Final Report

RFP02-02
Assessment of Information Needs for Air Pollution Health Effects Research
in Houston, Texas

Submitted by

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I. Executive Summary

This project, *Assessment of Information Needs for Air Pollution Health Effects Research in Houston, Texas,* was funded by the Texas Council of Environmental Technology (TCET) to assist in developing a multi-year air pollution health effects research strategy focused on high priority research for Texas in general and the Houston Metropolitan Area in particular. BRIDGES to Sustainability and the Mickey Leland National Urban Air Toxics Research Center were partners in this effort. The results of this project include:

- compilation of the epidemiologic and other pertinent studies that have been conducted to date on the air pollution health effects in the Houston Metropolitan Area and the rest of Texas;
- compilation of the data sources that can be used in future air pollution health effects research in the Houston Metropolitan Area; and
- identification of the most pressing research and information needs on air pollution health effects in the Houston Metropolitan Area.

Based on the information compiled in this project, most studies of air pollution health effects in the Houston area concentrated on the respiratory effects of ozone and particulates, and are either early studies from more than 10 years ago or parts of more-recent national studies that did not focus specifically on the Houston area. Further, the data sources on air quality, exposure, and health outcomes are constrained both in terms of their availability and usefulness for air pollution health effects research in Houston. Information on ambient air quality is of little value for understanding the air pollution–health effects relationship in the absence of Houston-specific data on exposure, exposure modifiers, and confounding factors. Limitations of specific data sources are discussed in this report.

A Strategic Health Effects Review Panel (SHERP) was formed to guide and advise the project, especially in identifying research and information needs. The SHERP was composed of air pollution health effects experts and technical representatives from academia, business, and government. The SHERP and other invited experts and community representatives met for a one-day Air Pollution Health Effects Workshop in which findings from this study were reviewed by the participants. The Workshop resulted in the development of a set of high-priority research questions in the areas of health effects of exposure, disparities, and data quality, formulated on the basis of participants' expertise and the information presented.

The project recommends an initial health effects investigation focusing on the association between exposure to pollutants of greatest concern for the Houston area (such as ozone and particulates) and well defined health outcomes (such as asthma) for a subgroup of individuals that have been identified as more susceptible to such exposures. Effort should also be made to determine the most important differentiators that could impact air pollution health effects in Houston and other metropolitan areas of Texas differently from other areas of the nation. This include the determination of air pollutant concentration

profiles, exposure profiles, personal time activity patterns, and demographic and lifestyle characteristics that affect exposure and health outcomes. Long-term investigation of actual health outcomes will build upon the results of these short-term research studies. The high-priority questions developed by the Workshop participants can serve as a guide in developing a long-term research agenda.

It was a consensus view of the SHERP members and other Workshop participants that air pollution health effects research for the Houston area specifically, and the State of Texas in general, is underdeveloped in spite of the presence of the Texas Medical Centers and interest of high quality researchers. There is limited financial support for this area of research in Texas, thus resulting in an inadequate infrastructure to support a significant research effort. To address this, the project also recommends the establishment of a center of excellence for environmental health research based in the Houston area, taking advantage of the resources available at the Texas Medical Center, other universities, and well-developed scientific communities in Houston.

II. Introduction

Air pollution is a challenging problem in the Houston Metropolitan Area and across Texas. There is a growing consensus among scientists, business, and community leaders on the negative effects of air pollution on human health. However, there is no current comprehensive assessment of the amount, quality, or applicability of current health effects research to the unique conditions in Texas (especially Houston).

BRIDGES to Sustainability (BRIDGES) and Mickey Leland National Urban Air Toxics Research Center (NUATRC) entered into an agreement with the Texas Council on Environmental Technology (TCET), commencing in September 2002, to assess information needs for air pollution health effects research in Houston and assist TCET in developing a multi-year air pollution health effects research strategy. Specifically, the work is aimed towards the following objectives:

- to identify studies that have been conducted to date on air pollution health effects in Texas, with focus on the Houston Metropolitan Area;
- to summarize what is known about air pollution health effects and factors that may modify exposure in the Houston Metropolitan Area;
- to identify available data sources on air pollution health effects; and
- to assess the most pressing research and information needs for the Houston Metropolitan Area.

As part of this work, a compilation of the existing literature was developed to identify epidemiologic and other relevant studies that have been performed on the health effects of air pollution in Texas, with an emphasis on the Houston Metropolitan Area. Sources of air pollution, exposure and health data that can potentially be used in future air pollution epidemiology research in Houston were also reviewed for their usefulness and limitations. High priority health effects research and information needs were assessed

Table 1. Composition of the Strategic Health Effects Review Panel (SHERP)

Panel Member	Role/Representation	Affiliation	Sector
Mr. Rob Barrett	Regulatory Agency	HGAC	Government
Dr. Pamela Berger	Mayor's Comm. on Health	City of Houston	Local Govt.
Mr. Walt Crow	Stakeholder Group	URS / HRM	Bus./Industry
Dr. Matt Fraser	Local Research	Rice University	Academic
Dr. Winifred Hamilton	Chronic Disease	Baylor College of Med.	Academic
Dr. Michael Honeycutt	Regulatory Agency	TCEQ	State Govt.
Dr. Lovell Jones	Health Disparities	UT - MD Anderson	Academic
Mrs. Jane Laping	Local Citizens	Mothers for Clean Air	Public
Ms. Jacqueline Lentz	Mayor's Comm. on Health	City of Houston	Local Govt.
Mr. Joseph Luspin	Stakeholder Trade Assoc.	Lyondell	Bus./Industry
Dr. Maria Morandi	Public Health Research	UT - SPH	Academic
Dr. Mark Wiesner	TCET Liaison	Rice University	N/A

through the identification of priority research questions for Texas and in particular Houston Metropolitan Area.

A Strategic Health Effects Review Panel (SHERP) was formed to accomplish the goals of this project. The SHERP is composed of air pollution health effects experts and technical representatives from academia, business, government and the community to guide the project team in the literature review, identification of research gaps and development of a preliminary research agenda. SHERP members are identified in Table 1.

The SHERP engaged significantly with the project team in meeting its objectives. A subset of the group met with the project team in September to further develop the concept of the SHERP. Then the SHERP met with the project team on October 8 to review the research methodology and findings and make recommendations. The group reconvened on November 6 to further discuss research findings and develop an agenda for the one-day Air Pollution Health Effects Workshop which was held on November 18. Further, the group participated in the Workshop as well as in a follow-up conference call to review recommendations post-Workshop. In addition to attending meetings, the SHERP was active in reviewing findings, reports and recommendations.

The Workshop was a milestone in the project. It provided an opportunity to engage other air pollution health effects experts recommended by the SHERP in the dialog, and it produced important insights into where the greatest research and information needs lie and the magnitude of the research gaps. The result was a consensus on a set of high priority questions that must be addressed in a significant way in order to advance the understanding of air pollution health effects. These research questions are critical to the purpose of this project. The workshop participants concluded that, in the absence of these research questions, it is futile to try to ascertain research and data gaps. Further, the group concluded that there is such an overwhelming absence of research to answer the key questions that it is not useful to quantify the gap. Therefore, the group focused

attention on the key questions of importance and the current barriers to answering those questions.

Attending the Workshop were the following people: Stuart Abramson (Texas Children's Hospital), Rob Barrett* (Harris County), Beth Beloff (BRIDGES), Craig Beskid (NUATRC), Daewon Byun (UH), Walt Crow* (URS), Matt Fraser* (Rice), Winifred Hamilton* (Baylor College of Medicine), Ann Johnson (Environmental Defense), Lovell Jones* (MD Anderson), Jane Laping* (Mothers for Clean Air), Jacqueline Lentz* (City of Houston), Joseph Luspin* (Lyondell), Maria Morandi* (UT School of Public Health), Mary Jane Naquin (Informed Futures), Peggy Rogers (City of Houston), Tom Stock (UT School of Public Health), Dicksen Tanzil (BRIDGES).

BRIDGES to Sustainability and NUATRC gratefully acknowledge the efforts on the part of the SHERP and other experts who attended the Workshop. This project could not have succeeded without their assistance.

Project Limitations

The project scope was limited by time and budget. As a project that was essentially 4.5 months long with a $50,000 budget, it was not possible to produce an in-depth research and database review with qualitative analyses for each research or database entry, nor to conduct an exhaustive global search of all air pollution health effects research. Such an analysis would have required the full review of the methodology, quality assessment and analysis, etc. for each study and was therefore not possible within the limitations of this project. The focus of research literature review was on research related specifically to Houston and to Texas in general. It was also limited to outdoor air and therefore did not include either indoor air issues or occupational exposure. Further, the research priorities proposed do not nor were intended to constitute a strategic research agenda. Instead, they suggest where to go next in formulating a more robust and strategic long-term research agenda for the State of Texas. The team relied heavily on the input and review of the SHERP to guide the direction of the research review and to form general opinions about the limitations of research and database findings.

III. Background

Obtaining direct evidence on the effect of air pollution on a specific population requires the use of epidemiology: the study of the distribution and determinants of a disease process in a specific population. For outdoor air quality health studies, epidemiologic studies analyze the effects from ambient exposures on groups of people actually living in the community. However, there are a number of limitations involved in such studies. Some limitations are:

(a) There are a very large number of confounders, or variables that may distort the true relation between exposure and outcome, in large population studies; for

* SHERP member

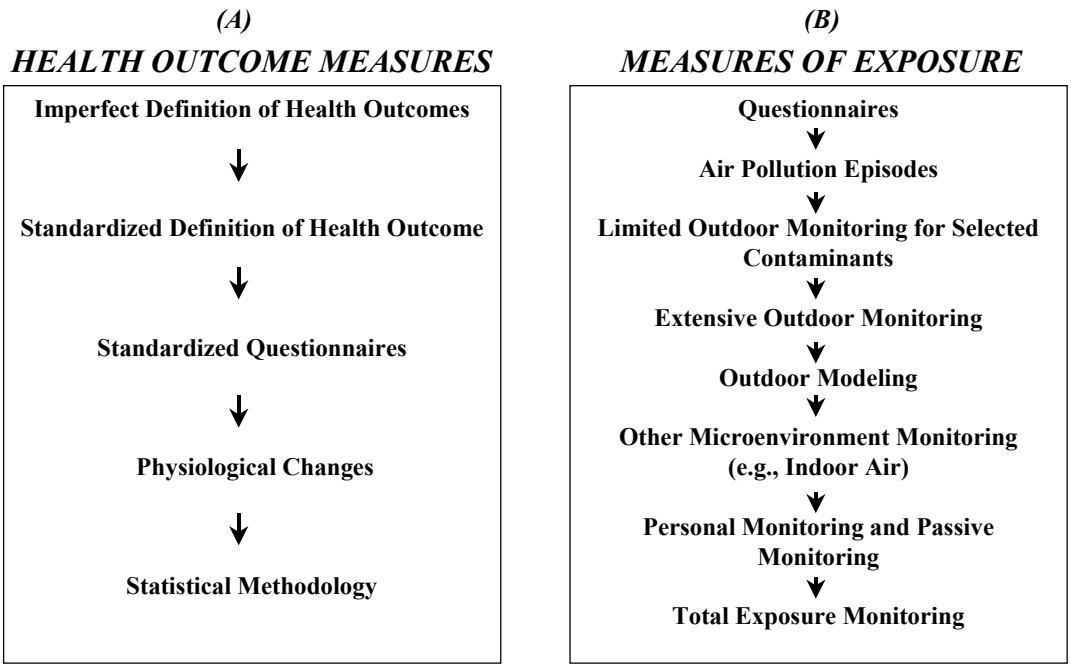

Figure 1. Timeline of health outcomes and measures of exposure for outdoor-air-pollution epidemiology.
Source: National Research Council, 1991.

example, lifestyle factors such as smoking habits, socioeconomic levels, population density, local climate, ethnic background of the population (certain groups have high susceptibility to certain diseases). Before air pollution can be identified as the cause or contributor of health effects the interactions of these other variables must be investigated.

(b) Many pollutants may cause similar effects, yet it is difficult to find large populations exposed to individual pollutants. The effects of synergism among pollutants may also be important. Furthermore, the concentrations of different pollutants do not necessarily follow the same trends over time during the day, month, or year.

Epidemiologic studies are important to the study of air pollution health effects; they are, in fact, a good source of information on long-term chronic exposures. One must look with care, however, at interpreting results from such studies by understanding their limitations.

Trends in Air Pollution Epidemiology Methodology

Designs of environmental epidemiologic studies can be divided into two general categories: descriptive and analytic.[1] Descriptive studies include ecologic and cluster studies, which examine the link between the environmental hazards (i.e. air pollution)

[1] National Research Council, 1997.

and health effects for a relatively large population. These studies are relatively inexpensive and quickly conducted, if based on data already collected.[2] However, these studies may be confounded by a large number of risk factors and their estimates of the association between exposure and disease may be biased towards the more susceptible or more affected persons.[3] These weaknesses are largely addressed by analytic studies, such as cohort and case-control studies. A cohort study typically involves detailed exposure assessment for a limited group of study participants and follows the development of health outcomes of interest for that particular group. Case-control studies compare exposures between people who have an adverse health condition (case) and those who do not (control) to determine if an environmental exposure may have caused the diseased or health conditions. These analytical studies establish a more proper sequence between exposure and health outcomes,[4] although case-control studies cannot necessarily establish a temporal sequence. Nevertheless, analytical studies in general have become more frequently used to study air pollution health outcomes, following the trend in epidemiologic methodologies from more descriptive measurements towards detailed analysis of exposure and health outcomes (Figure 1).

Air pollution epidemiological methods for measuring the effects of outdoor-air pollution concentrated on the definition, measurement, and verification of disease outcomes and physiological changes that were indicative of disease development (Figure 1A). Considerable efforts have been made to standardize reporting of signs and symptoms and disease definition, particularly for pulmonary symptoms, the measurement, interpretation, and reporting of lung-function measurements, and definitions of chronic lung disease (e.g., chronic bronchitis and emphysema). Other efforts were made to develop and apply statistical methods to outdoor-air epidemiologic databases.

Early data on potential exposure to contaminated air were derived primarily from questionnaires filled out by individual study participants, identifying each individual's residence and indicated whether that individual had been exposed to a high level of air pollution (see Figure 1B). Categories of exposure to outdoor pollutants were assigned with little information on confounders, such as smoking status or occupation, which led to misclassification of exposure into exposure categories. In addition, when data were available on the spatial and temporal variations of the actual outdoor concentrations, they were limited to a few air contaminants. The factors affecting the type and concentration of outdoor air pollutants (e.g., sources, meteorology, and chemical transformations) were poorly characterized or understood by the epidemiological investigators.[5] It commonly was assumed that one or two routinely monitored contaminants or indicators (e.g., usually total suspended particles or sulfur dioxide) at fixed sites either were related to the health outcomes under study or were proxies for contaminants that posed a potential health threat.

[2] Samet and Jaakkola, 1999.
[3] Ibid.
[4] Ibid.
[5] Lippmann and Lioy, 1985.

Later, ambient monitoring expanded to cover a wider range of chemicals to better define the spatial and temporal variability, as well as to gather better information on the factors influencing ambient levels. In addition, models that examined community source-receptor relationships were developed and improved to better identify sources and evaluate mitigation strategies. These efforts, however, still were directed toward determining outdoor concentrations and ignored the presence of many of the same air contaminants inside homes and other indoor locations where individuals spend most of their time.[6]

Further problems with characterization of exposures remain since exposures continue to be considered as occurring from one media and through one route of entry into the body. It is currently recognized that for many pollutants that are primarily emitted to or formed in air, exposures can take place through multiple media and through different routes of entry. Thus, total exposure to such pollutants needs to be assessed by personal monitoring that incorporates multimedia sampling, biological monitoring, or indirect exposure estimation based on micro-environmental monitoring and multimedia sampling. Advances in personal active and passive monitoring methods are examples of steps taken in this direction.[7] Methods for air sampling and analysis continue to develop in parallel to air-pollution epidemiological methodology. Increasingly, air-pollution exposure monitoring has been included as an integral part of air pollution epidemiology. These data have indicated the potential importance of indoor sources of contaminants. For example, exposure studies have identified major indoor sources of NO_2 (e.g., gas home appliances) and have demonstrated that concentrations and exposures experienced in homes with these NO_2 sources frequently and significantly exceed NO_2 concentrations in outdoor air.[8] These studies have also shown that indoor NO_2 concentrations in homes without these sources can be lower that outdoor concentrations, that personal exposures to NO_2 are strongly associated with indoor levels because people spend more time indoors than outdoors, and that personal exposure is only weakly associated with outdoor concentrations even for occupants of residences with no sources.[9]

The advances in understanding exposure are due in part to the development of inexpensive passive personal monitors. As a result, measurement of personal exposures with particular emphasis on indoor air and personal sampling is now used in the evaluation of health effects. The trend to measure concentrations of air pollutants directly in the breathing zone of individuals has continued with methodologies developed for a broad range of contaminants of interest such as $PM_{2.5}$, volatile organic compounds (VOCs), and aldehydes. Indeed, the passive sampling technology needed to conduct personal exposure measurements for VOCs and aldehydes has already been developed and field validated via the "Relationship Between Indoor, Outdoor, and Personal Air" (RIOPA) and the "Air Toxics and Asthma in Children" (ATAC) studies funded by NUATRC. Houston-based researchers have conducted the development and or

[6] NRC, 1985.
[7] Palmes et al., 1976; Geisling et al., 1982; Lewis et al., 1985; Mulik and Williams, 1986; Hammond and Leaderer, 1987.
[8] Leaderer et al., 1986; Southern California Gas Co., 1986.
[9] Ott *et al*., 1988.

refinement of these passive methods and the seminal field studies that used these new techniques.

Recognized Health Effects

Recent review articles published on the health effects of ambient air pollution are summarized in Table 2, listed by the organ systems affected and for different groups of susceptible populations. The Table shows reported associations of ambient air pollution with various adverse health effects.

Cancer. Known and suspected human carcinogens are among the substances in the EPA's list of hazardous air pollutants (HAPs). Some of these substances, such as polycyclic aromatic hydrocarbons (PAHs), exist both in the gas phase and as suspended particles, and are believed to contribute to the mutagenicity of particulate matter.[10]

Cancer and non-cancer mortality. Epidemiologic studies have associated acute exposure to fine airborne particles (usually categorized according to the diameter of the particles, e.g., PM_{10}, $PM_{2.5,}$ etc) to pulmonary/respiratory mortality including those due to lung cancer.[11] Most deaths attributable to PM, however, are due to cardiovascular causes because of the greater prevalence on cardiovascular problems in the population.[12] Some studies have also associated ozone exposure to premature mortality. Although the evidence of the ozone–mortality link has been confirmed by recent studies,[13] it is not as well explored nor widely accepted as the PM-mortality relationship.

Non-cancer morbidity. Outdoor air pollution is also linked to various non-cancer health end-points. Infants, children, the elderly, persons with asthma, and persons who exercise outdoor are among population subgroups that are especially vulnerable. In particular, epidemiologic studies have demonstrated the association between outdoor air pollution and:

- respiratory effects (e.g. ozone with asthma exacerbation; fine particles with asthma and COPD exacerbation, decreased lung function, and bronchitis symptoms);[14]
- cardiovascular effects (e.g. PM with increased heart rate, decreased heart rate variability, and increased cardiac arrhythmias);[15]
- immunological effects (e.g. SO_2, NO_2, ozone, PM, and other air irritants with increased susceptibility to asthma and allergy);[16]
- developmental effects (e.g. ozone with deficits in growth of lung functions);[17] and

[10] Finlayson-Pitts and Pitts, 1997.
[11] Samet *et al.*, 2000; Pope, 2000.
[12] Dockery, 2001; Pope, 2000.
[13] Thurston and Ito, 2001.
[14] Brunekreef and Holgate, 2002; Leikuf, 2002; Peden, 2002, 2001; Dixon, 2002; Carlisle and Sharp, 2001; Schwartz and Neas, 2000.
[15] Dockery, 2001.
[16] Leikuf, 2002; Peden, 2002, 2001; Ring *et al*., 2001.

- reproductive effects (e.g. PAHs with low birth weight, premature birth, and possibly deficits in cognitive development; various air toxics with sperm quality and male reproductive function).[18]

Among these, respiratory and cardiovascular effects have received the greatest attention from researchers and are the most established; while understanding about the links between air pollution and immunological, developmental, reproductive, and other health systems remains under development.

IV. Compilation of Studies and Data Sources

Scope

Epidemiology. The compilation effort of this project was focused primarily on identifying epidemiologic studies of air pollution health effects for the inhabitants of the Houston Metropolitan Area. A number of epidemiologic factors were examined, as listed in the literature review matrix shown in Table 3. Texas-specific studies on health effects, exposure factors, and other determinants of air pollution health effects are included in the compilation. The review concentrates only on pollutants of concern in the Houston Metropolitan Area, namely ozone, particulate matter, and hazardous air pollutants (air toxics). The compilation included recent studies (past 10 to 15 years), as well as some relevant and important studies older than 15 years.

Toxicology. Toxicologic studies performed by Texas-based researchers were also reviewed as part of this work. The objectives of the toxicology compilation are to provide an overview of the current air pollution toxicology research in Texas and identify the investigators and institutions involved for purposes of evaluating the existing research infrastructure in the State. The compilation was focused at the most recent and representative toxicology publications by Texas researchers, particularly those related to the health effects of ozone, particulate matter, and hazardous air pollutants.

Databases and indices. Available population-based data used in air pollution health effect research are generally categorized into three categories:

(a) air quality measurements (including ambient air monitoring and emission inventories),
(b) limited data on exposure and lifestyle factors that modify exposure, and
(c) health outcomes measurements.

All three categories of data are necessary to construct the link between pollutants and health outcomes in a certain population. Compilation of data sources in these categories for the Houston Metropolitan Area formed the third component of the compilation effort.

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[17] Dixon, 2002.
[18] Sram, 1999; Perera *et al.*, 1999.

Table 3. Compilation Matrix for Epidemiology
Status: PR = peer-reviewed; NPR = non-peer-reviewed; OG = on-going

		Texas (outside HGA)			Houston Galveston Area (HGA)		
		PR	NPR	OG	PR	NPR	OG
Health Effects	Cancer				Buffler et al, 1988; Walker et al, 1982; Marmor, 1978; MacDonald, 1976		
	Non-cancer						
	Respiratory	Samet et al, 2000; Legator et al, 2001, 1998; Winchester, 1989			Samet et al, 2000; Kim et al, 1996	Gehan, 1988; Stock et al, 1988; Selwyn et al, 1985; Holguin, 1985	Hanania; Delclos et al.; Macias
	Cardiovascular	Samet et al, 2000			Samet et al, 2000; Morris et al, 1995		
	Immunological						
	Reproductive	Ihrig et al, 1998					
	Developmental						
	Symptoms, non-specific						
Exposure Factors	Local air pollution sources						
	Traffic						
	Industrial	Ihrig et al, 1998; Legator et al, 2001, 1998					
	Dry cleaners						
	Other/general					Smith et al, 1998; MacDonald, 1976	Morandi
	Personal exposure				Weisel, 2002; Naumova et al, 2002ab; Morandi et al, 1988	Gehan, 1988; Stock et al, 1988; Holguin et al, 1985	Weisel et al (RIOPA & NHANES)
	Housing characteristics						
	HVAC					Langenstein, 1997; Hail, 1991	Weisel et al (RIOPA)
	Indoor sources *)				Weisel, 2002; Naumova et al, 2002ab; Stock et al, 1986; Kim & Stock, 1986		Weisel et al (RIOPA)
	Other						
	Individual activities						
	Smoking *)						
	Hobbies					Hopkins et al, 1998; Selwyn et al, 1985	
	Occupation *)						
	Other						
	Time activity pattern						
	Indoor/outdoor time					Rifai et al, 1999; Stock & Morandi, 1988	
	Modes of transport				Long et al, 2002		
	Other						
Other	Temperature						
	Humidity						
	Socioeconomic/race/cultural					Harper et al, 2001; Gehan et al, 1989	
	Susceptibility						

*) In relation to outdoor air pollution health effects only

Please note that Tables 4 to 8 and Table 10 are located at the end of this report.

Epidemiology

There have been a number of studies linking ambient air quality to specific health effects for the Texas population and on the exposure factors and other determinants that affect the exposures and consequently, the extent of the health effects. Citations for the studies

identified in this review are shown in Table 3. These include published peer-reviewed and non-peer-reviewed as well as on-going studies that have been performed with respect to Texas populations in areas identified in Table 3. Most of the studies listed involve air pollution health effects in the Houston-Galveston area. While it reflects the greater number of studies performed for metropolitan Houston, the list is also partially due to the decidedly Houston-focus nature of this project.

Table 4 provides the descriptions of the published studies. A number of parameters are listed for each study, including study type, locations, subjects/population (including sample size), pollutants and health outcomes studied, exposure factors involved, and analysis time frame. Summary of findings are also presented, along with limitations reported in the original references. On-going studies are listed in Table 5, along with the study locations as well as pollutants, exposure factors, and health outcomes involved and brief descriptions on the on-going efforts.

The largest numbers of studies on health effects focused on the respiratory system. These studies have largely demonstrated association between air pollutants in Houston and respiratory problems, including between: ozone and asthma,[19] PM and respiratory mortality,[20] and SO_2 and invasive pneumococcal disease.[21] In addition to respiratory effects, a few studies have been conducted on cardiovascular problems in Houston, linking PM_{10} with cardiovascular mortality[22] and CO with congestive heart failure.[23] Most of these respiratory and cardiovascular health effects studies, however, are either early studies from more than 10 years ago or parts of more recent national studies that did not focus specifically on Houston.

For exposure factors, the largest numbers of studies were carried out to investigate personal exposure and the relation between indoor and outdoor sources. The Houston area is unique in terms of heat, humidity, and high air-conditioning use—factors that affect personal exposure.[24] Generally, the studies found Houston homes and buildings to have low air exchange rate, which result in lower exposure to outdoor air pollution sources but higher vulnerability to indoor source emissions.[25] The ambient air pollution particularly affects those who spend more time outdoor, such as joggers and children, as well as those that do not have air conditioning or limit air conditioning use. The caveat to these general findings is that for PM, lower air exchange rates may not affect the penetration of the smaller size particles of outdoor origin (e.g. $PM_{1.0}$) into the indoor environments.

The unfilled categories in Table 3 represent some of the current gaps in air pollution epidemiology research. The presence of studies in a category, however, does not necessarily indicate that the gap has been filled. The categories that have been studied in

[19] Gehan *et al*., 1989; Stock *et al.*, 1988, Gehan, 1988; Holguin *et al*., 1985.
[20] Samet *et al*., 2001.
[21] Kim *et al*., 1993.
[22] Samet *et al*., 2001.
[23] Morris *et al*., 1995.
[24] Levy *et al.*, 2001.
[25] Weisel, 2002; Hail, 1991; Contant *et al*., 1987.

the present literature tend to be important ones, and there remain many unanswered questions that need to be further identified in these categories. In fact, the areas of respiratory effects and personal/residential exposure remain the subjects of some on-going research efforts (Table 5).

Toxicologic Studies

Table 6 summarizes toxicology research focused on the health end points of air pollution carried out by Texas-based investigators/institutions. Descriptors including the health end points, pollutants, and subjects studied and summary of findings are reported in the Table. Most of the studies were performed on the effects of air pollutants on respiratory/immunological end points. Many of these key studies look at the effects of various air pollutants (PM, ozone, volatile organics) on induction of cellular inflammatory mediators in the lungs. Some look at adduct formation in the respiratory tissue, which may account for both carcinogenic and non-cancer health effects of these air toxics. These studies demonstrated the capacity of Texas-based researchers from different institutions to conduct air pollution health effects research, including on biomarkers of air pollution effects.

Data Sources

The compilation effort has identified a number of sources for Houston-specific air pollution, exposure, and health outcome data, as well as sources containing data that can be potentially linked back to the Houston Metropolitan Area. An overview of the available data sources is given in the following paragraphs, while a more in-depth discussion on the data usefulness and limitations for long-term air pollution health effects research in Houston is presented later in this report.

Air quality data. Table 7 provides the air quality data sources identified in this study, listed along with the geographic scope, parameters measured, design of methodology, and indices which are potentially useful for health effects research. Cursory assessment on the limitations of each data source is also presented. The identified sources include data from the ambient monitoring networks that have been set up in compliance with NAAQS that are run by the City of Houston, TCEQ, and the U.S. EPA as well as the Houston Regional Monitoring (HRM) network for criteria pollutants and VOCs. Most of these monitoring data are available from EPA's Air Quality System (AQS), formerly part of the Aerometric Information Retrieval System (AIRS). Other air pollution data sources identified include emission inventory and compliance databases maintained by TCEQ and the U.S. EPA. Data from past studies such as TexAQS 2000 may also contain a certain amount of useful information for future air pollution health effects research.

Exposure and lifestyle data. A list of the existing data sources of exposure and exposure modifiers are provided in Table 8. Similar to the listing on air pollution data sources, geographic scope, parameters, methodology used, and potentially useful indices for air pollution health effects research are also presented, along with cursory discussion on the limitations on the usefulness of each study.

The RIOPA study[26] has collected a large volume of data on indoor and outdoor concentrations and personal exposures to VOCs, $PM_{2.5,}$ elemental and chemical class components of $PM_{2.5}$, aldehydes, and PAHs, residential ventilation measurements, and household and personal activities in Houston (as well as Los Angeles and central New Jersey), most of which are still being analyzed. National data sources could also be applicable in epidemiology studies on air pollution health effects in Houston if the data can be traced back to the State and City. The National Health and Nutrition Examination Survey (NHANES) has recently added a personal environmental exposure component in their survey.

Exposure factors such as housing characteristics, time activity pattern, and modes of transportation are also being tracked at the national level by the relevant federal agencies, as listed in Table 8. Data on these exposure factors are organized such that city- or area-specific data can be easily retrieved. Nevertheless, time activity pattern information specific to the Houston area is very limited.

Measures of health outcomes. Table 9 lists some of the health effect indicators used in previous studies, by major organ system. These indices may be used to measure the health effects of pollutants in epidemiologic research. Most indices that have been developed to be suitable for air pollution research focus on the respiratory, immunological and cardiovascular system. The indicators listed under neurological and endocrine/reproductive systems, along with some listed under cardiovascular and respiratory systems are not specific to air pollution research.

Data sources on health outcomes are listed in Table 10. Sources are listed for each type of health data, including mortality, natality, epidemiologic registries, and categories of subject-oriented medical records. Again, descriptors for each study, namely geographic scope, parameters, methodology used, and potentially useful indices for air pollution health effects research, are included along with cursory list of limitations. Mortality and natality data maintained by the Texas Department of Health, based on information on death and birth certificates, respectively, provides indicators that are potentially useful for air pollution epidemiology studies in the Houston area, although they may be limited in terms of accuracy and reliability as discussed later in this report.

Epidemiologic tracking and surveillance for the State of Texas in the areas related to air pollution, however, are limited. The State maintains registries on cancer and birth defects. Information on hospital discharges is available from the Texas Healthcare Information Council. Data are also available from school nurses, Medicare (for over-65 population), and insurance records, although the quality of the insurance records has been questioned by the SHERP, as discussed below. A few on-going studies listed in Table 10 will provide additional and better-controlled data for the Houston area.

[26] See for example Naumova *et al*., 2002ab

Table 9. Health Effect Indices

General **[Samet and Jaakola 1999]**

- Overall mortality
- Morbidity indexes:
  - School/work absenteeism
  - Days of restricted activities
  - Rate of utilization of outpatient medical facility
  - ER visits
  - Hospitalization

Respiratory **[Samet and Jaakola 1999]**

- Acute and chronic symptoms
- Acute infections
- Chronic respiratory diseases
- Degree of non-specific airway responsiveness
- Reduced level of lung function
- Increased rate of lung function decline
- Decreased rate of lung function growth
- Exacerbation of a chronic respiratory disease
- Hospitalization for a chronic respiratory disease
- Lung cancer
- Death secondary to a chronic respiratory disease

Cardiovascular

- Rhythm disturbances:
  - Arrhythmias [Campen *et al*. 2002]
  - Myocardial infarctions [Dockery, 2001]
  - Heart rate variability change [Magari *et al*. 2001]
- Vascular changes:
  - Acute coronary deaths [Servoss *et al*. 2002]
  - Decreased blood pressure [Toda *et al*. 2001]

Immunological

- Exacerbation of allergy [Delfino 2002]
- Macrophage mediated immunosuppression [Koike *et al*. 1998]

Neuropsychological **[Samet and Jaakola 1999]**

- Reduced performance on neurobehavioral testing
- Neuropsychological syndrome
- Neuropsychological disease

Reproductive/Endocrinological

- Reproductive health in males [Selevan *et al*. 2000]
- Intrauterine growth retardation (IUGR) [Dejmek *et al*. 1999]
- Spontaneous abortions [Xu *et al*. 1998]

V. Development of Research Priorities

Priority Research Questions

Specification of priority research questions constitutes a critical first step in planning for long-term study on the health effects of air pollution. On November 6, members of the SHERP met to develop a preliminary set of questions. These questions were then categorized by the project team into three categories of concern:

(1) Health Effects of Exposure,
(2) Disparities, and
(3) Data Quality.

The final list of questions were subsequently developed by the Workshop participants, and they form a set of priority questions to be answered through both short- and long-term research.

Workshop participants were initially expected to develop a set of questions by category and rank all the questions in order of importance. After much discussion, it was decided that the three categories of concern were interconnected and of equal importance in the development of a research agenda. Within each category the questions developed by the group were roughly prioritized and are reflected by the number given.

Table 11. Priority Research Questions on the Health Effects of Exposure

(1) What are the acute health impacts of exposure to pollutants (acting singly or in combination)?
❑ Do better exposure estimates yield stronger associations with acute health effects? ❑ Do mortality and exacerbations of asthma and other respiratory diseases, cardiac arrhythmias, congestive heart failure, etc. correlate with daily fluctuations in exposure?
(2) What are specific causative characteristics(s) of PM (particulate matter)?
❑ How do particulate size and composition affect health? (especially for people with asthma, COPD, bronchitis, emphysema, heart disease)
(3) What are the chronic health impacts of long-term exposure to pollutants (acting singly or in combination)?
❑ Do better exposure estimates yield stronger associations with chronic health effects? ❑ What are the impacts of air toxics? ❑ How does long-term exposure affect cancer incidence? ❑ What are the impacts on children?

Table 12. Priority Research Questions on Disparities

(1) How is the relationship between air pollution exposure and adverse health effects influenced by extrinsic and intrinsic susceptibility factors affected by the unique nature of Houston?
❑ How do extrinsic factors such as activity pattern, residence characteristics, socioeconomic status, and lifestyle affect personal exposure? ❑ How do intrinsic factors such as age, race, gender, genetic susceptibility, and existing health status affect the occurrence and severity of adverse health effects? ❑ What are the health effects of early-age exposure (incl. prenatal and postnatal)?
(2) How do the health effects of Houston air differ from other cities?
❑ Higher rate of adult onset of respiratory disease? ❑ Do the incidence, prevalence and severity of respiratory and allergic diseases differ between migrants and native Houstonians? ❑ What factors contribute to the induction of asthma in greater Houston? ❑ How does HVAC (heating, ventilating and air conditioning) modify exposure and its association with health effects?
(3) Are there geospatial and/or temporal disparities in adverse health effects that correlate with exposure in Houston Galveston Area (HGA)?
❑ Are there geospatial clusters of disease in HGA?

Table 13. Priority Research Questions on Data Quality

(1) How can the quality, completeness, and accessibility of public health data be improved?
❑ How can we develop a uniform tracking system of public health data in Houston? What to track? What are the standards?
(2) How can we establish a consistent methodology/technology to insure reliability and completeness of data for community exposure assessment?
❑ Do we have sufficient monitoring sites for community exposure assessment? ❑ Are we monitoring the relevant environmental factors (e.g. pollutants, allergens, and meteorological variables) and at the appropriate locations? ❑ Need to assess comparability of different methodologies ❑ How well do personal exposure estimates correlate to personal exposure measurements?
(3) How do we acquire adequate personal exposure estimates and activity pattern data for HGA?

Some of the priority questions listed under each category could be addressed in the short term with initial emphasis on application to the Houston area. Most of the questions, however, require a long-term research perspective. It was recommended that a full strategic research agenda be developed to include the broader set of issues covered in this project as well as others such as indoor sources and occupational exposures.

Tables 11 to 13 exhibit the priority research questions resulting from the Workshop group process. They also capture some of the community's concerns and are structured in such a way that RFPs (request for proposals) can be generated for the research community to address.

Questions from Community

The community's interest in this subject was captured by Mary Jane Naquin in a report to the Workshop group. Ms. Naquin is a well-known facilitator of community advisory panels (CAPs) in the Houston area. Together with two other facilitators, Diane Sheridan and Peter Bowman, CAPs with which they work were asked to identify key questions that they would like to see addressed by Houston air pollution health effects research. Although the CAPs survey was superficial and informal, it provided some useful information.

The CAPs survey comprised 10 to 12 groups of about 12 to 35 people each who have been meeting monthly for 5 to 10 years with local industry leaders. They spanned a wide geographical area, from Sugarland to Baytown, and represent the concerns of their respective communities. Further, the respondents represent a diverse group, from well-educated professionals to high school students, from affluent to less economically able, and comprise significant age and racial mixes.

There was no question that there was great interest in the issue of air pollution health effects. The community members were grateful for the opportunity to have input into such an effort. They expressed interest in having continuing involvement in both the assessment of topics and the outcome of a research agenda. When asked what questions they would most like addressed, the following were posed most often:

- Are people living closer to industrial sources at greater risk?
- What are the health concerns with respect to exposure to specific chemicals?
- What should we worry most about? What is the hierarchy of sources of air pollution health effects for which people should be concerned: indoor versus outdoor, industrial versus lifestyle, single toxin versus mixed-reactive pollutants?

In addition, other important questions were:

- What are the natural air contaminants (such as pollen and dust) and their contribution to air pollution?
- What are the health effects associated with odors, like odors from sewer plants?
- To what degree are birth defects related to air pollution?

- To what degree, and if so how, are allergies and asthma related to air pollution?

Dr. Winifred Hamilton of the Baylor College of Medicine conducted a similar survey of citizen concerns at a Houston-area National Institute for Environmental Health Science (NIEHS) town meeting on environmental health concerns. This meeting was held on October 20, 2001. Participants were surveyed and asked to rank environmental research questions that they would like addressed. The questions were prepared from the results of pre-meeting written and telephone surveys, as well as from focus groups, and were ranked at the town meeting. The three top research questions were:

- What is the cumulative effect of multiple pollutants on human health?
- What is the effect of pollution on learning in children?
- Are there cancer clusters in the Houston-Galveston area?

Following, and ranked substantially lower, were the next 3 questions:

- What are the long-term effects of fine particulate pollution on children?
- How can one reduce exposure to pollution?
- What is the role of genetic susceptibility in pollution-related illnesses?

VI. Information Needs

Data Usefulness and Limitations

The issue of data usefulness and limitations must be examined through the lens of what research questions are to be asked, as pointed out in discussion with SHERP members. Good studies directed at finding answers, as opposed to reinventing the wheel, need to first pose the outcomes of interest that should be measured, based on prior research demonstrating that there is good evidence for association with a pollutant. Then, it would be necessary to define the pollutant metrics and other relevant metrics that would allow for a rigorous test of the hypothesis being proposed.

The nature of data requirements is also determined by the study design. General population data are useful for descriptive studies, which include ecologic and cluster studies. Analytic studies such as cohort and case-control studies, on the other hand, require detailed personal exposure measurements and health outcome data for individual study participants. There are two different opinions among SHERP members and other invited experts at the Workshop on the type of air pollution epidemiology study that deserve the highest priority. The prevailing opinion, especially among health effect researchers, is that there is a greater need for analytic studies. The second opinion, more common among community representatives, proposes a greater need for descriptive studies that directly examine the link between ambient pollution and health effects for the broad population. The descriptive studies, however, are less controlled and usually inconclusive, although useful in formulating hypotheses.

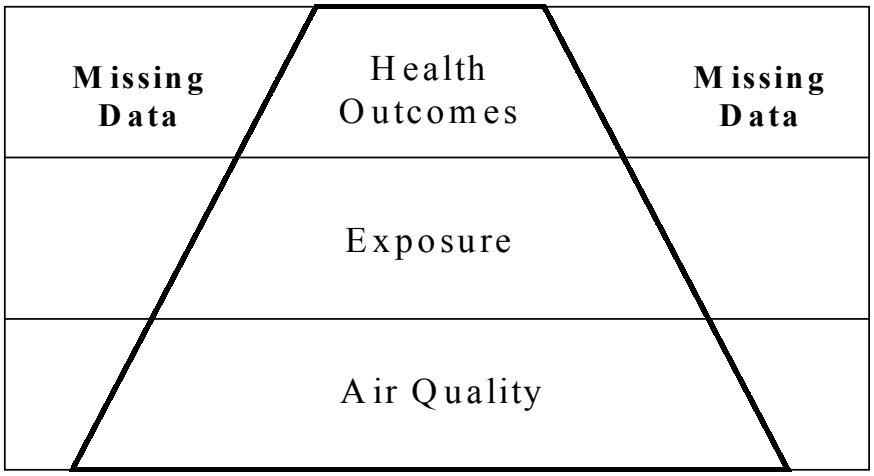

Figure 2: Information Needs

General population data do not usually provide sufficient details to be useful in analytic studies. Ambient air monitoring data need to be accompanied by solid information on individual exposure. Detailed personal exposure monitoring has been conducted in Houston through the RIOPA study, which remains on-going, but only to a limited set of pollutants and for a limited period of time. Health information for analytic studies is usually obtained from personal medical records, clinical or laboratory investigations, and questionnaire results.[27]

The availability of population-based data on air pollution health effects can be typically represented by the trapezoid depicted in Figure 2. There is usually a good availability of data with respect to air quality. However, data with respect to exposure and health outcomes are less abundant. Establishing the link between certain air pollutant(s) and health effects require the availability of the complete set of information. This is analogous to navigating one's way up the trapezoid through the path determined by the particular research question being addressed.

Air quality data limitations. Limitations for each source of air quality data are included in Table 4. It is a consensus opinion of the SHERP that, in general, the extent of available data on ambient pollution levels and air pollutant emissions in the Houston area are as good as any other U.S. metropolitan areas. Their usefulness for health effects research, however, is limited. Data collection parameters (including monitoring locations, pollutants sampled, and sampling frequency) are selected mostly for regulatory purposes only. A number of more limited data collection efforts (such as PAMS and TexAQS 2000) were designed for the study of atmospheric chemistry, but none were specifically intended for health effects investigation.

Specifically, there is inadequate pollutant characterization information for PM and to a lesser extent VOCs. Determination of PM characteristics (i.e. particle size distribution

[27] National Research Council, 1997.

and chemical composition) constitutes one of the national research priorities for airborne particulate matter formulated by the National Research Council (Research Topic 3: Characterization of emission sources)[28] and the lack of this type of information in Houston is representative of that of the nation. Approximately 150 VOCs are monitored by the HRM stations in the Houston Ship Channel industrial corridor. However, this set of information on VOC compositions is not publicly available at present.

Information on the ambient air quality represents a starting point in studying the health effects of air pollution. However, monitoring data may not correlate with personal exposure. Consequently, knowledge on ambient pollutant concentrations is of little use for air pollution epidemiology unless accompanied by spatial and temporal information on exposure in different microenvironments (i.e. places where people spend time) and for different demographic subpopulations.

Exposure and lifestyle data. Exposure information provides the critical bridge that links ambient air quality data and measurements of health outcomes. Yet, information on exposure and lifestyle factors that modify exposure is limited for Texas in general and the Houston area in particular.

Sources of information on exposure and lifestyle factors that can potentially be used in studying air pollution health effects in the Houston area are listed in Table 8. Cursory discussions on the limitations of each data source are also provided in the table. The RIOPA study, funded by NUATRC involving investigators from UT School of Public Health and out-of-state researchers, constitutes the most extensive effort on exposure assessment in Houston to date. This on-going study measures indoor and outdoor air concentrations of volatile organic compounds (VOCs), aldehydes, respirable particulate matter ($PM_{2.5}$), and air exchange rates (AER), as well as personal exposure in adults and children. In-vehicle exposure to aldehydes is measured. In addition, the fine particulate matter is speciated for chemical composition and source apportionment. The limitation of the study is the lack of a probability-weighted design. This limits the ability to extrapolate to larger populations than the sample itself. The study results can however be used to develop a health-based study in the locations (e.g. Houston Ship Channel) where the exposure data have been gathered.

Another project sponsored by NUATRC involves the expansion of the Center for Disease Control and Prevention (CDC)'s National Health and Nutrition Examination Survey (NHANES) to include information on exposure to air toxics. Exposure information is obtained through personal air monitors and questionnaires for 1000 participants in a number of U.S. urban areas, including Houston. The usability of the data for Houston-specific air pollution health effects investigation, however, may be constrained by the inability to make person- or site-specific exposure and health correlations data due to the strict subject confidentiality guideline of the National Center for Health Statistics (NCHS). As a result, specific linkages to the Houston area may be limited.

[28] National Research Council, 2001.

The above limitations suggest the need for comprehensive studies on Houston-specific exposure characteristics, especially for subpopulations with greater susceptibility due to their socio-demographic or lifestyle characteristics or proximity to ambient air pollution sources.

Reasonable amounts of Houston-specific information are available on a number of exposure modifying factors such as housing characteristics (U.S. Census Bureau's American Housing Survey) and modes of transportation (U.S. DOT's National Household Travel Survey). Houston-specific information on demographic factors that modify exposure, such as socioeconomic status and occupation, may also be obtained from the U.S. Census (not listed in Table 8). Information on certain behavioral risk factors such as tobacco smoking and exercise rates are available for the state level from CDC's Behavioral Risk Factor Surveillance System. However, the information may not be traceable to the city- or area-specific level.

Another gap in the category of exposure and lifestyle data is the scarcity of information on time activity patterns, i.e. information on the time people spent in different microenvironments during the course of a typical workday or weekend,[29] specific to the Houston area. A preliminary study[30] suggested that Houston children spend more time outdoors compared to the nation's average time activity pattern for the same age group. However, studies involving direct collection of time activity patterns information in a sizable population, namely RIOPA and the Houston Asthma Study, indicate that people in Houston spend on average the same proportion of time indoors and outdoors as people elsewhere. Nevertheless, time activity patterns differ among demographic subgroups and groups of susceptible population. Changes in time activity patterns over time also necessitate periodic tracking.

Furthermore, as a semi-tropical area, Houston has a extensive use of air conditioning, which makes it a major modifier of exposure. The use of air conditioning may lower the Air Exchange Rate and consequently reduce exposure to outdoor air pollution at the expense of increasing the risk of exposure to indoor sources. Information on the impact of air conditioning, and the heating, ventilation, and air conditioning (HVAC) system in general, needs to be further developed. This issue was brought up repeatedly in SHERP meetings and included as one of the priority research questions concerning disparities (Table 12).

Health outcome data. Sources of information on health outcomes include vital statistics data, registries maintained by the state epidemiologists, and subject-specific medical records, as listed in Table 10 along with the limitations for each data source. In general, very little air pollution-related health data are being tracked beyond the natality (specifically, birth weight) and mortality data from birth and death certificates, respectively.

[29] Özkaynak, 1999.
[30] Rifai *et al*., 1999.

The State epidemiological records are focused on communicable diseases and exposure to environmental hazards such as spills and superfund sites, not air pollution. Similarly, the City of Houston tracks only diseases reportable by law, mostly infectious and food-borne diseases. Out of the currently available epidemiological records maintained in the State of Texas, only Texas Department of Health's cancer and birth defects registries can potentially be used in air pollution health effects investigation.

Most of the data sources on health outcomes suffer from potential misclassification. As summarized by Samet and Jaakkola,[31] accuracy of the cause-specific mortality data is influenced by the following factors:

- the extent of population contact with medical care;
- clinicians' diagnostic acumen in the particular area of study; and
- accuracy of the death certificate and the rate of error of coding to a particular cause of death.

The validity of cause-specific mortality data in the State of Texas, especially on the designation of deaths due to lung cancer, asthma, and other air pollution-related causes of mortality, deserves systematic examination. The use of death certificate data may also be limited by the lack of information on the decedent's health and exposure history.

Potential misclassification also affects the accuracy of subject-specific medical records, including information on hospital discharges and physician and emergency room (ER) visits. Hospital discharge records are maintained by the Texas Healthcare Information Council using diagnosis (ICD-9) codes. Data on hospital, physician and ER visits may be obtained from Medicare and insurance records. Diagnosis misclassification may be due to a number of factors including the lack of standardized and uniform criteria for diagnosis for several diseases, including respiratory infections.[32] Deliberate bias in diagnosis classification also occurs in corresponding to the requirements for insurance reimbursements, as brought up by the SHERP. Furthermore, these subject-specific medical records usually lack in information on the severity of illness as well as health and exposure history. Patient identifiers are also needed when collecting data from various sources to ensure the same person is not counted more than once.

On-going studies, in particular the asthma study led by Dr. Nick Hanania and the pilot pediatric asthma surveillance project led by Dr. Charles Macias (both of Baylor College of Medicine) should provide higher quality information on ER and hospital admissions related to asthma. An on-going project by Dr. George Delclos and co-workers (UT School of Public Health) would also result in data on asthma in middle school with greater accuracy than regular school nurse records and personal measurements of the exposures experience by the asthmatic children.

The City of Houston Department of Health and Human Services is currently embarking on a project funded by the CDC to develop an environmental public health tracking

[31] Samet and Jaakkola, 1999.
[32] Ibid.

network. The project is currently at the planning stage, which involves cataloging data sources on environmental hazards, exposures, and chronic disease outcomes for the City of Houston. The work will also seek to devise methods to link hazard, exposure, and health outcome data. The CDC grant has funds for an information technology vendor to assess what data sources exist; their suitability for linking hazards, exposure, and outcomes; and how they might be made available for analysis.[33]

Data accessibility. Most of the data sources listed in Tables 7, 8, and 10 are public data. Particular arrangements with the source agency or organization, however, are usually necessary to obtain the specific information useful for the future air pollution health effects research. Exceptions to the public availability most notably include HRM monitoring data, which contain the most comprehensive data on VOCs in the Houston area, although restricted to the Ship Channel. Data from specific studies, such as RIOPA and the on-going asthma projects, are obtainable only through special agreements with the principal investigators. Medicare and insurance medical records are also accessible through special arrangements only.

Identification of Information Needs for the Long-Term Research Project

Data quality issues relative to accuracy and reliability beyond what is discussed in the preceding paragraphs cannot be addressed within the constraints of this project. Nevertheless, they are important questions to address in evaluating data gaps. Tables 7, 8, and 10 include some information about the parameters of the data sets and the methodology for collecting data. Both of these points should contribute to a further assessment of the quality of the resulting data at a later date.

Data accessibility and usability issues are also of importance in evaluating the usefulness of data in future studies. Data sources have been supplied in the tables at the end of the report, and source of data is indicated. To the extent that it is publicly available, the results should be accessible; however, this does not guarantee that the underlying assumptions and ancillary data will be accessible. Proprietary databases are historically difficult to access.

Data usefulness issues include evaluating the format of the data and querying whether it can be easily adapted to another format. In the absence of a study design, it is not possible to evaluate this. In general, there will be difficulty in adapting data developed for one purpose into another form.

Evaluation criteria to determine usefulness of data. The data are useful only if we can overlay or otherwise link personal exposure data, health outcomes and air quality data. It therefore would be a useful exercise in further characterizing data needs in a subsequent effort to overlay the data both spatially and temporally on a map of the areas of interest in order to 1) generate hypotheses about air pollution health effects, and 2) find the specific data gaps.

[33] Peggy Rogers and Isaac Joyner, City of Houston Department of Health and Human Services, personal communication.

In order for data to be useful, it should be evaluated along some or all of the following criteria:

- Addresses a key research question;
- High degree of confidence in the reliability of the data;
- Robust and can be assessed and adjusted for confounders;
- Categorized by a geographic region and can be aggregated geographically;
- Easily accessible to multiple researchers;
- Stackable, i.e. can be aggregated with other exposure, health outcome, and air quality data;
- Cost effective in data collection;
- Protective of proprietary information;
- Understandable to a variety of audiences (technical and non-technical); and
- Not perishable, i.e. stays in date for a long time.

Development of future research. Based on the consensus view of the SHERP and the project team, air pollution health effects research, resources, and information needs for Texas and the Houston area are incomplete and underdeveloped. However, based on an examination and inventorying of the existing available research, resources, and information, there are significant useable research studies, resources, and information in Texas and the Houston area. Making this research and information available, and effectively using it for future air pollution health effects research projects is critical in the development of an efficient, effective, and comprehensive health effects research program for Texas and the Houston area.

An essential task in developing an air pollution health effects research program for Texas and the Houston area is the design of a process able to leverage these existing relevant resources, research and information as source material for future research projects.

One goal for the TCET project entitled "Assessment of Information Needs for Air Pollution Health Effects Research in Houston, Texas" was to identify the existing relevant research, resources, and information needs. The results of this effort are shown in Tables 4 to 10 of this report. The tables include specific existing information such as air quality data, exposure data, and health outcomes data necessary as a foundation for future research. Effectively using the identified resources, research studies and available information would benefit from a process to evaluate the available resources, research studies and information during the design and development of a planned or proposed specific research project. In Section IV of this report the research questions developed by the SHERP and the TCET project team are presented. These research questions represent the consensus view of the SHERP of relevant future research questions for Texas and the Houston area. By combining the existing resources, research, and information with the specific research objectives (e.g. research questions); a process for efficiently identifying, accessing, and using these existing identified research studies, resources and information can be described. Figure 3 illustrates an example of this process.

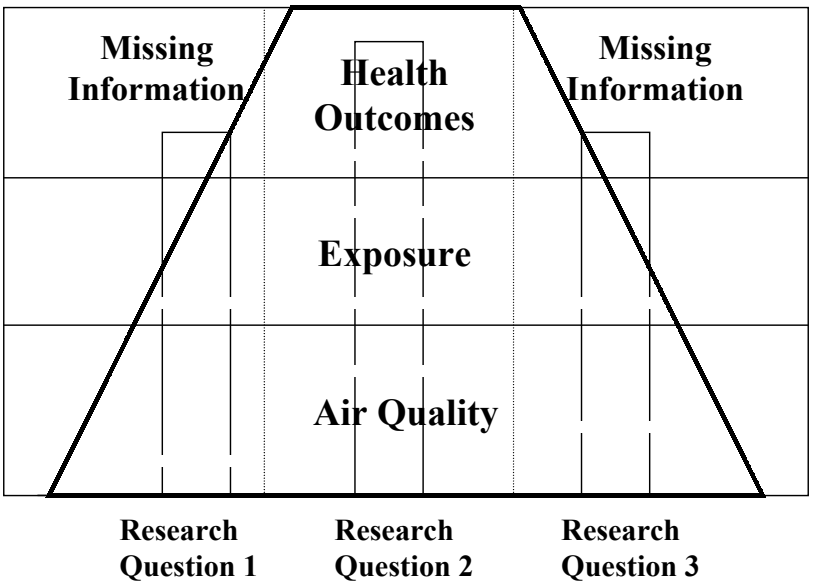

Figure 3. Future Research Development Process Example

To determine the first step in planning for long-term studies on the health effects of air pollution, the SHERP developed a set of relevant research questions. These research questions were grouped into three categories. The categories are: health effects of exposure; disparities; and, data quality. The detailed questions for each category are shown in Section IV. As shown in Figure 3 each research question can be evaluated considering the identified existing resources, research and information. By applying this process to the design of each future research project, significant leveraging of existing research, resources, and information will occur. This process will significantly enhance, improve, and accelerate the value and results of future air pollution health effects research. This process will also improve the cost effectiveness of future funded research by decreasing the potential data collection efforts and the possibility of redundant research studies.

"Universal" data gaps. While specific information needs must be identified for each particular research question of interest, there are a number of information gaps that are universal across a broad range of research questions related to air pollution health effects. The most significant of these is information on exposure and time activity pattern. The absence of comprehensive data on exposure and time activity pattern specific to the Houston area represents a major obstacle in establishing the link between ambient pollution level and health outcomes.

General mortality and morbidity indicators (see Table 9) are also "universally" applicable for a wide range of research questions related to air pollution health effects. These pieces of information are available from Vital Statistics and subject-specific medical records, with their limitations especially with respect to potential misclassifications.

Example: Information Needs on the Causative Characteristics of PM

To illustrate how one can go about identifying specific information needs with respect to a research question, let us examine the following example.

One of the priority research questions identified by the Workshop participants is on the causative characteristics of PM, in particularly on how particulate size and composition affect health especially for people with asthma, COPD, bronchitis, emphysema, and heart disease (see Table 11). While the question falls in the category of health effects of exposure, many of the data needs also belong to other categories of concern: disparities and data quality. To evaluate information needs, one must consider the nature of the study and methodology used.

Role of epidemiology. The answer to the research questions cannot be obtained entirely through the use of epidemiologic methods, which is subject to methodological limitations including the influence of large number of confounders, some of which are difficult to assess even with the latest statistical analysis techniques. Identification of the causative factors requires toxicologic studies under controlled laboratory conditions. Nevertheless, complementary population-based epidemiologic studies remain essential in providing evidence directly from the human population.

Direct vs. indirect exposure assessment. Epidemiologic studies can be broadly divided in terms of exposure assessment into two categories: direct and indirect.[34] In the direct category, exposure assessment is performed using a personal air monitor that samples the air encountered by each individual over time. It is measured with little need for information on emission inventory and ambient air quality. To investigate the causative characteristics of PM, the personal monitors must register over time the relevant variables, including PM size distribution and the concentration of key ingredients such as sulfate, nitrate, and organic components. Pertinent health end points, such as lung functions and exacerbation of specific cardio-respiratory diseases, can then be determined for each individual participant through direct observations, questionnaires, and/or biomarkers. Because of the equipment requirement, direct exposure assessment is limited to relatively small groups of study participants. However, it remains the method of choice in many recent analytical studies on air pollution health effects[35] due to the greater level of specificity and accuracy obtained through this approach.

Studies on larger populations require the use of indirect exposure assessment. The following information is required to estimate exposure:[36]

(a) pollutant concentrations over time in different microenvironments; and
(b) time spent in different microenvironments, i.e. time activity pattern.

[34] Samet and Jaakkola, 1999.
[35] E.g., RIOPA [Naumova *et al*. 2002].
[36] Samet and Jaakkola, 1999.

Data on the ambient air quality must be combined with mathematical models to calculate the concentration-time in different microenvironments. The indirect approach enables the analysis of data for the larger population; however, it lacks in robustness and in the levels of detail and specificity despite its complexity. This approach is more commonly used in descriptive studies. Information needs with respect to indirect exposure assessment and the research question on the causative characteristics of PM are discussed in the subsequent paragraphs.

Air quality information needs. Information on ambient air quality can be obtained directly from air monitoring stations or indirectly using air quality models. The latter requires an accurate inventory of emission levels and sources of primary particulates as well as precursors of secondary particulates such as SO_x, NO_x, and VOCs. Accurate mathematical models of the meteorology, dispersion, and secondary particulate formation are also necessary. Estimates on PM size distribution and composition may be obtained from the source-oriented models. However, these models are still under development. More certain emission inventories and an improved knowledge on the physical and chemical processes that govern the size distribution and particulate composition are necessary for the use of these models.[37]

Information on ambient air particulates is more readily obtainable from air monitoring stations. Yet, such information is also limited. $PM_{2.5}$ is measured in a subset of the monitoring stations in the Houston metropolitan area. However, the chemical compositions are determined in only a few of the monitoring stations. Characterization of the particulate size and composition represents a major gap in the ambient air information with respect to the research question on the causative characteristics of PM.

Exposure information needs. The use of indirect exposure assessment necessitates linking outdoor measures to actual human exposure. As discussed above, the approach requires the use of mathematical equations or models to determine concentration-time in different microenvironments and information on time activity pattern. Information needs in this area coincide with the "universal" data gaps identified earlier.

The relation between the particulate concentrations and characteristics outdoor and in the different microenvironments (such as in public and residential buildings, motor vehicles, etc.), especially in connection with the particular climate and lifestyle attributes of Houston, is not currently well understood. In fact, these issues are among the priority research questions concerning disparities identified by the Workshop participants (see Table 11). Development of a model that relates outdoor and indoor PM characteristics, taking into account the HVAC operation and other building features, represents one set of information needs.

Furthermore, information on time activity patterns specific to the Houston area is inadequate. The determination of personal exposure and time activity patterns are among the top research priorities for airborne particulate matter established by the National

[37] National Research Council 2001.

Research Council (Research Topic 1: Outdoor measures versus actual human exposures).[38]

Health outcome information needs. The last step of a population-based epidemiology study is to link exposure assessment to measures of health outcome. Several indices related to the adverse health outcomes of particulate matter have been used in previous studies, including:

- Respiratory and cardiovascular mortality;[39]
- Incidence of lung cancer;[40]
- Asthma exacerbation and COPD/chronic bronchitis;[41]
- Hospitalization for cardio-respiratory causes;[42]
- Low birth weight;[43] and
- Days of restricted activities.

Most of the above information is available from death and birth certificates data and hospital and physician's records, although they suffer from limitations described in Table 9 and earlier in this section. Information on days of restricted activities, however, is not readily available.

Furthermore, indices such as incidence of lung cancer and low birth weight are affected by confounding factors that have much greater effects on measures of the health outcome (e.g. smoking and lung cancer). Population-based epidemiologic studies on these health effects require highly accurate data on both the health outcomes and the confounding factors and large sample size.

Short-Term Research Considerations

In order to develop a long-term research agenda with emphasis on Texas-specific characteristics that may impact the accepted air pollution–health effects paradigm, it is necessary to establish in a detailed and scientifically rigorous manner the current specific attributes of the airsheds in the State (such us meteorology and air pollution profiles), socio-demographic and lifestyle patterns that may impact the exposure to air pollutants, and exposure profiles. The primary questions to be addressed are directed at identifying the characteristics that may render air pollution effects in Houston and other metropolitan areas of Texas different from other well-studied areas of the nation (such as Los Angeles and the northern East Coast). Addressing these questions could potentially allow for the extrapolation of the pollutant–health effects relationships established for the well-studied areas to Houston and other Texas metropolitan areas, or could facilitate extrapolation of the epidemiologic studies to other areas of the country that share similar characteristics

[38] Ibid.
[39] Samet *et al*. 2000.
[40] Buffler
[41] Brunekreef and Holgate, 2002
[42] Samet *et al*. 2000.
[43] Sram, 1999; Perera *et al*., 1999.

with Texas cities. Most importantly, the findings from this effort could identify critical variables not adequately considered by existing research, thus increasing the opportunity for leveraging resources with out-of-state funding.

In particular, the first phase in the development of a long-term research strategy should involve the development of a detailed and comprehensive set of data on variables and exposure modifiers that are most likely to differentiate Houston and other Texas areas. This includes:

- evaluation of the mixture of air pollutants and characteristic air pollutant profiles;
- lifestyle and time-activity patterns,
- air-conditioning use and building/residential ventilation; and
- demographic disparities in exposure.

Most of these data have been compiled and are available for the well-studied areas of Los Angeles and the northern East Coast. The compilation and comparative critical analysis of the existing data for Houston and other metropolitan areas of Texas is the necessary first step in identifying the primary differentiators for future studies of the health effects of air pollution in Houston and elsewhere in Texas.

The initial research would be a hypothesis-generating activity that will provide useful information for developing health effects studies in later phases and for attracting research funding from outside the State. The emphasis on air pollutant characterization and exposure issues represents the most important differentiators on the link between air pollution and health outcomes for the Houston region relative to other parts of the country. Long-term investigation on actual health outcomes will build upon the results of these short-term research studies.

In the very near term, an initial health effects investigation should focus on the association between exposure to pollutants of greatest concern for the Houston area and well defined health outcomes for a subgroup of individuals that have been identified as more susceptible to such exposures [see Table 11: What are the acute health impacts of exposure to pollutants (acting singly or in combination)?]. The study should consider different exposure indicators (i.e. ambient concentrations and exposure modeling estimates) and direct personal exposure measurements to elucidate such association in a robust manner and to establish the contribution of pollutants of outdoor origin to the health effects. A study of the association between exposure to ozone and PM and asthma exacerbation in children would meet these criteria because:

1) both ozone and PM are the two pollutants of greatest concern in Houston (and nationally),

2) children are at greater risk from exposure to air pollutants than adults because they are more active and, consequently, inhale more air per unit time and body weight, and

3) multiple studies have shown an association between asthma exacerbation and outdoor concentrations of ozone and/or PM.

The Houston-based, on-going pilot study "Air Toxics and Asthma in Children" (ATAC) to be completed in 2003 provides some methodology approaches than can be applied to this near-term study. ATAC makes use of lightweight monitoring devices to measure personal exposures to indoor and outdoor aldehydes for a panel of young children with asthma, but will model exposures to ozone and PM because of limited resources. Exacerbation is tracked through self-reported symptoms, and direct measurement of pulmonary function and the amount of bronchodilator medication used.

As indicated above, ATAC is limited by the resources available. A more comprehensive study should include a broader range of personal measurements (including PM and ozone, as well as potential confounders). It should also select participants using a stratification sampling design that includes the geographic proximity of homes and schools to major sources of the target contaminants (e.g. heavy traffic roads in the case of PM) or areas of higher outdoor concentrations of the target contaminants as shown by ambient monitoring as one of the criteria for participant selection. This type of study would not only be the most comprehensive ever in Houston, but would be unique in the nation and highly likely to attract additional interest and resources from Federal agencies.

VII. Infrastructure Considerations

Based on the results of the project review of existing research literature and on the Workshop discussion, there is a firm consensus on the need for a comprehensive infrastructure supporting research on the effects of air pollution on human health.

The basis for all air pollution policy, regulation, and research is the protection of human health and welfare. To date most air pollution research in the Houston area (and in Texas) has been focused on the regulatory aspects of ozone non-attainment, not health effects. While this research is important and valuable, it is not the whole story with regard to important and necessary research. Air toxics are pollutants known to cause or suspected of causing cancer or other serious human health effects or ecosystem damage. Section 112 of the Clean Air Act now lists 188 pollutants as air toxics and targets sources emitting them for regulation. Air pollution (criteria pollutants and air toxics) is a challenging problem in the Houston Metropolitan Area and across Texas. However, there is no current, comprehensive, organized infrastructure to lead, manage, direct and prioritize the amount, quality, or applicability of health effects research to the unique conditions in Texas (especially Houston). In short, current air pollution health effects research is performed on an ad-hoc, fragmented basis, largely dependent on the dedication and ability of a few individual investigators to obtain modest amounts of research funding from federal agencies and NGO's. In addition to being fragmented, it is the consensus among researchers that air pollution health effects research in Texas (and specifically the Houston area) contains many important research gaps regarding important health effects questions. This is true both as compared to research performed

in other areas of the U.S. and in the context of local research needs. Also, historical financial support for this area of research has been limited.

The Texas Medical Center is the world's largest medical center. The Texas Medical Center contains the highest concentration of research institutions capable of addressing air pollution health effects issues. If a research infrastructure were in place, federal and state funding sources such as USEPA, NIH, NIEHS, CDC, TDH, TCEQ, etc. would be more likely to fund Texas air pollution health effects research. Such a structure would benefit the state by attracting significant funding for much needed health effects research with highly leveraged funding from several funding sources.

The participation by several noted researchers and the subsequent results of this project confirm that there is not only a highly trained, educated and experienced pool of well qualified researchers and interested parties at institutions such as Baylor, UT School of Public Health, Rice, UH, TSU, NASA, TCEQ, TDH, etc., there is also high interest and motivation to perform the important research. In addition to these traditional research organizational links, consideration should be given to the more direct or clinical studies that may be performed and funded through the large number of hospitals in the Texas Medical Center area with interest in cardio-pulmonary effects of air pollution on their patients. There is currently significant interest in the establishment of specific Lung and Heart Institutes to specialize in evaluating patients concerned with these effects.

To benefit from the resources available in the existing Texas Medical Center and the greater Houston area, as well as from the availability and motivation of well qualified researchers, consideration should be given to the creation of an inter-institutional and multi-disciplinary Center of Excellence for Environmental Health Research located in the Houston area to either coordinate or perform research on health effects from air pollutants. Before creating this Center of Excellence, a critical examination of existing health effects research organization models should be performed. Existing models such as the NUATRC, HEI, CARB, GCHSRC, HARC and others should be thoroughly evaluated with respect to strengths and weaknesses before a recommendation is formulated as to the mission, objectives, and structure of the Center of Excellence. The proposed Center should aim at developing and supporting research which will yield a better understanding of the potential risks posed to human health by exposures to air pollutants, including criteria pollutants and air toxics as defined in the Clean Air Act Amendments of 1990. The proposed Center's research program should be developed collaboratively by scientific experts from academia, industry, and government and seek to fill the gaps in scientific and public health research that are required to make sound environmental health policy decisions.

VIII. Conclusions and Recommendations

Current State of Knowledge

The current state of knowledge on air pollution health effects in Houston was assessed through the compilation of available studies and data sources in this area. Discussion with SHERP members further sheds light on the limitations of the studies and data sources.

A number of studies have been conducted on air pollution health effects of the general population in Texas, especially in the Houston Metropolitan Area. Respiratory effects of exposure to ozone and PM have received the greatest attention in these studies. Nevertheless, most of the studies are either early studies from more than 10 years ago or parts of more-recent national studies that did not focus specifically on Houston.

Recent studies have begun to address personal exposure and factors that modify exposure specific to the Houston area. The scope of these studies, however, remains limited in terms of the number of affected population sub-groups, exposure factors, and pollutant species that were investigated. Major exposure and health effects modifiers for the Houston area, such as the characteristic pollutant mixture and air-conditioning use, have not been systematically studied.

Data sources on air quality, exposure, and health outcomes are also constrained both in terms of their availability and usefulness for air pollution health effects research in Houston. Information on ambient air quality is of little value for understanding the air pollution–health effects relationship without being accompanied by Houston-specific data on exposure, exposure modifiers, and confounding factors. The availability of these pieces of information, however, is limited. Furthermore, the accuracy of information in subject-specific medical records and death certificates, especially pertaining to the classification of diagnosis and cause of death, respectively, needs to be systematically evaluated.

Information Needs

A set of priority research questions have been developed at the Air Pollution Health Effects Workshop conducted as part of this project. The research questions were constructed in three interrelated categories: Health Effects of Exposure, Disparities, and Data Quality. Specific information needs must be assessed based on the particular set of research questions being addressed in each study.

There exists, however, pieces of information that are critical in addressing a broad range of research questions. This includes information on exposure and time activity patterns, which are largely inadequate for the Houston area and represent a pervasive information gap in air pollution health effects research.

Mortality and morbidity indices, including cause-specific death rates and information on physician and hospital visits, are also used universally in answering a broad range of research questions. Systematic assessment of their accuracy will improve the reliability of the information and facilitate the investigation on air pollution health effects in general.

Research Infrastructure

The consensus among the Workshop attendees was that air pollution health effects research for the Houston area specifically, and the State of Texas in general, is underdeveloped in spite of the presence of the Texas Medical Centers and interest of high quality researchers. There is limited financial support for this area of research in Texas, thus resulting in an inadequate infrastructure to support a significant research effort. Furthermore, the primary focus from a regulatory perspective on ozone seems to have displaced the much-needed attention on other pollutant exposures. Yet the public and the research community represented in the Workshop place a high value on the addressing the many questions raised about the impact of air pollution on health in Texas.

Future Research Project Development Process

An essential task in developing an air pollution health effects research program for Texas and the Houston area is the design of a process able to leverage existing relevant resources, research and information as source material for future research projects. This process is called the Future Research Project Development Process.

To determine the first step for this process, the SHERP developed a set of relevant research questions, grouped into three categories: health effects of exposure; disparities; and, data quality. By applying this process to the design of each future research project, significant leveraging of existing research, resources, and information will occur. Implementing this process will significantly enhance, improve, and accelerate the value and results of future air pollution health effects research. This process will also improve the cost effectiveness of future funded research by deceasing the potential data collection efforts and the possibility of redundant research studies. Only during this detailed process of evaluating existing information in the context of a specific planned research project can the true relevance, applicability, and usability of the existing information be assessed.

Successive iterations of this process and the execution of additional planned research that is contributed to the inventory of available research, resources, and information will continually enhance and improve the research, resources, and information available to subsequent researchers and research projects.

Recommendations

The following recommendations were developed for a continuation of the research effort initiated by the TCET. The purpose of this effort is to build on the work developed

through this current project in order to develop an in-depth strategic research approach for the State of Texas to better understand the health effects from air pollution in the State.

Short-term research recommendations.

- *Support short-term research on the association between exposure to pollutants of greatest concern to the Houston area and well defined health outcomes for a subgroup of a susceptible population.*

  The short-term research should address some of the highest priority questions identified by the SHERP, while focusing on a more limited set of problems. The research should involve rigorous investigation of the link between ambient pollutants, exposure, and well-defined health outcomes for a specific group of individuals identified as more susceptible to such exposure. A study on the effects of PM and ozone on asthma exacerbation in children would meet these criteria. This would constitute an extension of the on-going Houston Asthma Study (ATAC) and may leverage on the interest and resources of federal funding agencies, such as the U.S. Department of Health and Human Services through its new initiative on asthma and other chronic diseases.

Long-term research recommendations.

- *Support initial research on the most important differentiators that could impact air pollution health effects in Houston and other metropolitan areas of Texas differently from the other well-studied areas of the nation.*

  As the initial step in the long-term research, this will involve the identification of air pollutant concentration profiles, determination of personal/community exposures and identification of demographic and lifestyle characteristics that modify exposure and the health effects. Use technology already developed and field validated via earlier NUATRC-funded studies to conduct personal exposure measurements. This research would be hypothesis generating and will provide useful information for developing health effects studies in later phases, and it will benefit not only Houston and Texas but also contribute to state-of-the-art air pollution-health effects research. Therefore, TCET funding for this initial effort will provide the foundation for the development of future, high quality health effects studies that will likely attract additional resources from outside the State.

  This research would be hypothesis generating and will provide useful information for developing health effects studies in later phases, and it will benefit not only Houston and Texas but also contribute to state-of-the-art air pollution-health effects research. Therefore, TCET funding for this initial effort will provide the foundation for the development of future, high quality

health effects studies that will also likely attract additional resources from outside the State.

- *Support the data development that would fill the gap in universal air pollution health effect data.*

  Development of Houston-specific exposure data with respect to different microenvironments and time-activity information for different demographic groups and susceptible subpopulations will fill some of the most pervasive information gaps. It is recommended that some of the data limitations identified in this study be considered for design input into the CDC's Environmental Health Tracking Project, funded through the Pew Environmental Health Commission grant and involving the City of Houston.

- *Develop a long-term strategic research agenda based on the priority research questions identified in the Workshop but expanded to include indoor air and occupational exposures.*

  Consider as a starting point the top questions identified in the Workshop for the categories of Health Effects of Exposure, Disparities and Data Quality, as well as the three areas of data described in the report: Air Quality, Exposure and Lifestyle, and Health Outcomes. First priority should be given to research in the Houston area but translatable to other areas in Texas. Include in the strategic research agenda phasing, funding requirements and strategy, as well as identification of institutions and researchers to be included in the core effort.

	Air Quality Data	*Exposure and Lifestyle Data*	*Health Outcomes Data*
Health Effects of Exposure			
Disparities			
Data Quality			

Programmatic recommendations.

- *Develop an inter-institutional and multi-disciplinary Center of Excellence for Environmental Health Research in the Houston metropolitan area to support or undertake research in the area on the effects of air pollution on health, with particular emphasis on Houston and Texas in general.*

  The first step is the development of infrastructure requirements for a major Texas-based research center. This would entail evaluating other research centers, their strengths and weaknesses, and developing a plan for a Center of

Excellence on the basis of this evaluation. It is recommended that the Center of Excellence be physically located in the Houston metropolitan area to take advantage of the resources available at the Texas Medical Center, other universities, and the rest of the well-developed scientific community assembled in Houston; however, research institutions throughout Texas would participate. It is also recommended that an expanded SHERP, including representation from CAPs, NGOs and the funding community, be utilized in the definition of future research planning and Center of Excellence definition.

Build a Houston component of a Texas-based health effects research program based on the three existing major studies with components in Houston; two of which are already completed and one in progress. These are the RIOPA study, the NHANES study, and the Houston Asthma Study (ATAC).

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Glossary

AC	Air-conditioning
ATAC	Air Toxics and Asthma in Children (also known as the "Houston Asthma Study")
BAL	Brochoalveolar lavage
CAP	Community Advisory Panel
CDC	Center for Disease Control and Prevention
COPD	Chronic obstructive pulmonary disease
CVD	Cardiovascular disease
DEP	Diesel exhaust particle
EPA	Environmental Protection Agency
ER	Emergency room
ETS	Environmental tobacco smoke
HAP	Hazardous air pollutant
HI	Heat Index
HVAC	Heating, ventilation, and air-conditioning
IUGR	Inuterine growth retardation
MW	Molecular weight
NAAQS	National Ambient Air Quality Standards
NHANES	National Health and Nutrition Examination Survey
PAH	Polycyclic aromatic hydrocarbon
PEF	Peak expiratory flow
PM	Particulate matter
RIOPA	Relationship Between Indoor, Outdoor, and Personal Air
RR	Relative risk
SHERP	Strategic Health Effects Review Panel
TCEQ	Texas Commission on Environmental Quality
TCET	Texas Council on Environmental Technology
VOC	Volatile organic compound