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AIR QUALITY IN TEXAS:

An Assessment of Research Needs

Prepared by a workgroup with representatives from the Texas Natural Resource Conservation Commission, Texas Universities and the regulated community

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Summary

The State of Texas faces challenging air quality problems. Three of the most pressing challenges involve meeting the National Ambient Air Quality Standards (NAAQS) for ozone, meeting the new NAAQS for fine particulate matter and preserving visibility in Class I areas, including Big Bend National Park. Developing cost effective approaches for addressing these air quality challenges requires a substantial body of information on emission sources, the fate of the emissions, and potential control strategies. The State of Texas, through the efforts of the Texas Natural Resource Conservation Commission and related agencies, has worked aggressively to develop scientifically sound air quality management strategies. While much of the information necessary for developing air quality improvement strategies has been collected, key information gaps exist. The goal of this document is to identify and prioritize those information gaps.

The document is organized into four major sections. The first section briefly summarizes the current level of understanding about the formation and transport of ozone, particulate matter and regional haze in the State of Texas. The next section presents the information gaps and research needs in a series of Tables. The research needs are prioritized in a third section, and the potential benefits of an air quality field study in the year 2000 are described in a fourth and final section.

The document was prepared by a workgroup with representatives from universities, regulatory agencies and industry. The opinions expressed and the priorities established are those of the individual participants, not necessarily those of the organizations with which they are affiliated.

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Chapter I: Air Quality in Texas:

State of the Science for Ozone, Particulate Matter and Regional Haze formation

Scientific understanding of the factors that control the formation of ozone, fine particulate matter and regional haze has evolved dramatically over the past decade. Critical reviews of the state of the science in these areas are available through NARSTO, which has developed a North American research strategy for tropospheric ozone, particulate matter and regional haze (documents available at http://narsto.owt.com/Narsto/). These scientific assessments, developed generically for the North American continent, provide information that is useful in guiding the development of air quality policies in Texas, however, the atmospheric processes that occur in Texas have unique features. These unique features, caused by high humidity, coastal meteorology and a unique mix of emission sources, require the development of region-specific air quality management strategies.

Much effort has gone into developing a sound, scientific understanding of the unique atmospheric processes that occur in Texas; however, critical gaps in our knowledge base exist. This section will briefly summarize the current understanding of the processes that control ozone and fine particulate matter/regional haze formation in Texas. The critical gaps in our understanding are also identified.

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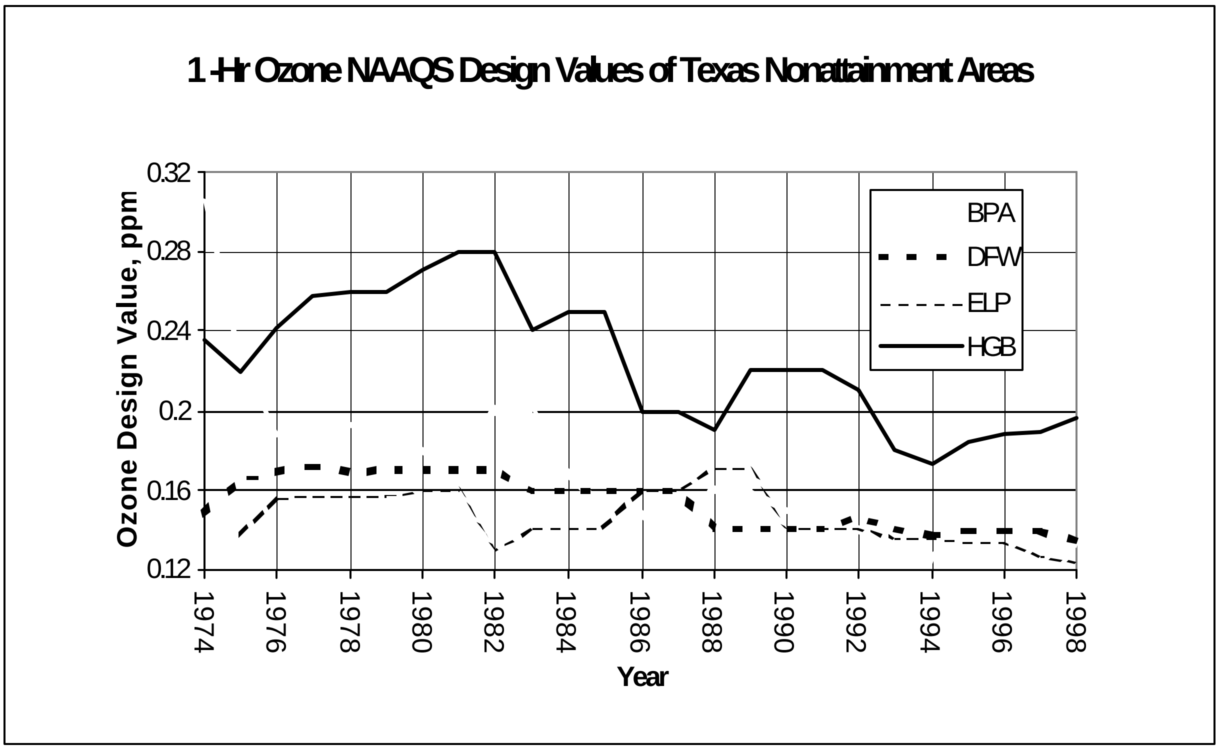
A. State of the Science for Ozone formation

The State of Texas has three areas that have not met the National Ambient Air Quality Standard (NAAQS) for ozone since it was first established in the early 1970s. These areas are Houston/Galveston (HG), Dallas/Fort Worth (DFW), and Beaumont/Port Arthur (BPA). For these areas, a succession of plans has been developed to bring the areas into attainment of the NAAQS.

The emission reductions defined in the plans have resulted in substantial reductions in ozone concentrations in the non-attainment areas, even as these areas have experienced dramatic population growth. But the regions still are not close to attaining the ozone standard. With cost-effective and publicly acceptable control measures already largely implemented in the non-attainment areas, new approaches to reducing ozone concentrations are needed if the NAAQS is to be met.

Ozone concentrations in Texas cities (Houston/Galveston (HG), Dallas/Fort Worth (DFW), and Beaumont/Port Arthur (BPA))



Further complicating the situation in Texas is a new NAAQS for ozone. In 1997, the U.S. Environmental Protection Agency (EPA) established a new NAAQS for ozone (more stringent than the previous standard and based on ozone concentrations averaged over 8 hours). Data indicate that several cities in Texas that meet the current NAAQS for ozone may not meet the new, more stringent ozone NAAQS. Based on current data it is possible that the U.S. EPA could declare Austin, San Antonio, and Longview/Marshall/Tyler non-attainment areas for ozone in the year 2000. In addition, the three areas that do not meet the existing NAAQS for ozone (HG, DFW, BPA) will also be subject to this new more stringent standard and, if they are not able to meet the existing standard, they may have to develop strategies designed to meet the two different standards.

Thus, it is likely that the State of Texas will have new regions that will need to develop strategies for reducing ozone concentrations. In addition, it is likely that areas in Texas that do not meet the current NAAQS will need to develop new approaches to reducing ozone. The plans that are developed must, of course, be based on the best possible scientific understanding of how ozone is formed in the atmosphere, and the State has made considerable investments in developing that understanding.

In Texas, it is now widely understood that ozone formation is both a regional and a local phenomenon. Episodes during which high ozone concentrations are observed in Texas fall into three basic categories:

Type 1 episodes involve high regional ozone concentrations and local ozone hot spots at sites in and downwind of urban areas. This type of episode involves addition of urban emissions to the regional air mass as the air flows past the urban area and results in high ozone concentrations downwind of the urban emissions. This type of episode often results in some of the higher ozone concentrations in urban areas in Texas, but usually not the highest.

Type 2 episodes involve flow reversal. A regional air mass with higher than normal ozone concentrations is often but not always involved. During the episode the air passes over concentrated emission areas, then reverses direction and passes over the same emission sources again. The highest ozone concentrations are observed downwind of the emission sources after the second pass. This type of episode is usually responsible for the highest ozone concentrations measured in major urban areas, particularly along the Gulf Coast, where land-sea breeze and land-bay breeze effects are common.

Type 3 episodes involve an isolated ozone hot spot with considerably higher ozone concentrations than the surrounding area.

These qualitative descriptions of ozone formation patterns emphasize the combined regional and local nature of the problem. Previous efforts at characterizing the science behind ozone formation in Texas have tended to focus more on the local phenomena, rather than the underlying regional phenomena. As we enter a new era in air quality management in the State of Texas, it is important that the factors controlling regional ozone formation in the State be well understood. Key questions that must be resolved include:

> How much ozone in each urban area comes from out of state, how much comes from other areas in Texas, and how much is generated locally?

What sources contribute to transported ozone?

What sources contribute to locally generated ozone?

What chemical and physical processes in the atmosphere control the formation and transport of ozone?

What is the projected effect of current and planned control programs on ambient concentrations of ozone?

Answers or partial answers to all of these questions are needed to design the most cost-effective and feasible approaches for reducing ozone concentrations in Texas. Summarized below is our current state of knowledge, and our current knowledge gaps, for each of these questions.

How much ozone in each urban area comes from out of state, how much comes from other areas in Texas, and how much is generated locally?
It is now well accepted that ozone and its precursors can be transported over hundreds of kilometers. In Texas this means that ozone and ozone precursors generated in rural areas can influence urban ozone concentrations. Ozone can also be transported from urban areas to rural areas, between urban areas in Texas, and across State and international borders. Although it is well accepted that this regional transport of ozone occurs, a quantitative characterization of how much ozone in each area comes from out of state, and how much is transported between areas in Texas, remains elusive. Current approaches to quantifying the extent of the regional ozone and ozone precursor concentrations generally rely on either rural monitors or photochemical models.

Rural monitors provide data on the concentrations of ozone at locations where there is believed to be relatively little local generation of ozone. These so-called background sites in the eastern half of Texas typically record maximum daily ozone concentrations of 30-50 parts per billion (ppb) during the summer, but, on an average of 10-30 days per year, these same background sites will record daily maximum ozone concentrations of 80-100 ppb. If these high rural ozone concentrations are distributed over broad areas, as the limited data from rural monitors indicate, then regional transport of ozone will make it very difficult for virtually any area in Texas to meet the new NAAQS for ozone based on local emission reductions. Regional strategies for air quality improvement would be required. More rural monitoring is necessary to resolve the extent of regional ozone episodes in Texas and to assure that the rural monitors are not recording isolated ozone hot spots due to rural emission sources.

In addition to enhanced rural monitoring, a significant effort in measurements aloft is necessary to understand the processes that control regional ozone concentrations. The transport of ozone over hundreds of kilometers is a phenomenon that occurs well above ground level, and direct measurements of the phenomena that control the transport of ozone over large distances is critical.

So, while the precise contribution of regional transport is unclear, it is qualitatively clear that regional phenomena are very important. More rural monitoring and aloft measurements of ozone and its precursors will be necessary for a more quantitative understanding.

What sources contribute to transported ozone?

Relationships between sources of emissions and concentrations of ozone at both regional and local levels are generally established using computer simulations. These simulations require data on meteorology, emissions of ozone precursors, and models of atmospheric reactions. The simulations can be used to estimate the contribution of individual emission sources, or groups of sources, to regional ozone formation. Extensive air quality simulations have been done for the HG, DFW and BPA areas, but integrated, regional modeling has only begun in the last few years. As a consequence, some of the inputs required by regional scale models are poorly understood. In particular, the extent of naturally occurring emissions of ozone precursors, upper atmosphere wind trajectories, and the chemistry of some key reactive species are not as well understood as would be desirable. These knowledge gaps limit the State's ability to understand ozone formation and transport at a regional level and the State's ability to quantify source contributions to high regional ozone concentrations.

What sources contribute to locally generated ozone?

Over the past 25 years, emission control measures in HG, DFW and BPA have resulted in improvements in air quality even as the State has grown dramatically in population. As emissions are reduced, the chemistry of ozone formation can change, so that as air quality management programs progress, the targets of emission controls may change. Current evidence indicates that many areas in the State may be at a point where a change in emission control strategies may be appropriate. In particular, ambient data and photochemical modeling indicate that reductions in the emissions of nitrogen oxides may lead to greater ozone reductions, in some areas, than reductions in the emissions of volatile organic compounds (VOCs). Additional data should be collected and additional photochemical modeling should be performed to assess this evolution in air quality management strategy.

What chemical and physical processes in the atmosphere control the formation and transport of ozone?

A significant amount of effort, both nationally and in Texas, has gone into characterizing chemical and physical processes that control ozone formation in urban areas. Based on these efforts, the processes that control ozone formation are understood in urban areas with well characterized meteorology and emissions. As noted earlier, however, regional processes are not as well understood. In addition, Texas has a number of atmospheric characteristics that make modeling the formation and transport of ozone difficult even at urban scales. Among these are:

- the complexity of the meteorology, with sea and bay breezes and flow reversals
- the unique mix of compounds emitted to the atmosphere; the atmospheric chemistry of many of these compounds are not well characterized

- a unique situation in which large quantities of emissions from industrial sources are released in close proximity to emissions from a major urban center (Houston)
- large, variable, and uncertain, naturally occurring emissions of certain ozone precursors

Systematic examination of these chemical and physical processes will be necessary to improve our understanding of ozone formation in Texas.

What is the projected effect of current and planned control programs on ambient concentrations of ozone?
Current models of air quality in Texas suggest that dramatic reductions in all emissions will be required for the State to meet the NAAQS for ozone. These emission reductions would require enormous investments, so these investments should be as effective as possible in reducing ozone concentrations. To ensure that air quality investments are made wisely, it is critical that scientific uncertainties outlined in this document be resolved.

B. State of the Science for Fine Particulate Matter and Regional Haze Formation

In 1997, the U.S. Environmental Protection Agency (EPA) established a new National Ambient Air Quality Standard (NAAQS) for particulate matter smaller than 2.5 micrometers (µm) in diameter ($PM_{2.5}$). This new standard joins an existing standard for particulate matter smaller than 10 µm in diameter (PM_{10}). The call for a new standard for fine particulate matter was based on studies which indicate that the human health effects of very fine particles, which can penetrate far into the human respiratory system, are more significant than the health effects of particles that are larger and do not penetrate as deeply into the human body.

Historically, El Paso has been the only area in Texas which has not met the federal standards for particulate matter smaller than 10 µm in diameter (PM_{10}). Recognizing that certain regions in the State might have difficulty meeting the new $PM_{2.5}$ standard, a consortium of governmental and industrial organizations funded an ambient monitoring program for $PM_{2.5}$. This monitoring program, which began in the spring of 1997, gave Texas some of the first data available in the country on $PM_{2.5}$ concentrations. The early monitoring confirmed that several areas in Texas (particularly metropolitan Houston) have annual average $PM_{2.5}$ concentrations that are very close to the new standard.

This situation offers both a challenge and an opportunity. The challenge is to keep all areas in the State in attainment of the NAAQS for $PM_{2.5}$. Not meeting this challenge will result in risks to public health and significant new regulations. The opportunity in meeting this challenge is provided by the timetable for NAAQS implementation. Since three years of monitoring data are required to determine attainment or nonattainment of the new $PM_{2.5}$ standard, and regulatory monitoring began across the State in 1999 and 2000, it will be 2002 or 2003 before the ambient data required for NAAQS determinations are available. It will likely be 2003 or 2004 before the EPA issues attainment/nonattainment determinations. Because of this timetable, there is an opportunity to design and implement strategies that may prevent areas from violating the NAAQS for $PM_{2.5}$.

The NAAQS for $PM_{2.5}$ is not the only challenge facing the State of Texas in dealing with fine particulate matter. Fine particulate matter has a number of impacts beyond those associated with human health. Of particular concern to Texas are the visibility reductions caused by fine particulate matter. Relatively low concentrations (much lower than those associated with human health effects) of fine particulate matter can cause substantial reductions in visibility over wide areas, creating regional haze. A number of regulations have been developed to protect visibility in pristine wilderness areas, and the National Park Service, the U.S. Environmental Protection Agency, and the State of Texas, together with Mexican officials are currently attempting to determine the types of sources contributing to visibility impairment in Big Bend National Park.

Thus, fine particulate matter will be of concern to the State of Texas because of both human health impacts and visibility impairment. To begin the process of assessing the concentrations and sources of fine particulate matter in Texas, the Texas Natural Resource Conservation Commission (TNRCC), the City of Houston Bureau of Air Quality Control (BAQC), and the Houston Regional Monitoring Corporation (HRM), an association of industrial firms, funded a one year study of $PM_{2.5.}$ The sampling for the study began on March 11, 1997 and ended on March 12, 1998. The data from this monitoring give a preliminary indication about the status of a number of areas in Texas under the new $PM_{2.5}$ NAAQS. The new NAAQS is a mass-based standard and the portion of the standard that is most difficult to meet is the maximum allowable annual average of $PM_{2.5}$ mass, which is 15 micrograms per cubic meter (µg/m^3). The averages of samples collected on scheduled days from March 11, 1997 through March 12, 1998 were 10.6 Fg/m^3 for Corpus Christi, 10.4 Fg/m^3 for San Antonio, 14.6 Fg/m^3 for Dallas, and 14.3 Fg/m^3 for El Paso. For seven sites in Houston, the means ranged from 12.7 Fg/m^3 to 16.3 Fg/m^3. Thus, there are a number of areas in Texas in danger of exceeding the NAAQS for annual average $PM_{2.5}$ concentration.

There is also a new NAAQS for maximum daily $PM_{2.5}$ concentration (65 Fg/m^3 or greater for the highest 2% of the measurements). In Dallas, San Antonio, Corpus Christi, and Houston, all measured daily $PM_{2.5}$ concentrations are 40 Fg/m^3 or less and therefore these areas do not appear to be in danger of violating the NAAQS for maximum daily $PM_{2.5}$ concentration. The El Paso sampling site had one sample with 71 Fg/m^3. All other El Paso samples were 40 Fg/m^3 or lower, so El Paso may or may not be in danger of violating the NAAQS for maximum daily $PM_{2.5}$ concentration.

These preliminary data should be viewed with caution, because there could be systematic differences between the $PM_{2.5}$ mass measured by the procedures in this study and the $PM_{2.5}$ mass that would be measured by the federal reference method and because there is only one year of data. Nevertheless, it seems clear that the new standards for $PM_{2.5}$ are a serious concern for

Texas.

After determining whether there is any danger of violating the NAAQS, the next critical issue is determining the composition of the $PM_{2.5.}$ $PM_{2.5}$ composition can help reveal the relative significance of potential sources

The composition data collected to date reveal that a number of sources contribute significantly to $PM_{2.5}$ concentrations in Texas. Sulfates, which result from emissions of SO_2 and ammonia, are significant. Also important are carbon containing materials - elemental carbon (from combustion sources) and organic carbon (from a wide variety of sources ranging from combustion sources to reaction products of VOCs to fatty acids in cooking smoke). Crustal material, the mineral component of soil, makes up roughly one tenth of the $PM_{2.5}$. Nitrates make up a small percentage of the collected $PM_{2.5}$, but the actual percentage of nitrate is larger in particles in ambient air. Much more detailed chemical characterizations of the $PM_{2.5}$ and more extensive profiling of potential sources is needed to quantitatively determine the contributions of the different sources.

These preliminary data have been useful in confirming that the new $PM_{2.5}$ standards may impact a number of regions in Texas. Designing strategies to keep the State in attainment of the $PM_{2.5}$ and regional haze standards, however, will require a better understanding of the sources, composition and chemistry of $PM_{2.5}$. Specifically, it will be necessary to determine:

> How much $PM_{2.5}$ in each area comes from out of state, how much comes from other areas in Texas, and how much is generated locally?
>
> What sources contribute to transported $PM_{2.5}$?
>
> What sources contribute to locally generated $PM_{2.5}$?
>
> What chemical and physical processes in the atmosphere control the formation and transport of $PM_{2.5}$?
>
> What is the projected effect of current and planned control programs on ambient concentrations of $PM_{2.5}$?

Answers or partial answers to all of these questions are needed to design the most cost-effective and feasible approaches for reducing particulate matter concentrations in Texas. Summarized below is our current state of knowledge, and our current knowledge gaps, for each of these questions.

How much $PM_{2.5}$ in each area comes from out of state, how much comes from other areas in Texas, and how much is generated locally?

Particulate matter can be transported over very long distances, as evidenced by the intrusion of smoke from fires in Southern Mexico into Texas in the spring of 1998. Preliminary analysis of data from the $PM_{2.5}$ sampling study have shown that particulate matter transported over large distances, such as transported smoke from agricultural burning in Central America, African dust, and transported continental haze, contribute, at least in some part, to $PM_{2.5}$ levels in Texas.

A more quantitative assessment of the fraction of $PM_{2.5}$ that is transported into the State can be derived from the Houston data. From the fact that two sites in the Houston area had average $PM_{2.5}$ concentrations below 13 $\mu g/m^3$ and that the sites in Galveston and Mauriceville (north of Orange) had averages of 10.3 $\mu g/m^3$ and 12.8 $\mu g/m^3$, respectively, it appears that regional background levels of $PM_{2.5}$ in Southeast Texas are in the range of 10-12 $\mu g/m^3$. Local additions to $PM_{2.5}$ play a significant part in producing the averages above 15$\mu g/m^3$, but the transported $PM_{2.5}$ contribute significantly to the measured ambient concentrations. Further analysis of the data from the 1997-1998 early monitoring may be able to provide an estimate of the contribution of local sources and of transport. The data can, however, provide only a rough estimate of the contribution of local sources and of transport to the annual average of each of the components of $PM_{2.5}$ at each of the sites in Texas. Additional analysis of samples and new sampling and analysis will be needed to determine quantitatively the contribution of source types and source areas to the annual average of each of the components of $PM_{2.5}$ in Texas.

To more fully characterize the contribution of long range transport, currently planned sampling should be augmented by size resolved sampling and by aircraft measurements. The size resolved sampling is necessary because the size of a particle determines how long it will remain in the atmosphere, what chemistry it will undergo, and how far it can be transported. Aircraft measurements are necessary to confirm the presence of particles from distant sources and track their transport aloft.

What sources contribute to transported $PM_{2.5}$?

Relationships between sources of emissions and concentrations of ozone at both regional and local levels is generally accomplished using chemical mass balance techniques and computer simulations. In the chemical mass balance techniques, chemical fingerprints of particulate matter sources are compared to the chemical profiles of ambient samples to deduce the fraction of the particulate matter that is contributed by each source. While chemical fingerprints for PM_{10} are available for many sources, few chemical signatures are available for $PM_{2.5}$. Thus, there is a clear need to collect data on source profiles for $PM_{2.5}$. Chemical mass balance techniques for identifying sources should be complemented with computer simulations of the fate and transport of particulate matter. These simulations require data on meteorology, emissions of $PM_{2.5}$, and models of the environmental fate of the particles. While simulations of this type have been done for decades in the analysis of ozone formation and transport, simulations of particulate matter formation and transport are in their infancy. In fact, computer simulations of fine particulate matter formation and transport have not yet been performed for Texas. An important first step in characterizing the sources of $PM_{2.5}$ observed in Texas will be to perform current, state of the art modeling of particulate matter formation and transport. While these state of the art models are likely to evolve and improve, it is important to begin the process of using them immediately to understand the phenomena that control $PM_{2.5}$ concentrations.

What sources contribute to locally generated $PM_{2.5}$?

As noted above, it is not entirely clear what fraction of the fine particulate matter is generated locally and what fraction is transported over long distances. It is even less clear what specific sources contribute to locally generated $PM_{2.5.}$ More extensive characterization of $PM_{2.5}$, particularly the organic and elemental carbon, is needed to better resolve the sources of particulate matter. Organic carbon compounds are a significant part of $PM_{2.5}$ at most sites in Texas. Chemical analysis for specific compounds that are useful as tracers of different sources would provide useful estimates of the contribution of different source categories to this component of $PM_{2.5}$. The contributions of agricultural burning and wild fires, wood burning, diesel vehicles, gasoline vehicles, off-road and non-road internal combustion engines, and cooking could all be estimated using these methods. Some of the organic carbon compounds in $PM_{2.5}$ form from reactions of volatile biogenic compounds; others form from the reaction of manmade volatile organic compounds. Identifying these contributions is difficult, but can be accomplished using recently developed tracer methods. Analysis of the carbon-14 content of particulate carbon can be used to determine how much is from contemporary sources and how much is from fossil fuels and related materials.

What chemical and physical processes in the atmosphere control the formation and transport of $PM_{2.5}$?

Most of the work that has been done on $PM_{2.5}$ in Texas has been observational. These data are useful in determining whether concentrations of $PM_{2.5}$ in Texas are likely to violate the NAAQS and in identifying major sources. The observational data provide limited information, however, about the chemical and physical processes that control ozone formation. There are uncertainties in how efficiently emissions of SO_2 are converted to the sulfate that appears in $PM_{2.5}$. There are uncertainties in the extent to which VOC and NOx emission reductions, designed to reduce ozone concentrations, will reduce $PM_{2.5}$ concentrations. There are uncertainties in determining whether ammonia emission reductions would reduce the amount of ammonium observed in $PM_{2.5}$. Additional insight into these questions will come from more extensive monitoring. Simultaneous monitoring for vapor phase ammonia and nitric acid and for particulate phase ammonium, sulfate, and nitrate will allow thermodynamic analysis to calculate the amount of ammonium nitrate that will replace ammonium sulfate that is reduced by sulfur dioxide reductions. As noted earlier, an important step in characterizing the sources of $PM_{2.5}$ observed in Texas will be to perform current, state of the art modeling of particulate matter formation and transport. While these state of the art models are likely to evolve and improve, it is important to begin the process of using them to aid in understand the phenomena that control $PM_{2.5}$ concentrations.

What is the projected effect of current and planned control programs on ambient concentrations of $PM_{2.5}$?

Currently, relatively little can be concluded about the effect of current economic trends and of current and planned control programs on ambient concentrations of $PM_{2.5}$. Too little is known about emission trends and about the quantitative relationships between $PM_{2.5}$ sources and $PM_{2.5}$ concentrations in Texas.

Directionally, however, it is clear that controls designed to reduce ozone should reduce $PM_{2.5}$ by lowering the emissions of $PM_{2.5}$ precursors and by reducing the reactivity of the atmosphere (and thereby reducing the conversion of VOC and NO_x into particulate matter). A substantial modeling effort would be required to quantify these potential benefits.

It is also clear that, directionally, SO_2 emission reductions associated with national acid precipitation programs should reduce $PM_{2.5}$. Quantitative projections of the potential particulate matter reductions have not been made, but directionally the SO_2 emissions from coal fired power are decreasing. National efforts are underway to model the regional SO_2 to sulfate relationship, but the past relationship between SO_2 emissions and sulfate deposition has been roughly linear, so knowledge of the projected percentage reductions in SO_2 emissions in the region upwind of Texas could be used to project the percentage decrease in regional sulfate affecting Texas. The U.S. EPA is working on projects to model this impact, but it is too early to evaluate the adequacy of the results that will come from these projects.

To move beyond a directional understanding of the effectiveness of $PM_{2.5}$ controls requires 1) additional source characterization for sources of $PM_{2.5}$ emissions and the chemical species that can be used as tracers of the different source categories and 2) the use of models capable of tracking the emissions, chemistry, formation, transport and deposition of particles and particle precursors.

Used together with the results of careful source characterization, analysis of ambient $PM_{2.5}$ samples for the chemical tracers can determine the percentage contribution of different emission sources of organic carbon materials and of elemental carbon as well as some other components to the ambient $PM_{2.5}$. Specialized analysis of crustal material shows promise of differentiating among windblown dust, dust from excavation, and dust from roadways. When the contribution of specific source categories can be identified, the impact of emission changes on ambient $PM_{2.5}$ concentrations can, under some circumstances, be assessed directly.

Preliminary modules for modeling particulate matter have recently been developed, but have not yet been applied to Texas air sheds. Therefore, a necessary first step is to incorporate state-of-the-science particulate matter modeling into the regional photochemical models available for Texas. While even the current state-of-the-science models have substantial uncertainties associated with them, they can be used to assess the sensitivity of $PM_{2.5}$ concentrations in Texas air sheds to a variety of emission reduction scenarios. Use of the models is necessary for $PM_{2.5}$ components formed in atmospheric reactions because the relationship between emissions and the concentration of the materials formed by atmospheric reactions is often non-linear. Some effects of emission reductions can be counterintuitive. For example, recent modeling done for the South Coast Air Basin indicated that reductions in SO_2 emissions decreased sulfate levels but increased particulate nitrate levels.

Additional studies should be done to develop emission projections for particulate matter and particulate matter precursors. These data used together with source-receptor relations and with models can then be used to project the impact of emission trends, of the Federal Clean Air Act Amendments mandated controls, and of other planned regulatory actions.

C. Hazardous Air Pollutants

While the focus of this document is on the challenges faced by the State of Texas in meeting national ambient air quality standards for ozone and fine particulate matter, it must be noted that substantial efforts are also underway to reduce the emissions of hazardous air pollutants (HAPs). National Emission Standards for Hazardous Air Pollutants (NESHAPs) will be developed and implemented over the same time periods that ozone and $PM_{2.5}$ management strategies are developed. Because may HAPs are precursors for ozone and possibly particulate matter, emission reductions required by NESHAPs may help in reducing ozone and $PM_{2.5}$ concentrations. Quantifying these effects will require advances in photochemical modeling.

Currently, computer simulations of ozone and particulate matter formation use simplified descriptions of hydrocarbon chemistry to reduce computation times. Much more detailed chemical mechanisms will be required to accurately predict the effective of HAP emission reductions on ozone and $PM_{2.5}$ concentrations.

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Chapter II: Research Needs

Chapter I summarized our current understanding of the formation and transport of ozone, particulate matter and regional haze in the State of Texas and identified key information gaps. This Chapter summarizes those information gaps and research needs in a series of Tables. The Texas Natural Resource Conservation Commission and other agencies already have plans to address some of these information gaps. When such studies are planned they are noted.

The Tables are organized based on the key questions that the research seeks to address. Tables 1a-1c describe projects that address the following questions:

> How much ozone and particulate matter in each urban area comes from out of state, how much comes from other areas in Texas, and how much is generated locally?
>
> What sources contribute to transported ozone and particulate matter?
>
> What sources contribute to locally generated ozone and particulate matter?

Within this set of questions, research needs are grouped into monitoring, emission inventory, meteorology, chemistry, and model development categories. In Table 1a, a series of monitoring projects are outlined that would address source allocation and transport of ozone and particulate matter. Table 1b describes emission inventory projects and Table 1c describes meteorology, chemistry, and model development categories.

Table 2 describes projects that address the following question:

> What chemical and physical processes in the atmosphere control the formation and transport of pollution?

Table 3 describes projects that address the following question:

> What is the projected effect of current and planned control programs on ambient concentrations of pollution?

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Table 1a. Monitoring data needed to address source allocation and transport of ozone and fine particulate matter.

Ozone	**$PM_{2.5}$ and regional haze**
A. MONITORING 1. Add monitoring sites east of Dallas and between Houston and Beaumont-Port Arthur to monitor the ozone transported into these areas along these corridors. (To be funded in FY-99 by TNRCC) 2. Add high sensitivity NO and NO_y monitors to upwind sites to aid in assessing the impact of transport on local ozone concentrations. (Not currently funded - approximate annual budget of $400K) 3. Add dedicated NO_2 monitors to these same sites. (Not currently funded - approximate annual budget of $200K) 4. Add high sensitivity SO_2 sites to upwind monitoring sites that may be impacted by power plant plumes to use SO_2 as a tracer for plume impact. (Not currently funded - approximate annual budget of $160K) 5. Continue the use of aircraft monitoring to help determine the contribution of transported regional pollution to urban ozone concentrations. (To be funded in FY-99 by TNRCC; funding requested by TNRCC for FYs-00-01) 6. Continuous monitoring of ozone transport aloft among Texas cities using tall broadcast tower(s) (Not currently funded - approximate annual budget of $160K per tower for first year, $60K/yr. thereafter)	**A. MONITORING** 1. Complete the state PM 2.5 network, including sites for chemical analysis of the PM 2.5 on the borders of the state and upwind of Houston, DFW, and El Paso (To be funded in FY-99 and 00 by TNRCC through EPA 103 funding) 2. Add size fractionated monitoring and chemical analysis of the size fractions to obtain data required to assess the interaction of incoming aerosol with local emissions (Not currently funded - approximate annual budget of $100K per site) 3. Carry out special aircraft based sampling and analysis to aid in analysis of the dynamics of aerosol formation, transport and deposition (Not currently funded - approximate annual budget in excess of a million dollars)

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Table 1b. Emission inventory data needed to address source allocation and transport of ozone and fine particulate matter.

Ozone	**$PM_{2.5}$ and regional haze**
B. EMISSION INVENTORY 1. Complete improved inventory of biogenic emissions in the eastern part of Texas (To be funded in FY-99 by TNRCC) 2. Use field sampling and data analysis techniques to check the performance of biogenic emissions inventories. (To be funded in FY-99 by TNRCC) 3. Collect source profiles and ambient measurements of VOCs and conduct chemical mass balance analysis to determine which sources are overestimated and underestimated in the current emission inventories (To be funded in FY-99 by TNRCC for the Houston area) 4. Improve NOx and VOC emission inventory for construction equipment for Houston to check on possible overestimates of NOx emissions (To be funded in FY-99 by TNRCC) 5. Improve VOC and NOx emission inventory of ship related emissions in Port of Houston (To be funded in FY-99 by TNRCC)	**B. EMISSION INVENTORY** 1. Determine sulfate precursor emissions (an inventory for sulfur dioxide) for the Houston area (already being performed), the eastern half of Texas (power plant and major point source data are available and reliable; area and minor point sources are not currently inventoried), and the parts of the continental U.S. that are frequently upwind of Texas under continental haze conditions. 2. Estimate crustal material emissions in the Houston urban core, the Ship Channel area, Dallas/Fort Worth and El Paso. (Not currently funded - approximate annual budget of $150K) 3. Carry out size resolved sampling and analysis for crustal material in conjunction with the inventory to assess the area of influence of the inventoried sources and prepare for dispersion modeling if it becomes necessary.(Not currently funded - approximate annual budget of $70K)

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Table 1c. Meteorology, chemistry, and model development needed to address source allocation and transport of ozone and fine particulate matter.

Ozone	$PM_{2.5}$ and regional haze
C. METEOROLOGY 1. Continue to run and archive HYSPLIT trajectories for each ozone season day for each urban area (To be funded in FY-99 by TNRCC) 2. Analysis of trajectories to assess contribution of upwind areas (Not currently funded - approximate annual budget of $80K) 3. Add additional radar wind profilers to the state network (Not currently funded - approximate annual budget of $270K per site) **D. CHEMISTRY** **E. MODELING** 1. Modeling will continue to be a prime technique for assessing the impact of emissions on both local and regional ozone concentrations. (Continuing; TNRCC and near-nonattainment areas)	**C. METEOROLOGY** **D. CHEMISTRY** **E. MODELING (DATA ANALYSIS AND RECEPTOR MODELING)** 1. Organic and elemental carbon - Analyze ambient samples for tracers to determine the percentage contribution of different source types to the organic carbon portion of $PM_{2.5}$ Initially use source profiles from other parts of the country, and add local source profiles as they become available (Not currently funded - approximate annual budget of $100K for the Houston area)

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Table 2. Research needed to address the chemical and physical processes that control formation and transport of ozone and fine particulate matter.

Ozone	$PM_{2.5}$ and regional haze
A. MONITORING 1. Based on high ozone and on high VOC concentrations, conduct event-triggered sampling for VOCs near major industrial source areas to determine whether unusual composition or concentrations of VOCs are associated with high ozone events. (To be funded in FY-99 by TNRCC) **B. EMISSION INVENTORY** 1. Include chlorine emissions in the modeling inventory. (Not currently funded - approximate budget of $50K) **C. METEOROLOGY** 1. Conduct nighttime airborne monitoring to determine overnight transport of ozone and ozone precursors. (Not currently funded) 2. Incorporate NEXRAD wind field data to improve wind fields in grid models (Not currently funded) **D. CHEMISTRY** 1. Airborne monitoring across the sea-breeze front during Houston ozone episodes. (Not currently funded - budget in excess of 1,000K) 2. Complete exploratory work on possible impact of chlorine emissions on ozone formation in Houston. (To be funded in FY-99 by TNRCC) **E. MODELING** 1. Continue support of development of MM5 application in the eastern part of Texas to improve meteorological modeling in simulation of ozone formation and transport in the region . **F. CONTROL STRATEGY**	**A. MONITORING** 1. Conduct nighttime airborne monitoring to determine overnight transport of PM fine and PM fine precursors (Not currently funded) 2. Monitor for ammonia and nitric acid in conjunction with full chemical analysis of PM 2.5 to provide the data needed to determine what limits the formation of ammonium nitrate (Not currently funded) **B. EMISSION INVENTORY** **C. METEOROLOGY** **D. CHEMISTRY** 1. Airborne and ground based monitoring for PM fine and its precursors to determine the extent to which PM fine coincides with ozone in urban plumes (Not currently funded) **E. MODELING** 1. Incorporate state of the science particulate matter formation models into the regional photochemical models currently used in air quality simulations - use the models to assess the sensitivity of particulate matter concentrations to various classes of emission reductions **F. CONTROL STRATEGY**

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Table 3. Research needed to address the projected effect of current and planned control programs on ambient concentrations of ozone and fine particulate matter.

Ozone	$PM_{2.5}$ and regional haze
A. MONITORING **B. EMISSION INVENTORY** **C. METEOROLOGY** **D. CHEMISTRY** **E. MODELING** 1. Conduct seasonal modeling to improve the robustness of control strategy development for both eight-hour standard modeling and one-hour standard. (Not currently funded - approximate budget of $500K) **F. CONTROL STRATEGY** 1. Analyze monitored concentrations of ozone precursors to determine if changes in ambient concentrations match predicted effect of control strategies. (Not currently funded - approximate budget of $130K)	**A. MONITORING** **B. EMISSION INVENTORY** 1. Project reductions in sulfate precursor emissions due to current acid rain and other regulations for the Houston area, the eastern half of Texas, and the parts of the continental U.S. that are frequently upwind of Texas under continental haze conditions (Not currently funded) 2. Project reductions in ammonia emissions that will occur due to planned regulatory actions (Not currently funded) 3. Project reductions in emissions of precursors of organic particulate matter that will occur due to planned regulatory actions (Not currently funded) **C. METEOROLOGY** **D. CHEMISTRY** **E. MODELING** 1. Sulfates - Evaluate EPA's assessment of sulfur dioxide emission reductions and corresponding reductions of sulfate transported into Texas (Not currently funded) 2. Organic and elemental carbon - assess whether secondary organic carbon concentrations are significant (Not currently funded) 3. Nitrates - assess whether nitrate mass is significant; assess uncertainty in nitrate-sulfate-ammonia relationships **F. CONTROL STRATEGY** 1. Analyze monitored concentrations of particulate matter and precursors to determine if changes in ambient concentrations match predicted effect of control strategies. (Not currently funded - approximate budget of $150K)

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Chapter III: Research Priorities

Addressing the research needs outlined in Chapter II will require substantial resources, committed over at least 5 years. While these research needs are being addressed, however, the State of Texas will need to meet a series of federally imposed deadlines, developing plans for reducing ozone and particulate matter concentrations.

To ensure that investments made in air quality research provide timely and valuable information in policy development, the research needs outlined in Chapter II should be prioritized based on the following criteria:

- significance - does the research address a topic that is a major factor in controlling ozone or particulate matter formation and transport in Texas?
- reducing uncertainty - will the research contribute to a significantly better understanding of ozone or particulate matter formation and transport in Texas?
- timeliness - can the research be completed in time to inform policy decisions?

It is anticipated that this prioritization will occur on an on-going basis.

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Chapter IV: Year 2000 Field Study and Other Leveraging Opportunities

Many of the research needs outlined in this document are best addressed through large coordinated studies, where many investigators make measurements simultaneously, and many scientific questions are addressed in parallel. Only large, coordinated studies can address phenomena that occur over the large spatial scale of Texas. Further, making many measurements and addressing several scientific issues simultaneously allows complex interactions between ozone and particulate matter to be addressed.

It is therefore in the best interest of the State of Texas to address the high priority research issues identified in this document in a large, coordinated study of air quality in Texas. The earliest feasible date for such a study is the year 2000. Planning for such a study has begun and is described in a separate document. To leverage State resources to the maximum extent possible, externally funded investigators have been recruited to participate in this study. Researchers at federally funded laboratories will bring unique air quality measurement instrumentation to Texas in the year 2000

Other air quality research leveraging opportunities have also been pursued. For example, the U.S. Environmental Protection Agency is funding several field sampling sites that will investigate the factors that influence the formation and transport of fine particulate matter. A consortium from the State of Texas, led by the University of Texas, has obtained $3.65 million from the U.S. EPA for the operation of one of these sites.