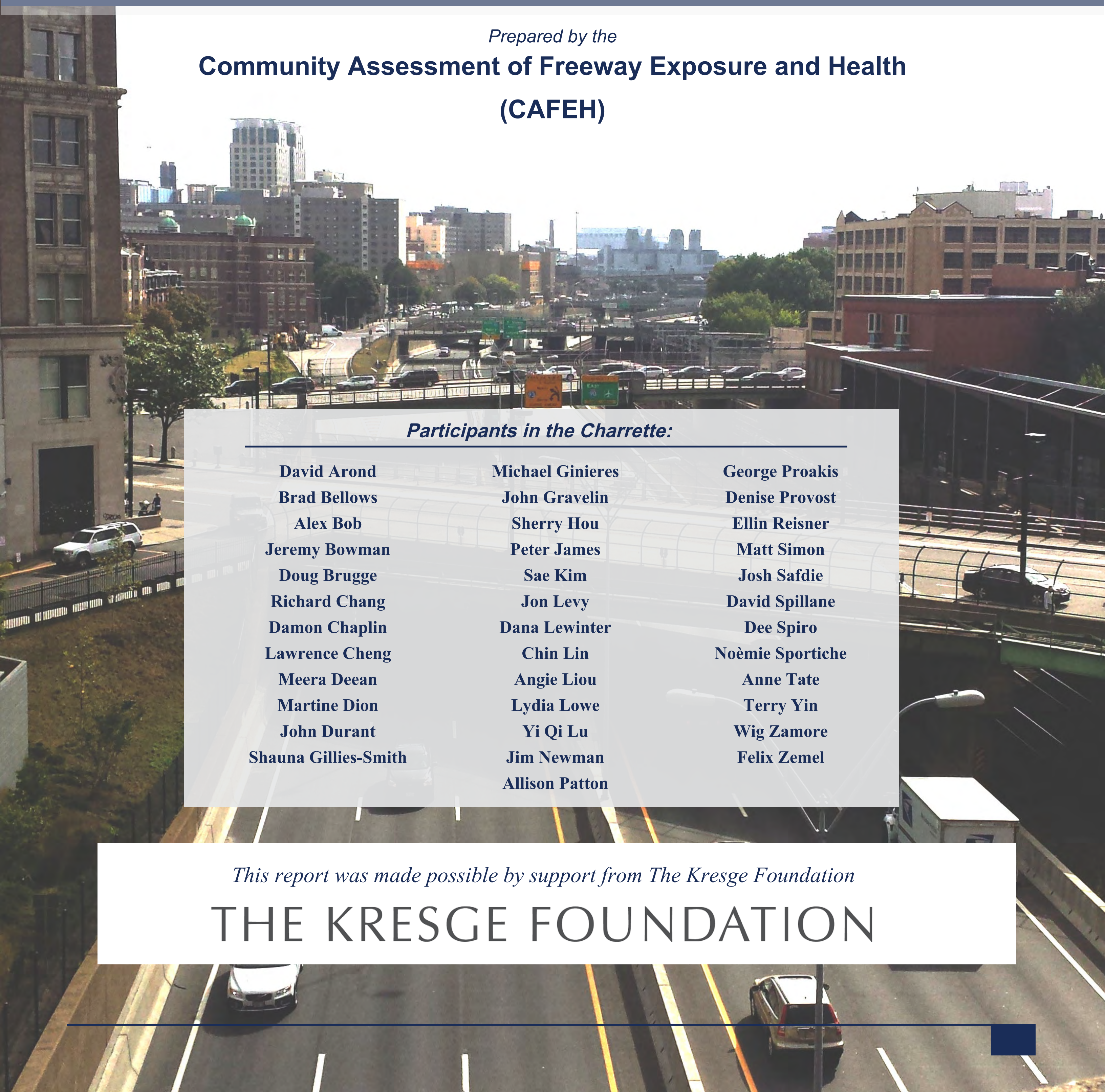
# Improving Health in Communities Near Highways

*Design Solutions from a Charrette*



*Prepared by the*

**Community Assessment of Freeway Exposure and Health (CAFEH)**

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THE KRESGE FOUNDATION

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The Community Assessment of Freeway Exposure and Health (CAFEH) study is a series of community-based participatory research projects studying localized pollution near highways and major roadways in the Boston area (http://sites.tufts.edu/cafeh/) and developing design approaches to protecting human health. The partners in the collaboration led by Tufts University come from universities, local communities and municipal agencies.

The work described here was funded by the Kresge Foundation to develop policy and practice approaches, specifically for the City of Somerville and the Chinatown neighborhood of Boston, and potentially for wider application.

***Partners to the many CAFEH projects include:***

# Executive Summary

'Improving the Health of Near-Highway Communities' is a project, funded by the Kresge Foundation, which seeks to enact positive changes at the community level and disseminate research results regionally, starting with near highway locations in the Boston area, including Boston's Chinatown and communities in the City of Somerville. The project is part of the larger Community Assessment of Freeway Exposure and Health (CAFEH (http://sites.tufts.edu/cafeh/)) project, and is a collaboration of Tufts University, Boston Public Health Commission (BPHC), Metropolitan Area Planning Council (MAPC), Chinese Progressive Association (CPA), Somerville Transportation Equity Partnership (STEP), and the City of Somerville, with help from Linnean Solutions. The CAFEH study is a series of community-based participatory research projects studying localized pollution near highways and major roadways in the Boston area, and developing design approaches to protect human health.

The goal of this part of the CAFEH project, and of the design workshop represented in this report, is to influence both projects and municipal policies to reduce exposure to ultrafine particles (UFP) near highways and busy roadways in Somerville and Boston and improve human cardio-vascular health. This report is part of the dissemination of CAFEH's earlier work, with the intent to spur changes in other near highway communities and other projects. The report provides ideas for designers and policy-makers on how to reduce exposure from traffic related air pollution in building and development projects.

The first phase of the CAFEH project was to gather expertise in the areas of highway air pollution, and to collect data for an exposure assessment to validate current research on health impacts. A number of environmental health reports now exist which show significantly elevated cardiovascular mortality risk, lung cancer and childhood asthma for people living near heavily travelled freeways. Emerging studies also show elevated risk of autism. Section I of this report outlines the current research on both the characteristics of traffic related air pollution and the effects on near highway communities. Section II outlines 11 design tactics developed from empirical research that looked at the reduction of exposure in real-life applications.

# Executive Summary *(cont'd)*

A major part of the second phase of the project was to assemble a group of designers, urban planners, city officials, public health advocates and other community members to consider how the list of tactics might be applied in specific project designs. Sections III and IV summarize the results from an 'expert elicitation' design charrette. The charrette engaged this multi-disciplinary group of experts in a 2-day meeting in which the group first learned about near highway pollution, health effects, and possible mitigation solutions, and then developed design ideas aimed at real locations and real problems in our target communities.

Section V outlines practical municipal actions to consider as a result of the research and design collaboration between key stakeholders. These actions aren't prescriptive, and should be used as a guide to develop municipal policies to reduce the health effects of traffic related air pollution in near highway communities.

Design solutions generated by the charrette participants ranged from earthen and built walls to shield people from pollution exposure to building ventilation design. The scale of interventions ranged from the neighborhood scale (decking over the highway) to the individual building scale (Somerville retrofit plan). All of the design solutions from the charrette are presented in section IV of this report.

This report, and the work described herein, was funded by the Kresge Foundation to develop policy and best-practice approaches, specifically for the City of Somerville and the Chinatown neighborhood of Boston, with potential for wider application.

## *Example Diagram from the Design Charrette*


*Credit: Giamportone Design, Linnean Solutions.*

# Table of Contents:





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LINNEAN Solutions

Report Prepared by Linnean Solutions;
Jim Newman, John Gravelin.
January, 2015.

*Photo Credits on Cover Page (1) and Executive Summary (4): John Gravelin.*

# Introduction

The Community Assessment of Freeway Exposure and Health Study (CAFEH) is a community-based participatory research project. Community partners participate in all aspects of the science, including: developing the proposal, leading the study, collecting, analyzing, and interpreting the data. CAFEH began studying pollution in Boston communities near major highways in 2008, looking at Somerville, Boston's Chinatown, and other communities.

The aim of the overall project is to assess the association between exposure to air pollutants emanating from highway traffic and cardiovascular health in communities near highways. The CAFEH project is collecting and comparing measurements of highway-generated air pollution, including ultrafine particulates (UFP) less than a millionth of a meter in diameter, with measures of health including blood pressure and C-reactive protein (CRP), a measure of systemic inflammation in adults. The CAFEH team is measuring changes in air pollution levels and health impacts as a function of distance from highways.

'Improving the Health of Near-Highway Communities' is a sub-project of CAFEH, funded by the Kresge Foundation, which seeks to enact positive changes at the community level and disseminate research results regionally, starting with the CAFEH study areas of Boston's Chinatown and communities in the City of Somerville. To this aim, the project team organized a design charrette to introduce these research results to the local design community and engage participants in developing design solutions to minimize the negative health effects of near-roadway air pollution for the communities of the two case study sites in Boston and Somerville.

Extensive outreach and recruitment was conducted to have a critical mass of participants with the needed range of expertise. Approximately 35 individuals attended at least one of the two all-day charrette sessions. The range of expertise was appropriate and effective, including a key designer and the headmaster from the school that was slated to occupy one of our charrette sites. The charrette was held on May 9-10, 2014.

Materials were prepared for the charrette participants that accurately represented both the pollution sources and proximity to each site, as well as proposed uses of the sites. Design teams were educated about the issues of near highway pollution with two slide presentations, represented in this report. The first presentation discussed the health effects of living near highways and major roadways and of exposure to the pollutants that are elevated near heavy traffic, including the findings of the CAFEH study. The second presentation covered the ways in which traffic-related pollution behaves, including factors that affect its distribution such as wind speed and direction, framed as "10 easy to remember slides."

A report outlining possible design strategies or tactics was prepared for the charrette participants by Allison Patton, a graduating PhD student associated with the CAFEH studies. Tactics were developed through a literature review of building design and urban planning strategies that appeared to have some potential to reduce pollution exposures from highways. The review produced 11 tactics, each with an estimate of efficacy and a degree of (un)certainty in the science. These tactics were documented in a summary that is included in this report.

# I. Research: Understanding Pollution Near Highways

## Health effects of traffic pollution near highways and major roadways

*by Doug Brugge - Professor in the Department of Public Health and Community Medicine at Tufts University School of Medicine*

In order to understand near highway pollution, it is helpful to know a little bit about ambient particulate matter and especially fine particulate matter. Particulate Matter (PM) comes in different sizes; coarse PM is 10 microns or smaller, fine PM is 2.5 microns or smaller, and Ultrafine Particles (UFP), which CAFEH is studying, are 0.1 microns or smaller. There is a large body of scientific literature about the health effects on fine PM that include strong evidence of associations with cardiovascular disease, lung cancer, asthma, and lung function. Coarse and fine PM are currently regulated by the Environmental Protection Agency (EPA); UFP is not regulated.

The Global Burden of Disease analysis of 2010 included fine PM because of well-established health consequences, suggesting fine PM is responsible for over 3 million deaths annually around the world. Even in the United States, fine PM is thought to lead to 100,000-200,000 deaths each year.

The strong evidence base for health hazards from fine PM suggests we should also be concerned with UFP since they are included in fine PM but show different behavior. For example, the presence of UFP is elevated near major roadways and highways, while fine PM is spread more evenly across large metropolitan areas.

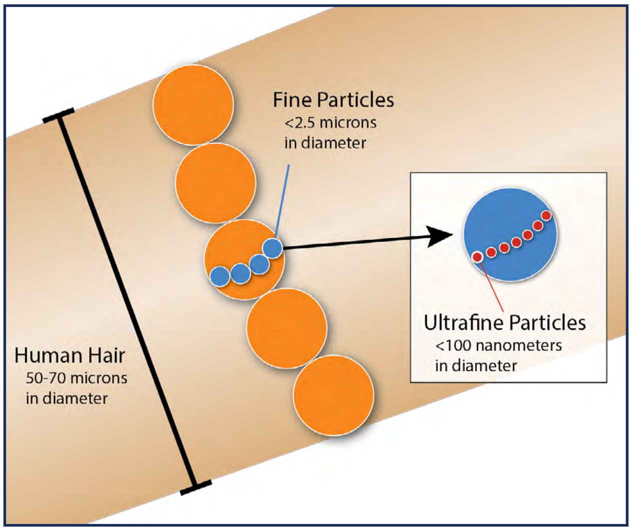



Figure 1: Diagram shows relative scale of ultrafine particles. Ultrafine particles (UFP) are very small-sized pollutants, much smaller than a human hair. *Credit: Linnean Solutions.*

It is well established that people living near highways and major roadways are more likely to experience a range of adverse cardiovascular and respiratory health problems. Since UFP are elevated in the same near-highway areas, UFP are good candidates for being associated with these negative health effects, but there is a need for better scientific evidence.

CAFEH is a community-based participatory research study that was designed to generate evidence about whether there is an association between UFP and molecules in the blood (biomarkers) that indicate risk of developing cardiovascular disease.

CAFEH recruited about 700 participants in Boston and Somerville, MA. In order to include people with different levels of exposure to UFP, some participants lived near Interstate-93 (I-93) and others lived further away from it. Of these participants, about 450 provided blood samples. While the final results are not published as this report goes to print, the bottom line is that CAFEH has shown that UFP are associated with these biomarkers which, in turn, are associated with cardiovascular disease risk.

Estimated hourly values of UFP outdoors at the residential locations of all of the study participants made it possible for researchers to adjust expected participant exposure to pollution for where the participants spent their time - inside their home, at work, driving on a highway, etc. It was found that these adjustments changed the predicted exposure for many participants and improved association with the biomarkers.

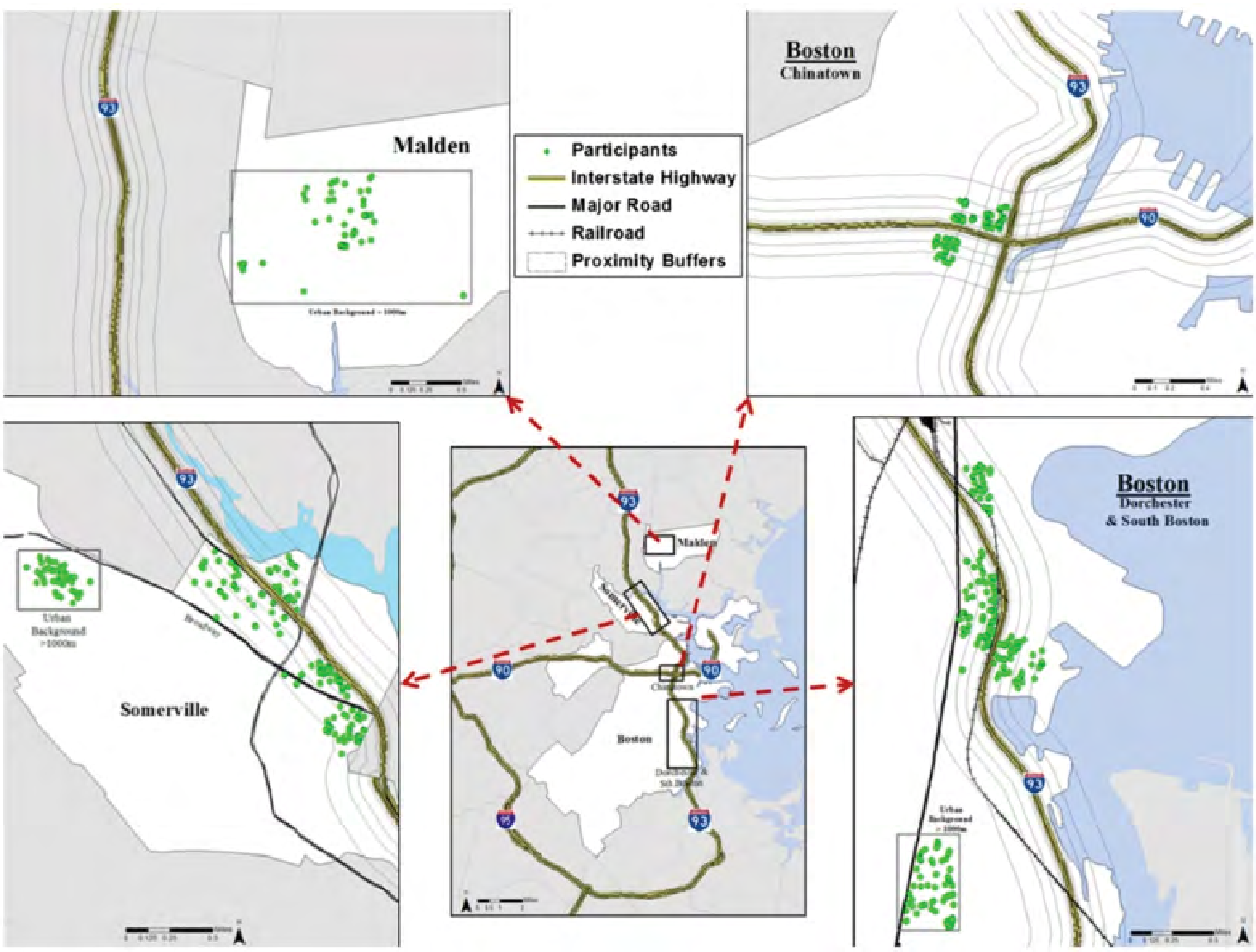



Figure 2: Participants in the CAFEH study were recruited in near highway and urban background neighborhoods. The green dots represent the location of each participant in the study.

*Credit: Lane KJ, Scammell MK, Levy JI, Fuller CH, Parambi R, Zamore W, Mwambri M, Brugge D. Positional error and time-activity patterns in near-highway proximity studies: An exposure misclassification analysis. Environmental Health 2013, 12:75.*

The air monitoring data was used to create statistical models that predict UFP levels at all locations for every hour of the year in our study areas. Air pollution levels were determined by driving a retrofitted RV around the study areas to monitor air pollution levels, including UFP. Preliminary maps of particle number concentration were developed based on four statistical models of measurements from mobile monitoring. All of the models incorporated wind speed and direction, highway traffic, temperature and day of week.

The distribution and levels of air pollution were different in each of the CAFEH neighborhoods, even though the neighborhoods around I-93 are only a few miles apart. In general, pollutant levels were elevated near highways and had measurable decreases within approximately 1,300 ft (400 m) of the highway. Higher levels of UFP were recorded on days with heavy traffic. Lower levels of UFP were recorded on hot or windy days. Higher UFP were predicted on and near major roads, and in near-highway areas, especially in Somerville and Chinatown.

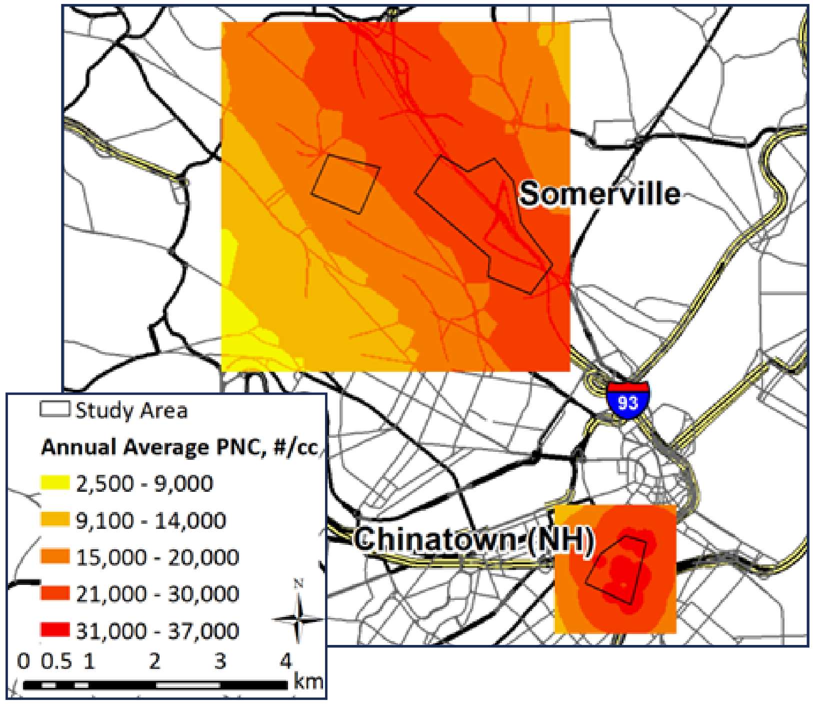



Figure 3: Preliminary estimates of annual average UFP measured as the Particle Number Concentration (PNC) for Somerville and Chinatown.

*Credit: Patton, A. P. (2014). Developing time-resolved models for predicting atmospheric concentrations of ultrafine particles in near-highway urban neighborhoods. (Order No. 3627767, Tufts University). ProQuest Dissertations and Theses, 210.*

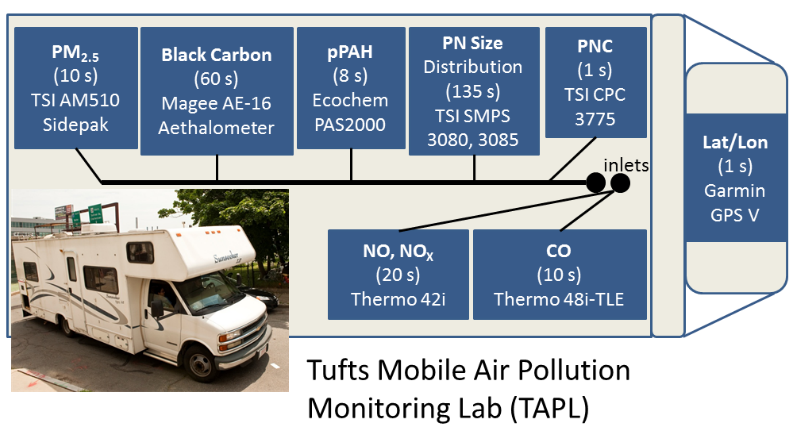



Figure 4: This RV has monitoring equipment to measure all of the pollutants listed in the diagram. The data is geolocated in order to create the map of pollutants above.

*Credit: Allison Patton.*

# Fate and Transport of Traffic-Related Air Pollution Near Highways: Implications for Interventions. A primer in 10 easy to remember lessons.

*by John Durant - Associate Professor in the Department of Civil and Environmental Engineering, Tufts University School of Engineering*

It is likely that people living near highways are at risk of adverse health effects caused by exposure to elevated levels of traffic-related air pollution. We know that these exposures can be quantified and that the effects of interventions can be measured. An important challenge is to integrate our knowledge of pollutant chemistry and atmospheric physics to develop tactics to effectively reduce exposures. Developing a good understanding of the behavior of traffic-related air pollution (TRAP) will lead to better tactics for reducing exposures. The material that follows describes 10-easy-to-remember lessons to keep in mind when designing tactics.

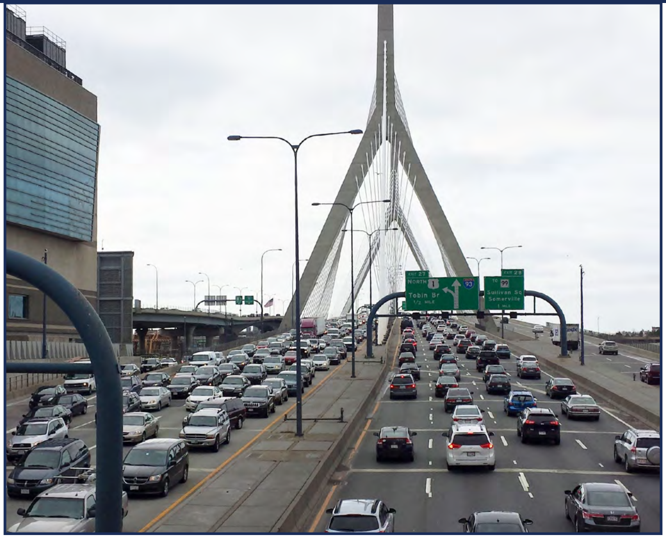


*Photo Credit: John Gravelin*

## Summary of lessons and implications for design tactics to reduce exposures to Traffic-Related Air Pollutants (TRAP):

1) Vehicles on highways emit high levels of gases and particles
   Consider both gases and particles
2) TRAPs behave in different ways
   Develop interventions for specific pollutants of concern
3) Highway traffic patterns are predictable
   Consider the 'worst case' for estimating pollution exposure
4) Wind direction affects exposure
   Locate interventions relative to predominant wind direction
5) Wind speed affects exposure
   Size interventions appropriately
6) Distance from highways affects exposure
   Site interventions appropriately
7) Time of day affects exposure
   Consider the 'worst case' in terms of diurnal effects
8) Time of year affects exposure
   Consider the 'worst case' in terms of annual effects
9) TRAPs can penetrate inside buildings
   Consider airflow patterns for near-highway buildings
10) Exposure to TRAP can be estimated
   Be quantitative in your thinking!

## Lesson 1: Vehicles on highways emit high levels of gases and particles

Gaseous pollutants include carbon monoxide, carbon dioxide, oxides of nitrogen, oxides of sulfur, and volatile and semi-volatile organic compounds. Particulate pollutants include black carbon or soot (a common characteristic of diesel truck emissions) and non-volatile compounds such as polycyclic aromatic hydrocarbons (PAH).

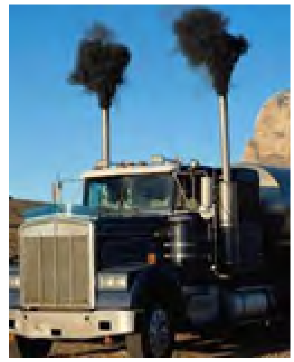


Figure 5:
Gasoline and diesel vehicles produce different mixtures of pollutants.
*Photo Credits: John Gravelin, Environmental Protection Agency.*

## Lesson 2: TRAPs behave in different ways

Some of the gases present in vehicle exhaust are very reactive, such as nitric oxide and volatile organic compounds, and have relatively short residence times in the atmosphere. Others, like carbon dioxide, are stable and have very long residence times. Similarly, particles come in many shapes and sizes and can be very reactive or stable depending on their composition. For example, inorganic particles are very stable and can travel 1,000's of miles without being chemically altered, while polycyclic aromatic hydrocarbons (shown below) are readily photo-oxidized within minutes of their formation and can form new chemicals that differ in toxicity relative to their parent compounds.

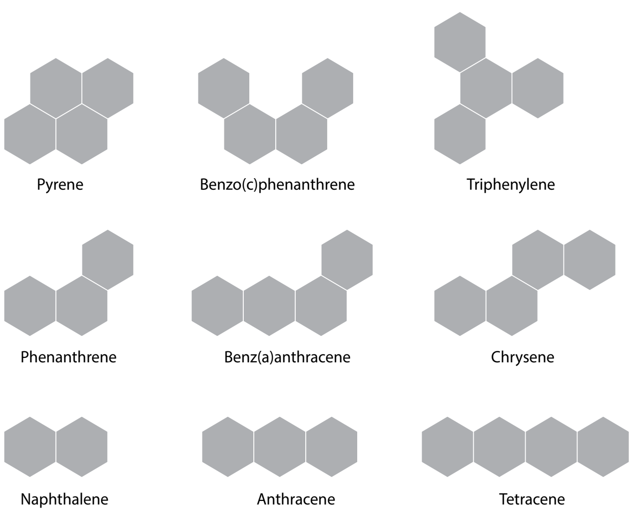



Figure 6: Some of the polycyclic aromatic hydrocarbons present in gasoline and diesel exhaust. *Credit: Linnean Solutions.*

## Lesson 3: Highway traffic patterns are predictable

Hourly highway driving patterns are generally very predictable, making it easy to develop a good understanding of TRAP emissions rates for use in air pollution models. The figure below shows hourly traffic volume for weekdays, Saturdays and Sundays on I-93 in Somerville (MA) for 2009-2010.

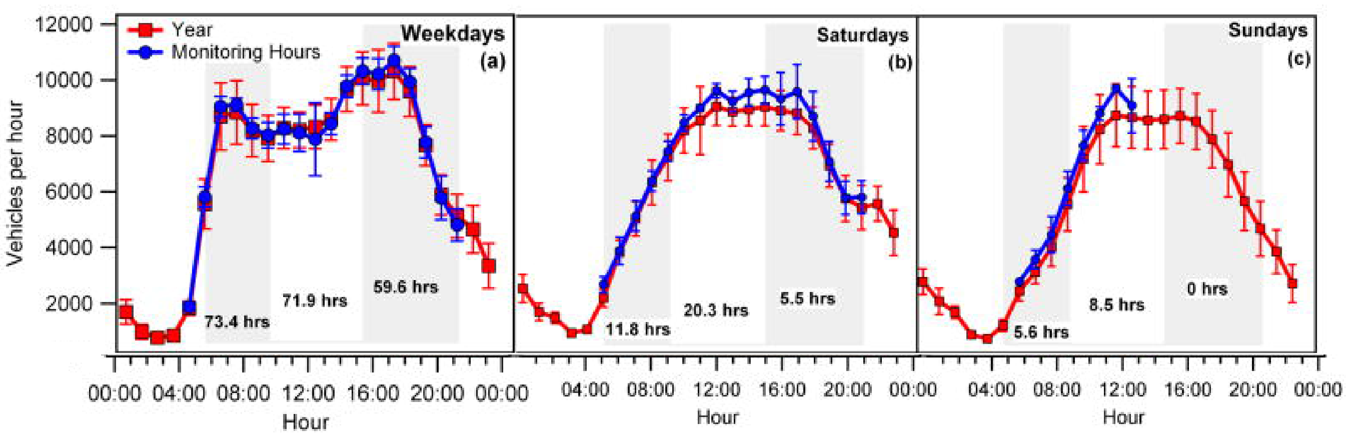


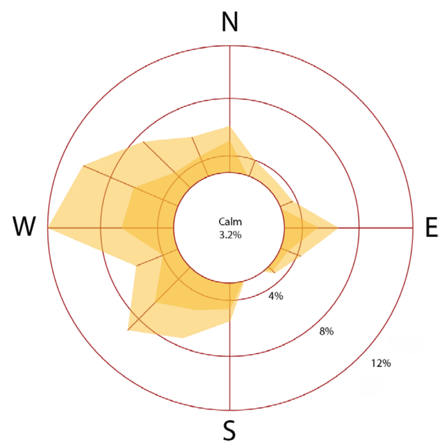

Figure 7: Traffic density shown by time of day during a) weekdays, b) Saturdays and c) Sundays. Time-series of traffic volume on I-93 (total of all lanes) in vehicle counts per hour. Red lines show annual trends and blue line represents hourly monitoring.

*Credit: Padró-Martínez LT, Allison P. Patton AP, Trull JB, Zamore W, Brugge D, Durant JL. Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year. Atmospheric Environment. 2012; 61:253-264.*

## Lesson 4: Wind direction affects exposure

Having a good understanding of the predominant wind directions near a highway is essential for developing accurate predictions for where pollution is likely to be transported. The figure below shows an annual wind rose of the prevailing winds. Since vehicles on a highway move in a relatively continuous stream along a defined path, the highway can be modeled as a line source for TRAP.

Figure 8: This wind rose shows the annual wind direction for the greater Boston area. Prevailing winds in Boston typically come from the northwest in winter and the southwest in the summer. Storms will occasionally come off the Atlantic Ocean from the east.
*Credit: Linnean Solutions.*



## Lesson 5: Wind speed affects exposure

Having a good understanding of the wind speed near a highway is essential for developing predictions about the extent of mixing as TRAP moves away from the highway. The two pictures below show the impact of wind velocity on how well the plumes are mixed downwind of the stacks. In the first photo, there is very little wind, and thus mixing (dilution) is poor and pollutant levels are high near the stack. In contrast, in the picture on the right the wind speed is much higher and therefore mixing is better and pollutant concentrations are lower near the stack.

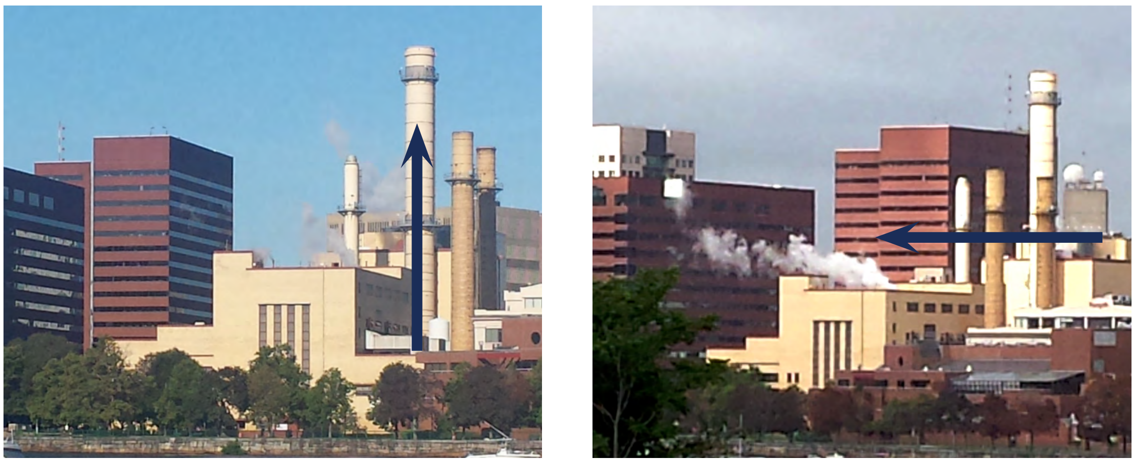
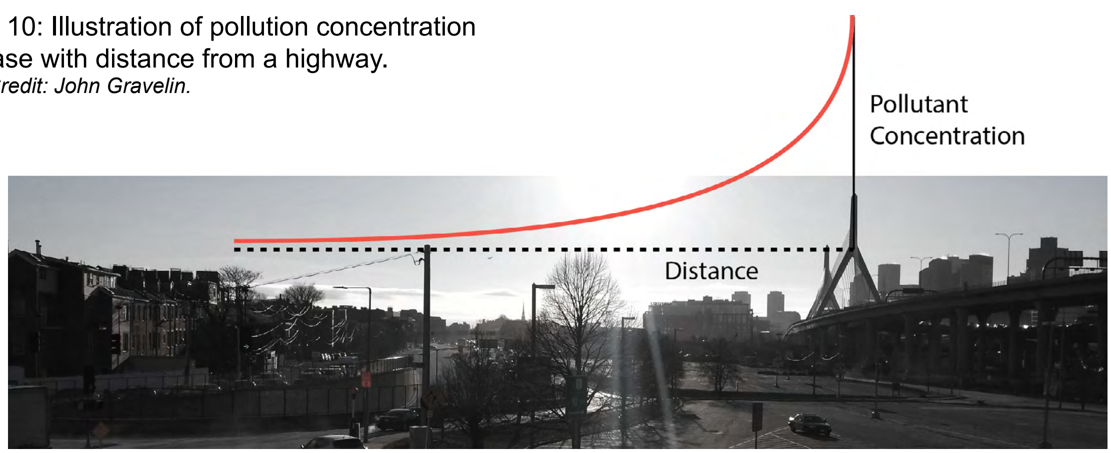


Figure 9: These images illustrate the effect of wind speed on pollution mixing. Left: Low wind speed results in little mixing near the stack. Right: High wind speed causes greater mixing near the stack. *Photo Credits: John Gravelin.*

## Lesson 6: Distance from the highway affects exposure

Many studies have shown that TRAP concentrations are highest near the highway and decrease to background within about 200-300 meters (650-1,000 ft) of the highway.

Figure 10: Illustration of pollution concentration decrease with distance from a highway.
*Photo Credit: John Gravelin.*



## Lesson 7: Time of day affects exposure

The figure below shows that pollutant concentrations can change rapidly over the course of a typical morning during a rush-hour period (Wednesday, January 16, 2008). The earliest measurements were collected before at 6:30 AM (before sunrise); the latest at 10:40 AM. The rapid decrease in concentrations near the highway was due to the combined effects of increasing wind speed and increasing atmospheric mixing height after sunrise.

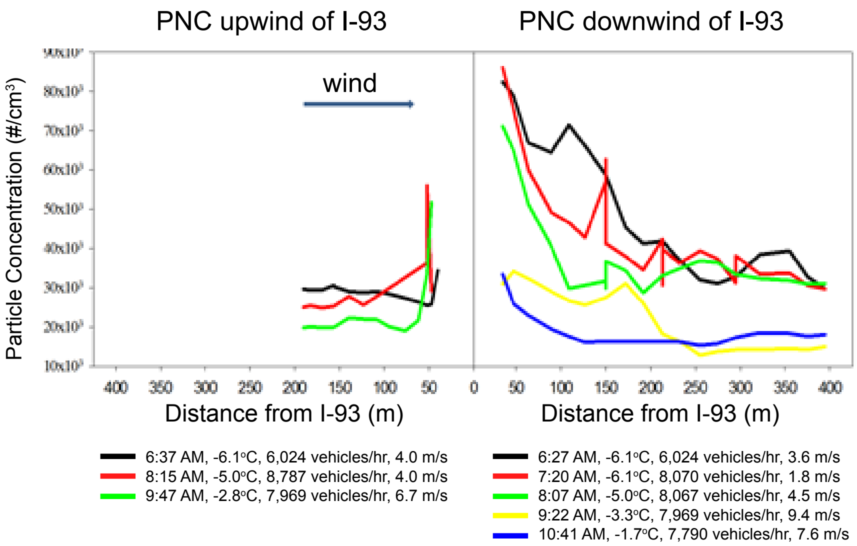



Figure 11: Shows PNC both upwind and downwind during different time intervals throughout the morning. The highest levels of PNC were recorded in the morning, while the lowest were recorded during the afternoon.

*Credit: Durant JL, Ash CA, Wood EC, Herndon SC, Jayne JT, Knighton WB, Canagaratna MR, Trull JB, Brugge D, Zamore W, and Kolb CE. Short-term variation in near-highway air pollutant gradients on a winter morning. Atmospheric. Chemistry and Physics. 2010, 10, 8341–8352.*

## Lesson 8: Time of year affects exposure

The figure below shows the effect of time of year on particle number concentrations (PNC) near I-93 in Somerville. The concentrations were higher during the colder seasons (winter and spring) compared to summer and fall.

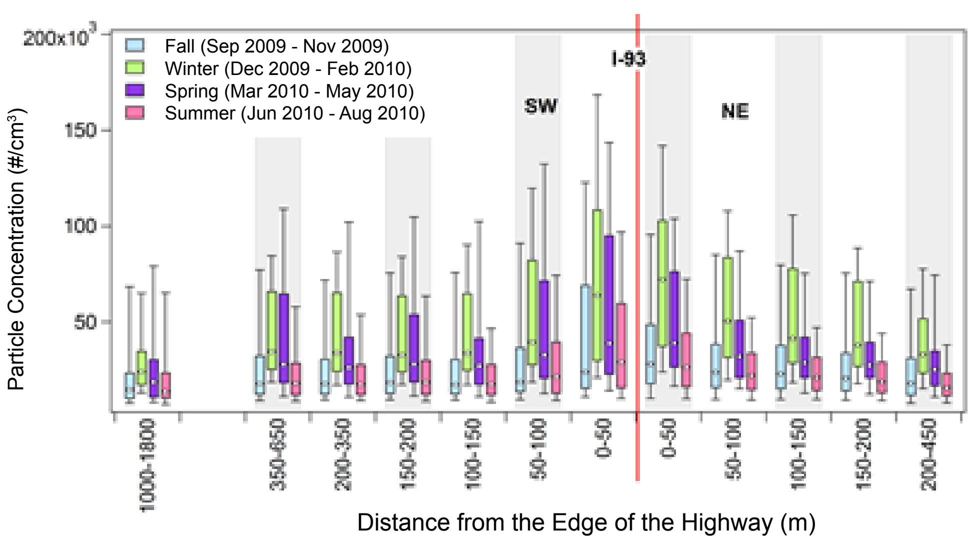



Figure 12: This graph displays seasonal monitoring results, showing increases in PNC during winter and decreases in PNC during the summer, relative to the distance from the highway.

*Credit: Padró-Martínez LT, Allison P. Patton AP, Trull JB, Zamore W, Brugge D, Durant JL. Mobile monitoring of particle number concentration and other traffic-related air pollutants in a near-highway neighborhood over the course of a year. Atmospheric Environment. 2012; 61:253-264.*

## Lesson 9: TRAP can penetrate inside buildings

The figure below shows the outdoor (thin line) and indoor (thick line) particle concentrations in a home near I-93 in Somerville over the course of a day. The close tracking between the two time-series plots indicates that particles of outdoor origin are readily penetrating into this home. TRAP penetration can be exacerbated by windows being open (as was the case in this home), but penetration can be minimized by filtration systems such as HEPA filtration or air conditioning.

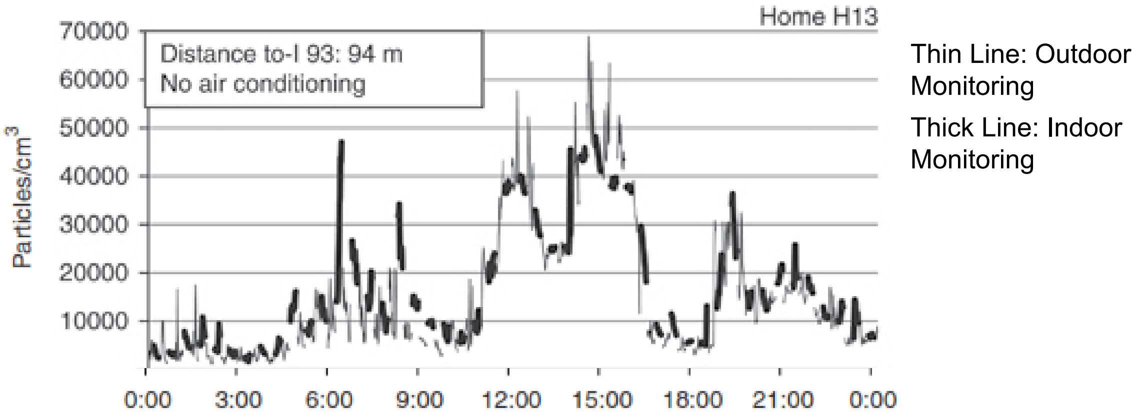



Figure 13: Pollution concentrations indoors can be as high as they are outdoors.

*Credit: Fuller CH, Brugge D, Williams PL, Mittleman MA, Lane K, Durant JL, Spengler JD. Indoor and outdoor measurements of particle number concentration in near-highway homes. Journal of Exposure Science and Environmental Epidemiology. 2013:1-7.*

## Lesson 10: Exposure to TRAP can be estimated

If we have a good understanding of things like wind speed and direction, air temperature, mixing height, and pollutant emissions rates, models based on the advection-dispersion-equation can be used to estimate pollutant concentrations over space and time. Even zones of poor mixing can be modeled if the scale and geometry of the zone can be characterized. Models are critical for developing an understanding of pollutant fate and transport and are widely used in air pollution science and engineering and for exposure assessment for studies of health effects.

$$\frac{dC}{dt} = -v \cdot \frac{dC}{dx} + \frac{d}{dx}\left[D \cdot \frac{dC}{dx}\right]$$

Figure 14: Illustrates the advection-dispersion-reaction equation.

# II. Tactics for Reducing Negative Health Effects

*by Allison Patton - Civil and Environmental Engineering, PhD at Tufts University;*
*Current Postdoctoral Trainee, EOHSI, Rutgers University*

These tactics were developed for designers, policymakers, urban planners and concerned citizens to reduce the exposure for communities near highways. These tactics derive from empirical research and are intended for consideration in and around building and community design.

## List of Tactics:

1) Filtration
2) Air Inlet Locations
3) Sound Proofing
4) Land Use Buffers
5) Vegetative or Built Wall Barriers
6) Trees and Plantings
7) Decking Over Highways
8) Urban Design
9) Garden Locations & Healthy Vegetables
10) Park Locations
11) Active Travel Locations

*Additional information on each Tactic can be found in the Appendix.*

## 1) Filtration

Filtration is an effective method for improving indoor air quality with reductions up to 50-90% (excluding intoor sources). Filters for residences and schools near busy roadways should be Minimum Efficiency Reporting Value (MERV) 14 or above, mainly because the ultrafine particle removal efficiencies of filters with lower MERV ratings are not reported. Although existing standards are variable, a higher MERV rating is preferable, as long as the unit meets noise requirements. Filters with electrostatic precipitation should be carefully evaluated prior to use to avoid removing particulate pollution at the expense of increased ozone levels. If filters are to be used for air pollution reduction, steps should be taken to ensure maintenance and use.

*Additional information on this Tactic can be found in the Appendix.*


Figure 15: HEPA window mounted air filtration unit for houses or apartments.
*Photo Credit: Luz T. Padro-Martinez.*

## 2) Air Inlet Locations

To achieve improved indoor air quality, it is advisable to locate building air intake vents both vertically and horizontally as far from traffic as possible, preferably on the side or back of the building, away from the traffic source. The California Air Resources Board recommends separating air inlets from highways by 500 feet. Indoor air pollution reductions of ~50% (very large reductions) can be achieved with relatively little expense during building design and construction. Air inlet location has effect at the building scale and can have a large impact on indoor air quality.

*Additional information on this Tactic can be found in the Appendix.*

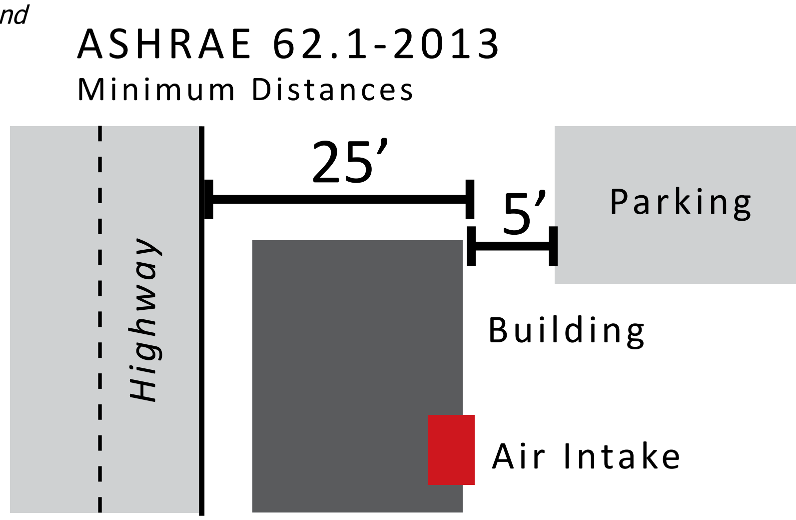



Figure 16: Diagram illustrates the ASHRAE minimum standards for placement of ventilation and air intake vents relative to pollution sources. The ASHRAE standards are far less stringent than the California Air Resources Board recommendation of a 500 foot buffer between air inlets and pollution sources.
*Credit: Linnean Solutions.*

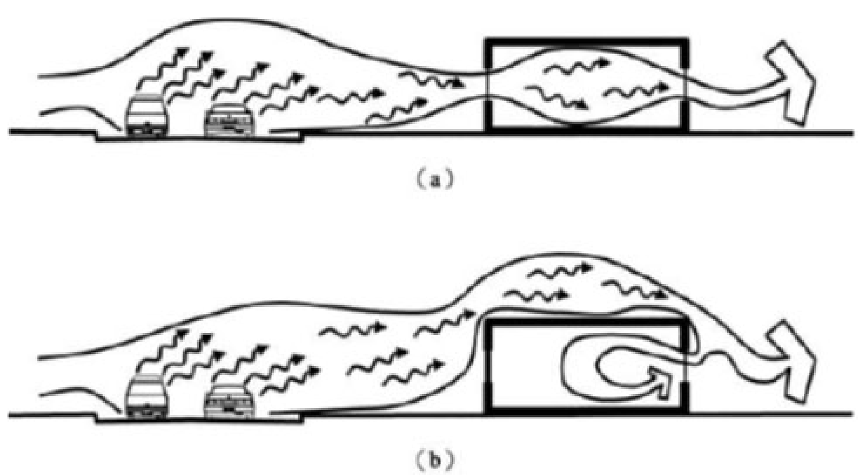



Figure 17: Sketch illustrates two scenarios for placing the building air intake. The top sketch shows the air intake close to the highway - allowing UFP to infiltrate through the building. The bottom sketch shows the air intake placed away from the highway, causing UFP to flow over the building and decrease building occupant exposure.

*Credit: Tsang-Jung Chang, Mei-Yu Huang, Yu-Ting Wu & Chun-Min Liao (2003) Quantitative Prediction of Traffic Pollutant Transmission into Buildings, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 38:6, 1025-1040.*

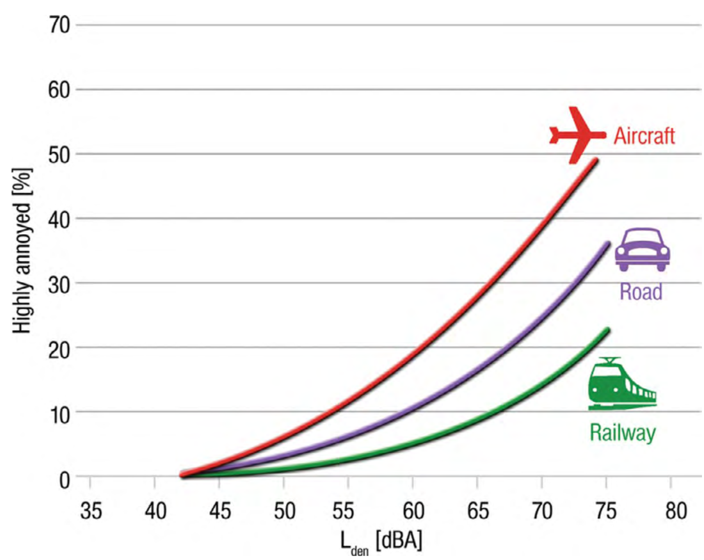
## 3) Sound Proofing

Decreasing noise exposure can increase quality of life (residences) and academic achievement (schools). Standards set by the World Health Organization (30 dB in residences and 35 dB in schools) should be followed as much as possible. Methods exist to decreased perceived loudness by a factor of 3-5 times, and should be used. These methods are outlined in guidance from the Federal Highway Administration, the Green Building Council, and others.

*Additional information on this Tactic can be found in the Appendix.*


Figure 18: Diagram illustrates sound waves travelling through an aggravated resident's home.
*Credit: Linnean Solutions.*

Figure 19: Graph illustrates noise disturbances as 'highly annoyed' percentages in relation to type of transportation.




*Credit: Munzel, T., et al., Cardiovascular effects of environmental noise exposure. Eur Heart J, 2014. 35(13): p. 829-36.*

## 4) Land Use Buffers

Siting sensitive land uses like residences and schools more than 200 m (~700 ft) from highways and other sources of air pollution can reduce exposure. This can be done by leaving open space or by trading land with less sensitive uses. This tactic must be done on a large-scale because it involves zoning and similar decisions, but it can result in exposure reductions of 40% or more (very large), and would affect any person using the new construction. This tactic is mainly a policy decision and may not be possible in cities with limited land available and needs for new residences, schools, or other services. It also does not address existing near highway structures.

*Additional information on this Tactic can be found in the Appendix.*


Figure 20: Image illustrates residences and schools well within the recommended 700’ buffer around the highway.
*Credit: Linnean Solutions.*


Figure 21: This diagrammatic image shows urban residential areas near a major highway, some of which are within 700’. These existing buildings should consider building-specific tactics to reduce exposure.
*Credit: Linnean Solutions.*

## 5) Vegetative or Built Wall Barriers

Noise barriers along roads have been shown to reduce air pollution levels (as well as noise levels) behind the barriers by 10% to 50% (moderate to large reductions) when the wind direction is across the road. Decreases have typically been less for other wind directions relative to the road and barrier. Noise barriers should be placed so that they are usually downwind of the major road, and should be avoided in neighborhoods with high levels of local traffic, where pollution from traffic on local roads might collect on the non-highway side of a barrier. Evidence of the effectiveness of vegetative noise barriers is less consistent than that for solid barriers, but suggests that reductions similar to those for solid barriers may be achieved from dense vegetation. A noise barrier is a medium-scale project because it is probably not effective at the single-building level (edge effects have not been studied) and probably requires cooperation of an entire municipality.

*Additional information on this Tactic can be found in the Appendix.*

Figure 22: A wall barrier separates a major highway from a residential neighborhood.
*Photo Credit: John Gravelin.*

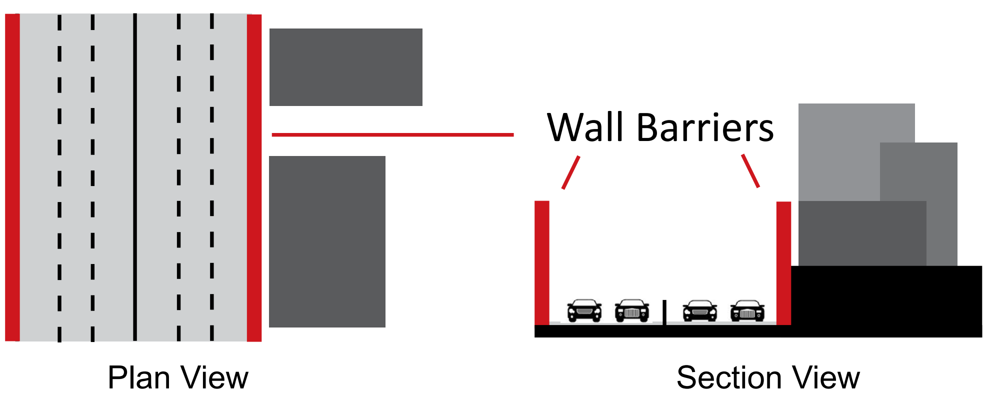
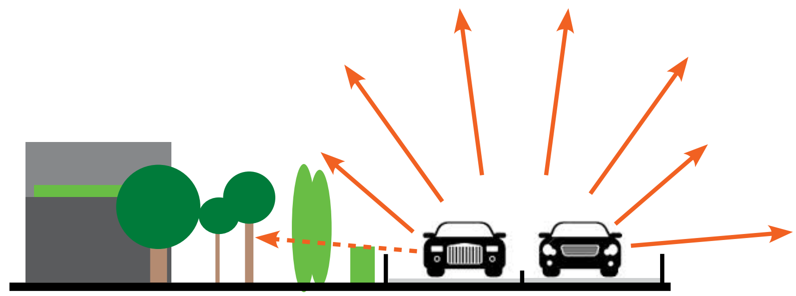



Figure 23: Diagram illustrates large wall barrier installed along the highways. Barriers are a practical tactic for urban environments, and many are already installed around highways today. *Credit: Linnean Solutions.*

## 6) Trees, Plantings and Other Barriers

Local reductions in air pollution might be achieved on green roofs or similar green infrastructure but with limited effective distance, so unlikely to affect human exposure. While vegetation and other barriers along major urban roads may reduce transport of pollution to nearby areas, these barriers can also increase local pollution levels by reducing ventilation. To maximize their effectiveness, vegetation and other barriers should be arranged so that they do not impede ventilation, particularly in street canyons. Vegetation may have a benefit at multiple scales if properly planned and implemented, but research is needed. Several studies suggest that air pollution may be reduced by ~60% to 90% (a large amount) within parks relative to nearby streets, indicating that the presence of a park with lush vegetation can have a positive effect on pollution exposure. Alternatively, traffic-related air pollutant exposures of people using parks can be decreased by ~70% by siting parks more than 700 ft from highways. There is also some limited evidence that parks bordering highways can reduce air pollution for nearby areas.



Section View

Figure 24: Vegetation and trees are planted between the highway and the building to reduce exposure.
*Credit: Linnean Solutions.*

*Additional information on this Tactic can be found in the Appendix.*

A playground is seen located right next to the highway.

Figure 25: Trees, wall barriers and other vegetation may reduce exposure from this playground directly next to this highway - a particularly vulnerable place for children.
*Photo Credit: John Gravelin.*

## 7) Decking Over Highways

Limited evidence suggests potentially moderate reductions (<40%) in air pollution due to decking over highways. This tactic is unlikely to be effective in areas with high volumes of local traffic, and decking may increase commuter exposure. The scale of this tactic would require municipal or state level action. Co-benefits include the linking of urban areas and creation of productive land, which might make it worthwhile to pursue this tactic (even though the air pollution effects have not been well described).

*Additional information on this Tactic can be found in the Appendix.*

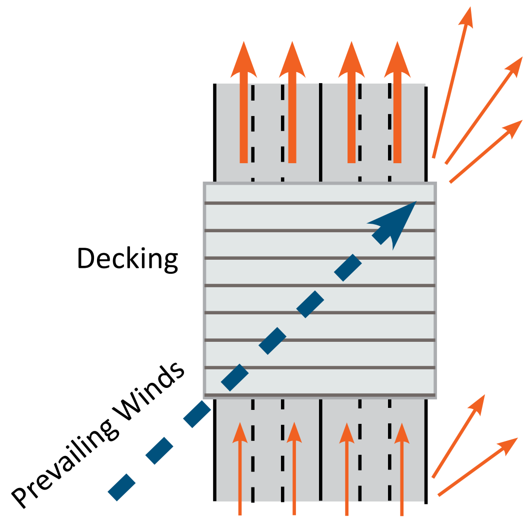



Figure 26: Diagram illustrates decking over a highway providing a relief in exposure. *Credit: Linnean Solutions.*

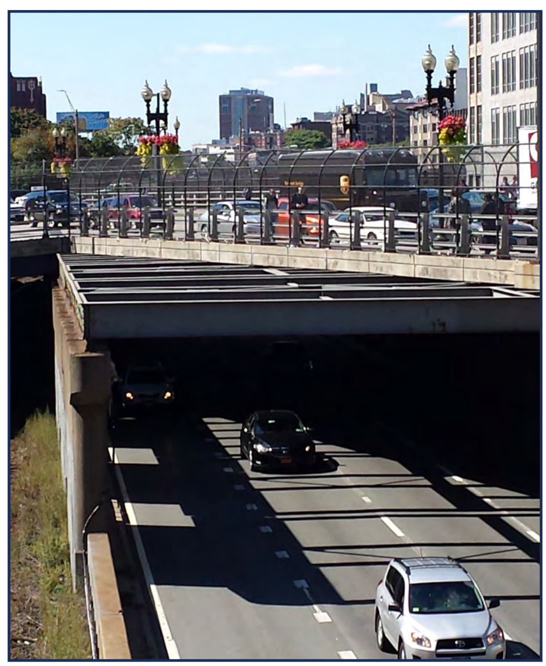


Figure 27: An example of a partially constructed decking over a highway in Boston's Back Bay.
*Photo Credit: John Gravelin.*

## 8) Urban Design

Urban air pollution can be reduced by 50% or more (large decreases) through the use of urban design practices like the careful placement of buildings and open space. This tactic would be achieved most readily in areas where the urban design was addressed as a whole (large-scale). Buildings should be oriented to readily allow dilution of polluted air, and a variety of techniques should be applied to reduce emissions in less well-ventilated areas.

*Additional information on this Tactic can be found in the Appendix.*

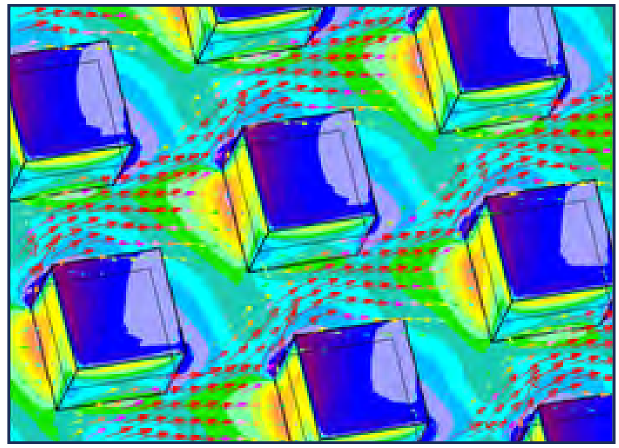


Figure 28: Image shows wind carrying pollutants (red arrows) through an urban development. Yellow areas indicate high exposure; blue and purple indicate low exposure.
*Credit: University of Southampton Computational Modeling Group.*

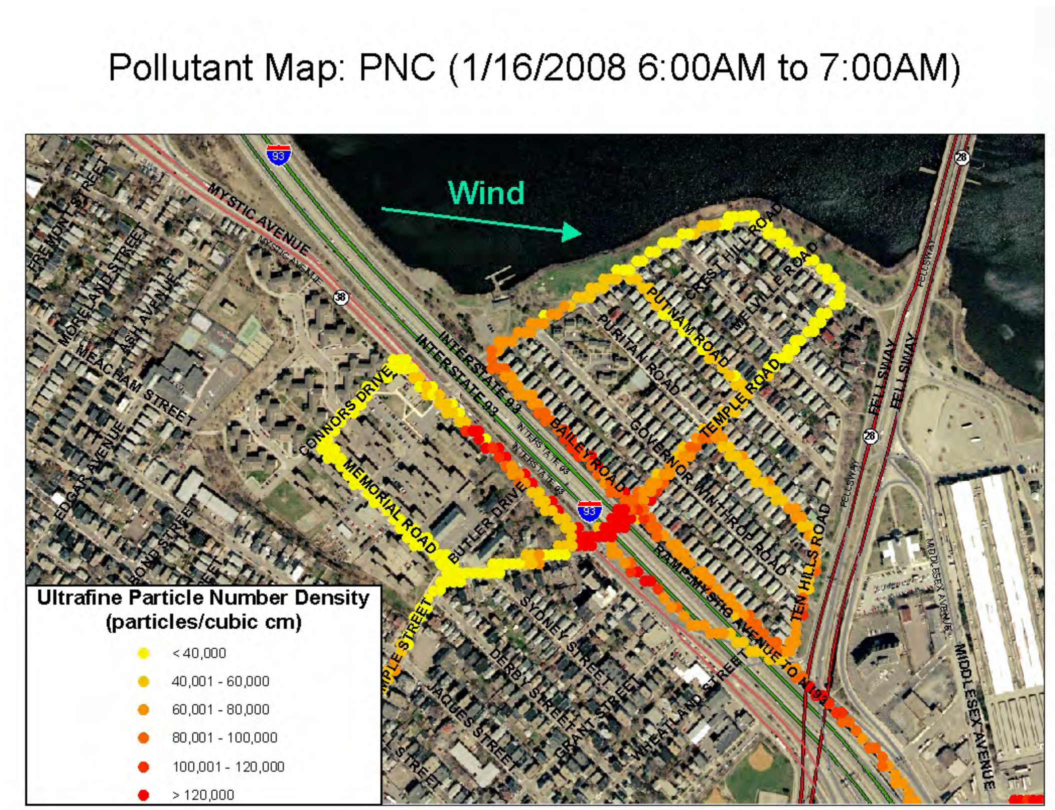



Figure 29: Image shows higher concentrations of ultrafine particles close to the downwind edge of I-93 in Somerville, MA. The wind aggregates pollutants to one side of I-93, leaving some of these residences exposed to high levels of pollutants. *Credit: John Durant and Allison Patton.*

## 9) Garden Location and Healthy Vegetables

To reduce exposure to traffic-related pollution, both through air and diet, food-producing gardens should not be located near highway traffic. For gardens that must be near highway traffic it may be preferable to grow root vegetables over aerial vegetables in potentially exposed areas because these vegetables tend to accumulate lower levels of air pollution in the parts of the plants that are consumed. Reductions in exposure due to this tactic are likely small, but gardening and local food can have other benefits that might make this tactic worthwhile. This tactic is very scalable and can be done on scales of local vegetable patches to large-scale urban gardening.

*Additional information on this Tactic can be found in the Appendix.*

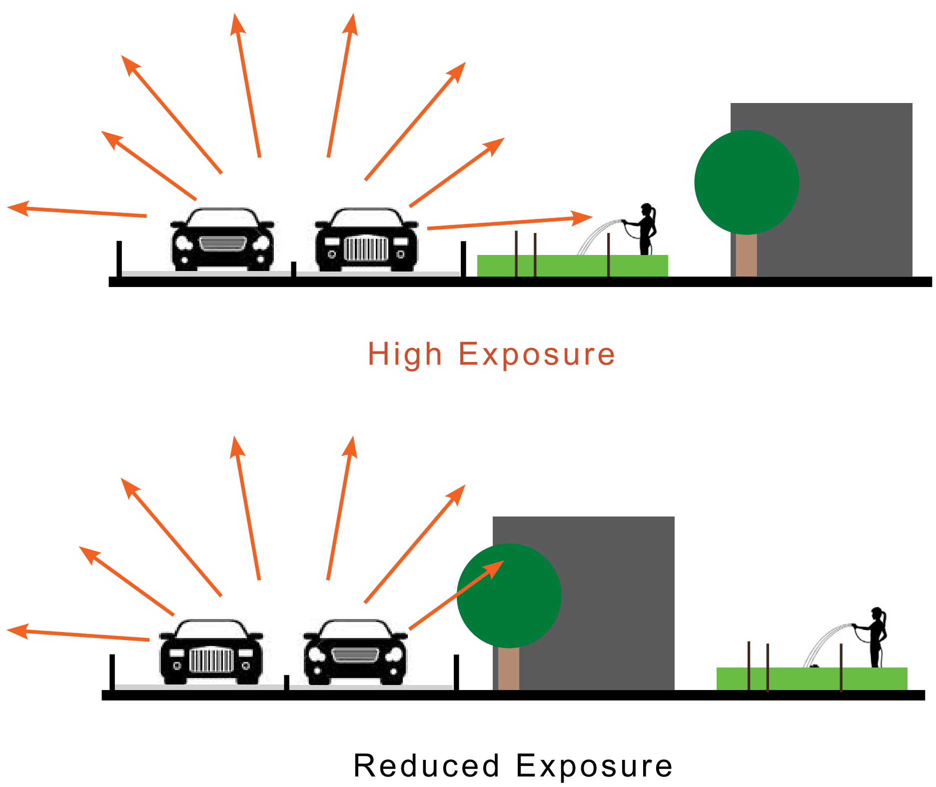



Figure 30: Diagram illustrates placement of gardens on the far side of highway, letting the building take the brunt of the exposure and allowing the garden and the gardener to have cleaner air.
*Credit: Linnean Solutions.*

## 10) Park Locations

Parks provide important environmental, ecological, and psychological benefits. Siting of parks already takes into account several competing needs. Since parks can play several different roles in mitigating exposure to air pollution, air pollution levels should be considered in future siting of parks to avoid encouraging active recreation or gathering of susceptible people (especially children) in highly polluted outdoor areas, while also helping reduce exposure in contiguous residential areas. This is a large-scale tactic, but can also improve the wellbeing of entire communities if correctly implemented.

*Additional information on this Tactic can be found in the Appendix.*

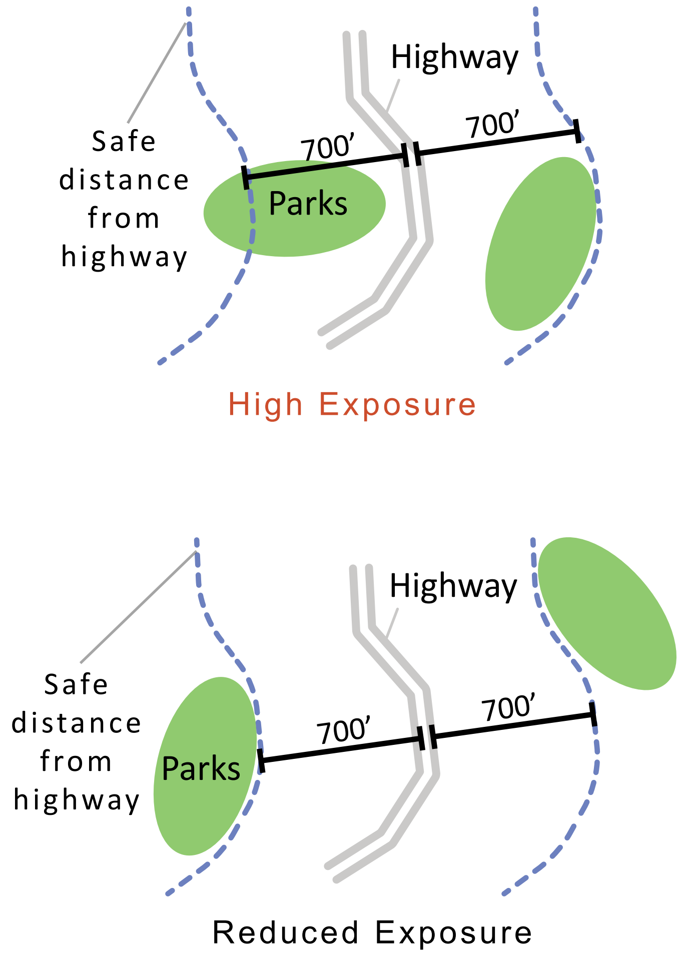



Figure 31: Diagram illustrates location of parks away from highways. The placement of public spaces, especially where children and athletes congregate should consider planning areas at least 700 feet away from main highways. *Credit: Linnean Solutions.*

## 11) Active Travel Locations

Bicyclists and runners breathe in more air (and therefore pollution) because they breathe harder when exercising. By moving bicycling or walking paths to areas with less traffic, exposure to traffic-related air pollution can be reduced from ~15% to ~30% (moderately large reductions). Implementing these tactics would require the cooperation of the municipality and surrounding landowners, and would likely impact the whole community and require working with individuals who use the active travel paths.

*Additional information on this Tactic can be found in the Appendix.*

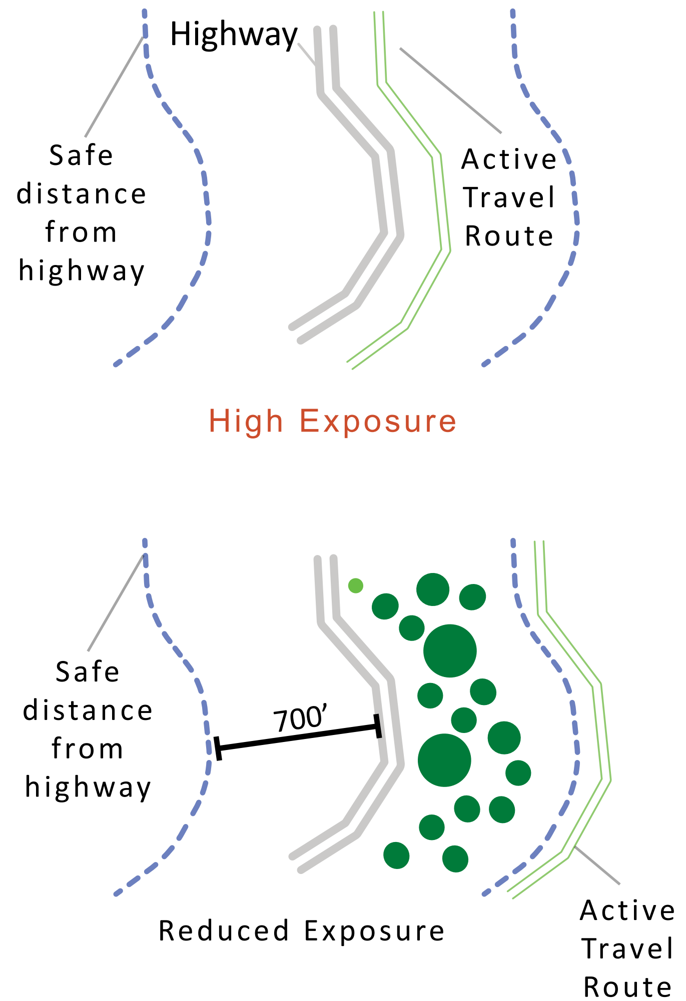



Figure 32: Diagram illustrates locating an active travel path (for bikers, daily walkers, etc) away from the highway. The path is also partially protected by trees.
*Credit: Linnean Solutions.*

# III. A Design Charrette: Two Sites, One Goal

On May 9th and 10th, 2014, the Community Assessment of Freeway Exposure and Health study team hosted a workshop with design and community planning experts, in the form of a 2-day design charrette. The goal of this charrette was to explore possible design solutions that might reduce pollutant exposure for people living, learning, and playing near highways. This report presents the research findings that support the goals of the charrette, as well as presenting the design ideas generated during the charrette.

The charrette engaged a multi-disciplinary group of experts in a 2-day meeting in which the whole group first learned about near highway pollution, health effects, and tactics to mitigate exposure, and then spent two days developing design ideas for projects in real locations in our target communities.

The charrette participants were presented with two sites that included proposed building projects, both near major freeways. One site was located in Somerville, MA near the intersection of I-93 and Route 28. The second site was located in the Chinatown neighborhood of Boston, MA near the intersection of the I-93 and Massachusetts Turnpike corridors. The two sites are quite different from each other – the Chinatown site is in the urban core of Boston. The Somerville site is filled with small-scale residential and commercial buildings near I-93. The CAFEH team chose to use the distinctly different sites to uncover appropriate design solutions for contrasting scenarios.

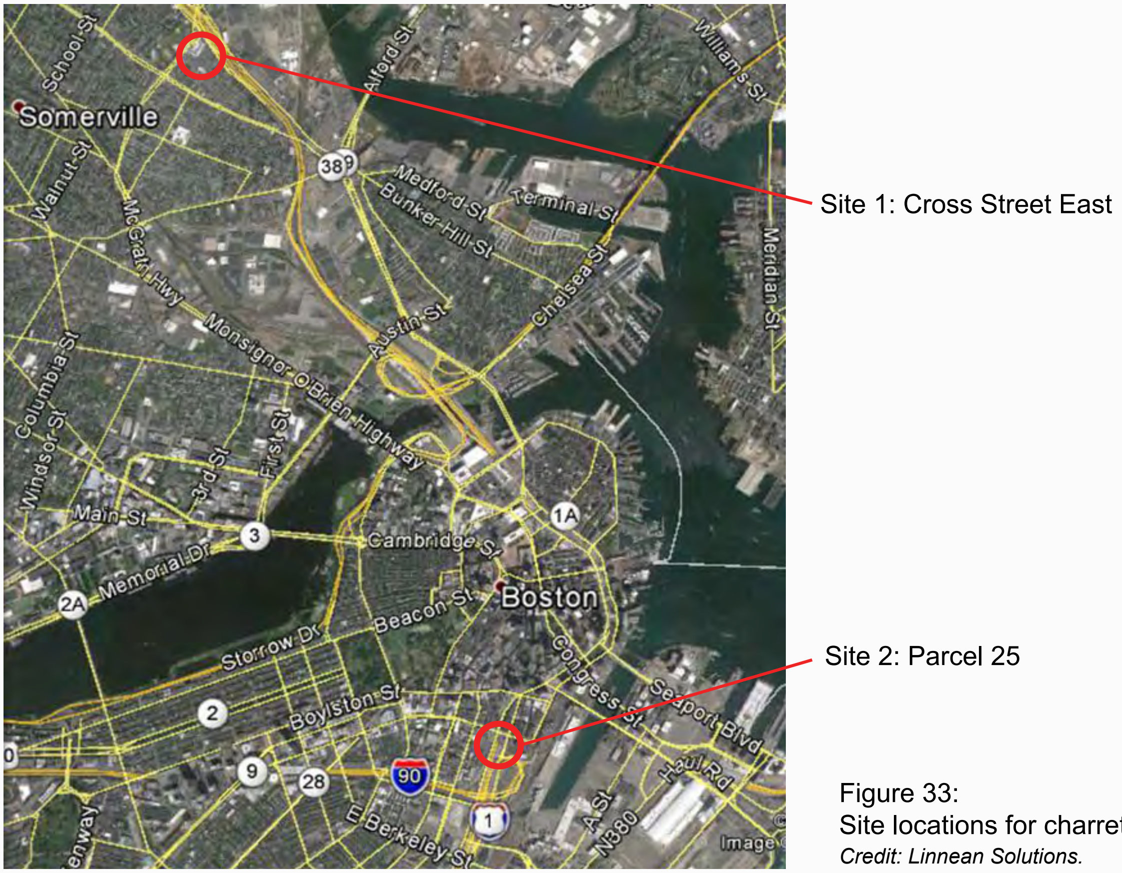



Figure 33:
Site locations for charrette.
*Credit: Linnean Solutions.*

# Site 1: 'Cross Street East' Somerville, MA

The primary site (highlighted in red on the next page) has three general uses - a parking lot, a residential park, and a small commercial building. The site is directly adjacent to a larger parking lot, a grocery store, and Foss Park. The greater area is surrounded primarily by three-story multi-family residential housing units. I-93 (including route 28) runs along the northeast edge of the site.

Along the main roads, there are mixed-use areas with ground floor retail and commercial space typically with second and third floor residential units. Foss Park is a large public outdoor area with tennis courts, baseball and soccer fields, a pool, and other outdoor recreational facilities. Assembly Square is across the highway - an area currently under major construction for large-scale commercial development.

I-93 is the only major corridor that runs north and south through the City of Boston. I-93 consists of two 3-lane routes elevated above ground level about 15 feet. Most of I-93 in Somerville is elevated and supported by steel and concrete infrastructure. This major artery typically experiences heavy traffic during morning and afternoon rush hours, 7-9 a.m. and 5-7 p.m. respectively.

Rte 28 consists of two 3-lane corridors at ground level. This corridor connects Malden, Medford and other parts of the greater Boston area to Somerville and Cambridge. Unlike I-93, street lights control traffic along Rte 28 and traffic stops frequently. A part of Rte 28 goes underground near the site, passing under I-93. There is public transportation that runs along this route.

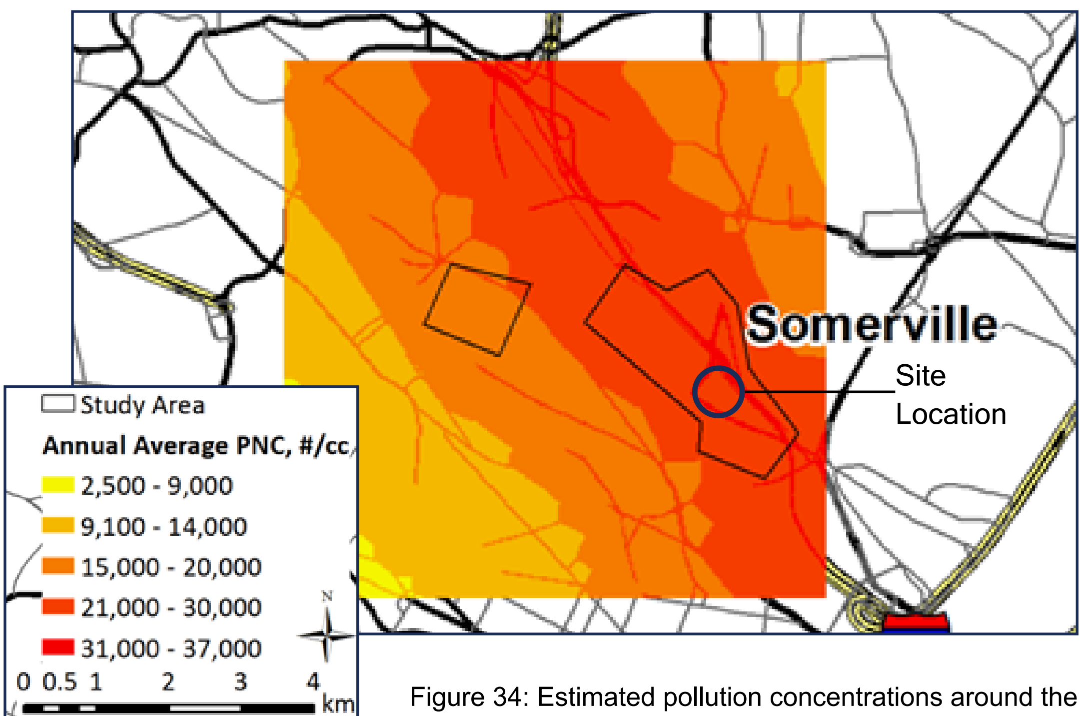
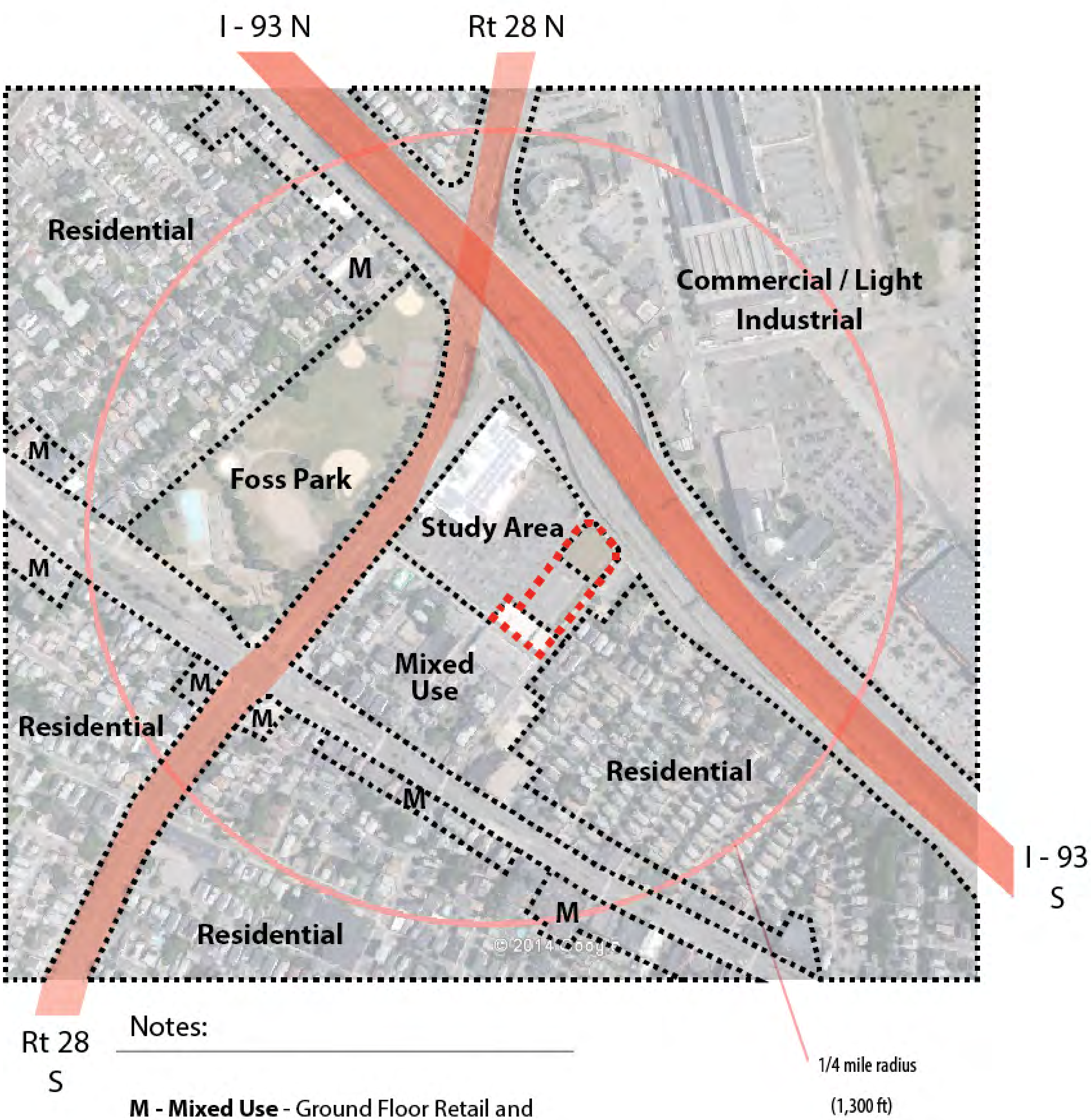



Figure 34: Estimated pollution concentrations around the Somerville site location.

*Credit: Patton, A. P. (2014). Developing time-resolved models for predicting atmospheric concentrations of ultrafine particles in near-highway urban neighborhoods. (Order No. 3627767, Tufts University). ProQuest Dissertations and Theses, 210.*

# Cross Street East, Somerville, MA

## Land Use Designations & Major Highways




Notes:

**M - Mixed Use** - Ground Floor Retail and top story residential

**Above-Ground Highway**

**Ground-level Highway**

**Site Location**

Figure 35: The Cross Street East site in Somerville is primarily 1 to 3 family residential buildings along with some mixed-use buildings. The site is located near both I-93 and Route 28.
*Credit: Linnean Solutions.*

# Site 2: 'Parcel 25'
# Chinatown - Boston, MA

This site is on the very edge of Downtown Boston, surrounded by highly dense, mixed-use development. I-93 runs north-south under the Financial District in Boston, runs parallel to the site and is a few feet below the actual site itself - running underneath it.

I-90 runs east-west through Boston, and is further away from the site than I-93. I-90 runs underneath I-93 and is 15' lower than ground-floor elevation. I-90 east heads toward Logan Airport and runs underneath the Fort Point Channel via tunnels.

The site is directly adjacent to a recreational area with two basketball courts which are adjacent to a steam generation power plant. The neighborhoods around the site consists of high-rise buildings with many different uses, primarily multi-family residential, commercial and street-level retail. The Tufts Medical Center and University complex is near the site.

Residential buildings are primarily old, brick buildings between 3-8 stories tall. These residential areas are in very close proximity to the highways. This site is surrounded by large sources of pollution, from the end of the I-93 tunnel where vehicle exhaust from the tunnel is released, to the rail and bus terminals through which hundreds of diesel buses and trains run each day.

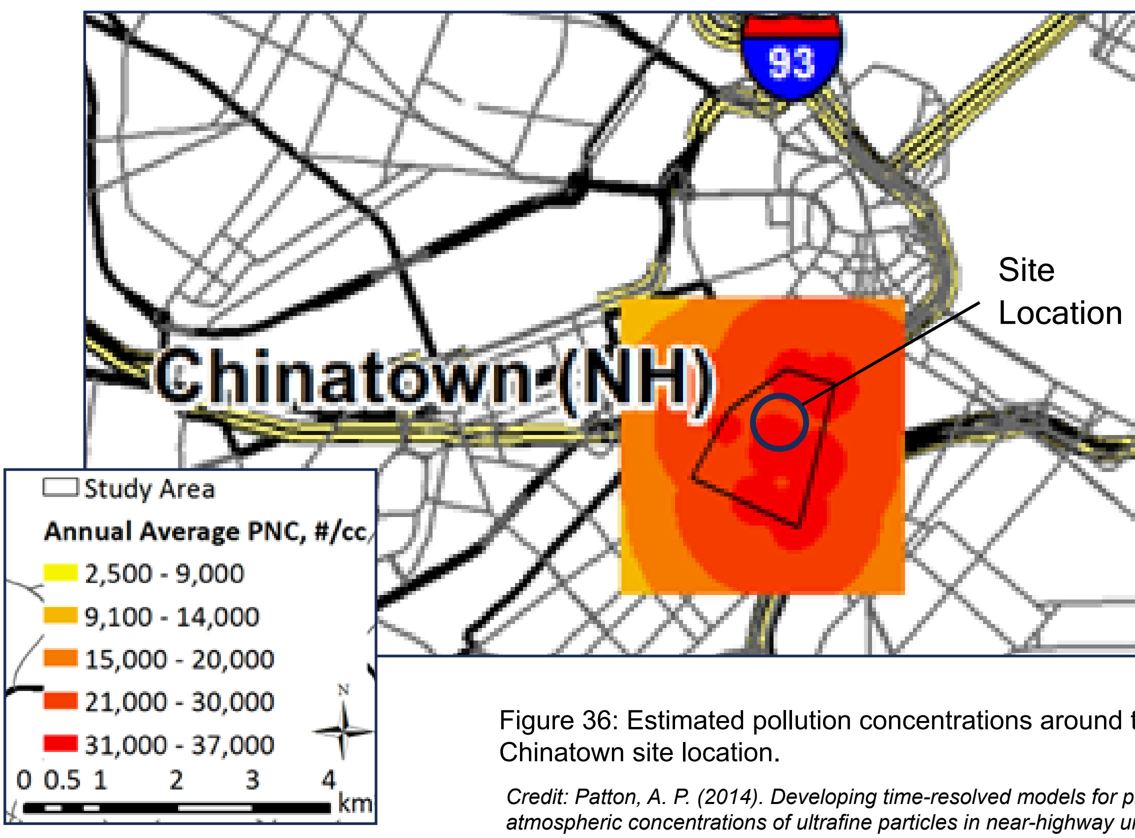
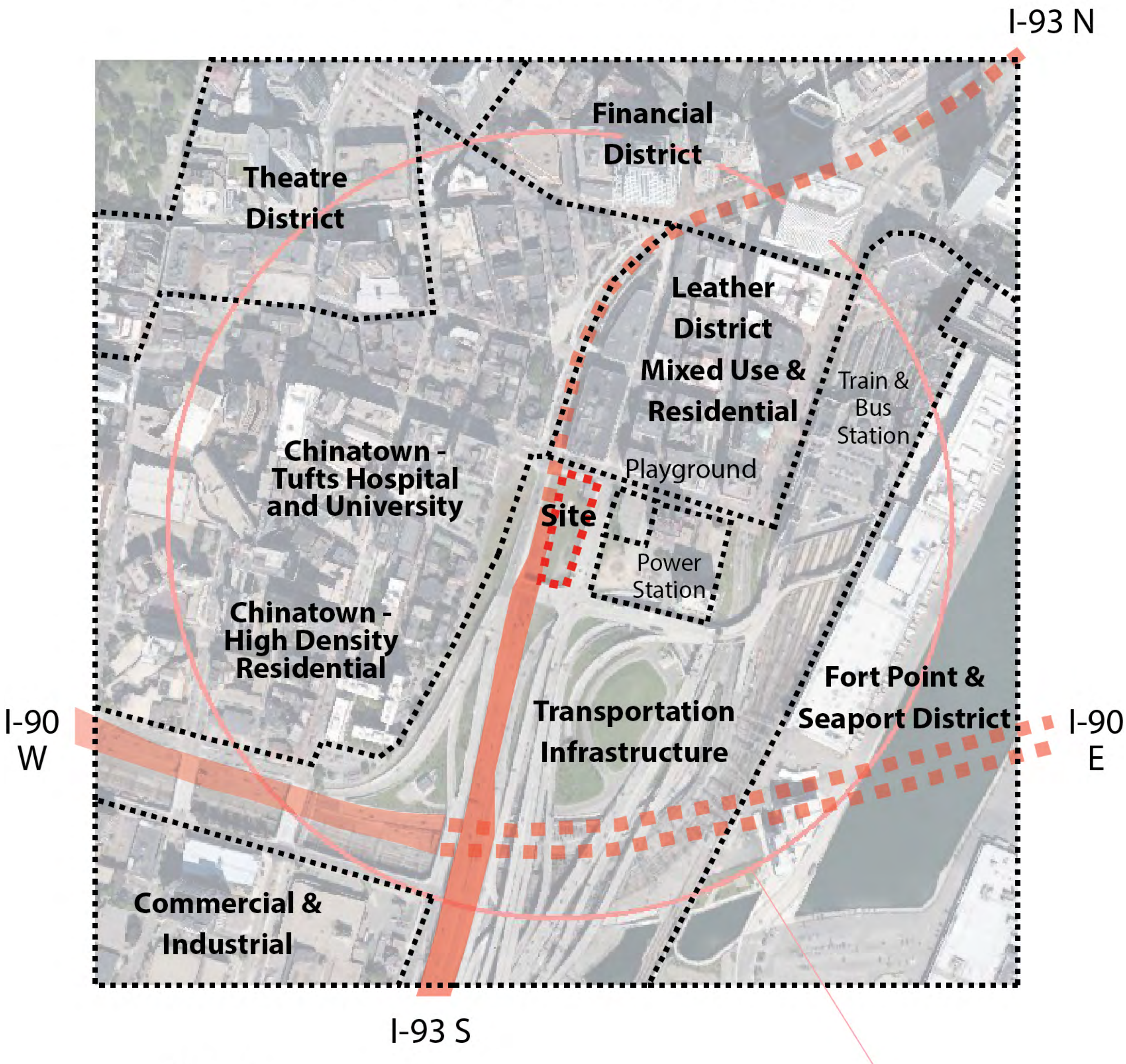



Figure 36: Estimated pollution concentrations around the Chinatown site location.

*Credit: Patton, A. P. (2014). Developing time-resolved models for predicting atmospheric concentrations of ultrafine particles in near-highway urban neighborhoods. (Order No. 3627767, Tufts University). ProQuest Dissertations and Theses, 210.*

# Parcel 25, Chinatown - Boston, MA

## Land Use Designations & Major Highways




1/4 mile radius

(1,300 ft)

Notes:

**Above-Ground Highway**

**Below-ground Highway**

**Underground Tunnel**

Figure 37: The Parcel 25 site in Chinatown is located adjacent to downtown Boston and the dense heart of Boston's Chinatown. This site is located directly on top of I-93 as it exits the Central Artery Tunnel.
*Credit: Linnean Solutions.*

# IV. Design Charrette: Ideas and Outcomes

Participants were asked to develop design solutions that might mitigate the health effects of pollution from the adjacent highways. Participants in the charrette listened to a series of lectures by the CAFEH team in order to understand the current research on the subject. Teams used the list of tactics as a way to sift through ideas most relevant to their site. They were given rolls of trace to draw over satellite images of the site.

The professional range of participants included a diverse mix of minds, including local governmental public health departments, architects, scientists, students and concerned citizens. Participants who had local knowledge of the sites chimed in to explain the primary use, pedestrian paths and information hard to obtain from images. Once familiar with the designated sites, teams felt comfortable re-designing and/or improving them. Ideas both large and small were discussed throughout this process. CAFEH facilitators walked around the charrette to guide and clarify research and information.

The most crucial part of the charrette for both the participants and the facilitators was seeing how several tactics were combined in order to reduce exposure. The teams thought of how to combine several tactics into one coherent design. Several of the outcomes created from the participants include interwoven tactics.

***The drawings in this section of the report show the ideas and outcomes created by charrette participants.***

*Photo Credit: John Gravelin.*

# Design Responses for the Somerville Site

Charrette participants working with the Cross Street East site in Somerville looked at activities and uses around the site location in relation to air pollution sources. This approach led to a set of integrated design solutions for both the specific site and the surrounding neighborhood. The participants focused on reducing exposure to pollutants for people using open space, on changing the planning paradigm to use commercial buildings to buffer residential areas, and on site design.

The Somerville team started by considering Foss Park, a large active park near, but not part of, the Cross Street East site. An integrated design approach used several different pollution mitigation tactics to direct UFP and other traffic-related pollutants over and around the park, attempting to shelter and protect people in the park.

The team also engaged in a more generalized planning approach to the Cross Street East site and the sites directly adjacent. The goal of this approach was to define a set of larger buildings, parking garages and industrial buildings nearest the freeway, to block pollution movement into the residential development.

The project scale was represented in an effort to define the most advantageous deployment of buildings on the Cross Street East site, with an eye toward sheltering residents from the most severe pollution levels and creating an indoor environment in the buildings that would draw cleaner air for ventilation and filter out pollutants.

This same vision of filtering out pollutants from residential units drove the policy approach to retrofitting housing in the existing neighborhood. The goal of this approach was to reduce exposure to pollutants for as many Somerville residents as possible.

The participants then tried to define who needed to participate at different scales of intervention. Large-scale interventions would require local governmental agencies to take action, such as building a wall barrier around the highway to block pollution. Larger land use planning solutions might also require governmental or zoning approval for new designs such as installing berms, artificial hills, or a band-shell to block pollutants from the highway.

# Sheltering Active Kids: Redesigning Foss Park

Although Foss Park was not part of the Somerville charrette site, the participants noticed how exposed the park is to pollutants from I-93 and Route 28. The Somerville charrette team designed multi-functional solutions to decrease exposure to pollutants for people using the park. Participants were also interested in planning the design interventions to improve the experience of the park for the public.

The Somerville team developed the idea of putting a band shell at the northeast end of the park, next to I-93, to act as a barrier to the pollution. The band shell could have vegetative plantings on the roof of the structure to further reduce exposure. The team developed the idea more with a continuous berm system that would shield pollution from Route 28. This earthen wall would need to be 10 feet tall and was designed to have a sidewalk along the top. The design included trees planted along the outside of the berm to add extra barriers to pollution from the roadways. The berm system could also provide elevated seating areas for spectators.

The berm in Figure 40 was designed for the side of the park bordered by Route 28, and is taller than the design shown in Figure 39, which is located away from I-93. This taller berm was designed to provide even more protection for athletes and pedestrians utilizing the park.

Participants also focused on the placement of athletic fields to give as much distance as possible from the roadways (even though the park is at the corner of these major highways). In theory, moving the playing fields away from the highways could reduce exposure, but the entire park is within 700' of both highways, and it is unclear if re-arranging the playing fields would reduce exposure.

### Tactics Utilized:

- Vegetative and Built Wall Barriers (band shell and berms)
- Land Use (rearrangement of playing fields and playgrounds)
- Trees and Plantings

## Continuous Berm Design

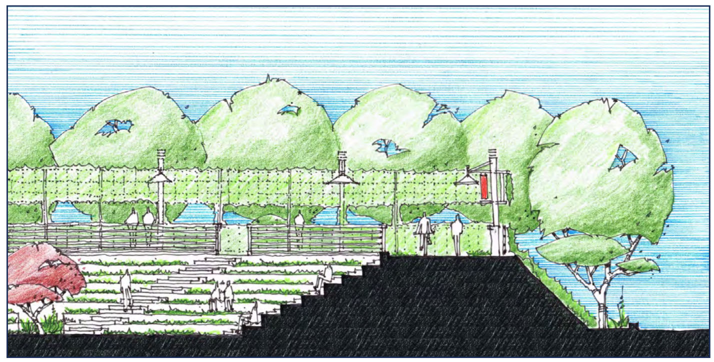


Figure 38: Section illustrates an earthen berm, creating barrier that mitigates exposure to traffic-related pollutants for users of the park (including children). The berm system incorporates seating for sports spectators, a continuous line of trees, as well as an elevated path.
*Credit: Giamportone Design.*

## Continuous Berm Design

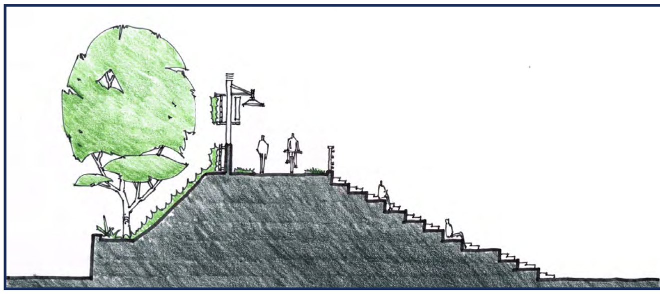


Figure 39: A taller design for the continuous berm system around Foss Park, along the Route 28 side.
*Credit: Giamportone Design.*

## Foss Park Design - Plan View


Figure 41: The plan of Foss Park is shown as redesigned, with the band shell, berm system, and plantings located to provide maximum shelter from pollutants for park users. *Credit: Giamportone Design.*

## Solid Band-Shell Sheltering Park

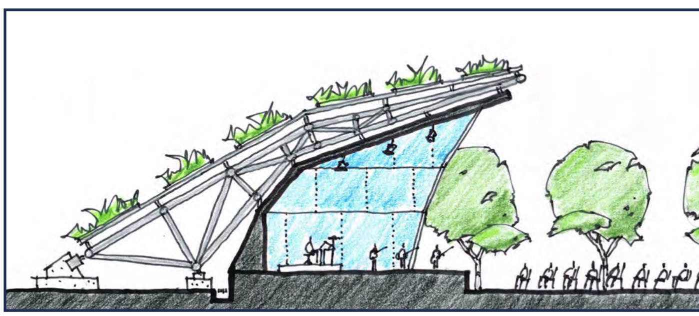


Figure 40: The band shell, shown in section, is designed to provide protection from near-highway pollutants. The roof of the band shell is shown covered in vegetation, further mitigating exposure to traffic-related pollution for people in the park (including people enjoying the concert.) *Credit: Giamportone Design.*

# Buildings as Buffers: The Urban Planning Scale

Charrette participants initially took a larger-scale planning approach to the consideration of the Cross Street East site and the properties directly adjacent to this site. The challenge was to design residential buildings right next to I-93. The proximity of the site to I-93 prompted the team to consider new buildings, themselves, as built wall barriers to block and redirect air borne pollution. The Somerville team placed larger, commercial or light industrial buildings with sealed windows closest to the highway, with more community-scaled residential development away from I-93. This plan could potentially benefit the existing residential community as the tall structures would block some exposure to pollutants. The team also considered placing buildings with less daily use than residences next to the highway, such as a structured parking lot for the new development.

Installing built barrier walls between the freeway and residential areas was also considered by the Somerville team as a highly applicable tactic for both cost and ease of implementation. The ground space required for a built wall would be minimal, the construction relatively simple, and space is available at the edge of the freeway for this kind of structure. A barrier wall could run along the edge of the neighborhood, adjacent to the highway. Walls and building barriers also have the added benefit of reducing sound pollution from freeway.

## Tactics Utilized:

- Urban Design (street and block pattern to protect existing neighborhoods)
- Built Barriers (non-residential uses against highway - parking garages and industrial buildings)
- Land Use Buffers (protected neighborhood housing and green areas)
- Built Wall Barriers
- Sound Proofing

## New Buildings as Physical Barrier

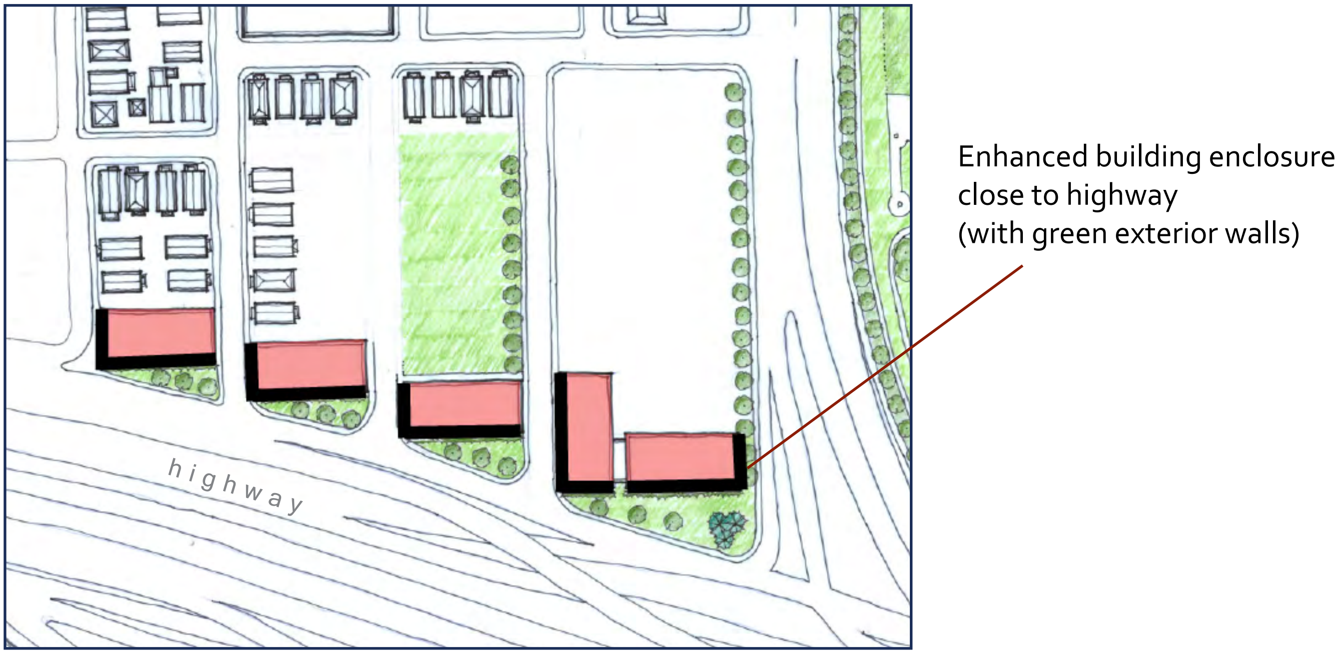



Figure 42: The urban planning goal of blocking pollution exposure to adjacent residences relies on placing larger non-residential buildings along the highway edge. Building facades closest to the highway are designed to keep pollutants out of buildings.
*Credit: Giamportone Design.*

## Vegetative Built Wall Barrier

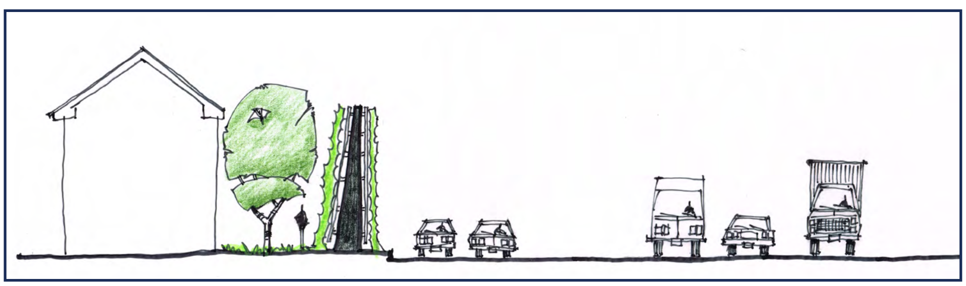


Figure 43: A wall barrier, shown in section, with planted vegetation along the side of the structure blocking exposure to near-highway pollutants for a residential building. The barrier is approximately 25 feet tall.
*Credit: Giamportone Design.*

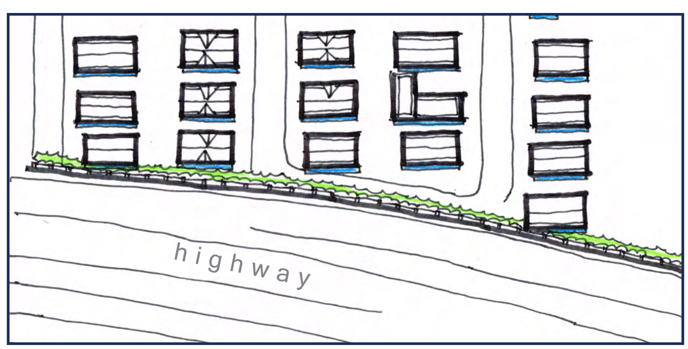



Figure 44: A wall barrier with vegetation, shown in plan, running along the highway and protecting the existing residential neighborhood. Currently there is no barrier along this section of I-93.
*Credit: Giamportone Design.*

# Shielding the Site: Designing the Site to Block Airborne Pollutants

The charrette participants had two main goals for the Cross Street East site. The first goal was to use a taller non-residential building placed on the edge of the site near the freeway to shield the rest of the site from traffic-related pollutants. The second goal was to pull ventilation air for all of the buildings on the site from a shielded location in the courtyard created by the building placement.

A 4-story parking garage was placed on the part of the site closest to the freeway, acting as a built barrier. A thick vegetated barrier made up of trees and shrubs was placed next to the parking garage to continue the pollution shield across the small park area on the site. The Somerville charrette team also considered adding vegetation to the freeway side wall of the parking garage to enhance the shielding qualities of the garage building (and help make it less imposing as a structure.)

The Somerville team recognized that there was no one-size-fits-all solution to reducing exposure for such a residential development, however, they worked through several iterations of locating the air inlets for the buildings, and came to a design that answered many questions. Utilizing several tactics together, the team located the air inlets in an area protected by a building shield, vegetation, and filtering.

The sectional diagram in Figure 47 shows a barrier parking garage building that is taller than the typical 3 story house in the neighborhood. The parking garage has vegetation planted along the side directly adjacent to the highway.

### Tactics Utilized:

- Built Barriers (‘U’ shaped exterior protects open space)
- Air Inlet Locations (draw air from park space and duct underground to filter)
- Urban Design (parking lot towards highway)
- Filtration (use excellent air intake filters)
- Trees and Plantings

## Integration of Several Tactics - Plan


Figure 45: This drawing shows how different tactics could work together to reduce exposure to near highway pollutants.
*Credit: Giamportone Design, Linnean Solutions.*

## Integration of Several Tactics - Section

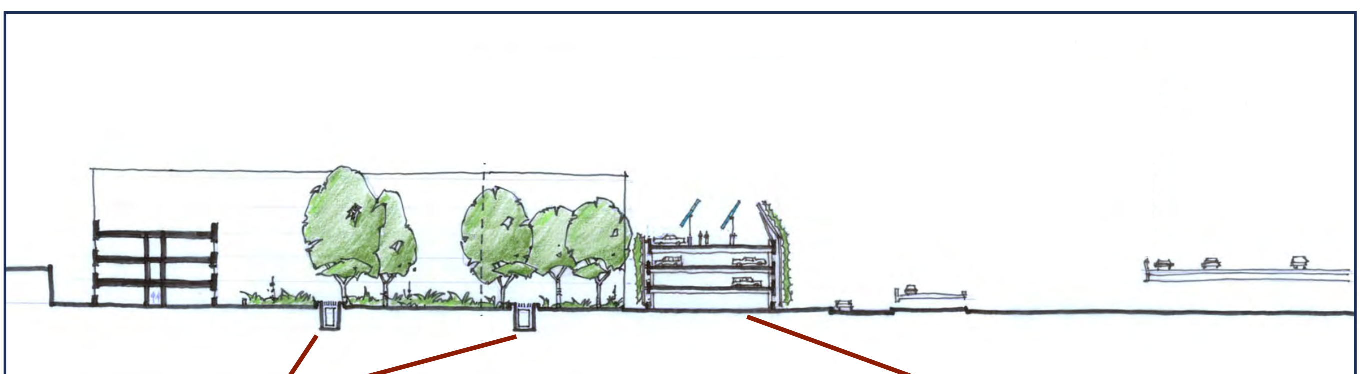



Figure 46: This section view shows the new parking lot higher than the existing highway. This helps protect the air inlets from collecting and distributing pollutants throughout the building. Trees are also planted near the inlets to further reduce exposure. *Credit: Giamportone Design.*

# Retrofitting Existing Buildings: A Plan for the Neighborhood

The Somerville team of charrette participants recognized the density of existing residential buildings in the area adjacent to the Cross Street East site and posed the question: What could be done for the residents of these existing houses? Could changes to individual building envelopes and windows make an appreciable difference in pollution exposure for the occupants?

Approximately 35 small-scale residential buildings fall within 200 feet of I-93 in the neighborhood adjacent to the Cross Street East site. While the scientific evidence suggests that exposure is elevated up to 700 feet from a freeway, the Somerville team decided to focus on the residences with highest exposure. This approach would include reducing the penetration of pollution into buildings by installing new windows and upgrading ventilation and filtration systems.

The team made some basic assumptions to look at feasibility of retrofitting existing houses within the 200-foot buffer – a residential building has 15 windows, which typically cost about $1,000 per unit to upgrade. There are 35 buildings in the buffer area, leading to a total cost to upgrade windows of $525,000. Adding air filtration to affected units would be approximately $15,000 per building, adding up to another $525,000.

Applying this model to the whole affected neighborhood, the cost is about $6 million per linear mile of highway. Based on the cost of urban highway reconstruction, this is about 1% of the cost of a linear mile of rebuilding a complex urban highway. Much like soundproofing efforts near Logan Airport, this approach could be a cost effective way to have a significant positive effect on the health of near-highway residents. Such a program might be similar to, or even work along with lead abatement programs and energy efficiency programs.

**Neighborhood Estimations:**

200 foot buffer around freeway

35 buildings in the buffer in this neighborhood

200 buildings per mile

15 Windows per House ($1,000 per unit)

$15,000 per building to upgrade ventilation and filtering

$30,000 per building total

~$6,000,000 per linear mile of highway

## Neighborhood Retrofits within 200' from Highway

200' buffer from highway - area of highest pollution

Figure 47: There are 35 buildings within 200 feet of I-93 in the neighborhood adjacent to the Cross Street East development site. These primarily residential building are particularly vulnerable to pollution exposure and could consider retrofitting windows and ventilation systems to reduce pollutant entry into buildings.
*Credit: Linnean Solutions.*

*Images from the design charrette.*


*Photo Credits: Doug Brugge.*

# Design Responses for the Chinatown Site

Charrette participants working on the Parcel 25 site in Boston's Chinatown neighborhood were initially overwhelmed by the intensity of air pollution at the site. Air pollution from vehicles is pervasive across Chinatown, and especially at the charrette site. Exhaust based pollution from the Central Artery tunnel, the Ted Williams Tunnel, the Massachusetts Turnpike, as well as from the busy surface roads in the area, and diesel combustion byproducts from the South Station train and bus traffic are concentrated in this area of Chinatown.

Parcel 25 was slated to be the new home of two Boston high schools, housed in a single new building on top of the exit for the Central Artery Tunnel. The high levels of both ultra fine particulate (UFP) and other types of air pollution led the charrette participants to look at more aggressive strategies for mitigation in this location. The Chinatown team looked at ways to engage the largest scale by covering the highways, including I-90, in the area of Chinatown near the Parcel 25 site. This approach was coupled with large-scale air filtering to reduce pollution levels from the tunnel exhaust.

Large-scale air filtering systems were also considered as interventions along the route of the existing underground roadways around Chinatown. In this context, the team considered large-scale air scoops and new ventilation shafts with built-in filtering. The Chinatown team even proposed building large-scale air filtration into the parcel 25 building, itself.

Building-scale interventions, where the participants focused most of their attention, included enclosed courtyard spaces that could act like outdoor space but with filtered air, how to best filter air to remove key ultrafine pollutants, and careful placement of air intake openings to avoid as much air-born pollution as possible.

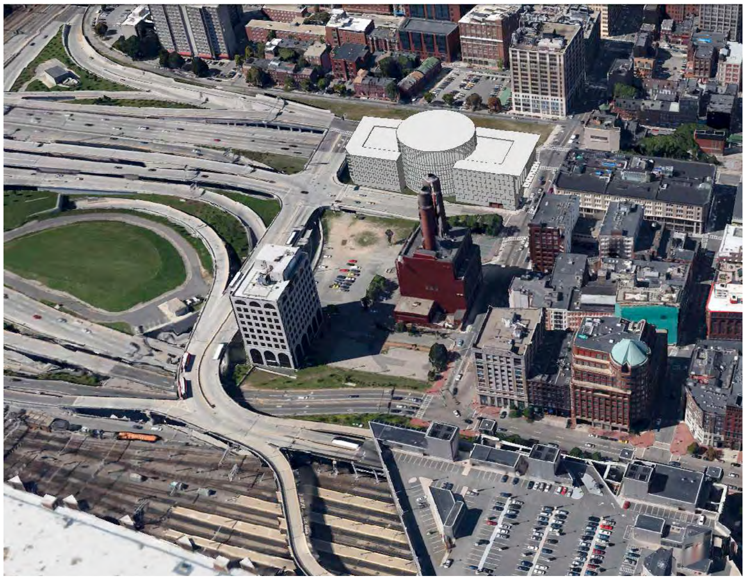


Figure 48: This image shows the Parcel 25 location for the proposed school surrounded by highways, busy local roads, and diesel rail tracks. The building sketch on the site illustrates a vision of a "Green Lung" building that provides an indoor active space with clean, filtered air.
*Credit: Brad Bellows Architects.*

# Keeping Air Pollution at Bay: Neighborhood Scale Design in Chinatown

Boston's Chinatown was a more interconnected and walkable community before it was cut up by I-90 and other transportation infrastructure. The Parcel 25 site is especially unwelcoming and disconnected from the community. This situation, along with the high levels of exposure to traffic-related air pollution, led the charrette participants working on the Chinatown site to design decking infrastructure over the highway, including an area of I-90 and the exit system for I-93. The large deck was designed to mitigate pollution from vehicle traffic and recreate a walkable streetscape in the neighborhood.

The tactic of building decking over highways is an idea with some history in the Boston area, with the 'Big Dig' and the air-rights development in Back Bay over I-90. This tactic would, in a way, be an extension of the Big Dig, but aimed at mitigation of pollution for the surrounding communities. The Chinatown team concluded that the large new area of land over the highways could be designated for specific community-oriented uses, such as schools, parks, and affordable housing.

The Chinatown charrette team also designed a series of ventilation shafts and openings with built-in filtering to directly manage air quality both inside the tunnels and in the community. The existing ventilation infrastructure along parts of I-93 that are underground could be transformed to use natural ventilation and filtering, focused on creating cleaner exhaust air. The team designed several structures as artwork to show how such systems could be attractive within the communities. Other existing buildings along the highway could integrate ventilation and filtering of tunnel exhaust air, as well.

Thinking at a larger scale, multiple buildings along the highway could install vents with filters that would mitigate pollution on-site and help clean the air for surrounding communities.

## Tactics Utilized:

- Filtration (small vents integrated over a large-scale area)
- Land Use Buffers (Relocate school entirely)
- Decking over Highway
- Urban Design (small, frequent ventilation outlets)

## Design Concept: Reconnect the Neighborhood

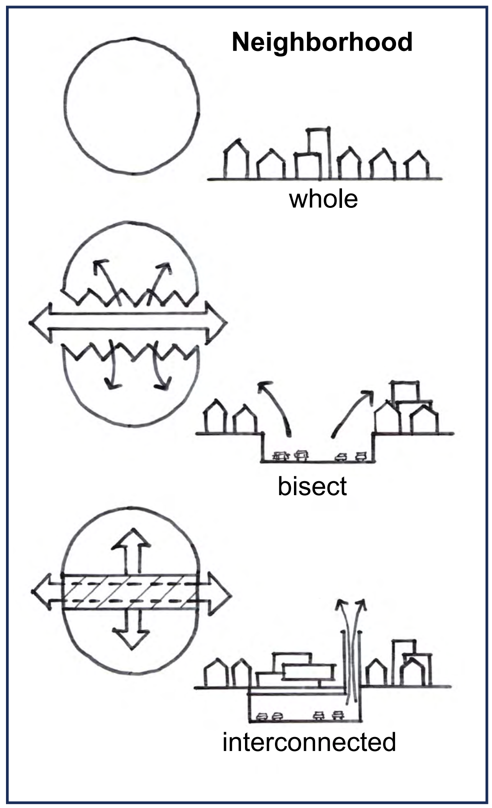



Figure 49: The Chinatown neighborhood has been transformed by highway construction. One goal for charrette participants was to re-knit the neighborhood and city back together.
*Credit: Giamportone Design.*

## Build Decking Over Highway

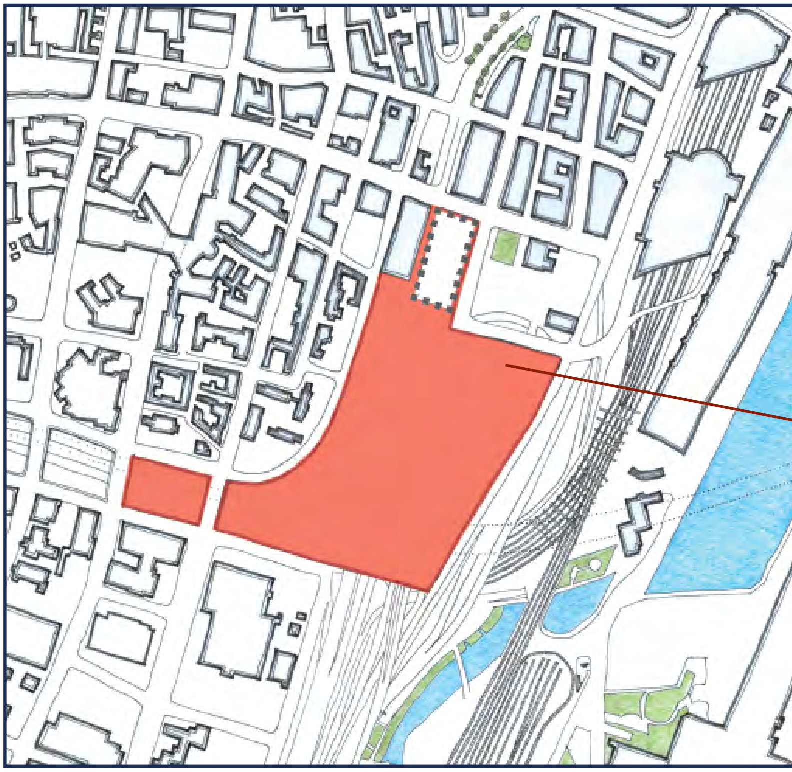



Figure 50: This design illustrates the extent of decking that could be installed over this major highway intersection. This design should be coupled with large-scale ventilation and filtration systems, as seen in the diagram below. *Credit: Giamportone Design.*

## Ventilate and Filter Pollution On-Site

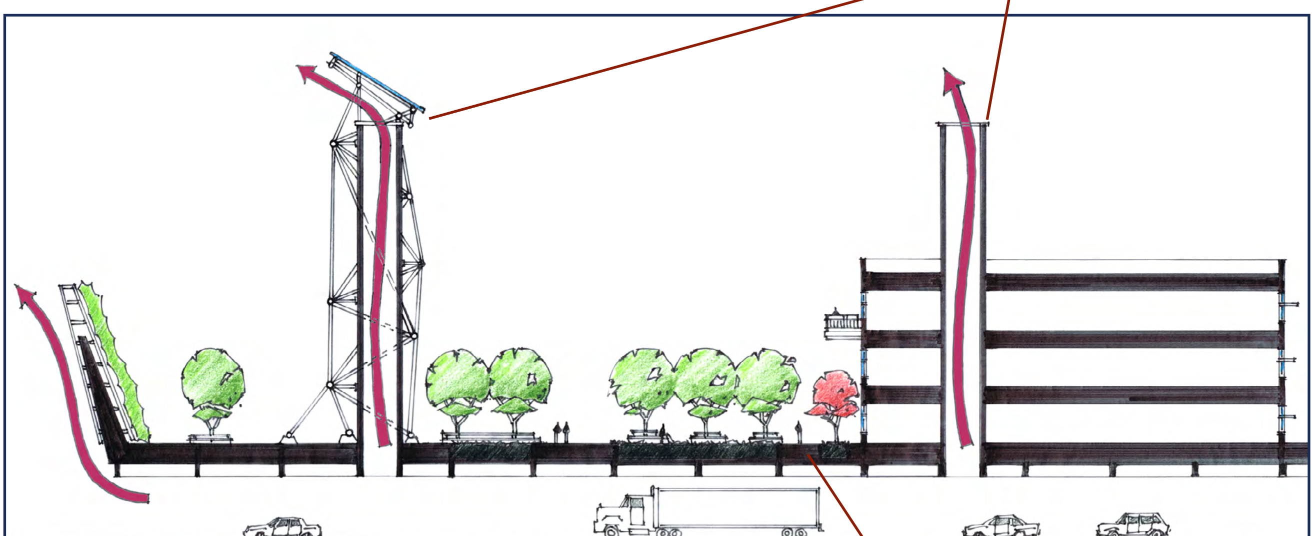



Figure 51: Natural and powered ventilation and filtering could be integrated into buildings as well as stand-alone ventilation shafts.
*Credit: Giamportone Design.*

# Building a Green Lung: Redesigning a School to Provide Pollution-Free Play

The charrette participants working on the proposed high school building on the Chinatown site spent most of their time and effort working out integrated approaches to providing a pollution-free environment for students while still integrating the new high school building into the neighborhood. The Chinatown charrette team had the good fortune to include both a member of the actual design team for the proposed high school building and the headmaster of one of the two high schools to be housed in the new building.

A typical building of this scale would have cooling equipment on the roof, but not necessarily air intakes for the ventilation system. Charrette participants discussed installing air intakes on the roof of the building with filters on the mechanical systems and sealing the building, as a route to providing clean indoor air. The practical solution was to enclose the entire building as a air-tight sealed volume. The ventilation system would need to draw large amounts of air from the roof, through large-scale filters and down into the rest of the building.

However, the team was concerned that a sealed up building would not create a space that felt welcoming for the students, and could have negative affects on the educational experience. The team began designing ways to integrate natural elements into the interior of the building. A natural enclosed atrium was designed into the program to provide a space for athletic activity and general "outdoor" experiences. The design created a sort of "green lung" for the whole building that both created inviting but clean spaces and allowed filtered air to circulate within the building.

The building design started to transform into two large volumes joined in the middle by the atrium. This design makes it possible to have two separately controlled and enclosed spaces while maintaining a habitable courtyard space that could be inviting

## Tactics Utilized:

- Air Inlet Locations / Filtration (enclosed envelope - two HVAC zones)
- Filtration
- Vegetation (indoor courtyard strategy)
- Decking Over Highway (to build the school)

### The 'Green Lung' Concept - Natural Interior Atrium

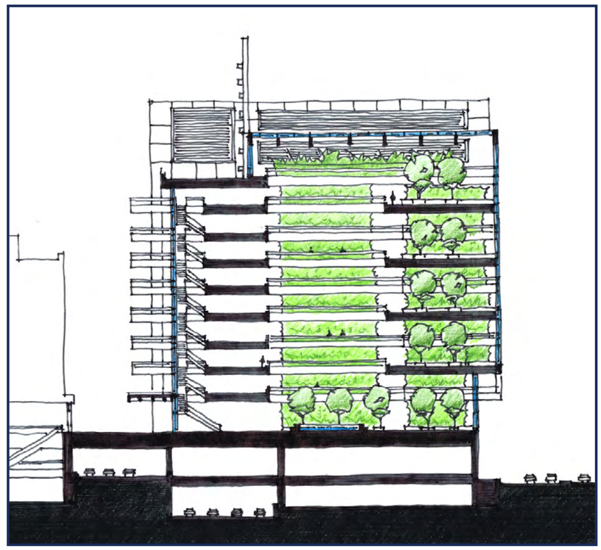


Figure 52: The "green lung" concept is shown with an atrium full of vegetation and trees. The building is shown incorporating plants and natural light throughout. A pedestrian bridge is shown connecting the school building to the rest of Chinatown.
*Credit: Giamportone Design.*

and enjoyable. This area could be considered as the courtyard entrance of the building and could even be used as the library or cafeteria. The Ford Foundation building in New York provided an example of a design in which there is a very dominant natural, but enclosed, environment with mature trees and a large landscape presence.

The overall goal of the Chinatown team was to design a diagram of a building that could provide clean, filtered air to students, while enhancing their connection to both the community and the landscape.

## Ventilation and Filtration with Atrium

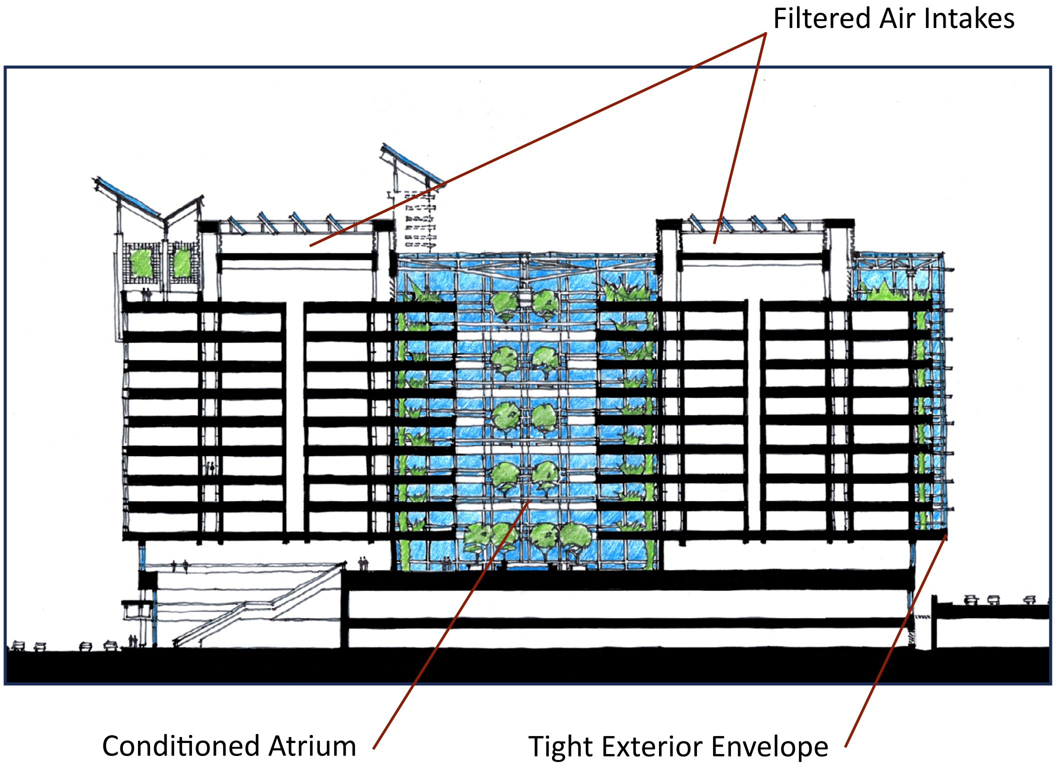



Figure 53: This building section illustrates two enclosed HVAC zones, with separate air intakes and filtration, joined in the middle by an atrium with it's own ventilation system and filled with plants and light. *Credit: Giamportone Design.*

## Ventilation and Filtration with Atrium

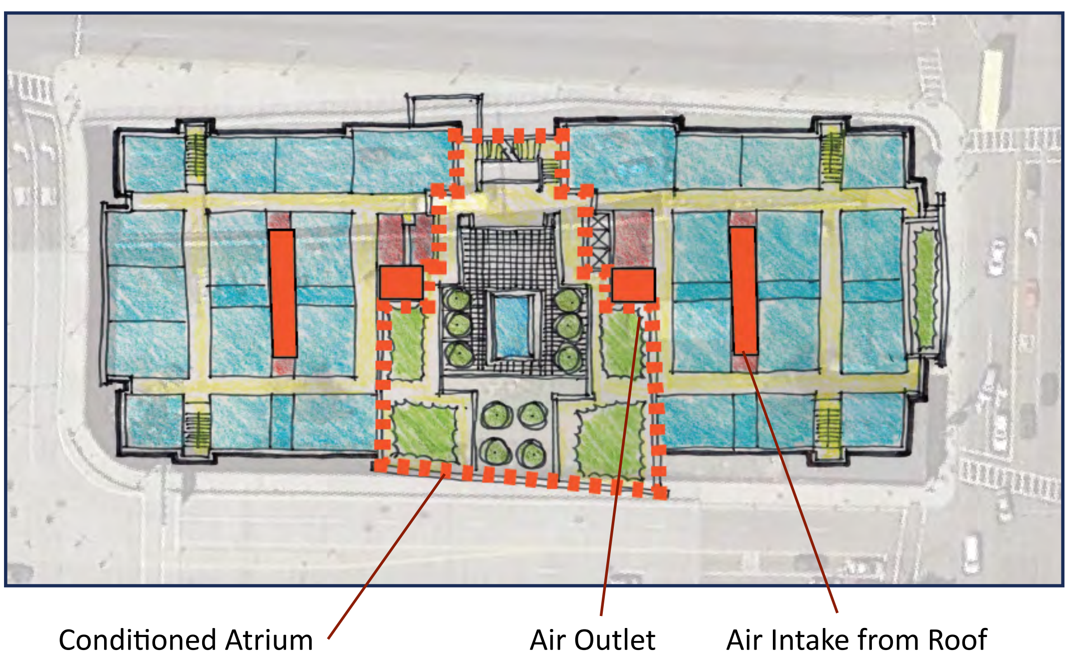



Figure 54: This building plan illustrates the two separate air intake shafts and the interior atrium with play space, views, and plantings. *Credit: Giamportone Design.*

# V. Going Forward: Suggestions for Municipalities

## Municipal Strategies for Mitigating the Health Effects of Near-Highway Pollution

*by Jim Newman - Principal, Director of Metrics at Linnean Solutions*

Municipalities have a range of tools at their disposal for enhancing the health and wellbeing of residents. However, the lack of federal and state standards on Ultra Fine Particle (UFP) exposure for humans has hampered municipal efforts to mitigate highway related negative health effects, especially those stemming from UFP exposure. Research undertaken by the CAFEH project joins a small but growing body of findings that link near-highway UFP exposure to negative health outcomes.

Zoning and public health regulations are the most likely tools for mitigating health effects from traffic pollution, especially UFP pollution that is the focus of this report. Community activism and litigation have also produced effective actions in very specific situations outside of zoning and building regulations in a few states and municipalities.

Defining buffer areas around pollution sources and heavy traffic is an established practice. A buffer of 500 to 700 feet has been used in several jurisdictions. Traffic flows ranging from 50,000 to 100,000 cars and more per day have also been used to define “High Pollution Potential” roadways. These definitions, while not codified by federal standards, set the stage for municipalities to define areas or zones likely to have high pollution exposure with corresponding potential health effects. Since ultra fine particulate concentrations are dependent on many factors, including proximity to high pollution roadways, many of the municipal responses so far have included some form of air quality testing as either primary or secondary requirements.

## Enforcing Buffer Zones

The most effective regulatory model, either through zoning or through law, is to restrict what can be built within a defined buffer zone around high pollution roadways. Such restrictions might include residences, schools, and active parkland, for example. Non-restricted building types could be permitted within a buffer zone, subject to indoor air quality standards.

This model of regulation can be very effective at limiting pollution exposure and associated health effects. However, in many urban settings, this is not a viable option, as urban building densities around highways and other high-traffic roadways are already established.

## Filtration

Communities may be able to require protective filtration for developments within a buffer zone of major roadways through stand-alone ordinances or conditions put on new developments by the permitting authority. This approach may be challenged by state building code or municipal permitting authorities that do not understand the severity of the near highway pollution problem. In California, community organizations, focused on very specific pollution conditions, have taken legal action and made settlements with companies and municipalities that mandate and fund installation of filtration on residences and schools. Several studies have shown that such air filtration can be effective.

The advantage of these requirements are that they are prescriptive and thus, easier for the building and development community to understand and implement. The great disadvantage is that this approach is less effective with buildings that have operable windows. However, the approach can be very effective for maintaining high air quality in schools and large multi-family residences. New affordable multi-family housing is being built near highways in many urban areas, offering an opportunity for municipalities to protect their most vulnerable populations by mandating filtration and other mitigation tactics.

## Outcome-Based Zoning Strategies

One clear but untested route to zoning requirements is for the municipality to require verification that buildings have acceptably low levels of ultra fine particulate concentrations inside. No national standard for UFP exposure exists, though standards for fine particulate are established. This approach requires some testing on the part of the building developer or owner, but does not prescribe specific building components or actions aimed at reducing pollution concentrations. The approach would be up to the builder or developer. The municipality can provide a list of suggested actions and a testing protocol to follow.

The advantage of this type of zoning regulation is that rather than prescribing an approach that may be obstructed by building regulations, it governs only the air quality outcome, which provides the developer with more options. The definitions of acceptable pollution concentrations could also be tuned over time to deliver optimal results. The disadvantages of this kind of zoning regulation include organizing and implementing air quality monitoring and easing developer’s uncertainty about how to comply with the standards. Such uncertainty might be moderated by defining a reasonable pathway to success in the event of testing failure.

## Vegetative and Built Barriers

Some municipalities have found it useful to consider requiring barriers between highways and new buildings within a defined vegetated buffer zone. Such zoning requirements might be useful for outdoor spaces associated with new developments. Appropriate species of vegetation need to be clearly defined to ensure effectiveness. For built barriers, some amount of airflow modeling is generally required to verify the effectiveness of the system.

Unfortunately, vegetated barriers need to be thick, dense and long in order to be effective at reducing pollution exposures, making it difficult to enforce in tight urban settings. On the other hand, this kind of zoning regulation might be more effective for open space.

## Conclusion

Living near heavy traffic, which includes exposure to ultra fine particulates, has been demonstrated to have negative health effects, especially during high-traffic times of day. Many types of buildings are built very near such high-pollution roadways in our urban areas, leading to high pollutant exposures and negative health effects for many residents. Municipalities have a number of different approaches available to them to reduce pollutant exposure for their residents and potentially improve community health. Different approaches are likely to be appropriate in different settings. The approaches described here have either been tried or proposed in either a state or municipal setting.

### Information Supporting Municipal Actions

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# VI. Appendix

## Tactic 1) Filtration - Precedents & Evidence for Recommendation

A variety of different filtration recommendations are available. Filter ratings in the United States are based on the ASHRAE standard 52.2 Minimum Efficiency Reporting Value (MERV rating, higher is more efficient) for particles in the 0.3-1 μm, 1-3 μm, and 3-10 μm size ranges [1]. Minimum efficiencies for the smallest particles are not tested for filters with MERV of 13 and lower. ASHRAE 62.2 'Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings' requires a minimum of MERV 6 for residential applications [1]. The US Environmental Protection Agency recommends MERV 9-12 for auto emission particles 1-3 μm, but MERV less than or equal to 11 for residential applications due to excessive noise [1].

The U.S. Green Building Council's LEED® for Homes Rating System requires a minimum of MERV 8 filters. MERV 10 can gain 1 LEED point and MERV 13 can gain 2 LEED points, for 2 out of the 21 possible Indoor Environmental Quality credits [2]. The American Lung Association requires a minimum of MERV 8 for recirculated air for the ALA Health House certification [3]. The New European Standard for General Ventilation Filters (EN779:2012), which replaces the original standard (EN779:2002) is based on removal efficiencies of 0.4 μm particles. This standard specifies filtration levels for coarse, medium, and fine particle removal based on outdoor air quality and CO2 as a measure of indoor air quality. For an area that is polluted but not excessively so, and a building that has low ventilation, the standard recommends M5+M6, approximately the equivalent of the combination of a MERV 10 pre-filter paired with a MERV 11 or 12 filter.

A problem with the existing filtration standards is that they don't require tests of the ultrafine (UFP, <100 nm) particle range, which is the dominant particle size for motor vehicle emissions. The South Coast Air Quality Management District in California requested technologies to remove more than 85% of black carbon, UFP, and PM2.5 while maintaining noise levels below 45 dB(A) from 150 manufacturers. Only 9 manufacturers responded, and of those, only one manufacturer provided a technology that met the standards (IQAir). The (MERV 16) filters meeting the requirements were used in a school pilot study and shown to remove almost 90% of black carbon, UFP, and PM2.5 in occupied classrooms [4]. Those schools were all near busy roads, shipping, and refineries.

A study evaluating a commercial stand-alone filter (technical specifications not available) in children's bedrooms found that a readily available "HEPA" filter on average reduced PM2.5 by ~51%, 0.3-1.0 μm PNC by ~71% and 1-5 μm PNC by ~86% [5]. They also found that while 84 ± 27% of households initially used the filters, only 63 ± 33% of households continued to use the filters, and 34 ± 30% of households used the filters in months that they were not visited by the researchers.

In a series of 6 filters from two different manufacturers, Stephens and Siegel [2] saw that UFP removal efficiency increased with MERV rating, even though the filters had not been rated for UFP. The estimated residential reduction in UFP based on applying test house measurements to typical residential conditions was 9-12% for MERV 4-6, 24-28% for MERV 10-11, 40% for MERV 13, and 51% for MERV 16. Removal efficiencies for most UFP sizes were 0-10% (MERV 4-6), 15-20% (MERV 10-11), 30-50% (MERV 13), and 60-80% (MERV 16). The filters in this study with MERV 10 and higher used electrostatic precipitators (ESPs). The problem with ESPs is that they produce ozone. In another study, removal of 8 nm to 14 nm by typical ESPs was less than 10% in test houses, with the additional problem of ozone generation that was only reduced by up to 39% by the presence of an activated carbon filter [6]. Candles have different emission profiles than traffic and other sources [7], but are often used to generate particles to test filters. Higher ESP efficiencies have been observed in the laboratory at lower flow rates, with efficiency ranging from 55-95% for ETS and NaCl [8].

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## Tactic 2) Air Inlet Locations - Precedents & Evidence for Recommendation

Adjusting the location of air inlets can significantly affect the amount of air pollution that is transmitted into buildings by ventilating buildings with cleaner air. Existing guidelines can serve as baselines for protecting building occupants from traffic-related air pollution. ASHRAE 62.1-2013 recommends the placement of air intakes a minimum of 5 ft from a “driveway, street, or parking place” and 25 ft from a “thoroughfare with high traffic volume”. These distances are relative to the “closest place that vehicle exhaust is likely to be located”. The ALA Health House criteria do not address vehicle exhaust, but do recommend 15 ft or more between air intake locations and driveways or exhaust outlets. Neither the ASHRAE nor ALA standards recommend a method for determining the extent of vehicle exhaust transport. The California Air Resources Board concluded that the distance of vehicle exhaust above regional levels is ~500 ft; however, we recognize the nature of building in the city and recommend distances as far as possible between air intake locations and busy roads.

Studies of indoor air pollution and air intake location have been conducted using wind tunnels [1] and computational fluid dynamic (CFD) models [2]. As long as street canyons are not formed, vertical separation between traffic and air intakes may reduce indoor concentrations by ~2% over the distance of several meters [1]. In order to minimize the intake of air pollution, air intakes could be located on the side of the building perpendicular to the street (up to 27% reduction [1]), on the back side of the building (up to 75% reduction [1]), or on both the side and back of the building (20%-60% reduction of the peak and mean indoor levels of traffic pollutants [2]).

## References

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## Tactic 3) Soundproofing - Precedents & Evidence for Recommendation

Noise from traffic can cause a variety of unwanted problems including interference with speech perception, sleep disturbance, difficulty with reading acquisition, and annoyance [1]. Noise from transit (both aircraft and highway) has also been shown to correlate with increased hypertension and blood pressure and decreased perceived quality of life and academic achievement [2, 3]. Although increased cardiovascular effects have not been measured due to the likelihood of high noise and air pollutant levels occurring at the same locations, future studies would be needed to confirm that there is no confounding of noise with air pollution [4].

Several noise standards are in use. The World Health Organization (WHO) recommends keeping noise levels in dwellings to less than 30 dB LAeq for continuous noise with a maximum for single sound events of 45 dB LAmax [1]. To meet this standard, WHO recommends levels of less than 55 dB LAeq outdoors. WHO also recommends that background noise levels in classrooms not exceed 35 dB LAeq with reverberation times of less than 0.6 s in classrooms and 1 s in assembly halls and cafeterias. Low-frequency noise is more problematic than high-frequency noise, and should be held to stricter standards than for noise in general [1]. The Green Building Council (GBC) also has noise requirements for background HVAC noise in classrooms. The prerequisite for LEED certification is 45 dBA in classrooms and other core learning spaces (http://www.usgbc.org/credits/reqeq10r1). Additional points can be earned by limiting background noise to 40 dBA (http://www.usgbc.org/credits/reqeq10r3) or 35 dBA (http://www.usgbc.org/credits/reqeq9r3-0). GBC recommends following best noise reduction practices including: ANSI Standard S12.60; the most recent ASHRAE Applications Handbook; AHRI Standard 885-2008; and local equivalents. In order to earn all possible LEED points related to noise, the classrooms much meet the sound transmission class (STC) requirements of S12.60-2010 Part I or the local equivalent.

Noise pollution can be controlled by sound proofing buildings or by building noise barriers. The Federal Highway Administration guidance document can be used to assess the extent of noise problems related to highways and how to address those problems [5]. Interventions must reduce sound levels by at least 5 dB to be noticeable, and highway noise levels above 55 dB will tend to dominate over other sounds [5]. Noise reductions due to structures range from 10 dB (open windows) to 25 dB (storm windows in light frame) or 35 dB double-glazed masonry [5]. The Massachusetts Port Authority claims that their Sound Insulation Program reduces noise levels from the Federal Aviation Authority limit of 65 dB to ~55 dB (http://www.massport.com/environment/environmental-reporting/noise-abatement/sound-insulation-program/).

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## Tactic 4) Land Use Buffers - Precedents & Evidence for Recommendation

Land use buffers can be used to separate sensitive land uses (residences, schools, daycare centers, playgrounds, or medical facilities) from traffic and other sources of air pollution. The California Air Resources Board recommended avoiding "sensitive land uses within 500 ft (150 m) of a freeway, urban roads with 100,000 vehicles/day, or rural roads with 50,000 vehicles/day" based on estimates of 70% decrease in most air pollutants at this distance [1]. A Health Effects Institute report concluded that exposure zones for traffic-related air pollution range from 50 m to 1500 m from roads, with most pollutants decreasing to background levels within 300 m to 500 m from highways and major roads [2]. Decay to background levels is faster upwind than it is downwind. A more recent review found that leveling begins or background is reached between 115 m (NOX) and 570 m (particle number with diameter > 15 nm) from the edge of major roads. Leveling begins or background is reached at 10% (CO) to 58% (NO2) of the near-road high concentrations. Near-road concentrations are 1.7 (NO2) to 7.1 (particle number with diameter > 15 nm) times higher than the background concentration [3]. Similar results were found for Somerville, MA, where annual median particle numbers 0-50 m from Interstate 93 were twice as high as background levels and factors such as traffic volume, temperature, and wind speed affected pollutant concentrations [4-6]. Overall, the evidence suggests that exposure to traffic-related air pollution can be decreased by 40% – 90%, depending on the pollutant, by siting sensitive land uses 200 m or more from highways and other busy roads.

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## Tactic 5) Vegetative or Built Wall Barrier - Precedents & Evidence for Recommendation

Evidence for the usefulness of noise barriers to block or absorb air pollution has been developed through field studies, wind tunnel studies, and computational fluid dynamic (CFD) modeling. Most of the relevant literature through 2013 was evaluated by Schulte and Venkatram in a report for the South Coast Air Quality Management District in California [1]. Concentrations of various particulate and gaseous pollutants immediately behind barriers were 15% to 50% (moderately large reductions) when the wind direction was perpendicular to the barrier. Barriers affected concentrations to distances about 50 times the barrier height; at greater distances the concentrations were what they would have otherwise expected or slightly higher. Concentrations upwind of the barrier (i.e., on the road side when the wind is towards the barrier) may be higher than they would otherwise be due to recirculation of wind at the barrier or due to the barrier blocking dispersion of local roads. The report outlines four topics that should be studied to build confidence in the models for reductions in air pollution due to noise barriers: (1) effect of barrier height, (2) changes in air turbulence and flow, (3) effect of road width, and (4) vertical concentration distributions.

When the wind direction is not perpendicular to the noise barrier, the barrier might be less effective. In one monitoring study, black carbon downwind of a barrier was reduced by an average of 12.4% (maximum 22%), but the reduction was only 7.8% for parallel winds [2]. This study also saw no change in particle number (0.5 – 1 μm) on different sides of the barrier.

Vegetation may also perform similarly to a solid barrier by both blocking and filtering air pollution, assuming dense enough vegetation [3]. At least one study has found decreases in ultrafine particle numbers of 36% behind a vegetation barrier along a road [4]. Another study has found that the effects of vegetation barriers on ultrafine particle numbers variable relative to roadside concentrations in a nearby clearing and depend on both wind direction and whether the roadside trees are deciduous or evergreen [5].

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## Tactic 6) Trees and Plantings - Precedents & Evidence for Recommendation

Modeling studies suggest that urban vegetation may decrease urban air pollution levels by <0.24% (10 U.S. cities [1]), <2% (Mexico City [2]), or <20% (all available space in UK planted [3]). While these urban aggregate reductions are small, larger reductions may be possible in small local areas. Green roofs or walls that replace built surfaces with vegetation might reduce levels of $NO_2$ by ~40%, $SO_2$ by ~20%, and PM up to 60% near the green infrastructure [4, 5]. They could also improve urban spaces by reducing urban air pollution by <5% by deposition to vegetation [4] and by reducing sound pressure on the opposite side of the building (linear relationship between sound pressure and percent of roof covered with vegetation [5]). In addition, green infrastructure may reduce $NO_X$ by as much as 10% due to reduced need for air conditioning [5].

Vegetation can block pollution from roads to protect nearby residential or recreational areas. Vegetation along the side of a busy road may reduce air pollution behind the vegetative barrier by up to 40%, although results vary greatly by wind direction and study [6, 7]. Increases in air pollution may be related to poor ventilation, especially in street canyons where vegetation reduces already impeded air flow [8-10]. Modeling and observational studies have reported higher $PM_{10}$, $NO_2$, elemental carbon in street canyons with vegetation relative to street canyons without added trees due to decreased ventilation [11, 12]. At least one model suggests that street canyons with trees may have $NO_2$ concentrations as much as 33% higher and $PM_{10}$ concentrations as much as 3% higher than equivalent street canyons with open space [13].

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## Tactic 7) Decking Over Highways - Precedents & Evidence for Recommendation

Decking over highways involves building solid structures across highways and constructing parks or buildings on top of the solid structures. It is commonly reported as a method to both link urban areas and block pollution [1]. Some notable decking projects include the decking of the Mass Pike to build the Prudential Center in Boston (http://www.boston.com/advertisers/bigdig/air.shtml) and the ongoing Park over the Highway (CityArchRiver 2015) project in Missouri (http://www.modot.org/stlouis/major_projects/ParkovertheHighway.htm). Projects like these can cost hundreds of thousands of dollars in decking costs alone.

Only one research project was found that studied the effects of a new decking project. Both air pollution and health were measured before and after construction of the Lane Cove Tunnel in Sydney, Australia. This study showed that $NO_2$ decreased by up to 29.3% (confidence intervals 40.0% to -8.9%) in different areas after construction of the tunnel, with $NO_X$ and PM10 (but not PM2.5) also decreasing in the eastern area [2]. Over the wider study area, there were no consistent reductions in PM or $NO_2$. This same research group found that people living near the tunnel stack had worse respiratory health after the tunnel opened, even though the air pollution measured in that area did not change [3]. Air pollution levels have also been shown to be elevated in highway tunnels both in Boston and elsewhere, leading to potentially higher exposures for commuters [4, 5, 6, 7].

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## Tactic 8) Urban Design - Precedents & Evidence for Recommendation

The largest reductions in local air pollution related to urban design are likely to be related to the relative directions of street canyons and wind. Decreases in CO and BC in the range of 38% to 54% have been observed in fluid dynamics models [1, 2]. Avoiding situations with wind flow through open areas of raised highways (“viaduct”) could reduce BC as much as 20% [2] (see images below). In general, lower concentrations are achieved when buildings surrounding street canyons are as short as possible and the wind direction is along the street canyon [1, 3].

Urban design can also lead to reduced emissions. One Swedish modeling study reported that parking garage emissions of CO, NOX, and CO2 were 40% to 45% higher than street parking emissions, mainly due to the increased driving needed to park cars in garages instead on the street [4]. These results may not be generalizable in areas where street parking is not readily available, and it is unclear what reductions in ambient pollution levels would occur. Low emissions zones would likely reduce PM10 and NO2 by about 7%, with little additional benefit achieved by substituting some of the vehicle fleet with electric vehicles [5].

Creative street planning, including moving bicycle lanes behind parked cars, has been suggested to reduce air pollution exposure. A parked car barrier in Dublin, Ireland reduced NO by as much as 11% for perpendicular winds (range: -7% to 11%), but increased concentrations by 14% to 25% under conditions of parallel winds [6]. Short noise barriers and parked cars likely have similar effects, which are highly dependent on wind direction.

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## Tactic 9) Garden Location and Healthy Vegetables - Precedents & Evidence for Recommendation

The City of Boston passed Article 89 (http://www.bostonredevelopmentauthority.org/planning/planning-initiatives/urban-agriculture-rezoning), which allows for commercial urban agriculture in Boston in December 2013 (City of Boston Office of Food Initiatives; https://www.cityofboston.gov/food/urbanag/). According to the City of Boston Office of Food Initiatives, the goal of urban agriculture is to improve “access to fresh, healthy, affordable food, which decreased transportaion [sic] costs and lower carbon emissions”. In addition, businesses have sprung up to help people build their own vegetable gardens (e.g., http://growmycitygreen.com/).

Most exposure related to garden location is probably related to breathing polluted air while in the garden. However, vegetables have been known to accumulate pollution from the air. Exposed fruits in particular can accumulate PAHs from polluted air [1]. Ingestion can be a major pathway for exposure to some semivolatile organic chemicals [1-3]. In addition, cucumber plants have been shown to accumulate CeO2 nanoparticles from the air into all parts of the plant, showing that particles the same size as the majority of traffic particles can end up in vegetables [4]. Washing leafy vegetables can reduce some pollutants in the vegetables by about 12%-62% [2]. It is expected that very small reductions in exposure will be achieved by this tactic. However, there is little evidence on the occurrence of pollutants in vegetables and more research is needed to quantify exposures [2].

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## Tactic 10) Park Location - Precedents & Evidence for Recommendation

Parks are desirable in urban areas to improve psychological benefits in addition to environmental and ecological services [1]. When siting a park, many competing factors are considered; these include population density level and where parks already exist, air pollution and noise levels, urban heat island effect level, and urban land use patterns [2, 3]. Both multi-objective optimization [2] and genetic algorithms [3] have previously been used to identify optimal park locations. At least one study has found that air pollution levels should have a significant impact on siting urban parks relative to other objectives [2]. The California Air Resources Board classifies playgrounds (a subset of parks) as a sensitive land use, and thus recommends that planners avoid siting parks “within 500 ft (150 m) of a freeway, urban roads with 100,000 vehicles/day, or rural roads with 50,000 vehicles/day” based on estimates of 70% decrease in most air pollutants at this distance [1]. A Health Effects Institute report concluded that exposure zones for traffic-related air pollution range from 50 m to 1500 m from roads, with most pollutants decreasing to background levels within 300 m to 500 m from highways and major roads [2].

Most studies that have considered air pollution as a factor for siting parks were more interested in using open spaces and vegetation to lower urban air pollution levels than in reducing exposure of people who used the parks. Some measurements of volatile pollutants in parks have shown levels 66% to 89% lower than street-side concentrations at distances 40 m to a few hundred meters inside of a park [4], with the exact rate of decay depending on factors such as traffic intensity, weather, and land use. In Shanghai, total suspended particulates, SO2, and NO2 concentrations decreased by less than 35% in the center of parks compared to near-road levels [5]. The type of park border can also affect air pollutant levels inside the park: One Swedish study reported higher concentrations just inside a park than at the source when winds blew across the park towards buildings due to canyon wind vortex effects [4].

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# Tactic 11) Active Travel Locations - Precedents & Evidence for Recommendation

Cities are encouraging active travel to reduce greenhouse gas emissions and to increase physical activity (e.g., http://www.cityofboston.gov/bikes/share.asp). Some of these initiatives include “bicycle boulevards” or other methods of separating bicyclists from vehicular traffic [1]. Protecting bicyclists from air pollution is especially important because people who are exercising breathe more air than people who are resting [2]. One study found that minute ventilation of bicyclists was 4.3 times higher compared to that of car drivers and that inhaled PM2.5, PM10, and PNC per km traveled were 6 to 9 times higher for the cyclists than the drivers [3]. Studies have estimated the effect of moving bicyclists off of heavily traveled roads by placing air pollution monitors on bicycles and having volunteers travel on scripted “commutes”. These studies found that exposures to ultrafine particle mass and number, PM2.5, carbon monoxide, and black carbon can be reduced by 7.7% - 32% through use of designated bicycle boulevards in the SF Bay Area [1] or 1.3% to 12% by bicycling on less busy streets in Montreal [2].

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Figure 55: Site map included in the charrette showing the Somerville site and a 2 kilometer buffer. *Credit: The Elbaum Group.*

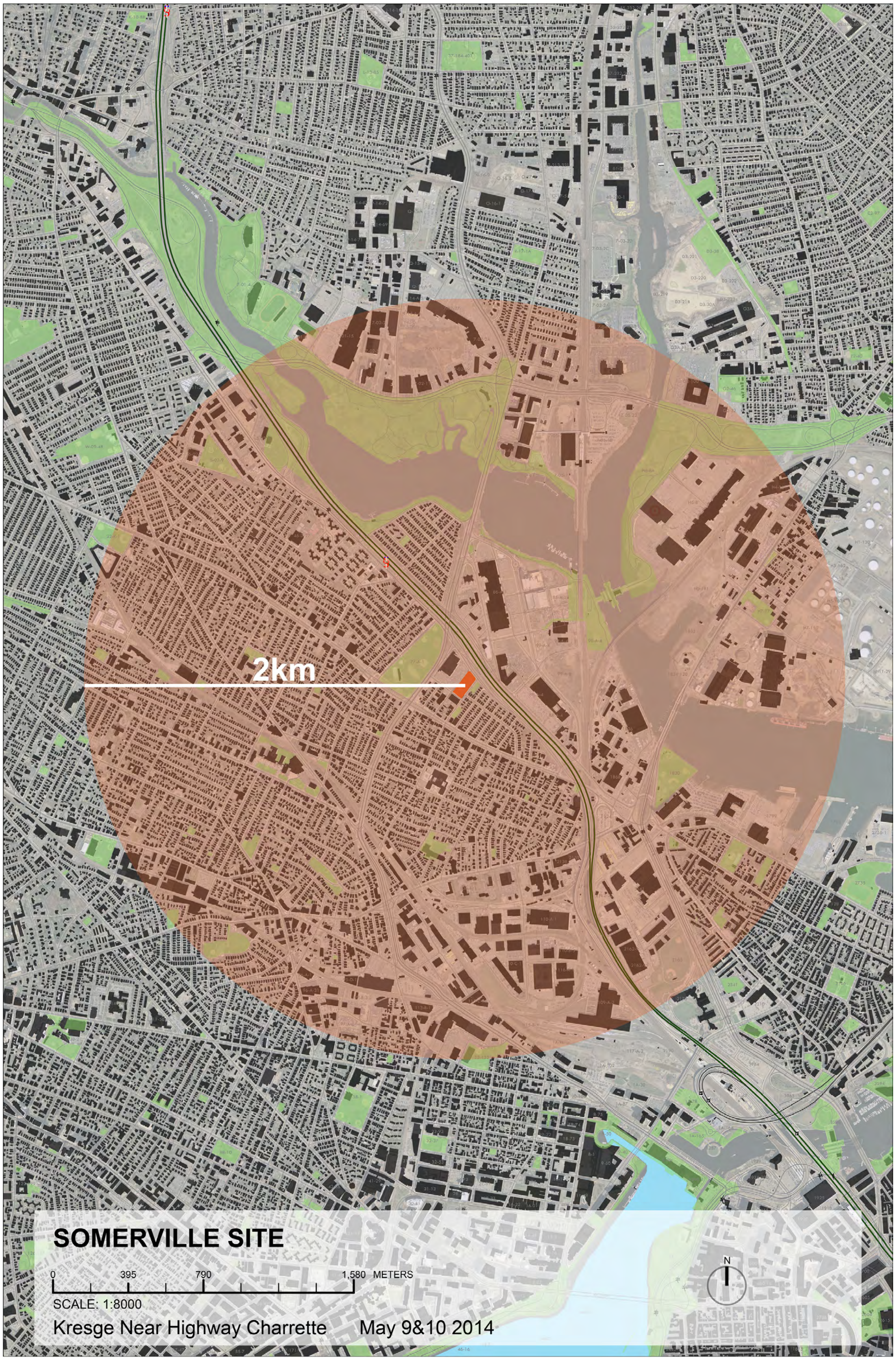

Figure 56: Site map included in the charrette showing the Somerville site and a half kilometer buffer. *Credit: The Elbaum Group.*

Figure 57: Aerial image of the Somerville site included in the charrette showing the immediate adjacent uses. *Credit: The Elbaum Group.*

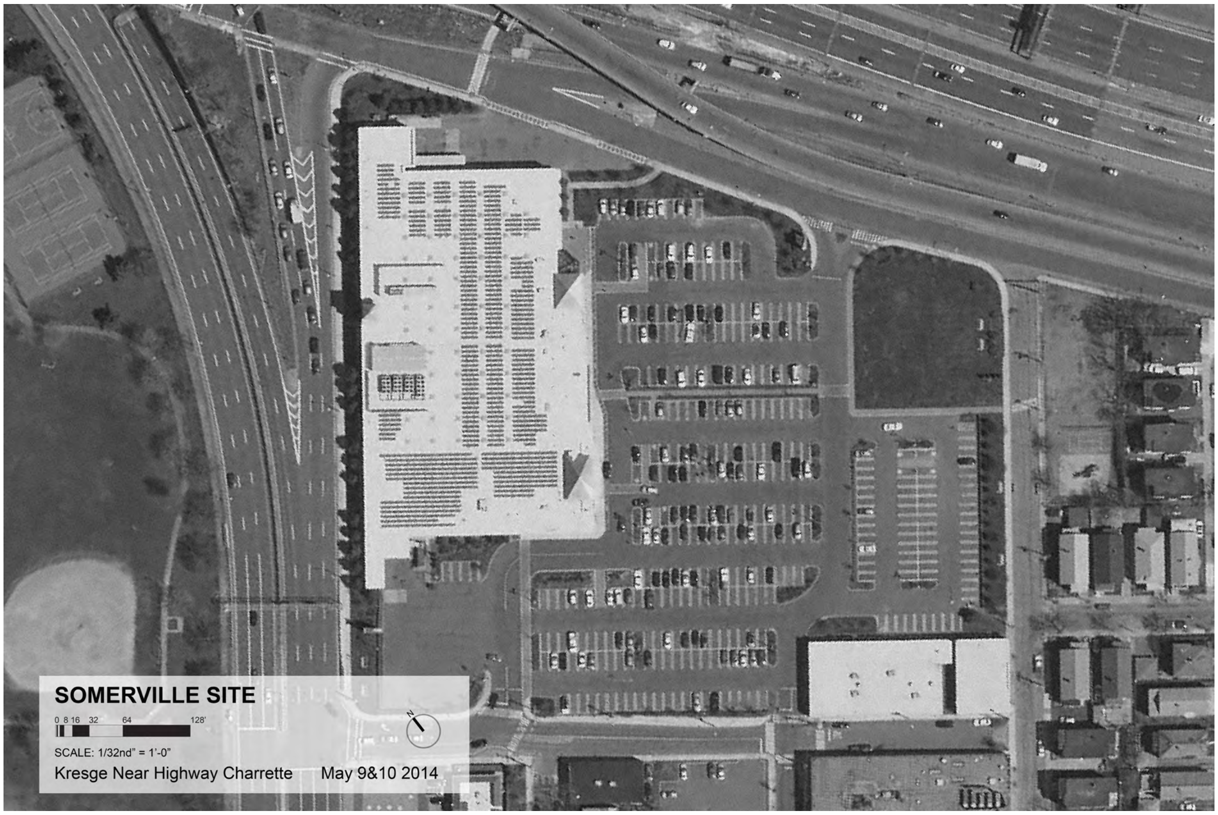


Figure 58: Aerial image of the Somerville site included in the charrette showing the site. *Credit: The Elbaum Group.*

Figure 59: Image from Google Earth showing an aerial perspective view of the Somerville site and its adjacent uses. *Credit: Google Earth.*

Figure 60: Site map included in the charrette showing the Chinatown site and a 2 kilometer buffer. *Credit: The Elbaum Group.*

Figure 61: Site map included in the charrette showing the Chinatown site and a half kilometer buffer. *Credit: The Elbaum Group.*

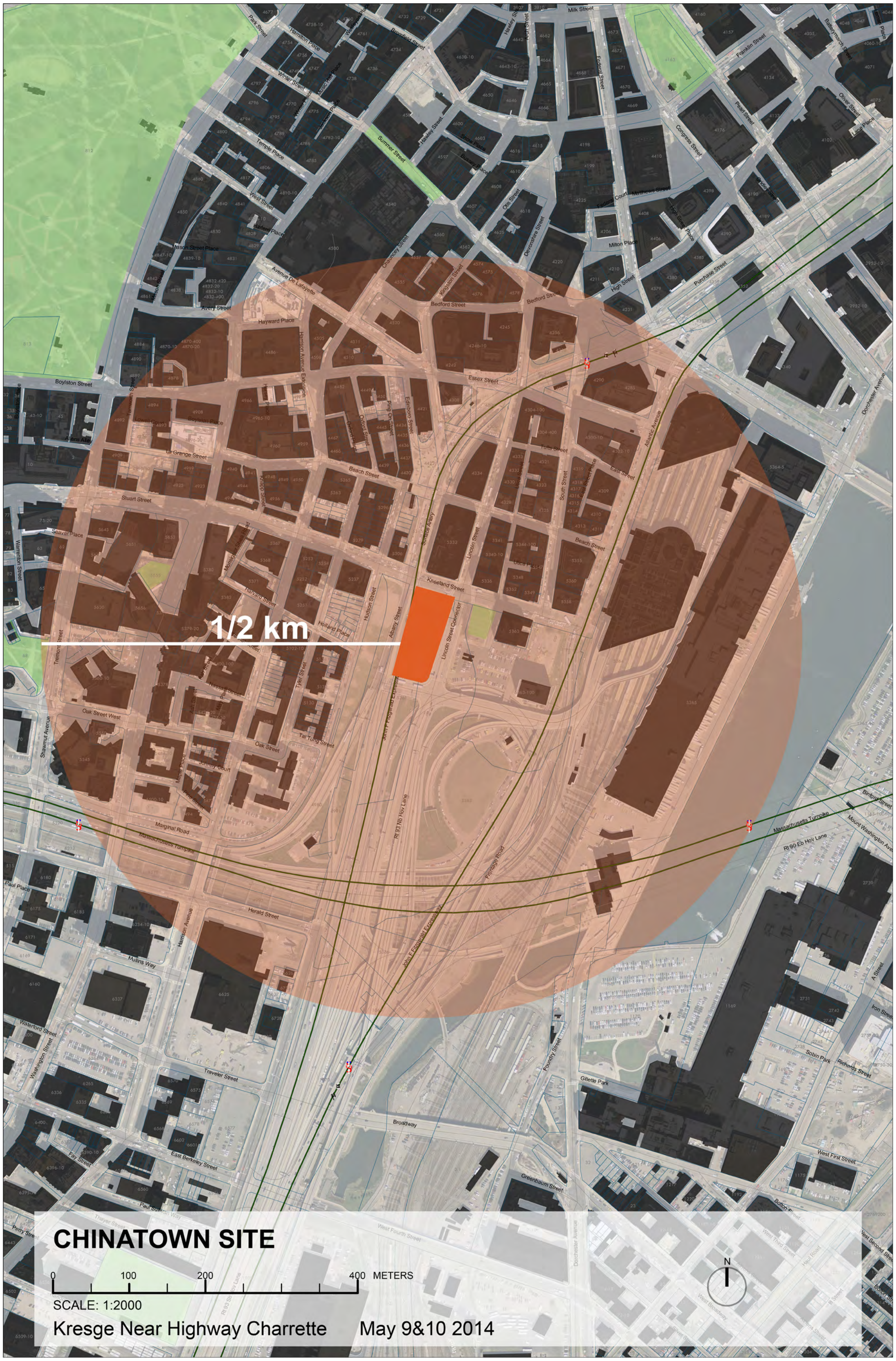

Figure 62: Aerial image of the Chinatown site included in the charrette showing the immediate adjacent uses. *Credit: The Elbaum Group.*


Figure 63: Aerial image of the Chinatown site included in the charrette showing the site. *Credit: The Elbaum Group.*

Figure 64: Image from Google Earth showing an aerial perspective view of the Chinatown site and its adjacent uses. *Credit: Google Earth.*

Photo Credit: John Gravelin