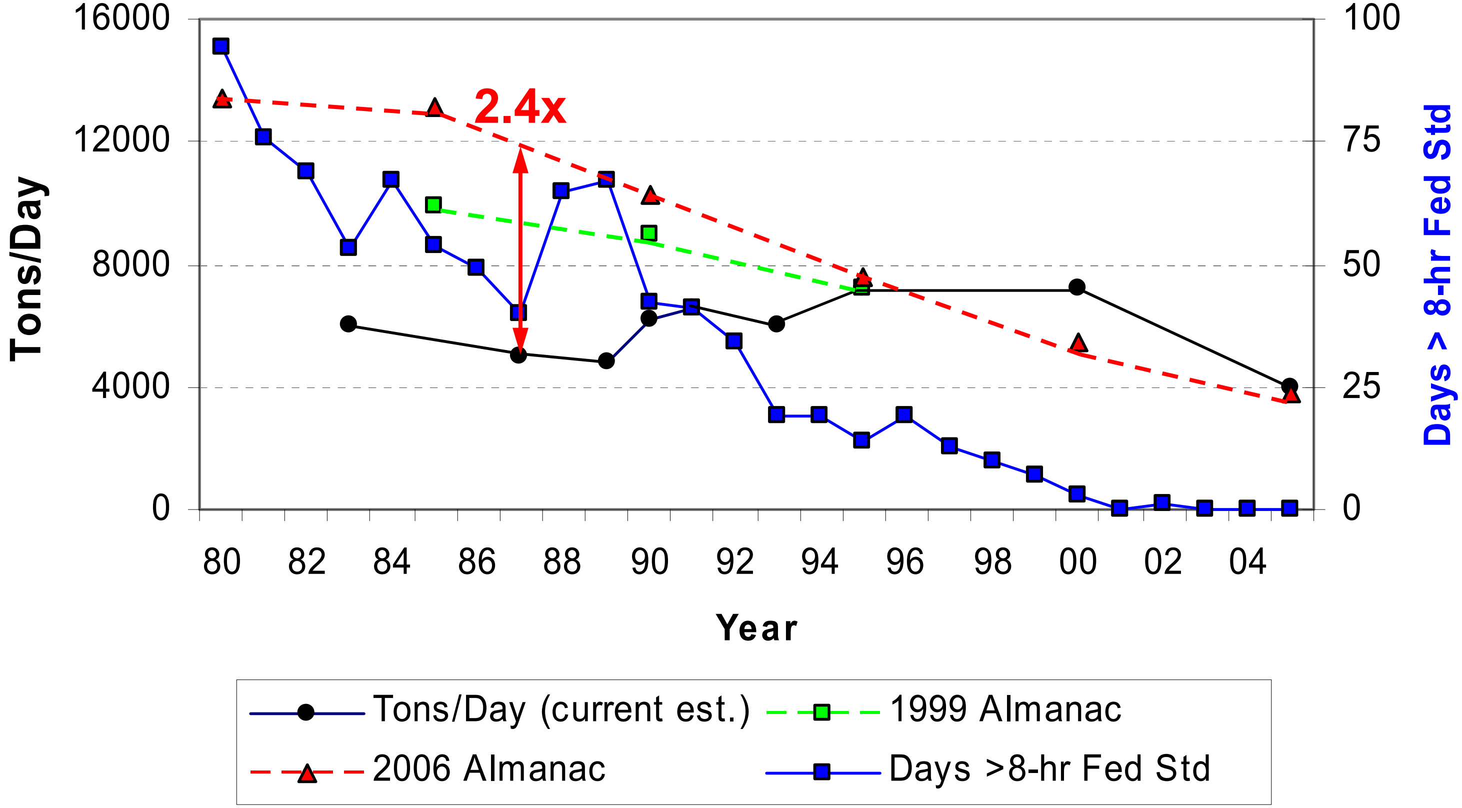
3 Questions to Address

1. What are the main causes/explanations for the slow down in ozone air quality improvements over the recent years?
   A. What new programs in the SoCAB have reduced NOx since ~1998? (RECLAIM and Moyer?) Weekend ozone studies suggest that local and national ozone reductions will be more difficult, given that there is increased emphasis on NOx reductions rather than on VOC reductions (similar to what happens currently on weekends relative to weekdays in SoCAB and remainder of United States).
2. What could be done differently to more effectively reduce ozone levels given the need to attain fine particle standards?
   A. Focus on high-emitting HC (and CO) LD vehicles; not being found/fixed/repaired by current Smog Check program. These few vehicles (~5% of on-road fleet) produce disproportionately high amounts of HC, PM, and air toxics. Also, Blanchard and Tanenbaum (2003) reported no statistically significant difference between weekday and weekend PM nitrate in Southern California, despite large weekend NO reductions.
3. What research and development should be emphasized in the near future to further air quality improvement and our understanding of the issues?
   A1. Implement AQMP recommendation for Smog Check enhancement to identify/ repair/verify repairs (or scrap) high-emitting HC (and CO vehicles). Would produce immediate benefit in air quality. Tightening Smog Check failure cutpoints/more frequent testing will do little to improve air quality because failure of Smog Check program is a human behavior problem, not a technological problem.
   A2. Understand why current ambient VOC speciation does not match existing inventory. 55 PAMS species are mobile-source/gasoline-related…what about solvent and other sources? We need to have a top-down study ASAP to understand if current ambient data match current inventory. Previous air quality simulation modeling has been incorrect because inventories have greatly underestimated mobile source emissions.

Fundamental Problem: Mobile Source Emission Inventory

South Coast Air Basin CO Trends

Ambient vs. Inventory, 1980-2005

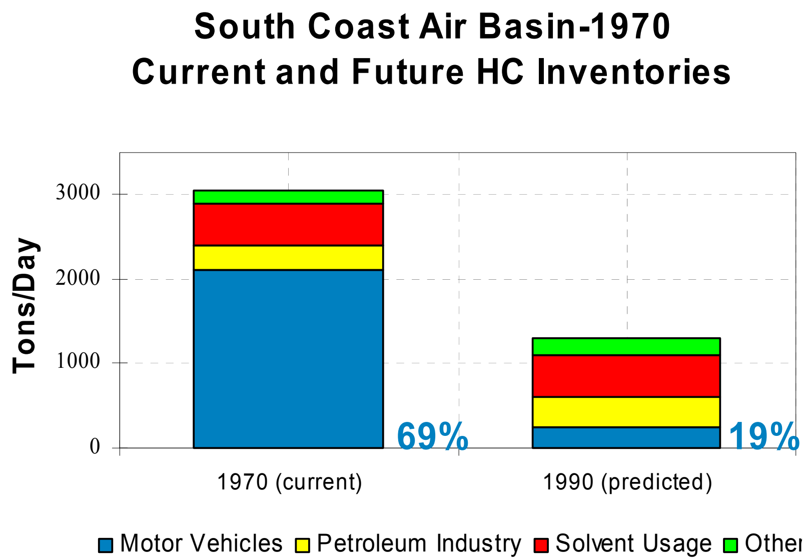


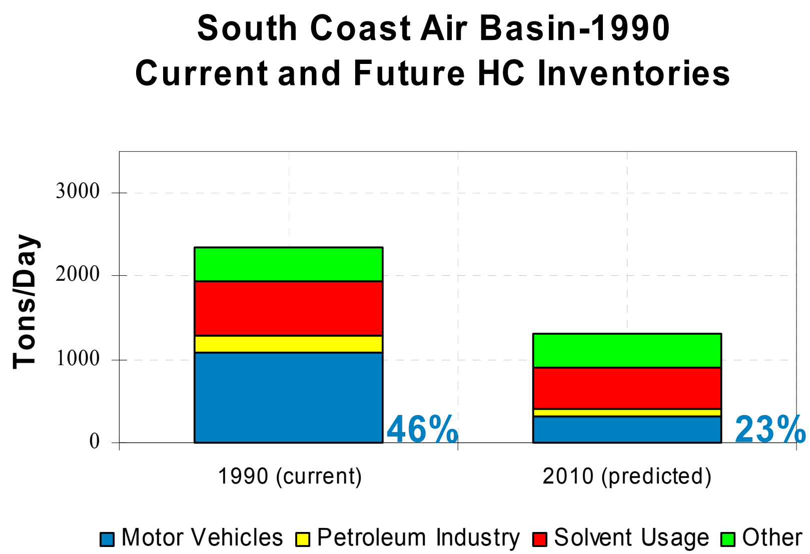
1987 SCAQS Tunnel Study (funded by CRC): On-road mobile emissions were 2.7 and 3.8 times higher for CO and NMHC than EMFAC7C model predictions

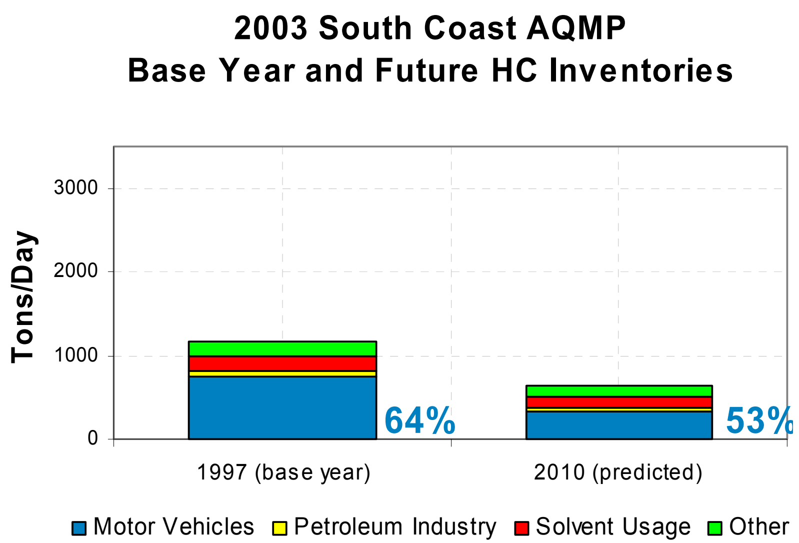
Projected Contributions of Mobile Sources to SoCAB Air Quality

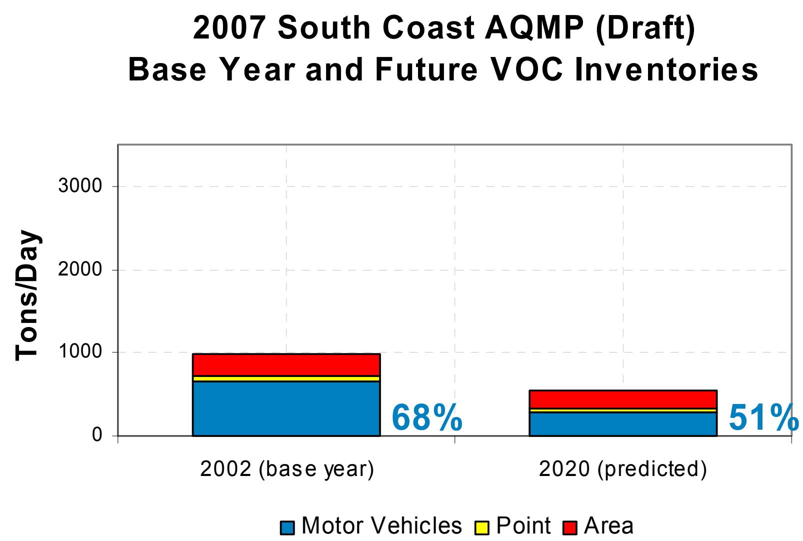
- “It is apparent that by 1980, motor vehicles will not be the major source of hydrocarbons and oxides of nitrogen, and greater emphasis will have to be placed on emissions from nonvehicular sources.” – *Air Pollution Control in California, 1971 Annual Report*, page 34.
- “However, contribution to VOC by mobile sources is reduced due to CARB regulations over time. Area sources become major contributors to VOC emissions (from 27 percent in 2002 to 42 percent in 2020).”, Draft 2007 AQMP, Appendix III, page III-2-14.

SoCAB HC Inventories
"Current" vs. Future

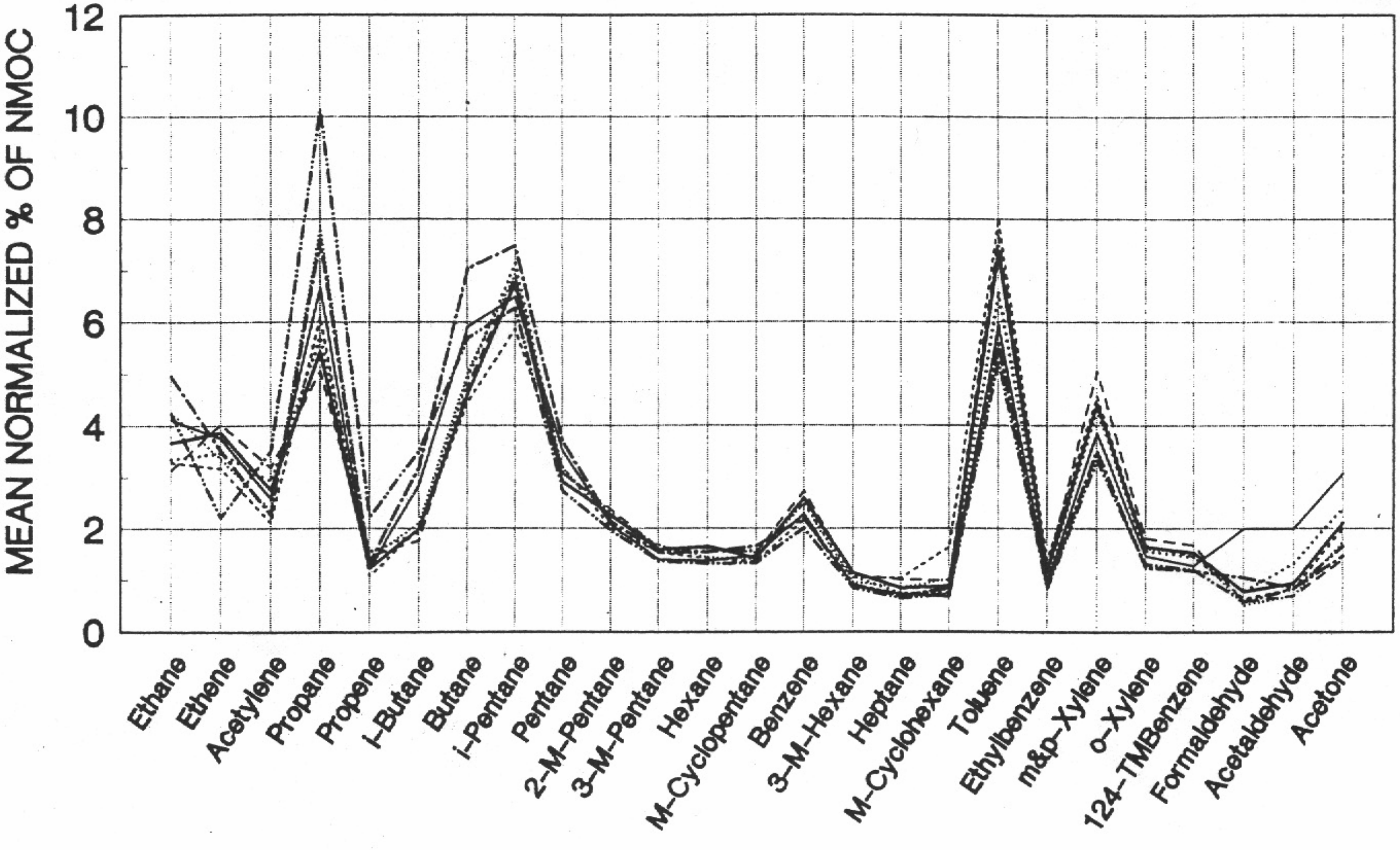








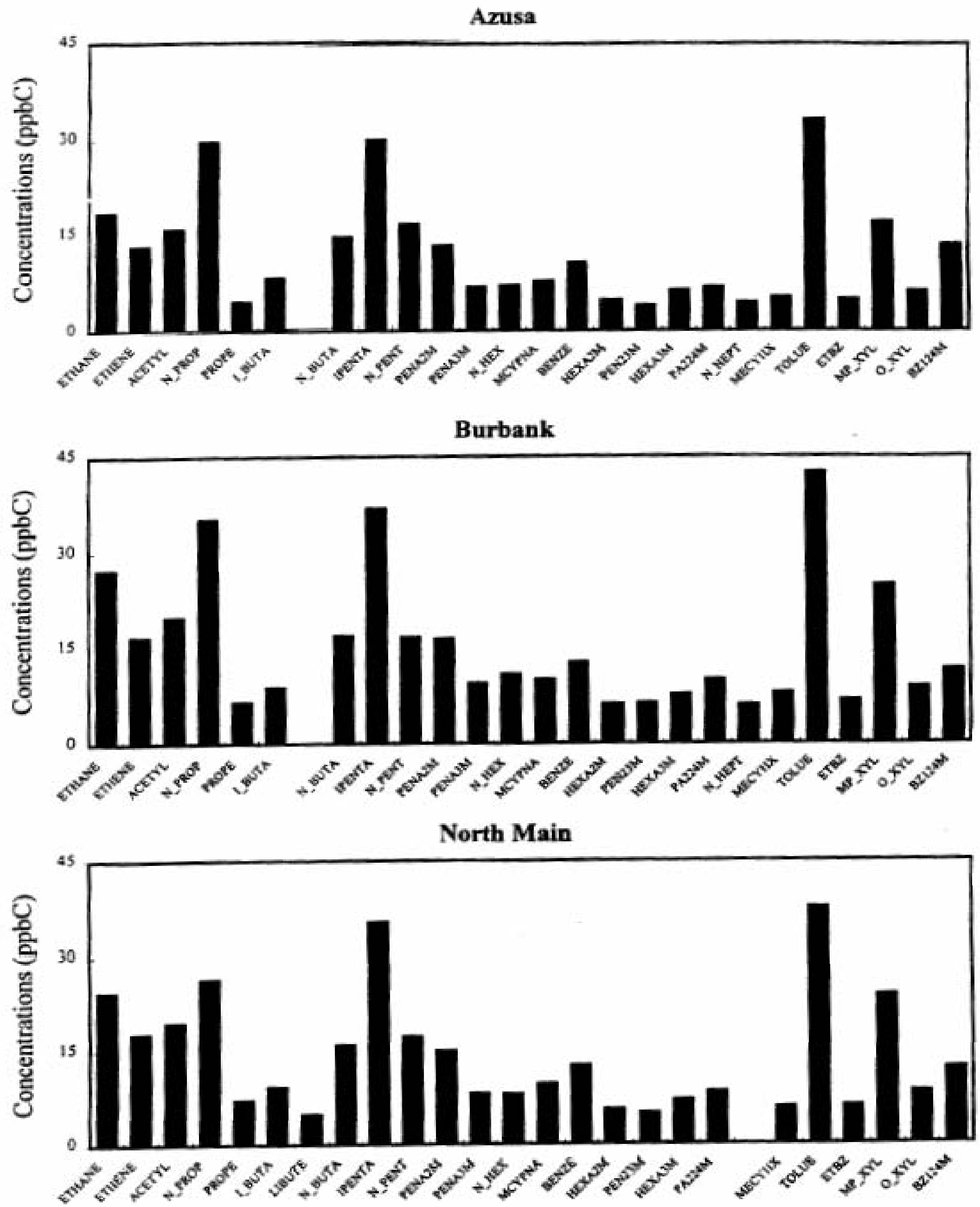
Summer 1987 SCAQS Ambient Normalized NMOG Speciation – 8 sites – One Common Source?



Ref: Fujita *et al.* 1992

Average concentrations for 25 most abundant species, 3 sites, averaged for all morning and afternoon samples; six 7-day periods, summer 1995.

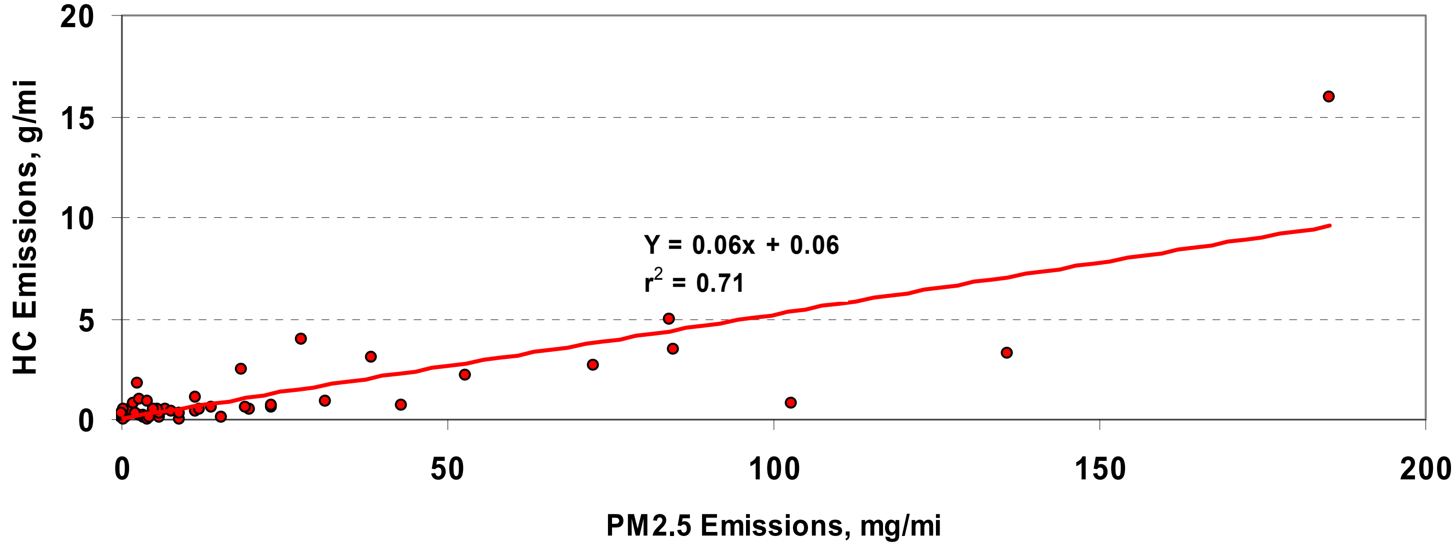
One common source?



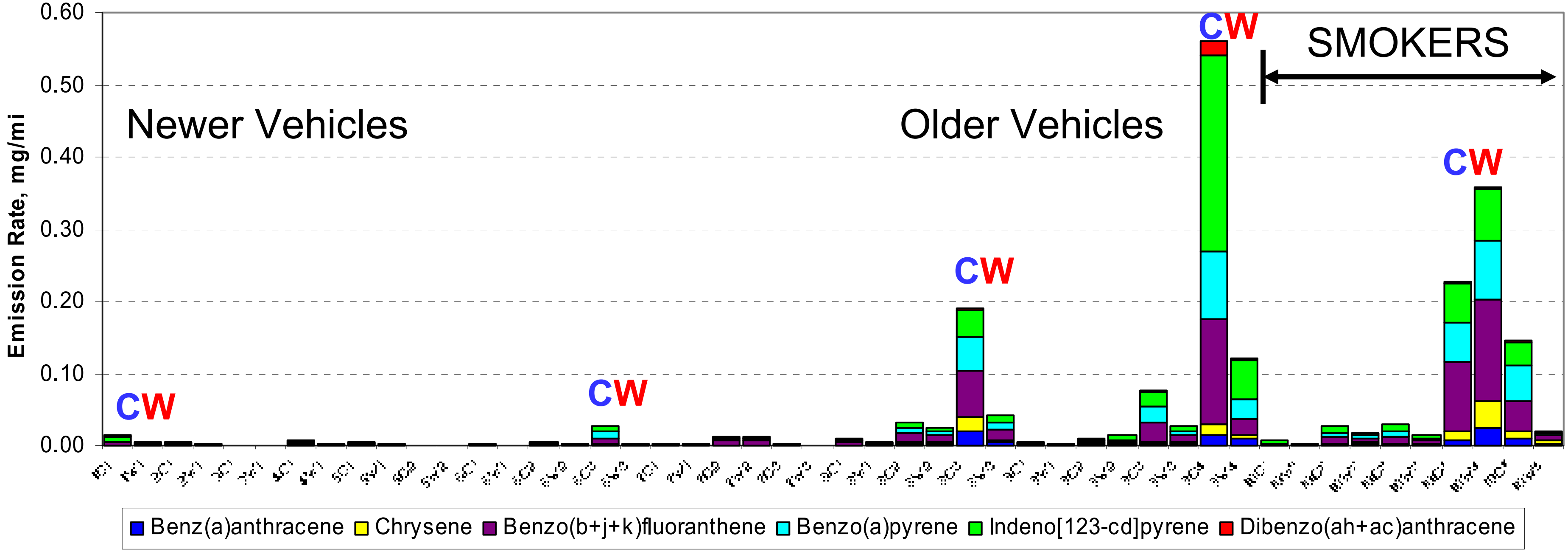
Ref: Zielinska et al., ARB contract no. 94-332.

DOE Gasoline/Diesel PM Split Study

57 LD Spark-Ignition Vehicles tested over the Unified Driving (LA-92) Cycle

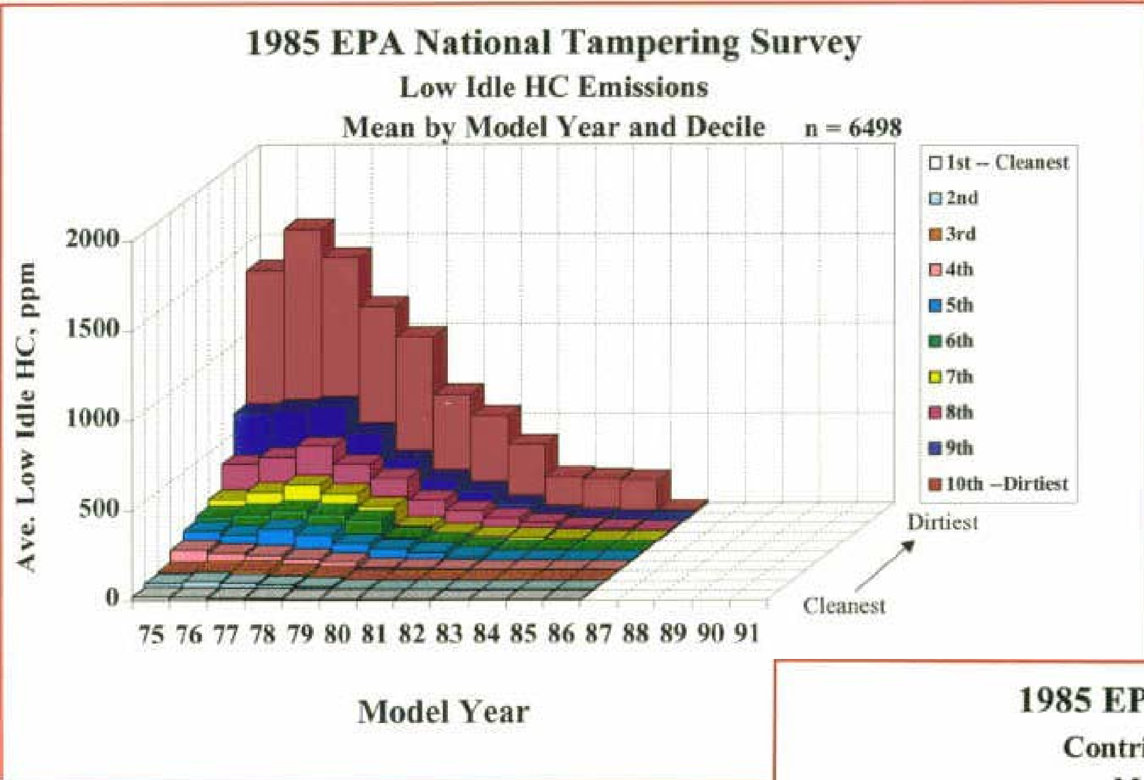


DRI Spark Ignition Source Profiles for Apportionment by CMB for 7 PAH Listed as Animal Carcinogens by IARC



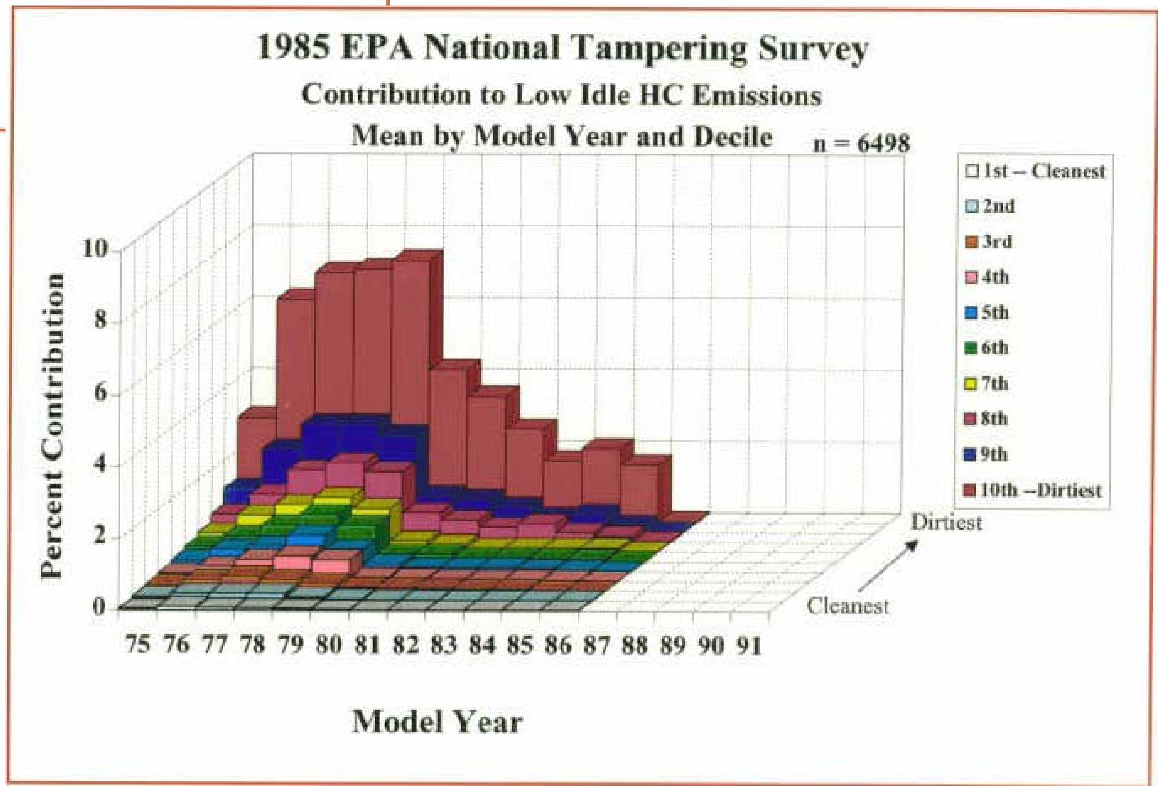
C = Cold phase of the UDC; W = Warm phase of the UDC

Nationwide On-Road Idle HC Emissions



EPA's 1985 National Tampering Survey

6498 vehicles



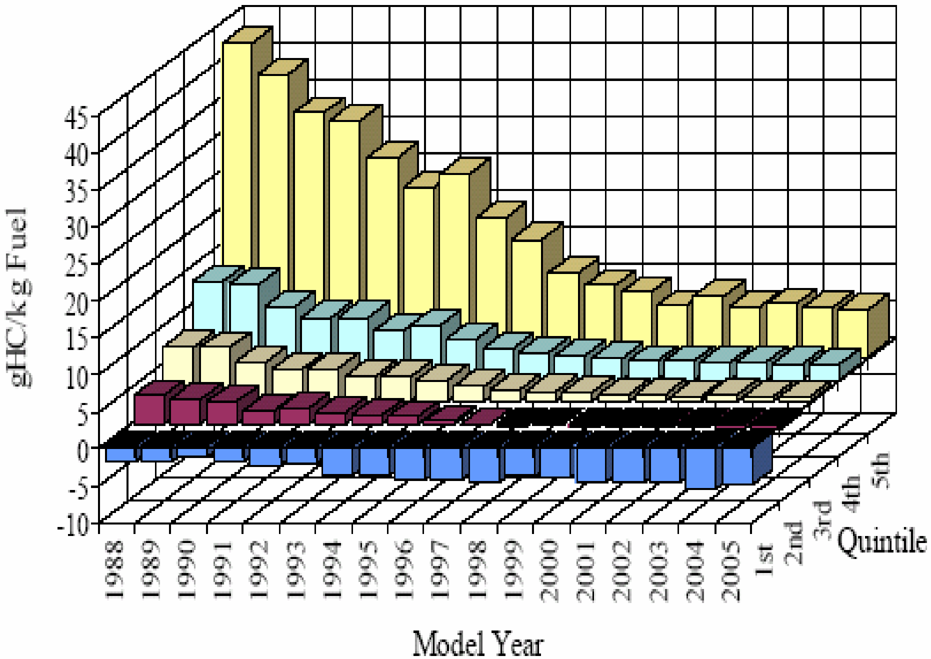
On average, fleet emissions increase as vehicles age; mean fleet emissions driven by high emitters

Most new cars are clean; a few new vehicles are dirty; new vehicles irrelevant to air quality

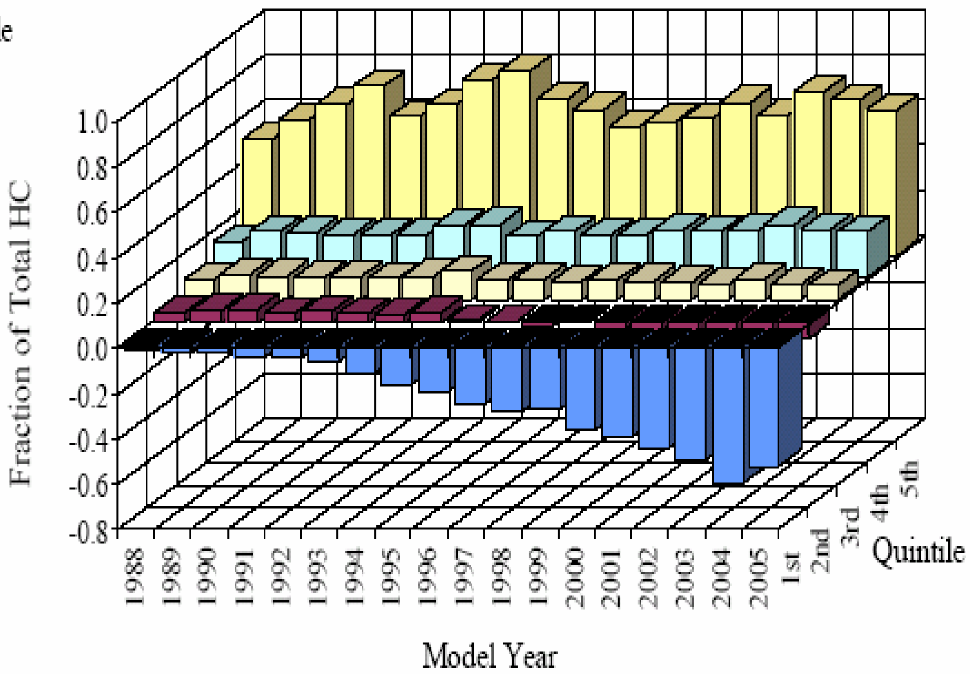
Most old cars are "clean"

Ref: Lawson *et al.* 1996

Remote Sensing HC Emissions by Quintile



19,500 measurements,
October 17-21, 2005



Ref: On-Road Remote Sensing of Automobile Emissions in West Los Angeles: Year 4, October 2005, CRC Contract E-23-9, April 2006 (http://crcao.com)

“We easily forget that smog is the price of freedom of our streets from manure, and from the flies and diseases it brought.” – Daniel J. Boorstin (1914-2004), Librarian of Congress from 1975-1987.

APPENDIX G

MR. MICHAEL JACKSON

In-Use Emissions Performance of On- and Off-Road Vehicle Applications

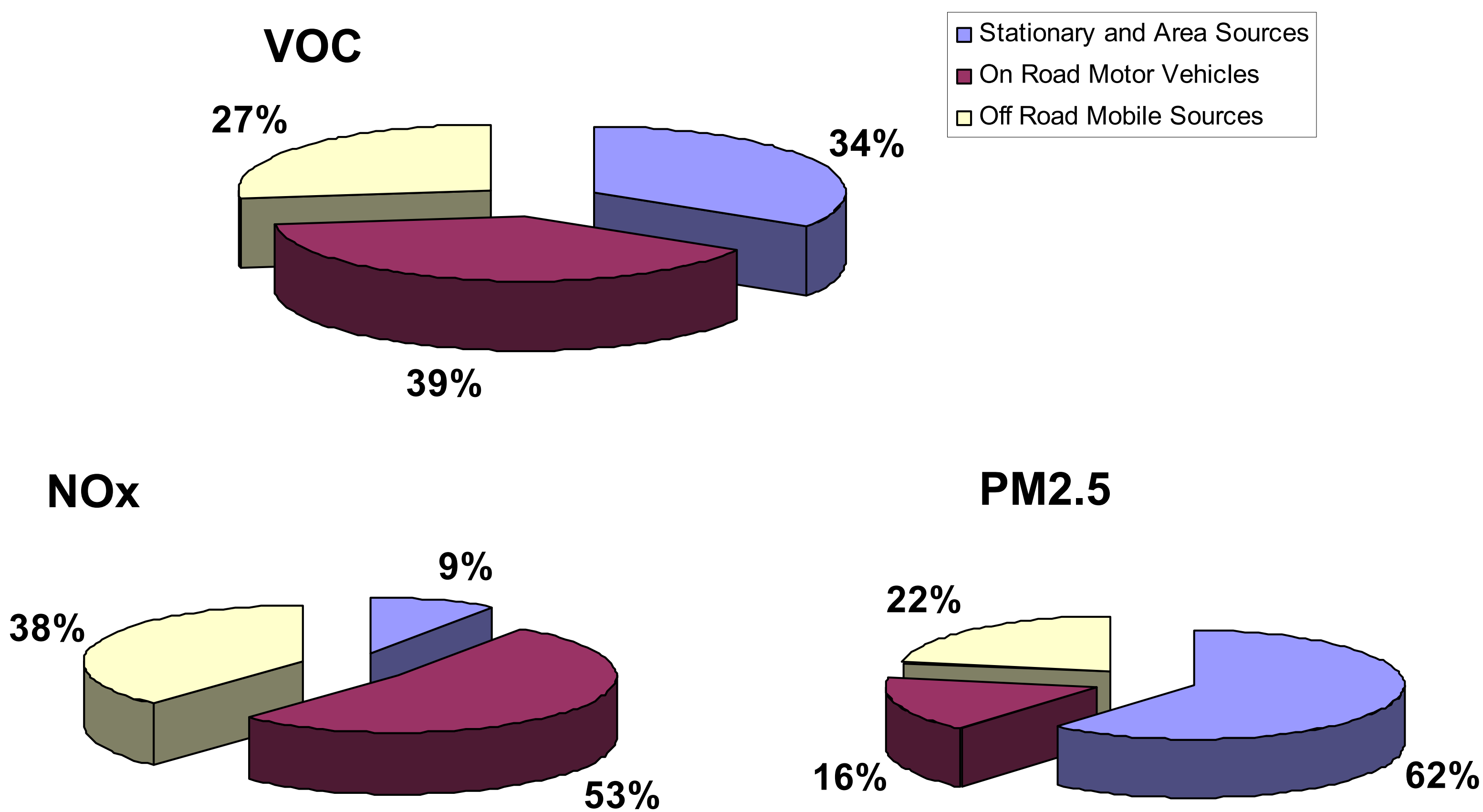
Presented at
Ozone Air Quality Forum and Roundtable Discussions
October 31, 2006
South Coast Air Quality Management District
Diamond Bar, California

Michael Jackson
TIAX LLC
1601 S. De Anza Blvd., Ste 100
Cupertino, California
95014-5363
(408) 517-1550

1. Mobile Emissions Inventories
2. Light-Duty Vehicles
3. Heavy-Duty Vehicles
4. Summary

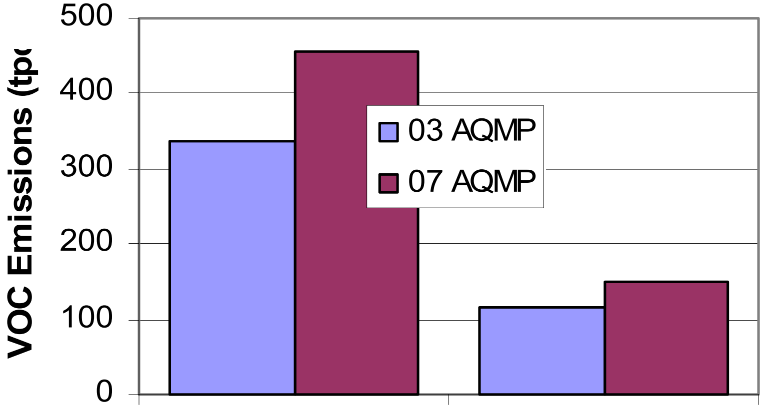
1	Emissions Inventories
2	Light-Duty Vehicles
3	Heavy-Duty Vehicles
4	Summary

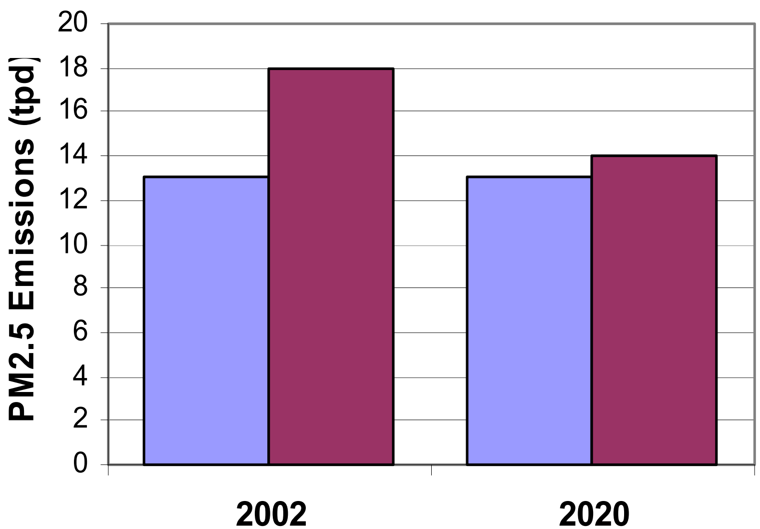
Inventory Contributions 2008 Summer Planning

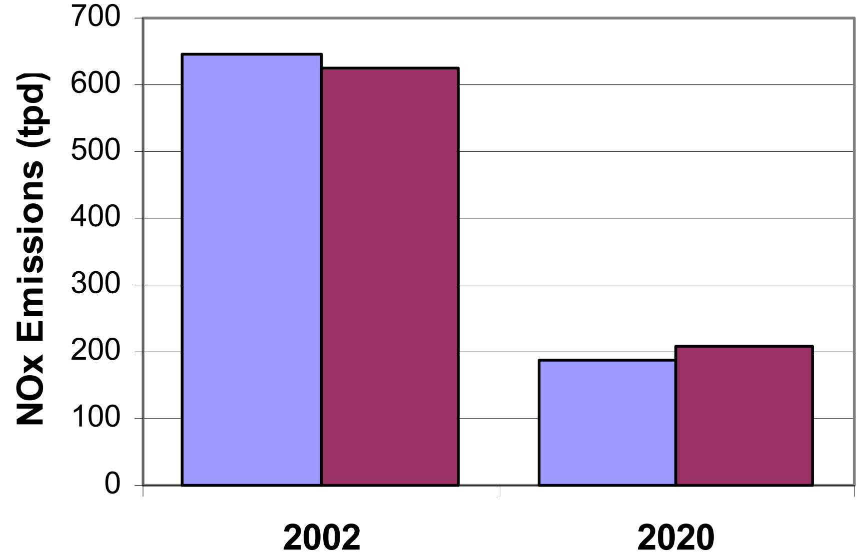


Source: SCAQMD 2007 AQMP, Appendix III, Attachment B

Comparison of On-Road Emission Inventories

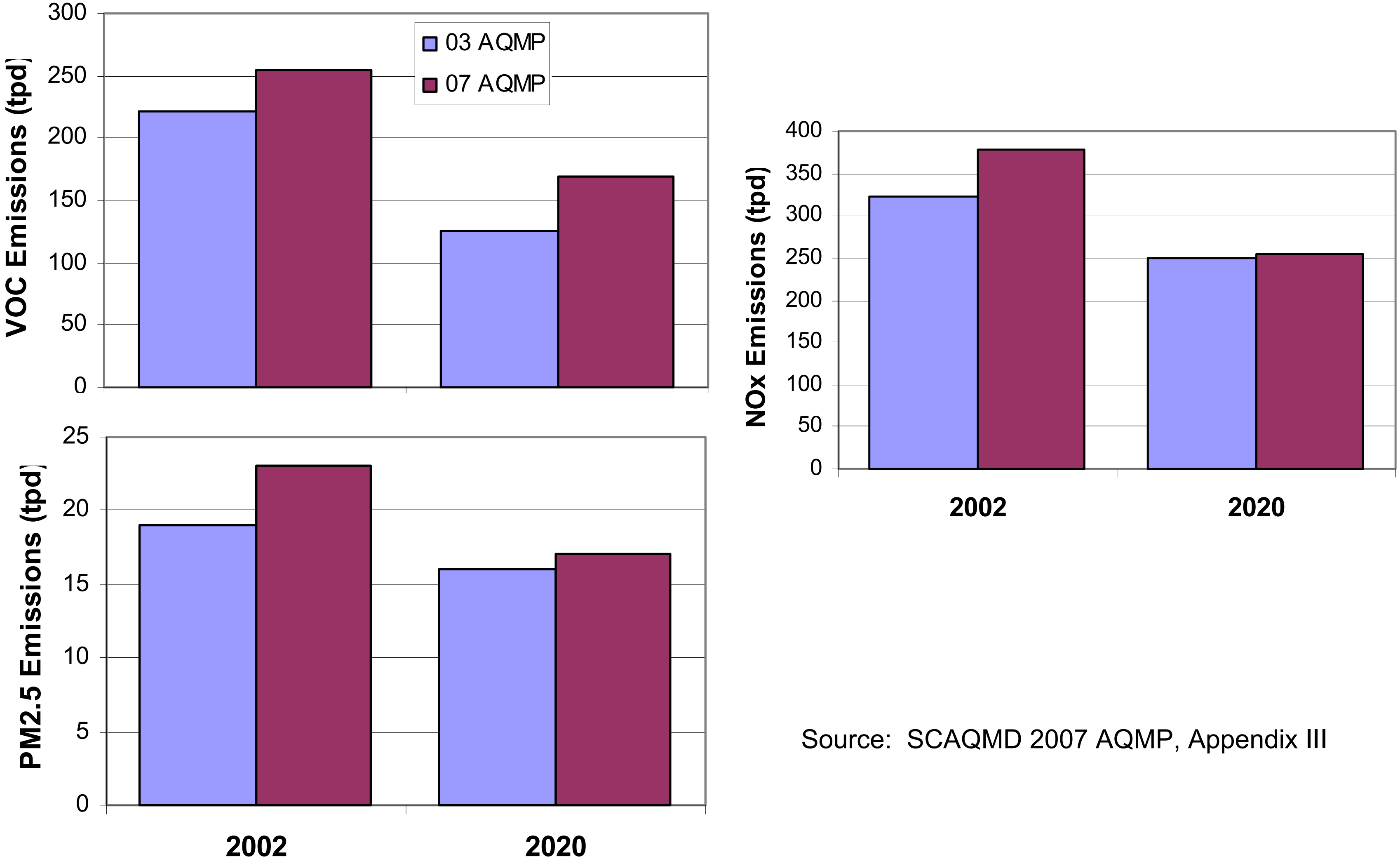






Source: SCAQMD 2007 AQMP, Appendix III

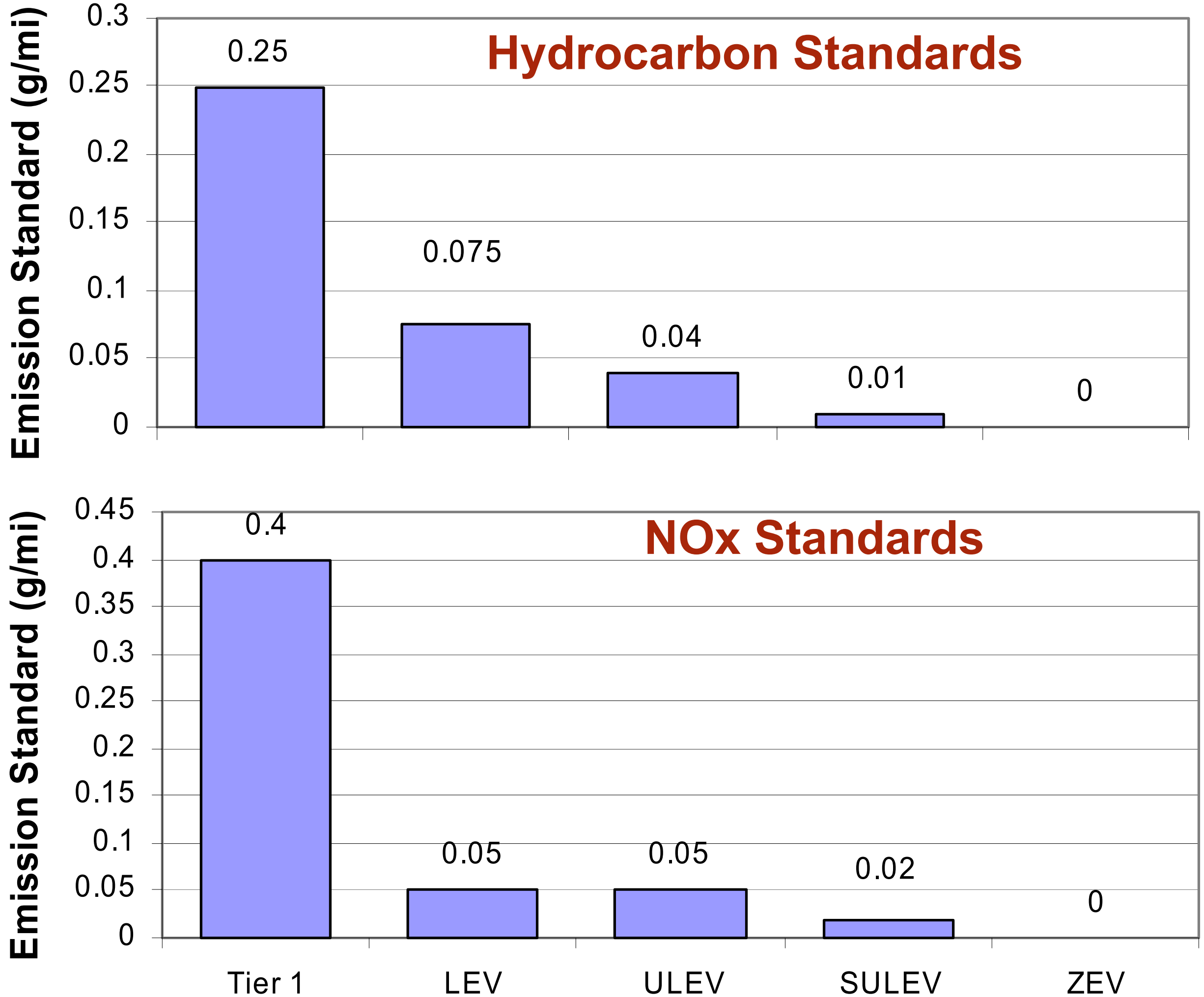
Comparison of Off-Road Emission Inventories



Source: SCAQMD 2007 AQMP, Appendix III

1. Mobile Emissions Inventories
2. **Light-Duty Vehicles**
3. Heavy-Duty Vehicles
4. Summary

Lower HC and NOx Emissions Achieved With Cleaner Fuels and Advanced Catalyst Technology

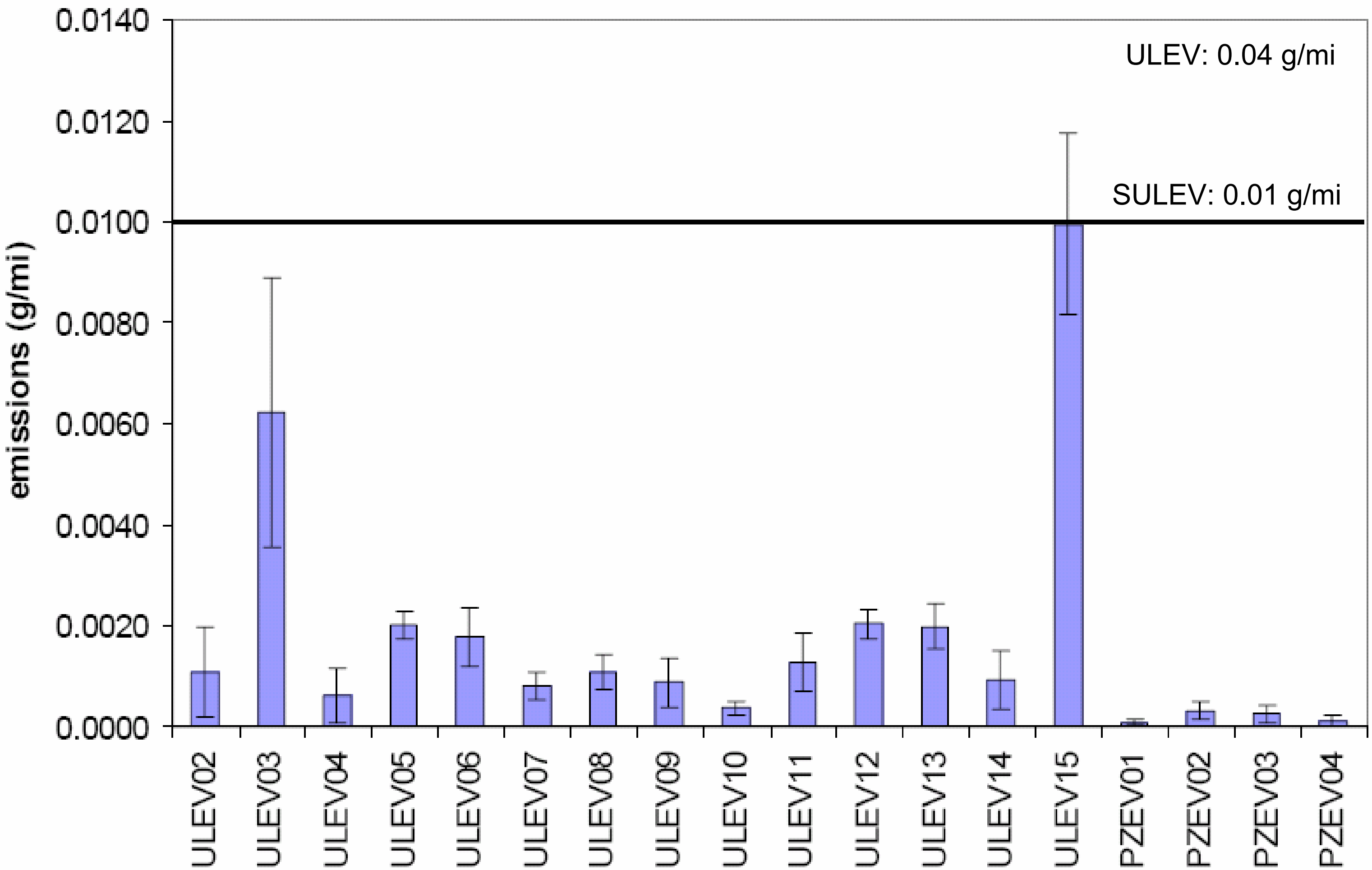


UC Riverside Testing of Ultra-Low Emission Vehicles

Vehicle ID	Certification	Model Year	Make	Model	Odometer
ULEV01	ULEV	2002	Acura	3.2TL	32,344
ULEV02	ULEV	2002	Buick	Regal	21,184
ULEV03	ULEV	2001	Ford	Focus	35,089
ULEV04	ULEV	2002	Ford	Mustang	23,894
ULEV05	ULEV	2002	Honda	Civic	26,632
ULEV06	ULEV	2003	Honda	Civic Hybrid	13,700
ULEV07	ULEV	2001	Mazda	Protégé	27,114
ULEV08	ULEV	2002	Mitsubishi	Galant	22,350
ULEV09	ULEV	2002	Mitsubishi	Lancer	13,300
ULEV10	ULEV	2002	Nissan	Altima	13,747
ULEV11	ULEV	2002	Saturn	L200	14,888
ULEV12	ULEV	2002	Toyota	Camry LE	13,098
ULEV13	ULEV	2003	Toyota	Corolla	21,835
ULEV14	ULEV	2003	Honda	Civic Hybrid	13,700
ULEV15	ULEV	2001	Volkswagen	Jetta GLS	101,049
ULEV16	ULEV	2000	Dodge	Neon	87,766
ULEV17	ULEV	1999	Honda	Accord LX	80,436
PZEV01	PZEV	2003	Honda	Accord EX	7,731
PZEV02	PZEV	2003	Honda	Civic Hybrid	1,502
PZEV03	PZEV	2003	Toyota	Camry LE	2,600
PZEV04	PZEV	2003	Honda	Civic GX	15,191

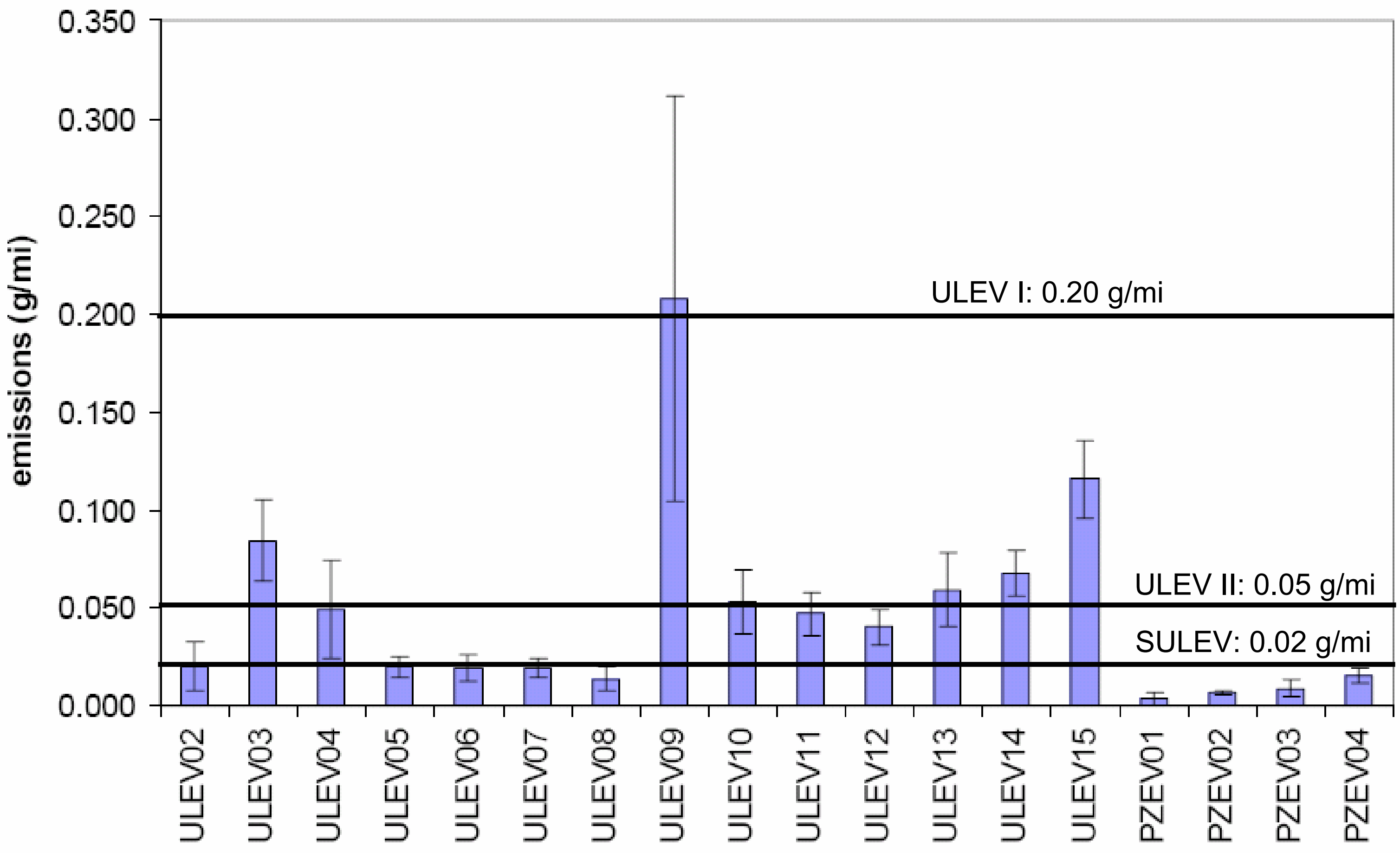
Source: A Summary of the Study of Extremely Low Emitting Vehicles Operating on the Road in California (Norbeck et al, 2005)

On-Road NMHC Emissions



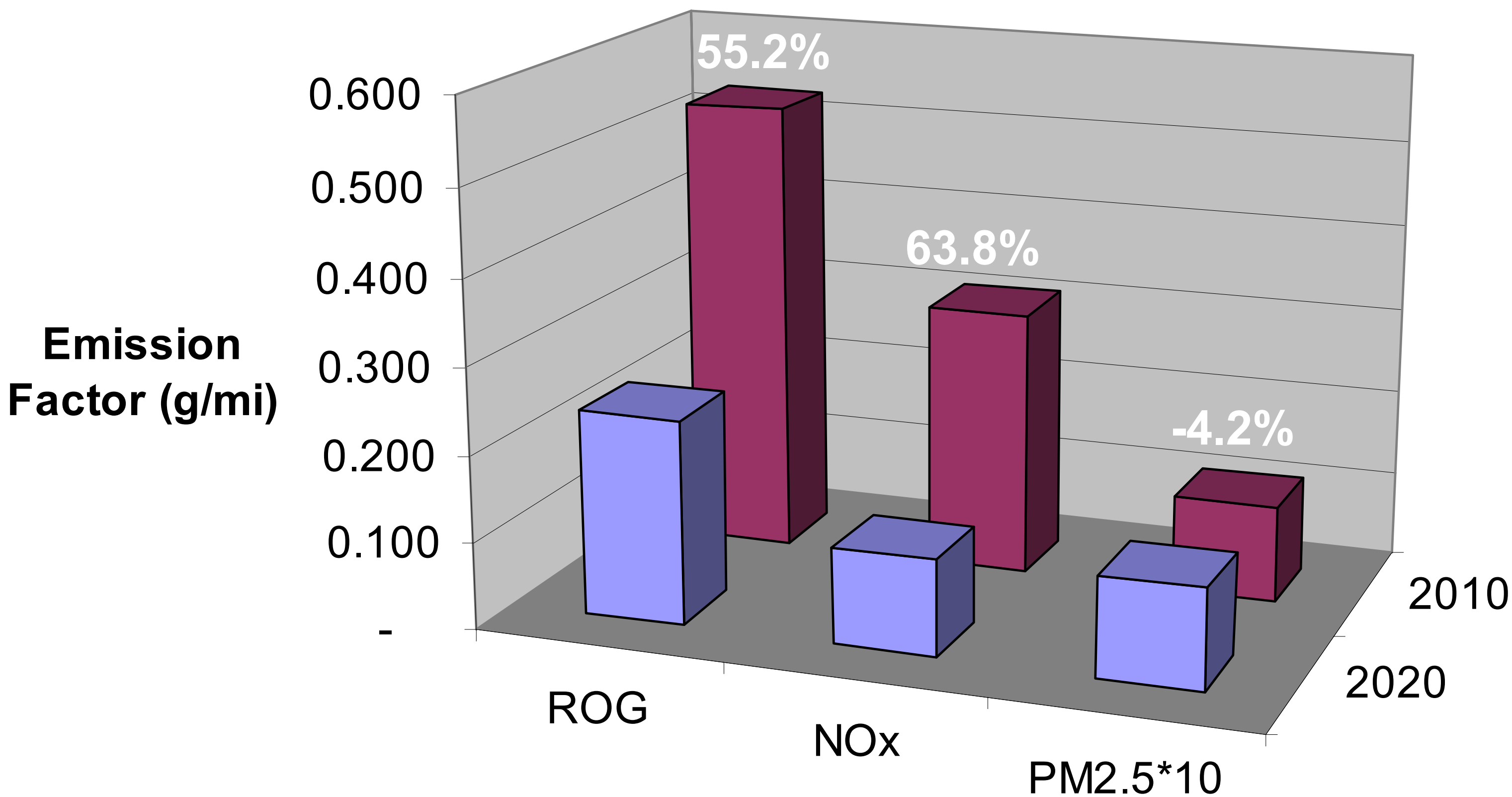
Source: A Summary of the Study of Extremely Low Emitting Vehicles Operating on the Road in California (Norbeck et al, 2005)

On-Road NOx Emissions



Source: A Summary of the Study of Extremely Low Emitting Vehicles Operating on the Road in California (Norbeck et al, 2005)

Passenger Car Emission Reductions in EMFAC2007



Source: SCAQMD 2007 AQMP, Appendix III, Attachment E

Most Light-Duty Emissions from High Emitting Vehicles

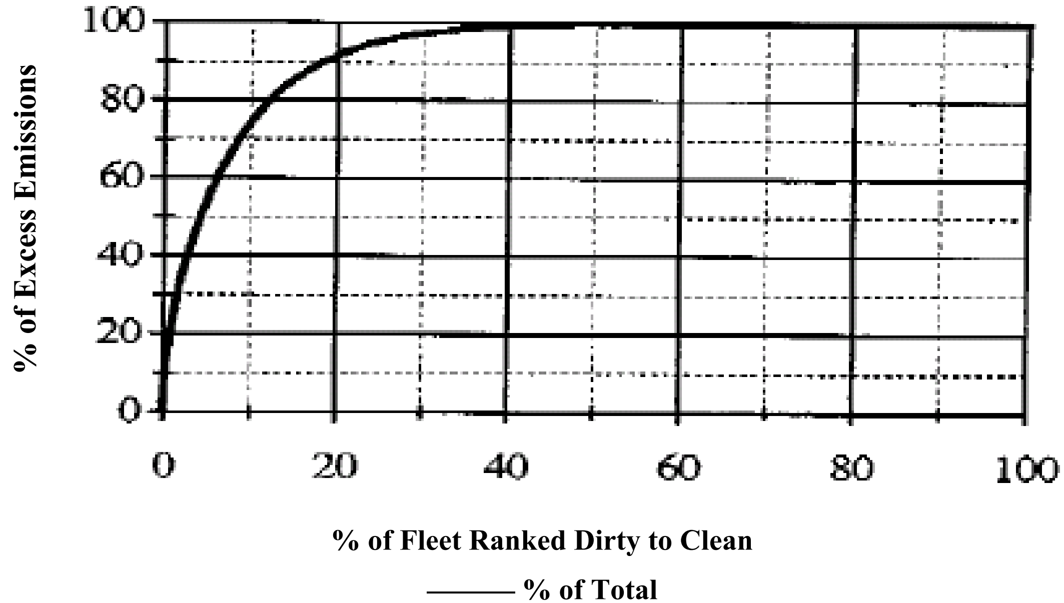


FIGURE 1-9 Aggregated excess FTP CO, HC NO_x emissions from the California I/M pilot study rank-ordered from highest to lowest emitters. Excess emissions for each pollutant are aggregated using the equation (1/7(CO) + NO_x + HC).

Source: Evaluating Vehicle Emissions Inspection and Maintenance Programs (NRC, 2001)

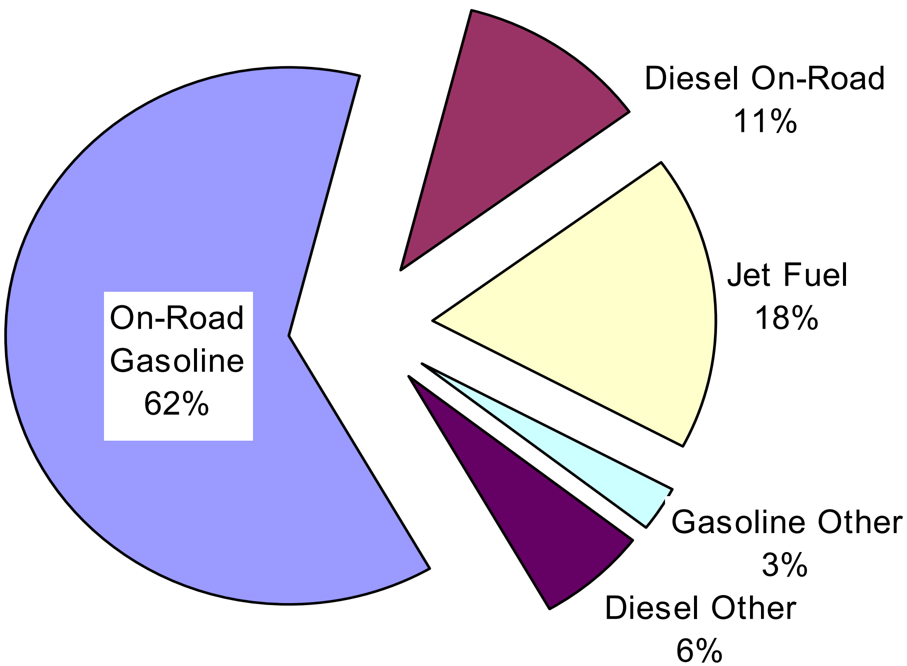
1 Mobile Emissions Inventories

2 Light-Duty Vehicles

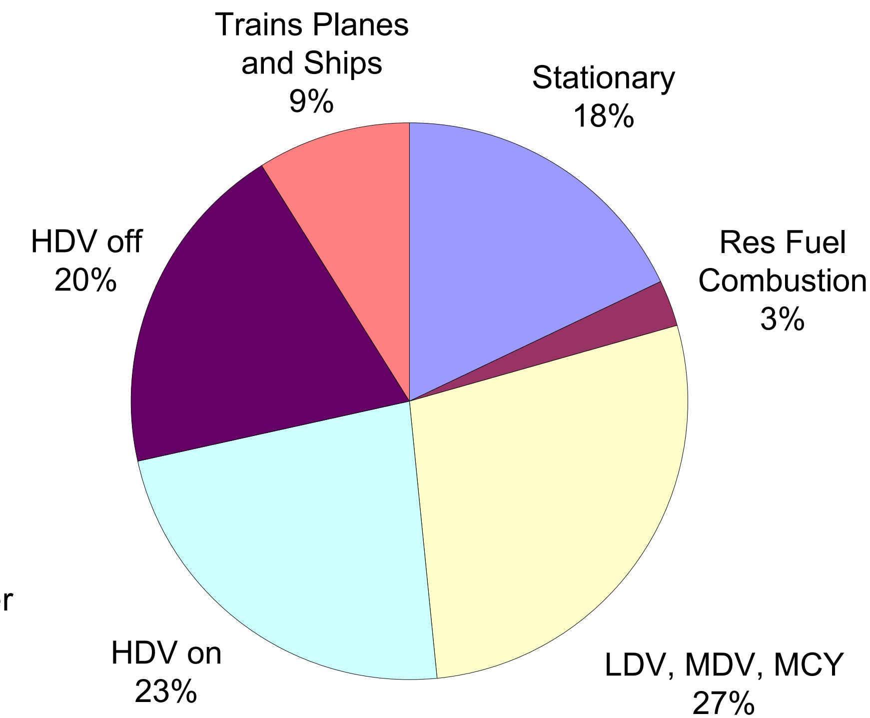
3 **Heavy-Duty Vehicles**

4 Summary

Diesel Applications Dominate NOx Emissions



Fuel Consumed



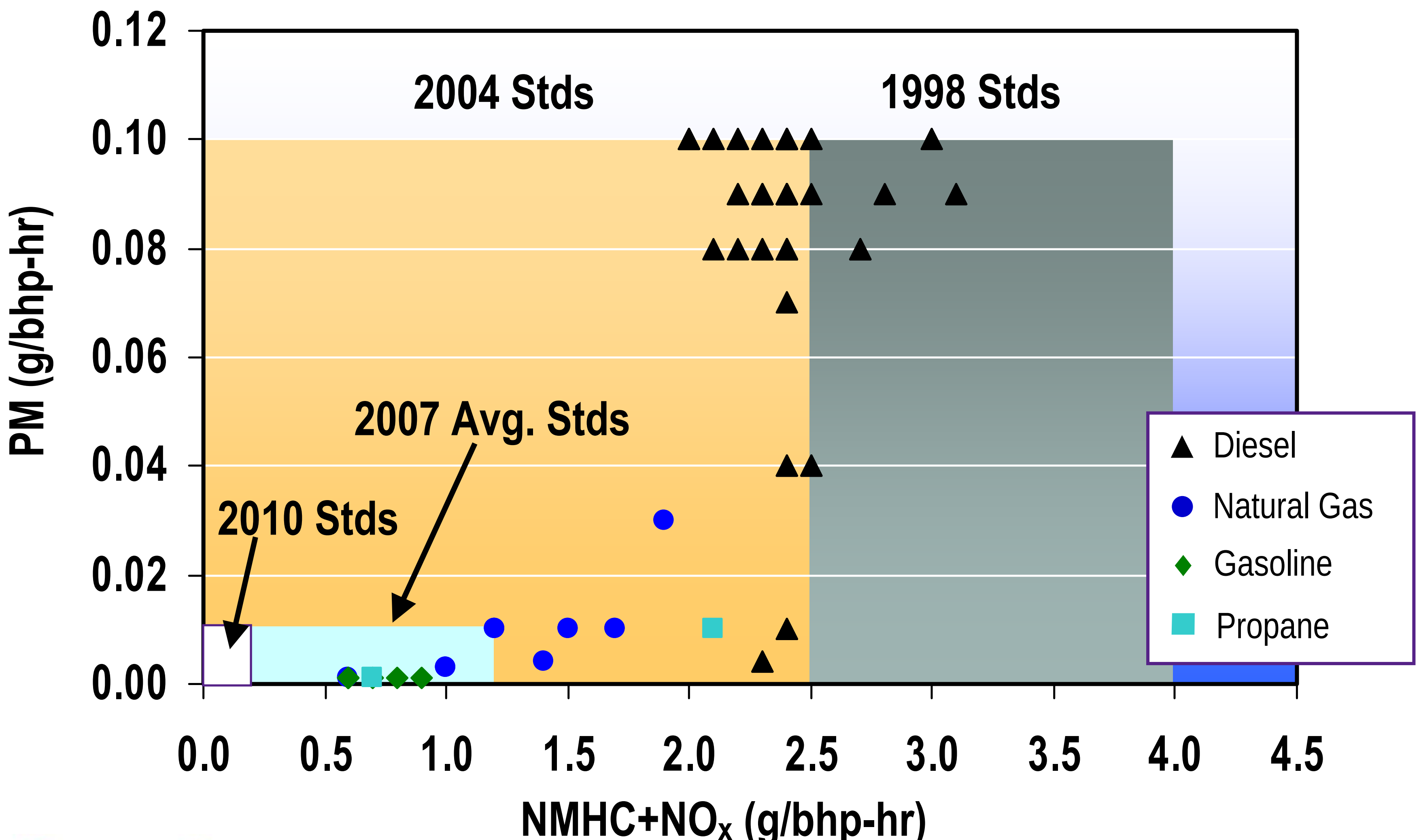
NO_x Emissions

Source: California ARB

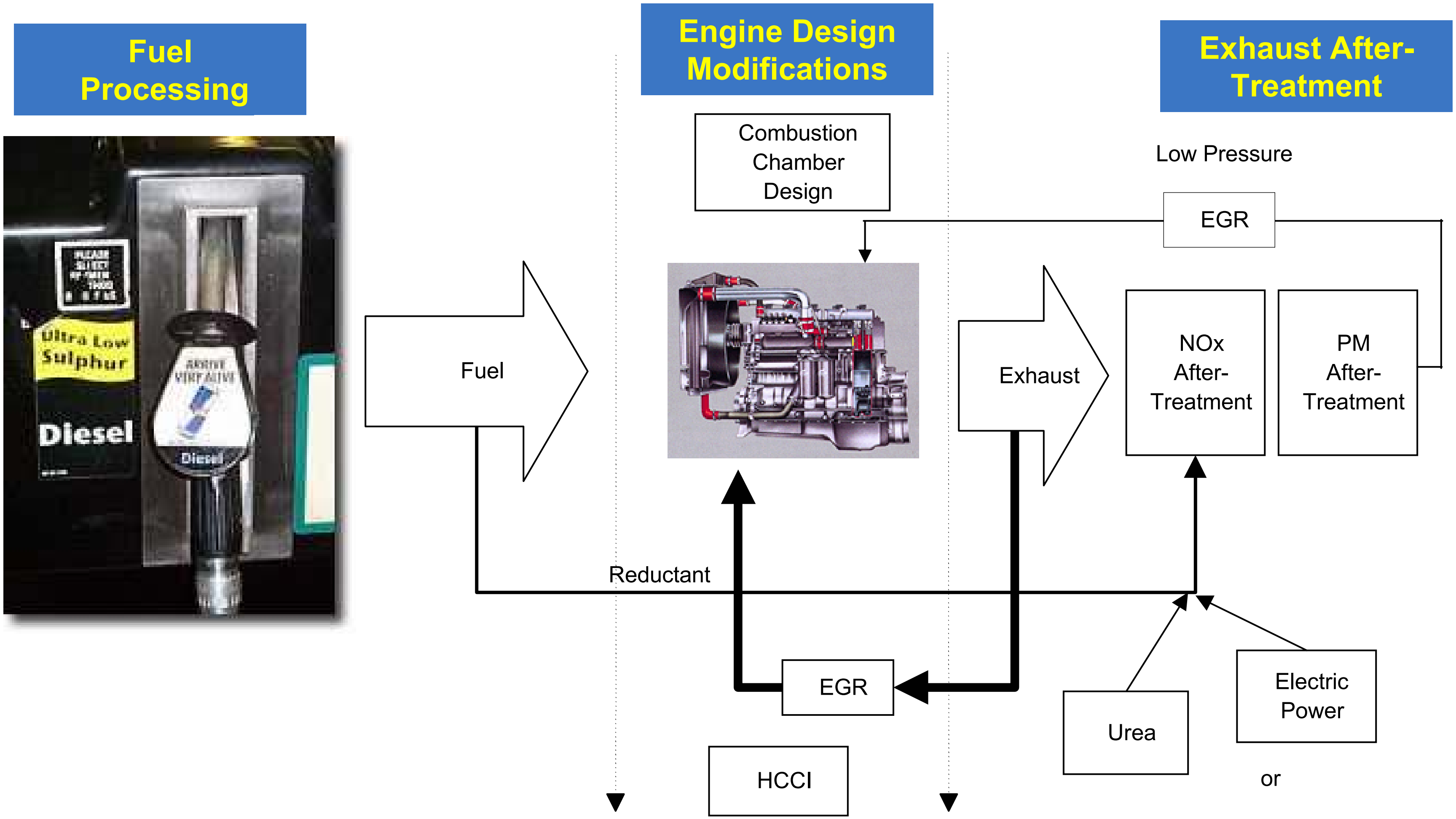
Diesel engines provide high efficiency/fuel economy

- Diesel engines predominate heavy-duty on-road, off-road, and marine applications
  - Good torque/hp performance over operating conditions
  - Extremely reliable and durable — “million mile engines” in over the road trucking applications
  - Excellent fuel economy in variety of applications from light-duty passenger cars and trucks to on-road heavy duty and off-road heavy duty vehicles
  - Excellent overall life-cycle costs in variety of applications

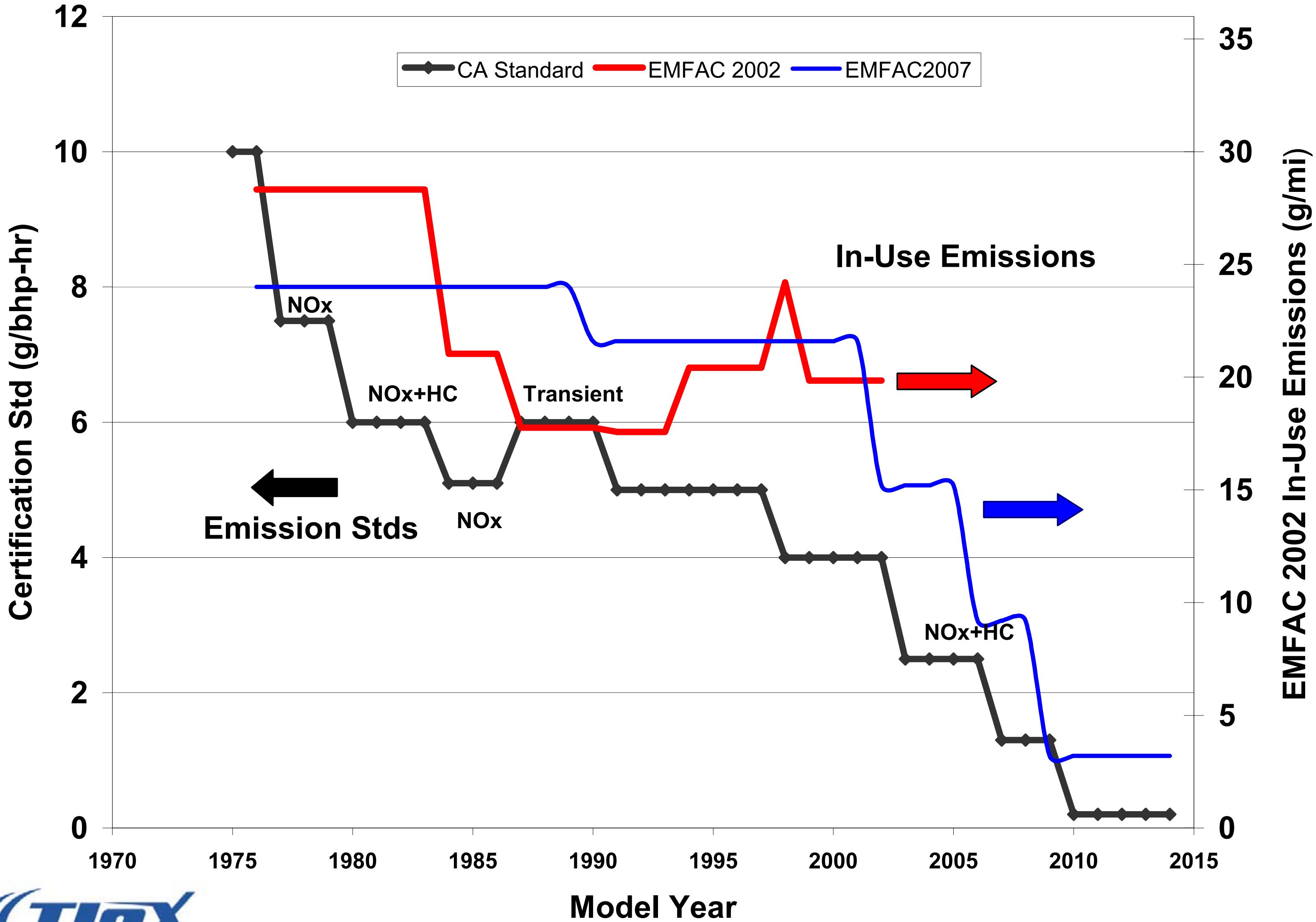
2005 heavy-duty engine certifications (as of June 17, 2005)



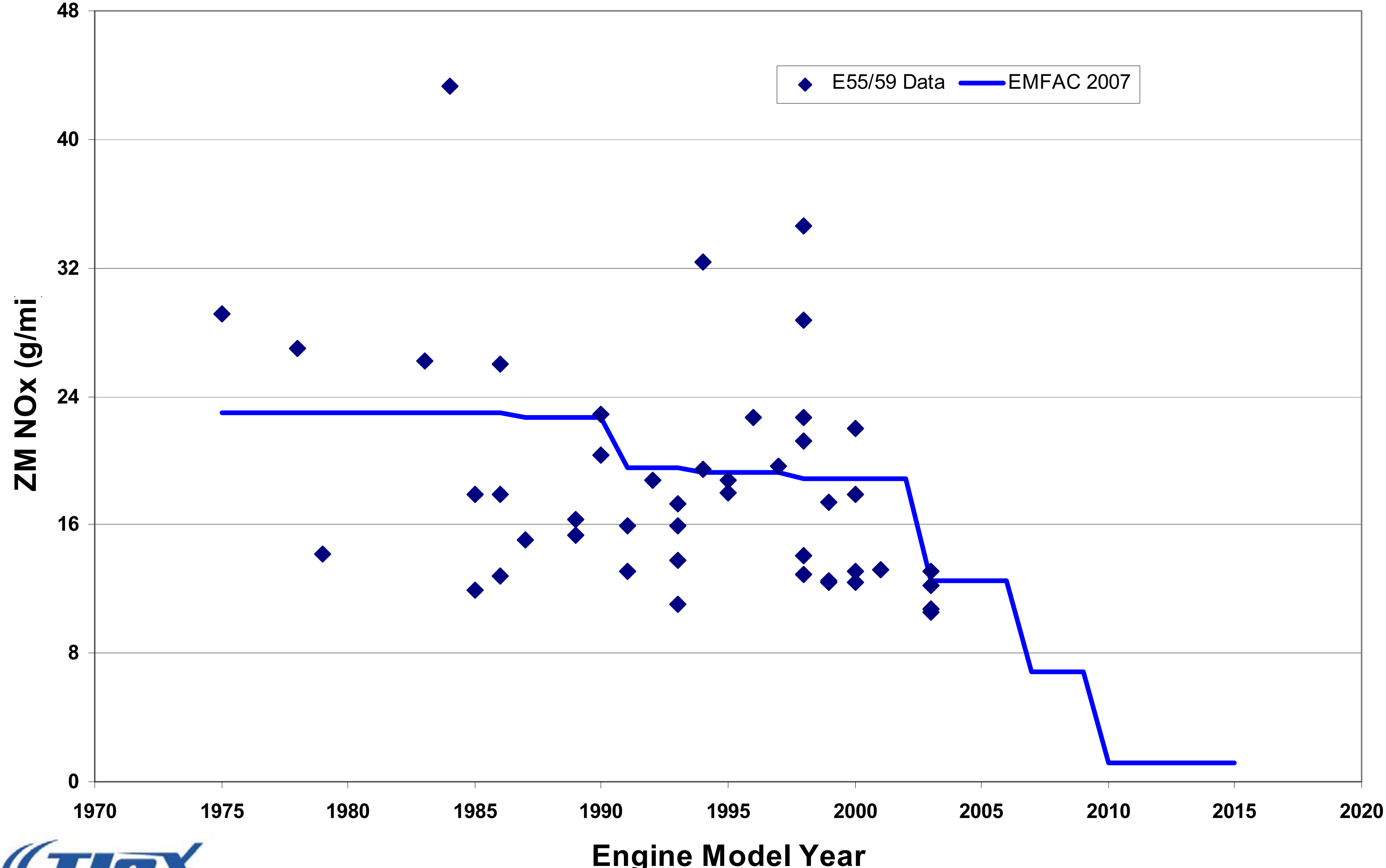
Technologies used to reduce NOx and PM from heavy-duty diesel applications center on three areas:



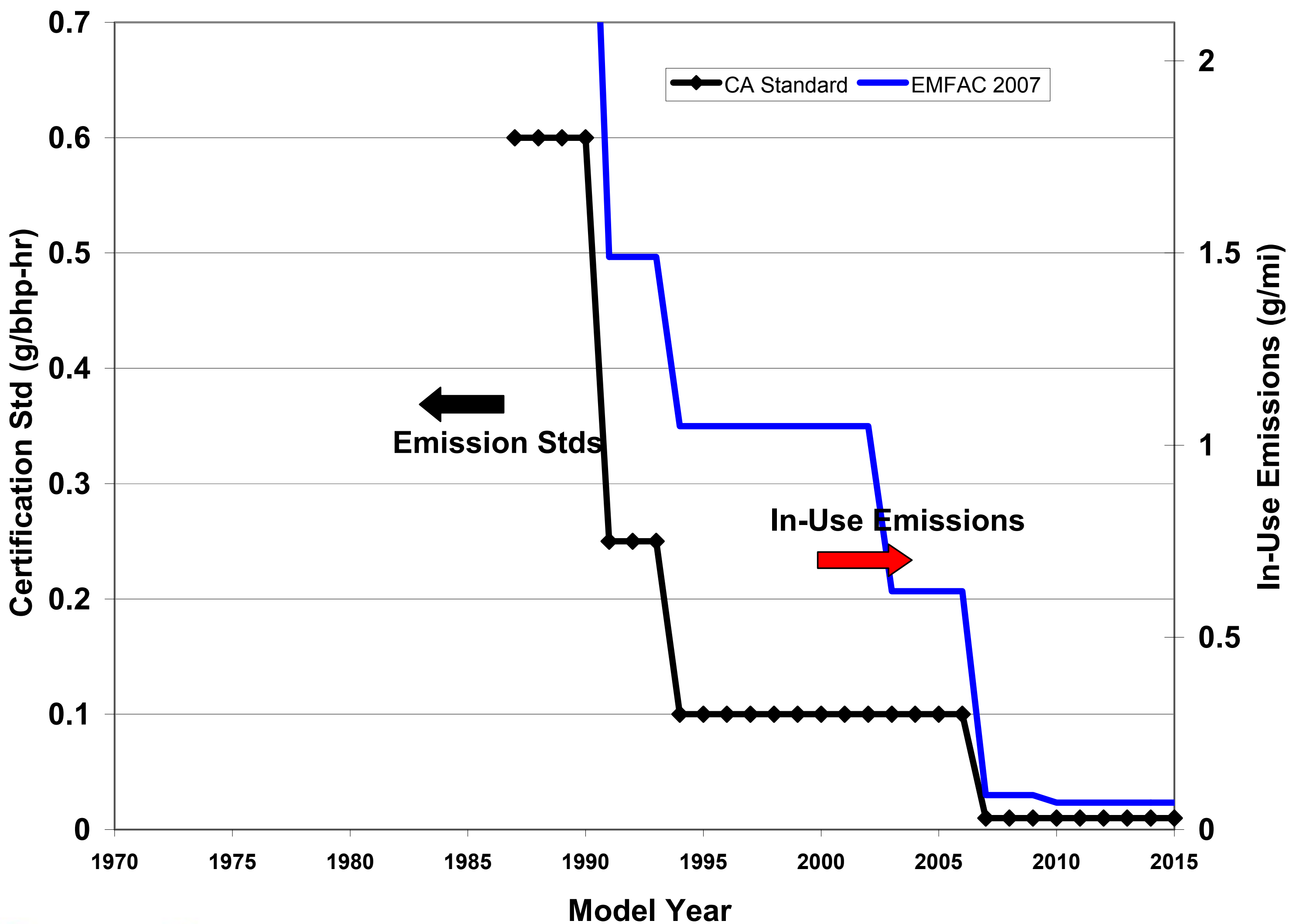
NO_x engine standards and in-use emissions



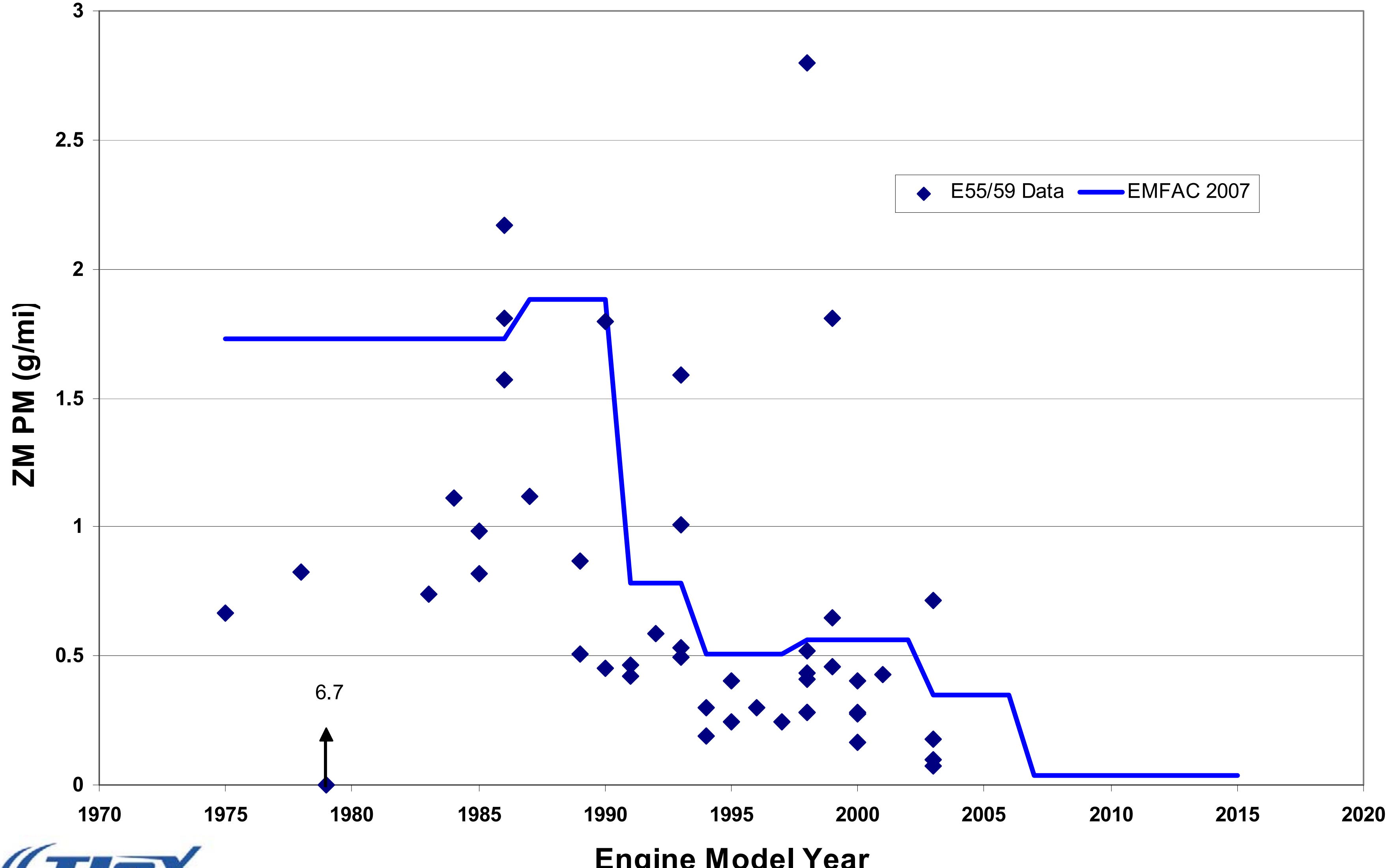
Comparison of In-Use Chassis Data to EMFAC2007



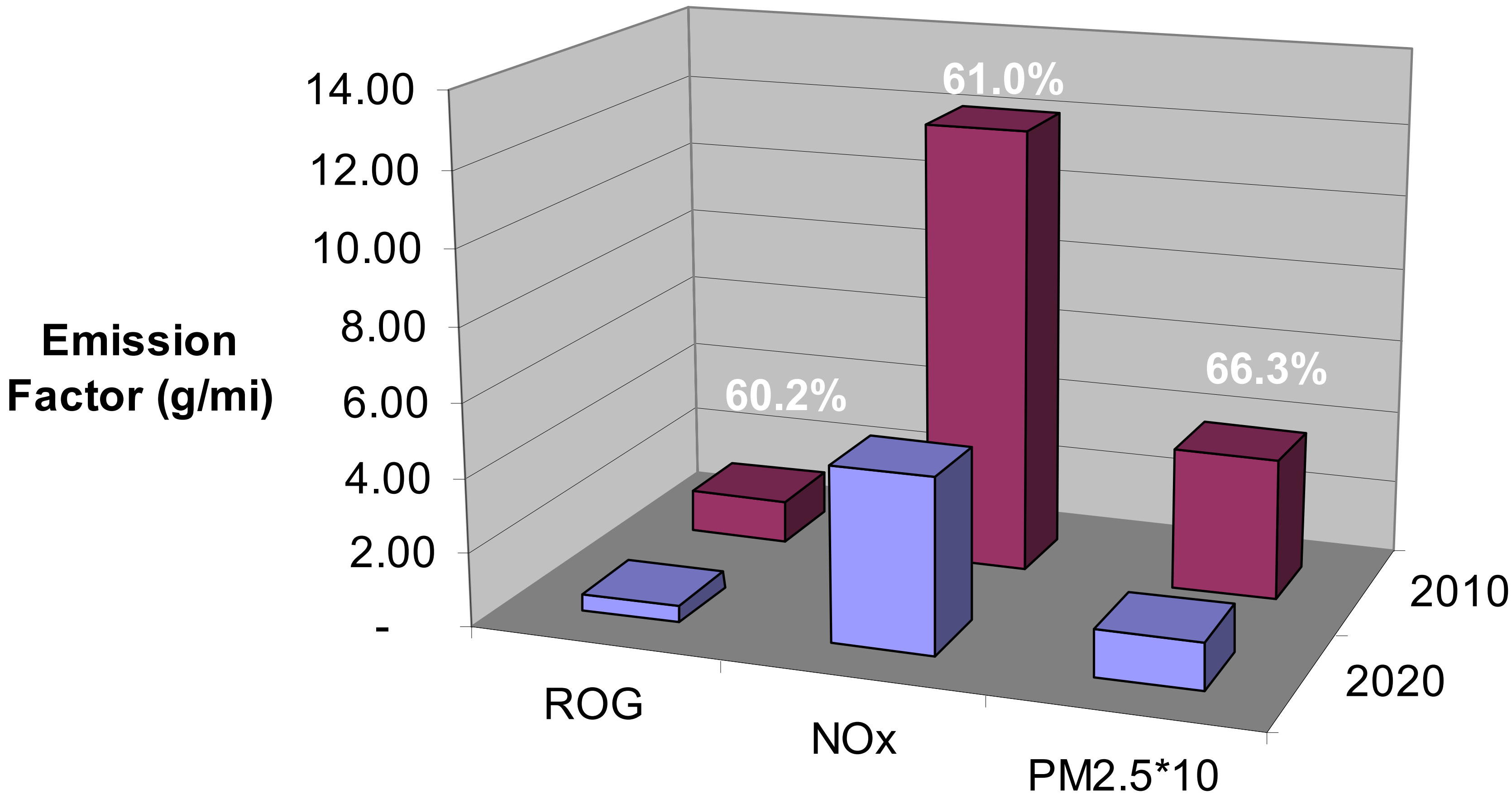
PM standards and in-use emissions



Comparison of In-Use Chassis Data and EMFAC2007



Heavy-Duty Truck Emissions Reductions in EMFAC2007

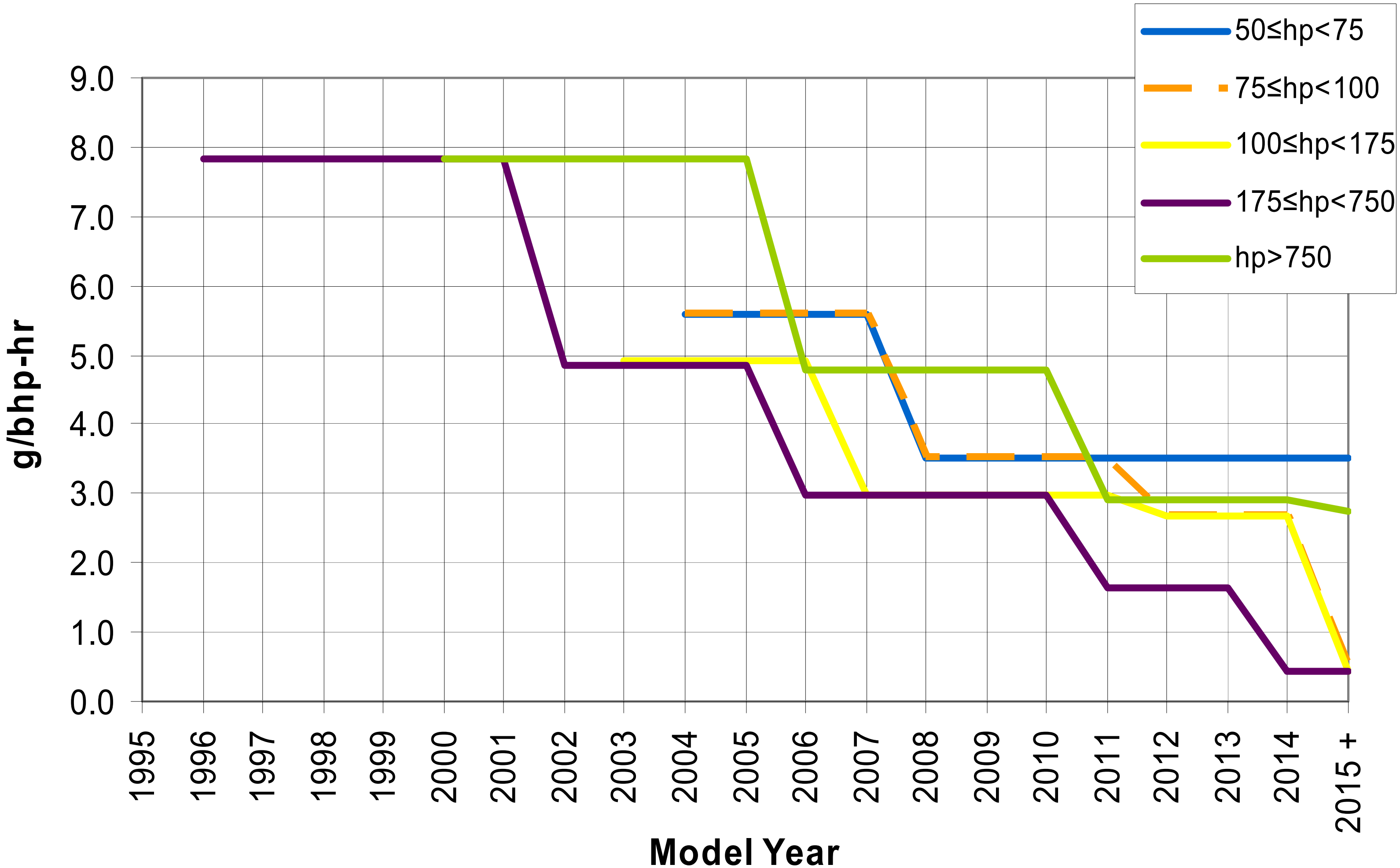


Source: SCAQMD 2007 AQMP, Appendix III, Attachment E

Example of Off-Road Construction Equipment

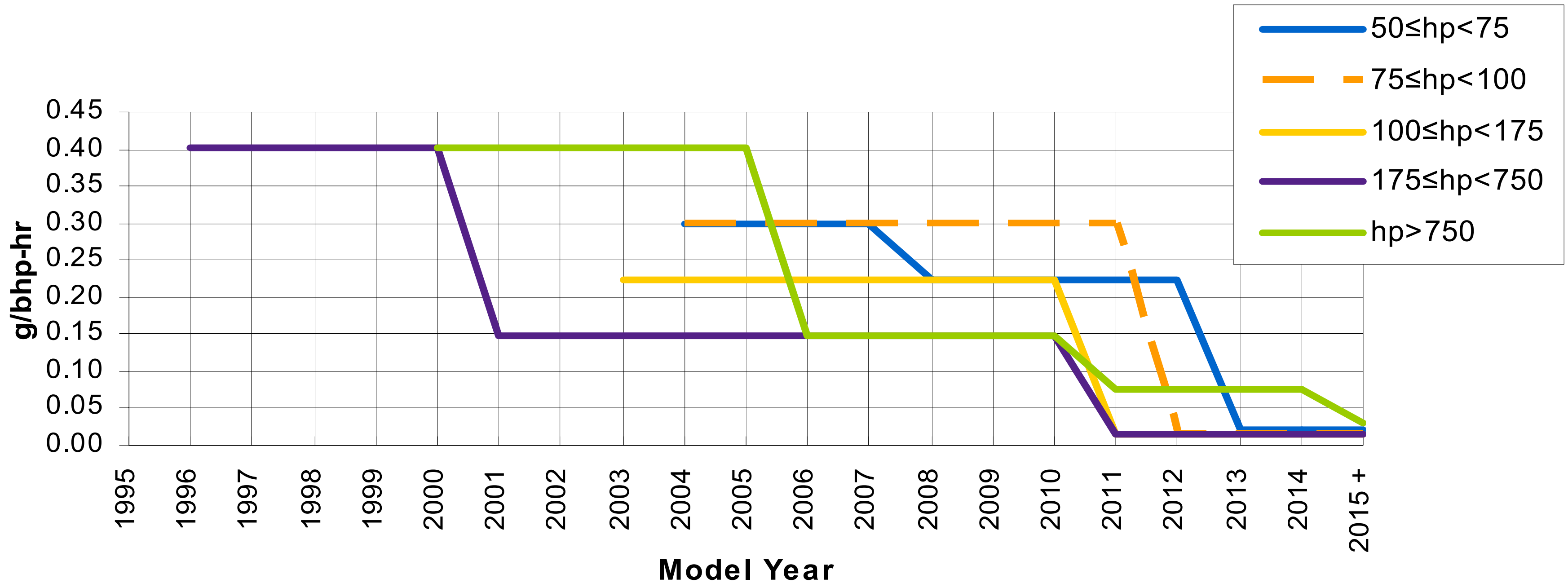
Source: eBay

Off-Road NMHC + NOx Emissions Standards



To obtain NOx emissions levels, multiply NMHC + NOx number by default fraction factor 0.95

Off-Road PM Emissions Standards



1	Mobile Emissions Inventories
2	Light-Duty Vehicles
3	Heavy-Duty Vehicles
4	**Summary**

Control of In-Use Emissions from Engines and Vehicles Needed

- Attainment of PM2.5 and Ozone standards will require substantial emission reductions from mobile sources
- Cleaner fuels and advanced technologies may provide needed reductions for attainment, but engine and vehicle standards will have to be achieved in-use and over their useful lives.
- Emissions from light duty vehicles have been dramatically reduced
  - New ultra-low, emission technology is appearing more robust
  - Still hard to find and reduce missions from gross polluters
  - Smog Check Program, On-Board Diagnostics (OBD), and fleet turn over may reduce impact of gross polluters
- New emissions standards for heavy-duty, on- and off-road vehicles will considerably reduced NOx and PM2.5 emissions
  - Need reductions in-use
  - Need emissions reductions over vehicle and equipment useful life
  - NTE requirements, road side testing, and OBD may reduce in-use impact

Thank You For Your Attention

Contact Michael D. Jackson
Jackson.michael@tiaxllc.com
408-517-1560

APPENDIX H

MR. PAUL WUEBBEN

Air Quality Impacts from Ethanol Use

Presented to

Ozone Forum & Technical Roundtable

October 31, 2006
Diamond Bar, CA

Paul Wuebben
Clean Fuels Officer
South Coast Air Quality Management District

Outline

- Ethanol Impacts on Ozone
- Impact on Control Strategies
- Low Level Blend Findings from AQMD Ethanol Forum
- Commingling Effects
- Perspective on E-85 Fuel Ethanol

Focus on 2003 Air Quality

- Highest ozone concentrations since mid 90's
- Exceptionally warm-stagnant year
- Co-mingling of ethanol and MTBE increase evaporative emissions
- Permeation adding to evaporative emissions increase
- Modeling sensitivity analyses (assuming co-mingling and permeations) suggest a 10-20 ppb potential increase in maximum ozone concentrations due to evaporative emissions enhancement

Ethanol Impact on Ozone Formation

- Different blends of ethanol have been suggested for future Basin distribution E6, E10, E85
- Chemistry Question:
  - > Implications are that increased ozone production from enhanced evaporative VOC emissions are partially offset due to reduced CO emissions for E6 – E10
- Meteorological Interference:
  - > Episode days are typically much hotter than average and evaporative emissions may increase faster and in greater totals

Impact on AQMD Control Strategies

- Federal oxygenate mandate is no longer in effect
  - > neighboring gas stations may have different blends – some with ethanol and some without
  - > potential return of co-mingling, and enhanced permeation
- Need to evaluate the impact of potential ethanol market penetration scenarios
- Nominal increases in VOC in future years may lead to ozone exceedances

Ethanol Blend Issues Addressed at June 15, 2006 AQMD Ethanol Forum

- Permeation
- Predictive Model Accuracy / Robustness
- Mitigation strategies
- CO / HC tradeoffs
- Commingling
- Certification test fuel
- Greenhouse Gas Benefits

Excess Permeation Emissions from Ethanol Use

2010, South Coast Air Basin, tpd

	Peak Summer Temperature Assumed	
	86 ° F	**97 ° F**
On-Road	8.7	17.4
Off-Road	11.3	22.6
Total	**20**	**40**

Predictive Model Accuracy / Robustness

- Current data set based on older vehicle and fuels data
- New data on ULEV and SULEV show complicated interaction between gasoline volatility and ethanol
- Update should ensure science is correct—model can have big effect on emissions as well as economic viability of reformulated gasoline
- 10% ethanol blends show an <u>increase</u> in NOx emissions

Mitigation strategies

- ARB required by state law to ensure control measures do not increase emissions (SB 989)
  - Permeation emissions impact of the transition from Phase 2 to Phase 3 gasoline must be mitigated.
- ARB will evaluate both fuel and non-fuel strategies to mitigate emission increases
- Predictive model could provide fuel strategy if resulting reformulated gasoline is economic
- Summertime zero ethanol policy is fuel strategy but would not be favored by refining or ethanol industries
- It’s not clear that fuel offset requirements alone will be sufficient.

CO / HC tradeoffs

- Suggestions that HC increases are fully offset by CO reductions if CO reactivity is adjusted as proposed by the ethanol industry.
- ARB is updating its analysis and the predictive model but do not expect for CO reactivity to significantly offset permeation increases

Commingling

- Commingling of ethanol in non-ethanol blends recognized as resulting in higher RVP and potentially higher evaporative emissions and could have been partially responsible for Basin’s high ozone in 2003

E-85 Fuel Ethanol

- Very limited fueling stations at present
- Some incremental toxic and evaporative HC benefits from FFV use compared to gasoline
- Need for P-ZEV certification
- Logical longer term synergy:
  - Plug-in Hybrid FFV optimized on Renewable E-100:
    - e.g., *Saab 9-3 prototype with 30% fuel economy benefit compared to gasoline*

Conclusions

- Low level blends of ethanol create excess emissions & AQ impacts
- Essential to fully mitigate these emissions
  - *one option: zero oxygenate gasoline in summer months*
- Need to address <u>off-road</u> as well as on-road emissions impacts
- Role of renewable E-85 fuel ethanol expected to grow, dependent on cellulosic conversion technology *(i.e., better enzymes)*

APPENDIX I

MS. CYNTHIA MARVIN

South Coast

Ozone Air Quality Forum and Technical Roundtable

October 31, 2006

Diamond Bar

ARB Perspective on Ozone and Goods Movement

Cynthia Marvin, Assistant Division Chief

Planning and Technical Support Division

Air Resources Board

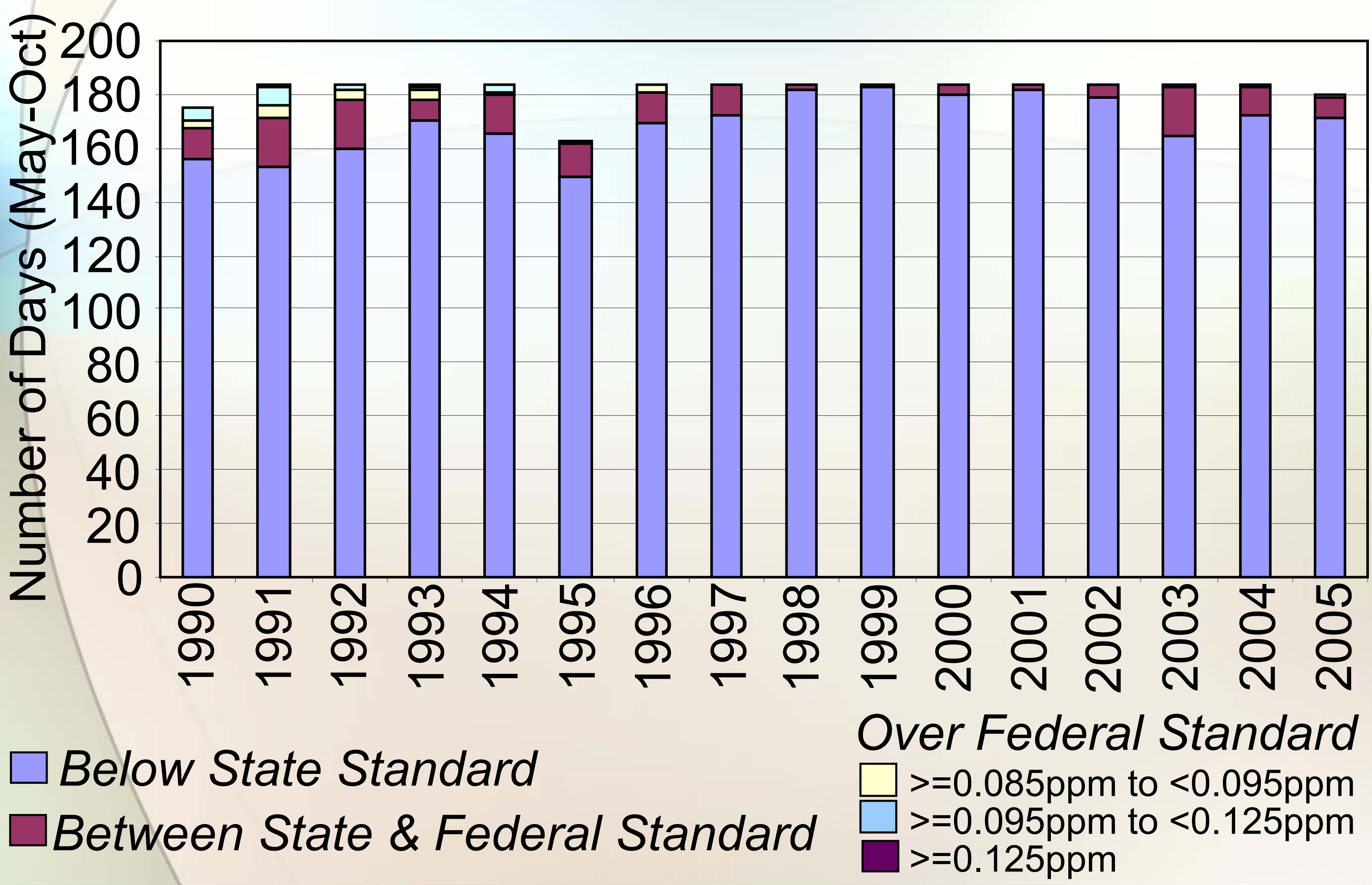
California Environmental Protection Agency

The Bottom Line

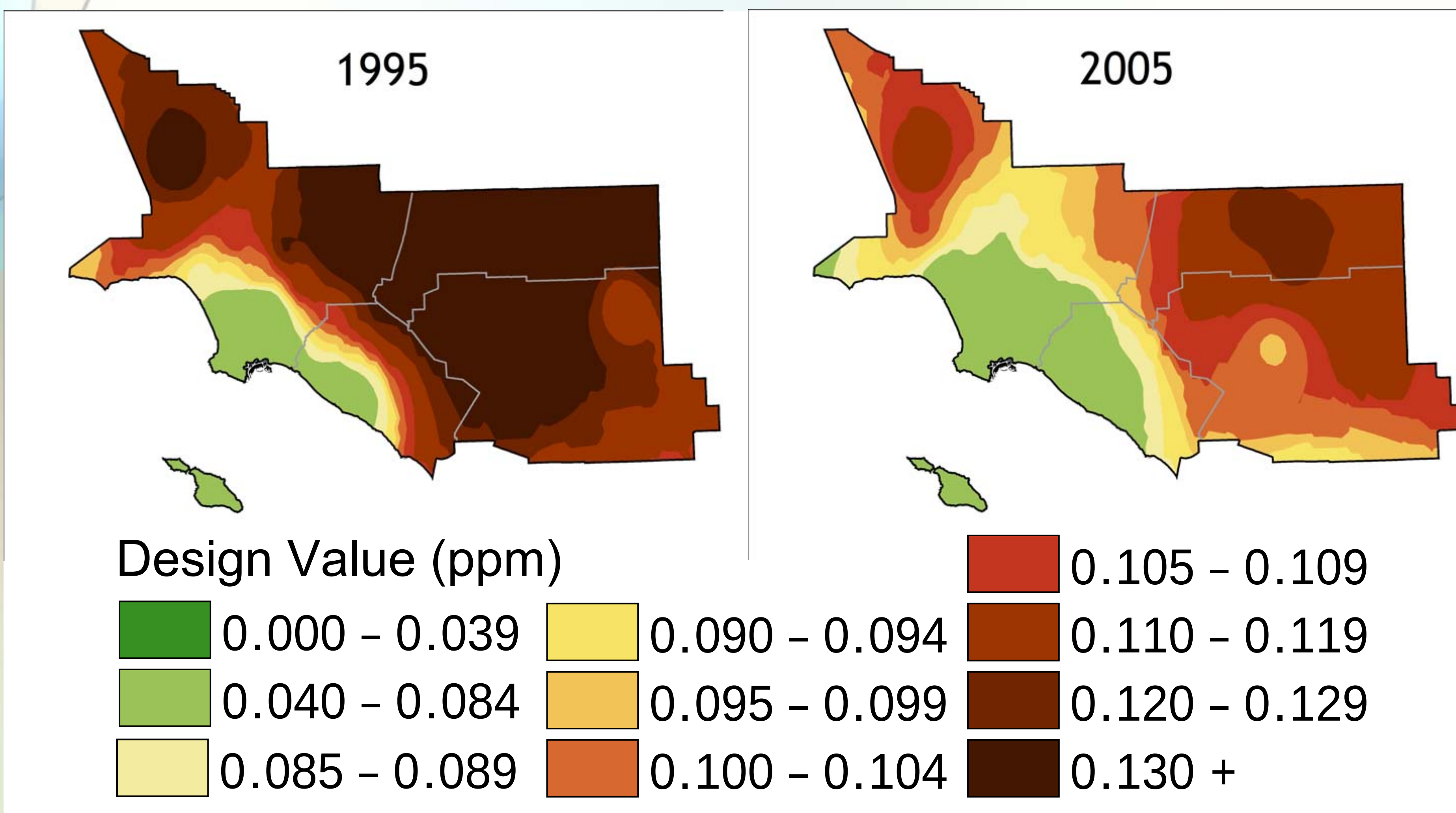
- **Long-term decrease in ozone due to VOC/NOx controls**
- **Decrease in PM2.5 levels driven by NOx and diesel PM reductions**
- **Dual pollutant strategy needed on ozone**
- **Goods movement is high growth**
- **New controls target health risk**
- **VOC controls need to keep pace**

Looking Back

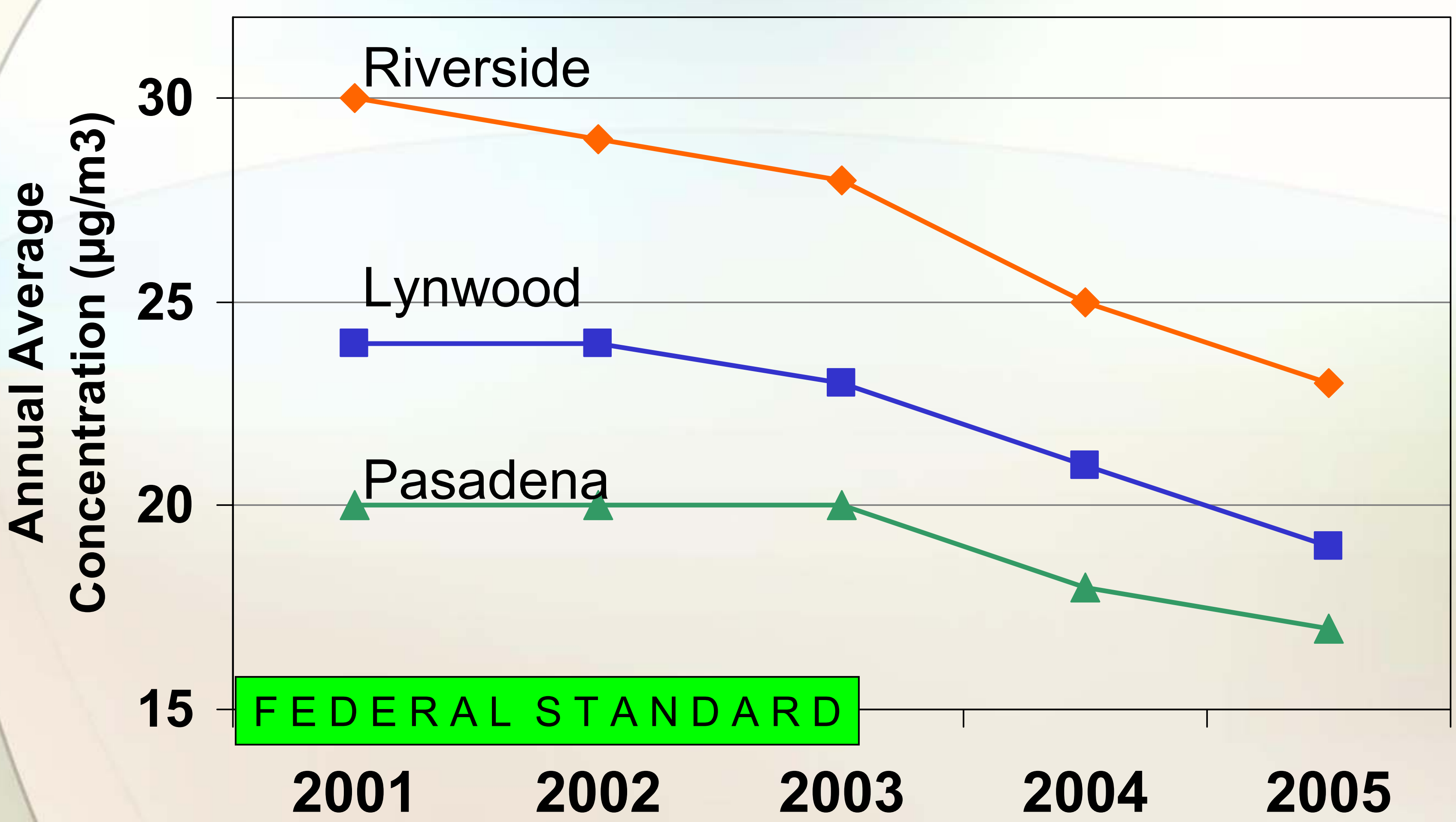
Ozone in Downtown LA Below <u>State</u> 8-Hr Standard ~170 Days of Season



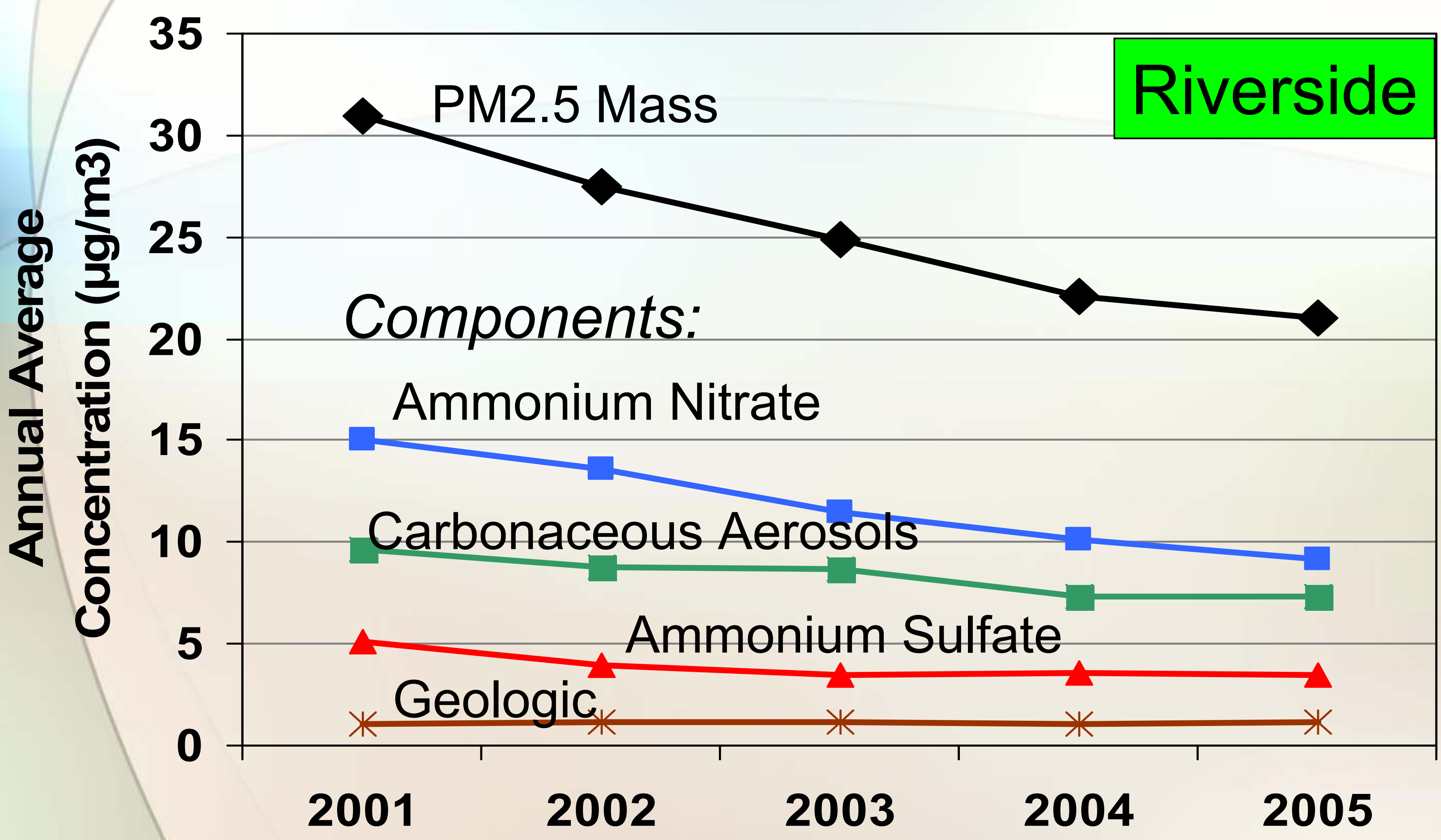
Half of South Coast Residents Live in Areas that Now Meet Federal 8-Hr Ozone Standard – But Half Do Not



PM2.5 Levels Down 15-20%



NOx Controls Driving PM2.5 Decrease



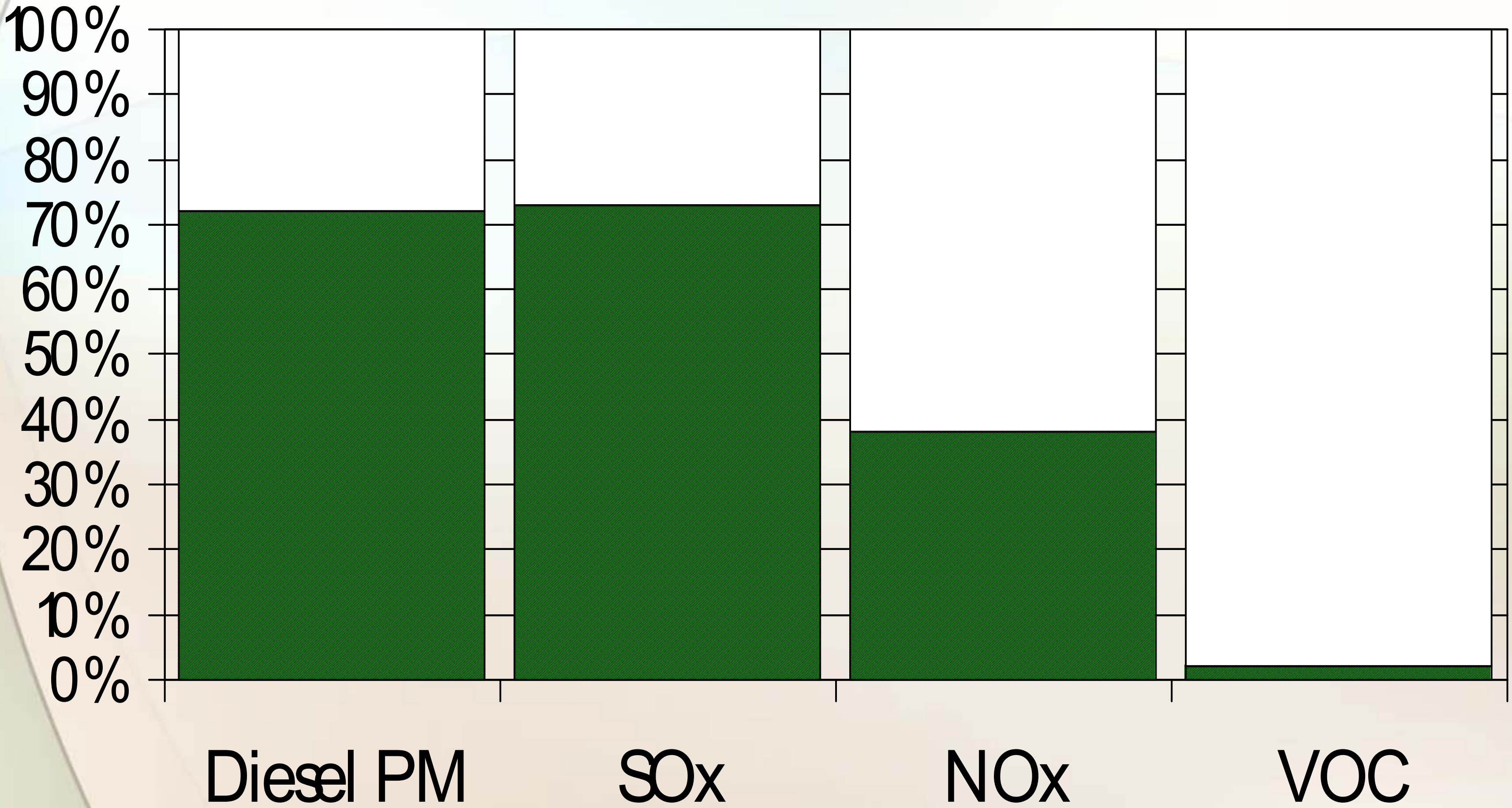
Looking Ahead

Goods Movement Growth
2001-2020

- **Cargo through ports triples by 2020**
- **California population grows 25%**
- **Truck travel increases 50%**
- **Rail cargo grows 110%**

Goods Movement* Contribution to South Coast Baseline Emissions in 2020

(to 100 nautical miles offshore)



*Includes diesel trucks over 33,000 lbs GVWR; local delivery trucks not included

2005 Health Impacts from Goods Movement in South Coast

- **1,200 premature deaths/year* associated with goods movement**
- **Key contributing pollutants:**
  - **Diesel PM**
  - **Ammonium nitrate PM**
  - **Ozone**

**Uncertainty range is 360 to 2,100 deaths/year*

ARB Goals for Goods Movement

Reverse growth in emissions

- **By 2010, reduce emissions as much as possible, at least to 2001 levels**

Reduce diesel PM risk

- **Rapid reduction in community risk**
- **By 2020, reduce statewide risk 85%**

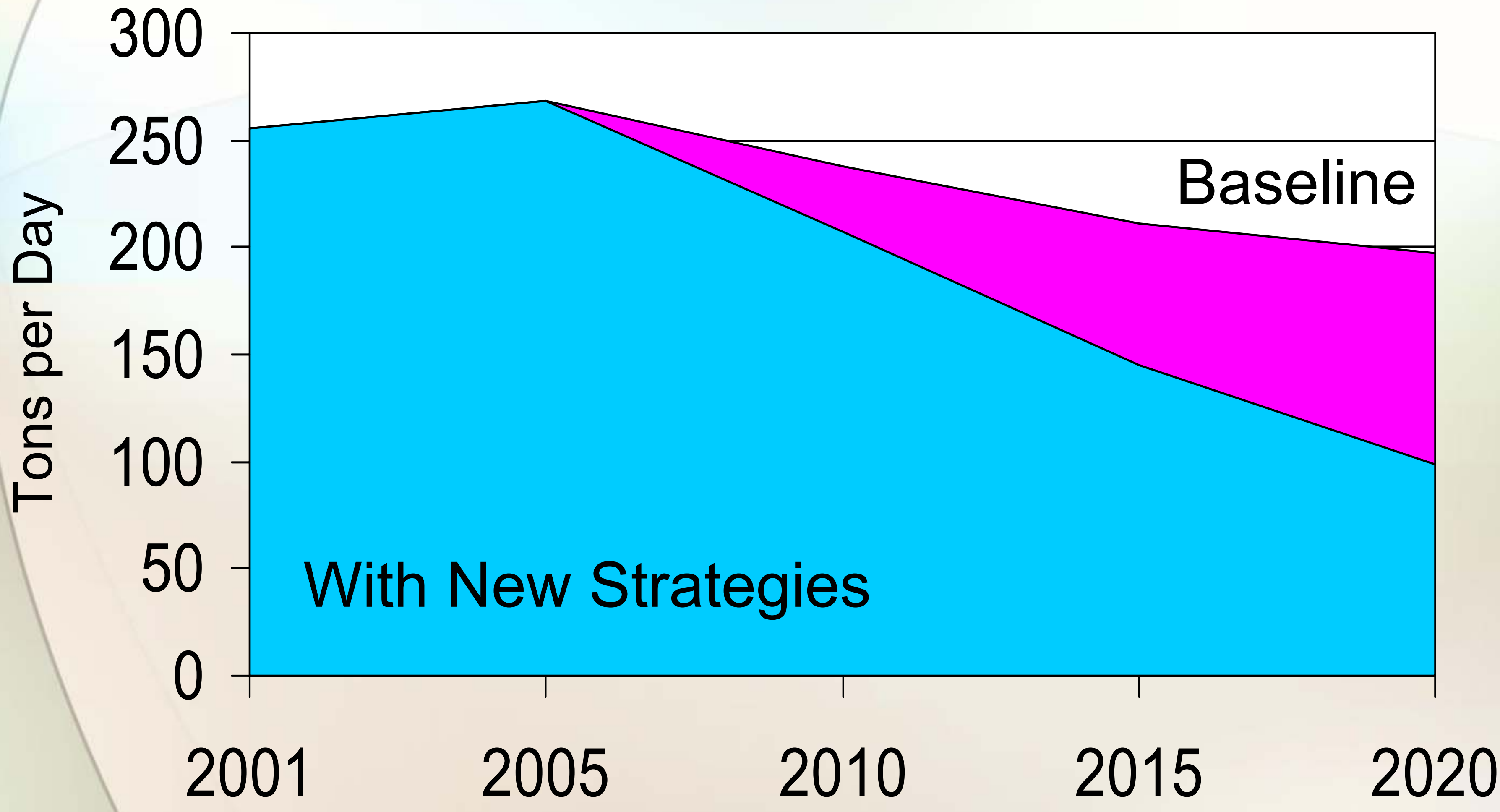
Attain federal PM2.5 & ozone standards

Goods Movement Strategies

- **Cleaner engines and fuels**
- **Fleet modernization (retrofit or replace)**
- **Speed reduction and idling limits**
- **Shore-based power for ships and tugs**

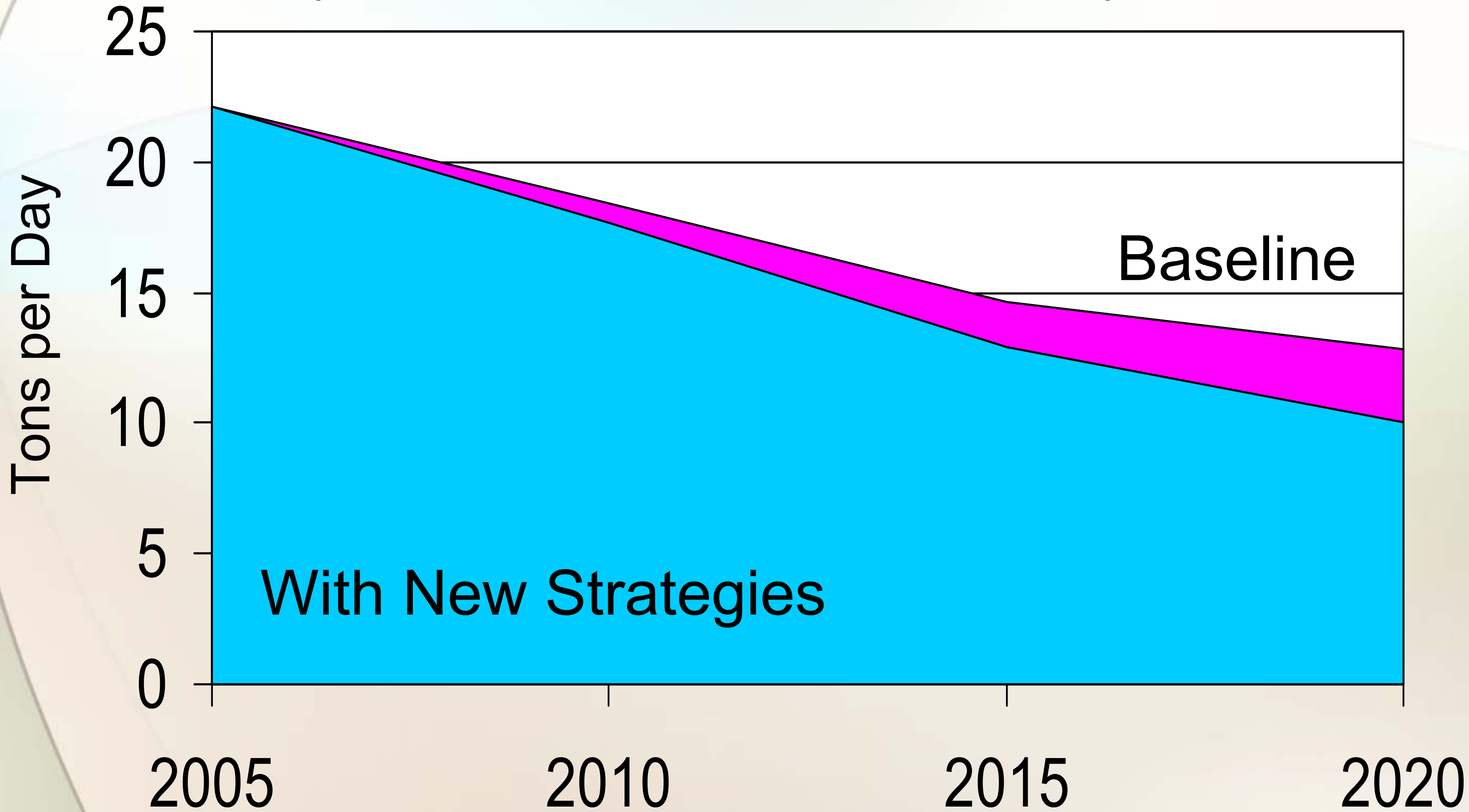
Reducing Goods Movement Emissions in South Coast – NOx

(to 24 nautical miles offshore)



Reducing Goods Movement Emissions in South Coast – VOC

(to 24 nautical miles offshore)



Improving Our Knowledge

- **More upper atmosphere measurements (ozone and precursors)**
- **Ability to assess control effectiveness over entire ozone season**

Conclusion

- **Continue seeking maximum feasible, cost-effective reductions of VOC+NOx**
- **Continue prioritizing controls for community health benefits**

APPENDIX J

MR. ERIC FUJITA

Observed and Predicted Weekday VOC/NOx Ratios

	1987	August 4-7 1997			1999-2000
Locations	SCAQS 07-08 Observed NMOG*/NOx	PAMS 06-09 Observed NMHC*/NOx	CAMx/MM5 06-09 CB4/E2K1 NMHC/NOx	06-09 Observed/ Predicted	PAMS 06-09 Observed NMHC*/NOx
Anaheim	9.3				
Azusa	8.1	4.6	4.0	1.2	4.4
Burbank	9.2				
Los Angeles	8.6	4.3	3.7	1.2	3.8
Claremont	8.7				
Hawthorne	9.5				
Long Beach	8.7				
Rubidoux	8.6				
Pico Rivera		2.9	4.1	0.7	3.7
Upland		3.9	3.0	1.3	4.0
Mean	**8.8**	**3.9**	**3.7**	**1.1**	**4.0**
Std Dev	**0.4**	**0.7**	**0.5**	**0.3**	**0.3**
EI MV ROG/NOx	**4.0**				
Amb/EI Ratio	**2.2**				

Emission inventory VOC/NOx ratios are in better agreement with corresponding ambient ratios in 1997 than 1987.

CAMx/MM5 modeling data courtesy of ENVIRON
EMFAC 2000 emissions prepared by the ARB
Source: CRC A-38 - Yarwood et al. 2003

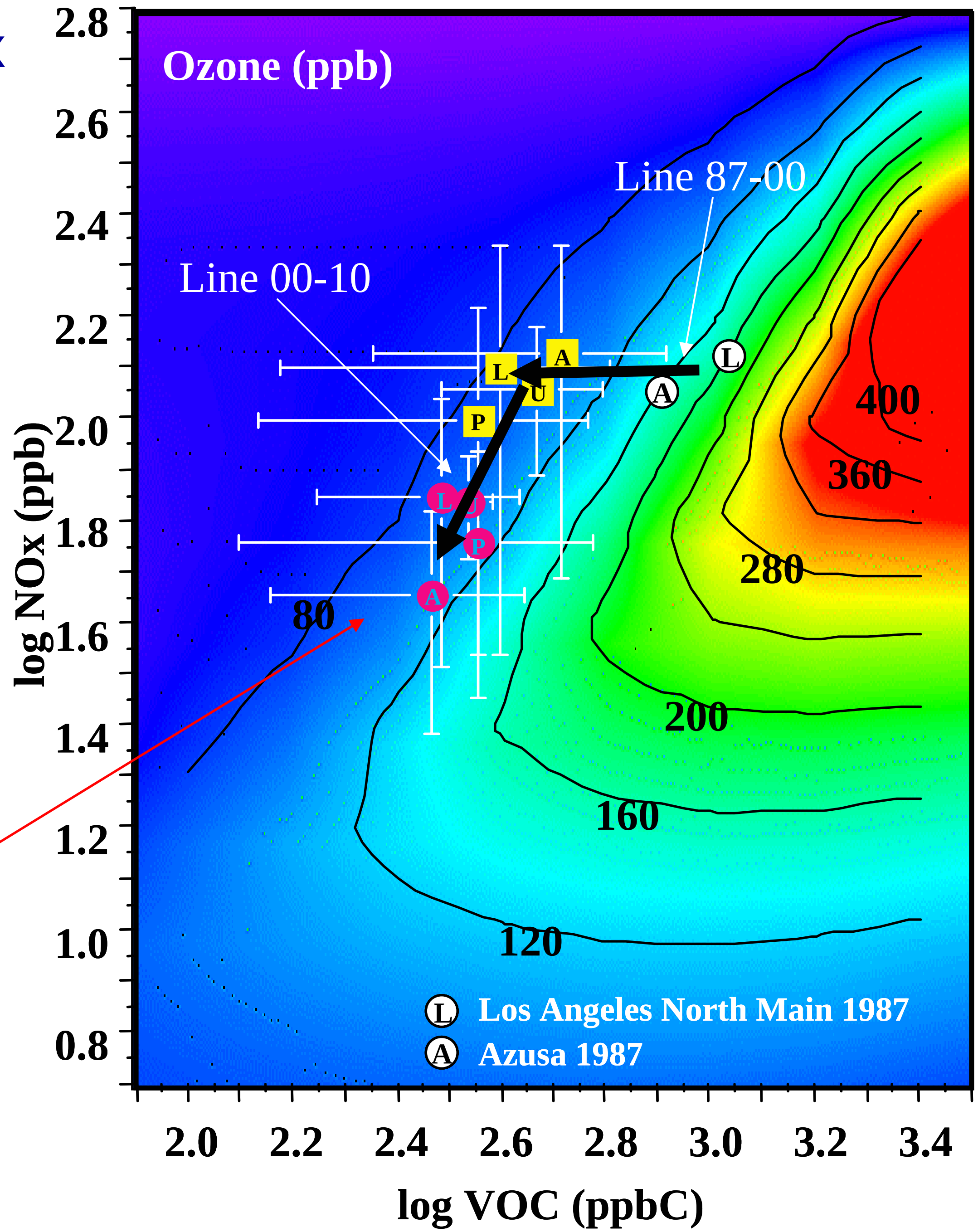
1999-2000 VOC & NOx

Mean Wednesday
± 1 sigma

Mean Sunday
± 1 sigma

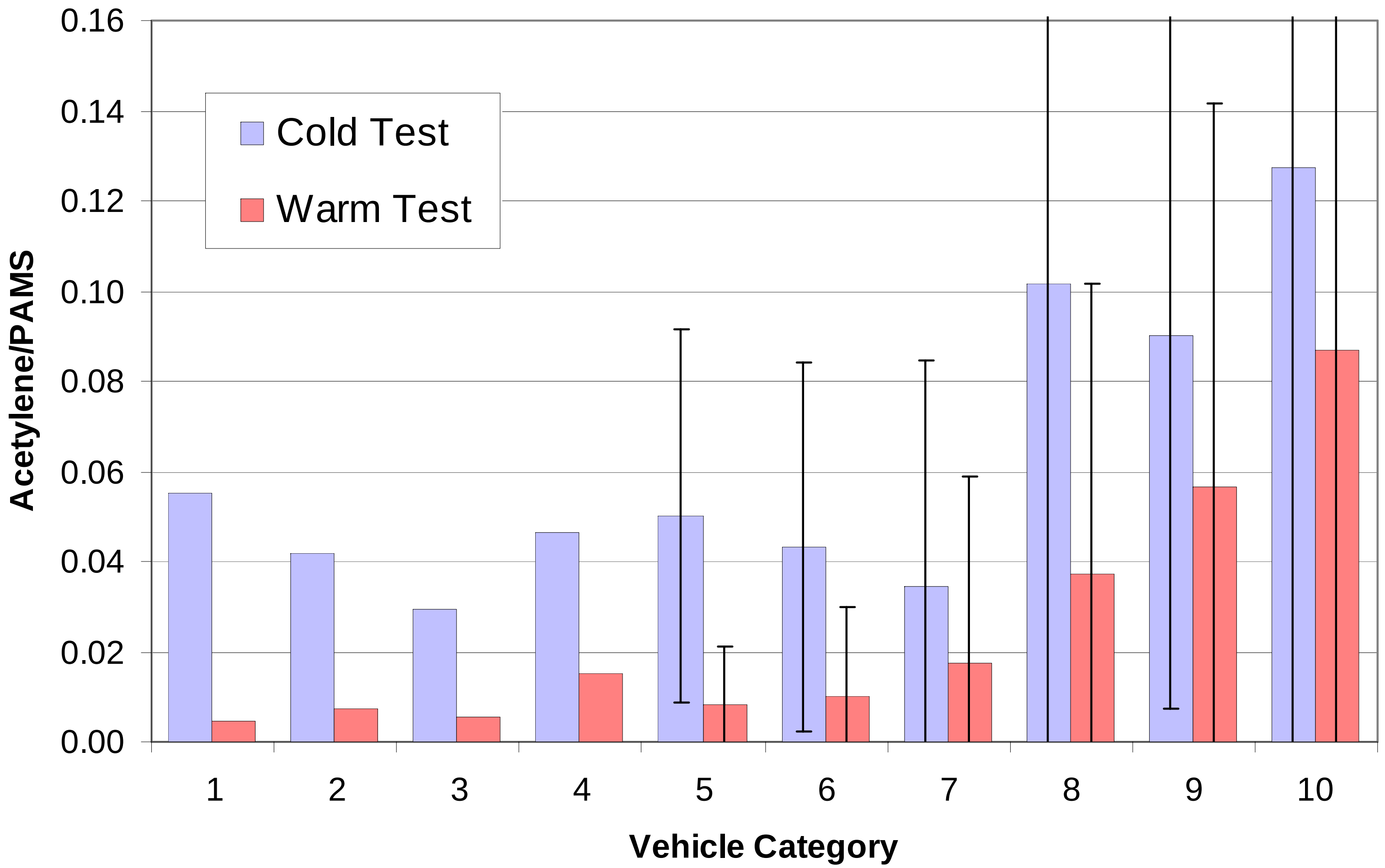
<u>Monitoring Stations</u>
A – Azusa
L – Los Angeles, N. Main
P – Pico Rivera
U – Upland

Weekday VOC and NOx emissions in 2010 are projected to be similar to weekend emissions in 2000.

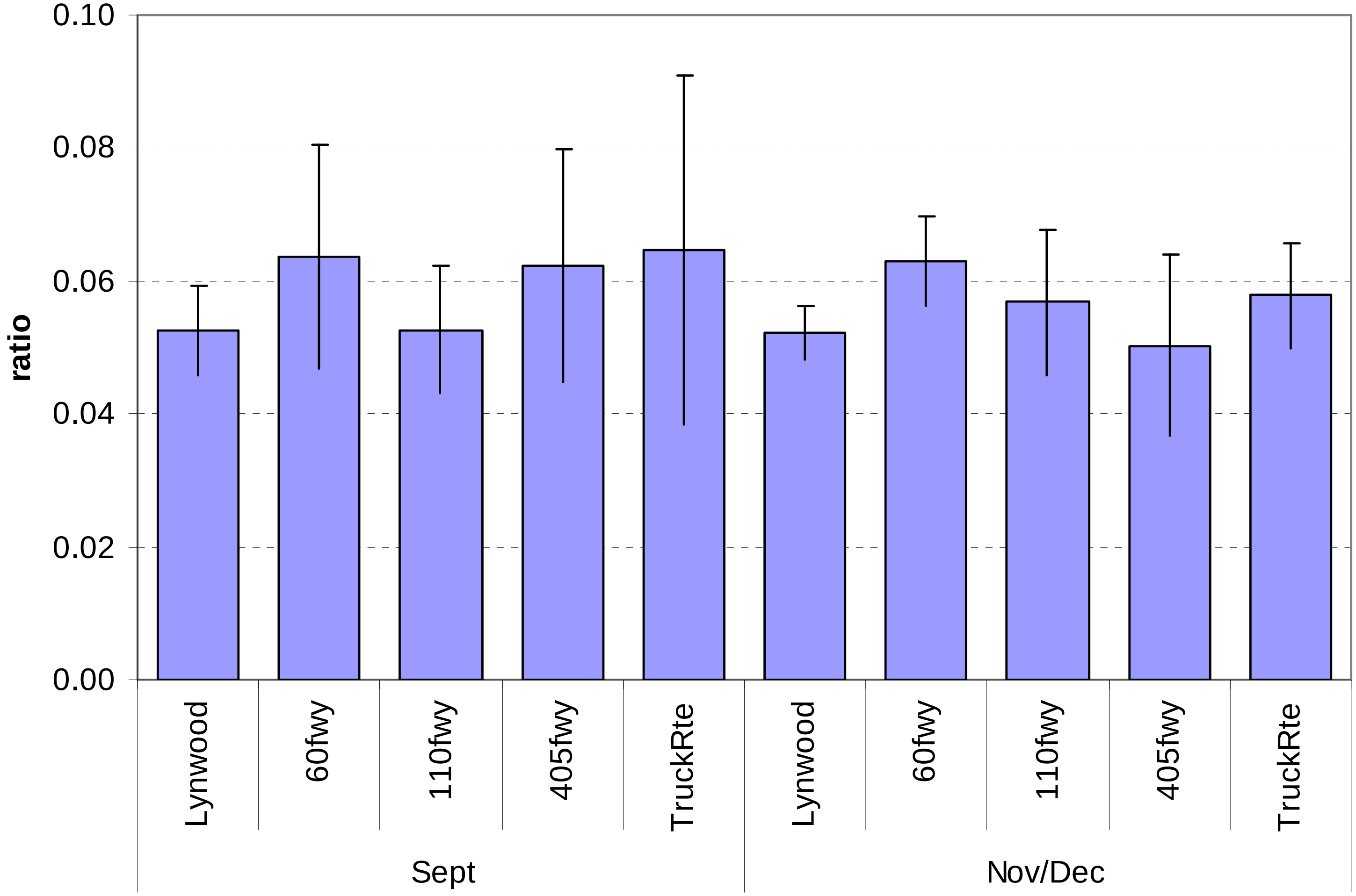


Ratios of Acetylene to Sum of 55 PAMS Species

Cold and Hot LA-92 Cycle by Model Year and Mileage Groups



Ratios of Acetylene to Sum of 55 PAMS Species Ambient and On-Road Samples in SoCAB



Health Effects Institute Project RFA03-1

SUMMARY

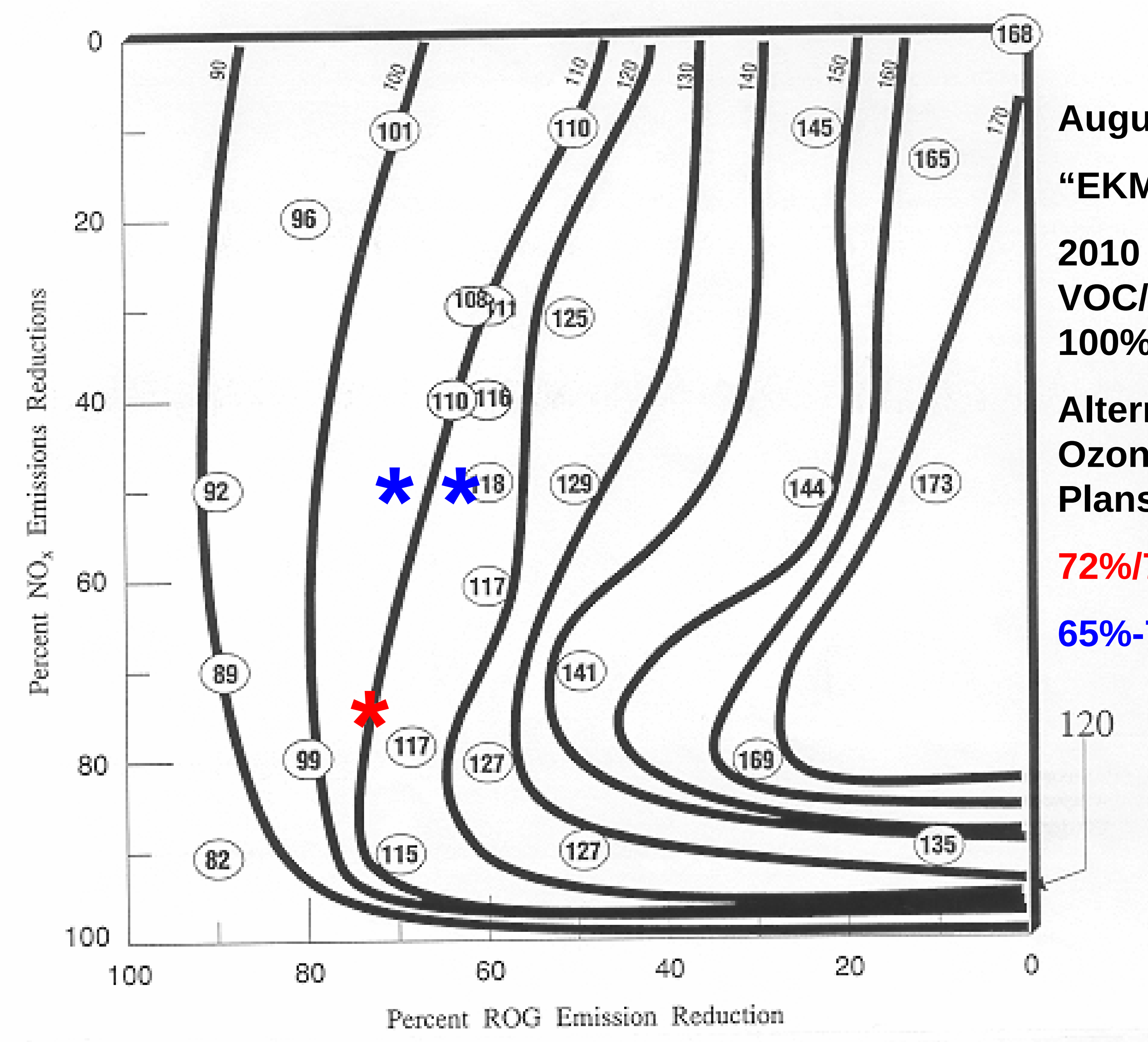
- What could be done differently to more effectively reduce ozone levels given the need to attain fine particulate standards?.
  - Ensure that VOC emissions are reduced sufficiently to avoid increasing VOC/NOx ratios and ozone in central basin.
- What research and development should be emphasized in the near future to further air quality improvements and our understanding of the issues?
  - Verify VOC emission reductions.
    - Conduct sampling in regionally representative areas away from roadway.
    - Expand the list of measured VOCs with species that are relevant to other potentially important VOC sources.
  - Effect of emission changes on mid-basin versus downwind ozone levels

APPENDIX K

MR. RALPH MORRIS

1994 AQMP

- Five SCAQS Episodes
  - June 5-7, 1985 – most limiting
  - August 26-28, 1987 – most representative
  - June 23-25, 1987
  - July 13-15, 1987
  - September 7-9, 1987
- Four 1-hour ozone control plans identified with alternative VOC/NOx controls (from 2010 levels)
  - (1) 72%/77%; (2) 65%/50%; (3) 68%/50%; and (4) 70%/50%
- How does today' ozone compare with 1994 AQMP modeling done 12 years ago?



August 28, 1987

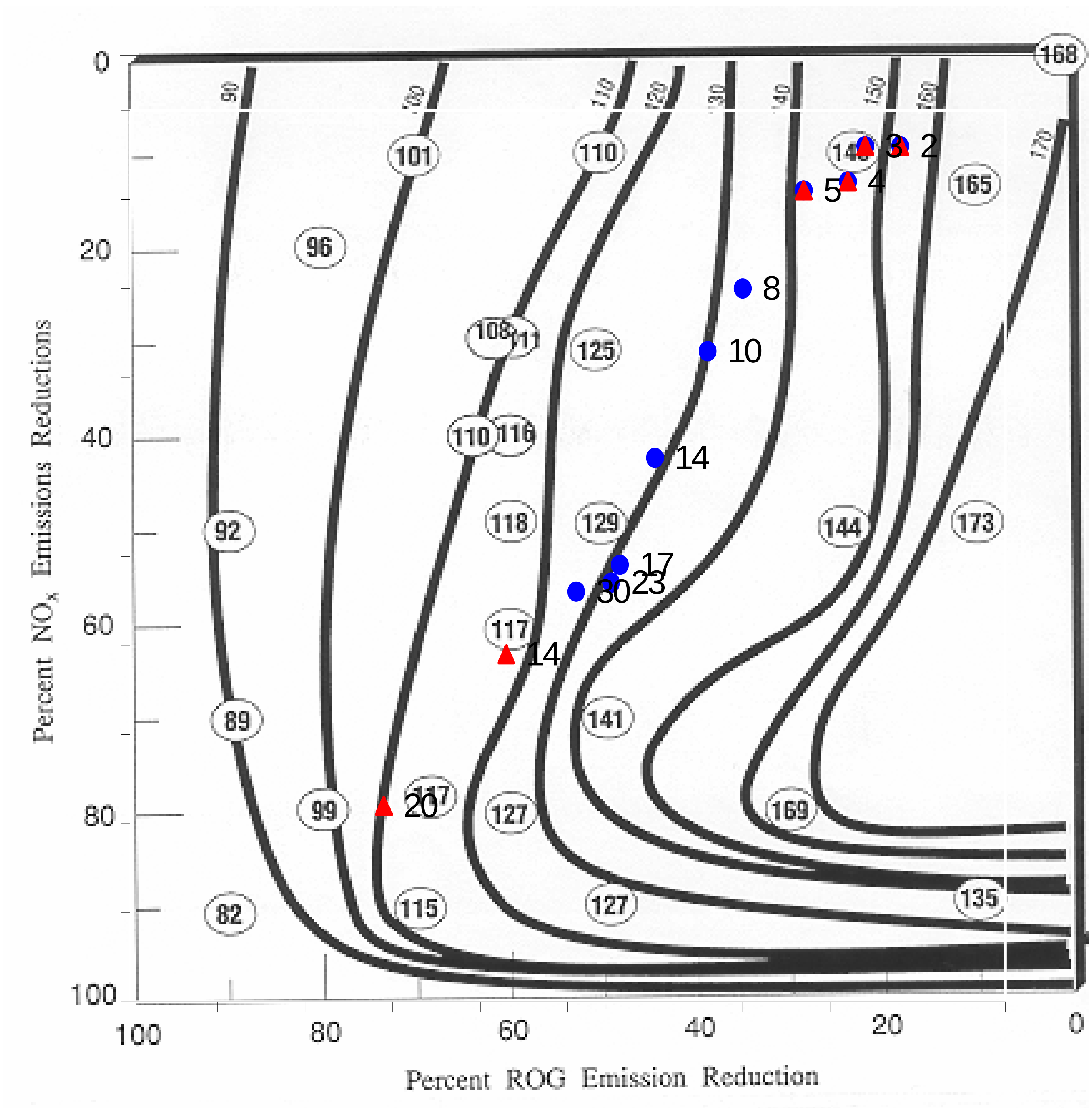
"EKMA Diagram"

2010 Uncontrolled VOC/NOx = 100%/100%

Alternative 1-Hour Ozone Attainment Plans VOC/NOx

72%/77%

65%-70%/50%



Superimpose Ozone Path on 1994 Isopleth

'02-'05 1-hr O3 in 155 to 145 ppb; actual =

'01= 170 ppb

'02= 171 ppb

'03= 180 ppb

'04 = 171 ppb

'05 = 173 ppb

<u>2007 AQMP</u>

Blue = Planning Inventories

Red = Controlled inventories ('14 and '20)

Lessons Learned: 1994 AQMP

- Overly optimistic relationship between transport and SoCAB emission reductions
  - Polluted air entering SoCAB from outside more likely increasing not decreasing
- Understated biogenic emissions inventory
- Meteorology is king (2003 effect)
- 2001 to 2005 saw 27%/12% reduction in VOC/NOx, & no change in ozone
- 2007 AQMP modeling better representation of transport, biogenics, chemistry, etc.