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Climate Change and Respiratory Health

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Climate Change and Respiratory Health

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Respiratory Health Association (RHA) is a 109-year-old public health organization, dedicated to improving lung health through research, advocacy and education. For the last several decades, RHA has been a leader in Illinois in the areas of air quality and environmental health. With a substantial client and grassroots base in the Chicago metropolitan area, the State of Illinois, and the Midwest, RHA is committed to exploring emerging issues that could affect vulnerable populations in these geographic areas.

Climate change poses an imminent and long-term threat to people with lung disease. For those tasked with caring and advocating for individuals with lung disease, this is a fact than can no longer be ignored. Given the number of at-risk individuals whose health and well-being will ultimately be put at stake by climate change, it will be necessary for medical and public health advocates to join ongoing and future policy discussions. RHA crafted this white paper to enable stakeholders in respiratory health – including public health officials, medical professionals, community organizations, advocates and policymakers alike – to engage in informed discussion on the impacts of climate change on chronic lung disease.

The primary focus of this paper is on major issues in respiratory health affected by climate change. Among the topics discussed within are extreme weather events, including heat waves, cold waves, floods, and droughts; wildfires; particulate matter; aeroallergens, including pollens, mold and fungus; vector-borne disease; and ground-level ozone. Regulatory action, both past and proposed, at the federal and local levels is discussed throughout. RHA hopes this paper will serve as a useful educational tool for local and regional stakeholders in respiratory health preparing to join the climate change policy forum.

I. INTRODUCTION

Climate change is poised to be the preeminent public health issue of the 21st century. As the health threats posed by climate change become more widely acknowledged, public health, medical and disease advocacy officials will need to familiarize themselves on how climate change may affect their patients, clients, and organizational members and supporters. For vulnerable populations, such as those living with a chronic disease, climate change poses both an imminent and a long-term threat. One such population that could see their lives dramatically impacted by the effects of climate change are those living with respiratory issues such as asthma, chronic obstructive pulmonary disease (COPD), allergies, and lung cancer. As the world continues to warm, a variety of predicted and unforeseen issues will affect respiratory health. Climate change-related factors contributing to increased respiratory illness include more extreme weather events, more wildfires, more airborne particulate matter, increased airborne allergens, increased vector-borne diseases, and higher levels of ground-level ozone.

Climate change discussions often focus on **extreme weather events** such as floods, droughts, heat waves, and blizzards. For people with respiratory health issues, extreme weather presents a number of hazards. As the climate changes, extreme weather events are on the rise; in the Midwest, these events do not negate each other, but compound effects. The Midwest has already seen an increase in extreme precipitation events, which punctuate longer, hotter summers that also foreshadow more frequent droughts. This increasing trend will lead to the Midwest having more frequent and intense heat waves and flooding. The ramifications of this are many and severe. Heat-related deaths in Chicago are likely to gradually increase by the end of the century and individuals with COPD could suffer disproportionately. More extreme precipitation in the Midwest will increase the likelihood of floods, thereby limiting access to care and medical supplies, and presenting additional challenges for people with chronic respiratory disease to access necessary services. In the aftermath of floods, molds and fungi grow more successfully, even in homes that have been cleaned and remediated. This will create a higher airborne spore burden and affect people with allergies and/or asthma.

Longer, hotter summers are also leading to a rise in **wildfire** prevalence and severity. Smoke from wildfires affects a large proportion of the U.S. population – in 2011, two-thirds of the US population was affected by wildfire smoke, and almost 12 million Illinoisans spent a week or more living in areas with medium/high-density smoke conditions, in spite of no wildfires occurring in the state that year. Wildfire smoke leads to increased respiratory hospital admissions (especially for people with asthma) and is worse for respiratory health than similar concentrations of typical ambient air particulate matter.

Wildfires and desertification are likely to also contribute more to airborne **particulate matter** in the future. Fortunately, other airborne particulate matter can be reduced to offset this, at least to some extent. Curbing emissions of nitrogen oxides (NO_X) and sulfur oxides (SO_X) will have a positive effect on public health, as these are the primary precursors for nitrate and sulfate fine particles ($PM_{2.5}$) that trigger respiratory events, but will also decrease the Earth's albedo (i.e., its ability to reflect light back to space and thereby cool the planet). This can be balanced by curbing black carbon emissions in concert with NO_X and SO_X emissions. Black carbon is a global warming driver, so reductions provide the dual benefits of increasing Earth's albedo and removing fine particulate matter from the air. Furthermore, black carbon has a short atmospheric residence time (a week or so), so the effects of reducing emissions would be immediate.

Likewise, people with **allergies** may have more of a struggle finding relief, as a host of changes in allergens have already been documented as the result of climate change. Due to rising atmospheric CO_2 concentrations, plants are producing more total pollen each season and some plants (like poison ivy and ragweed) are also becoming more allergenic. Rising temperatures mean that the pollen season is also lengthening and flowers are starting to bloom earlier, providing less of a reprieve for allergy sufferers. At the same time, increased temperatures and humidity will increase building dampness, air conditioner usage, and related respiratory issues (e.g., wheezing, asthma, and airway infections). Rising CO_2 has also been associated with increased allergenicity of some molds.

While increased ranges for **diseases** spread by insects and water are often discussed as immediate threats caused by a warming climate, most of these do not yet have a direct effect on respiratory health. There are, however, some worrying signposts relating climate change and vector-borne respiratory diseases, including increased precipitation leading to regional outbreaks of hantavirus cardiopulmonary syndrome and legionellosis.

Finally, changes in ground-level **ozone** due to climate change may also have an effect on people with respiratory issues. Overall, background surface ozone is increasing throughout the northern hemisphere, but what will happen next is unclear. Cities are likely to see ozone levels increase, even if background ozone decreases, while recent updates to the National Ambient Air Quality Standards will require a reduction in ground-level ozone by 2025.[1] Ground-level ozone is also a greenhouse gas, so reductions in ozone would result in "powerful, immediate benefits to public health,"[2] decreased global warming, and increased compliance with current and future health standards.

Overall, the impacts of climate change on respiratory health are already noticeable, significant, and likely to worsen with time. However, strategies to reduce global warming by reducing emissions generated by human industrial activity would have immediate, beneficial impacts on lung health in addition to curbing climate change. Each of these topics is discussed in detail below. The paper concludes with a brief discussion of ongoing policy and regulatory actions aimed at curbing global warming and the anticipated health benefits from such policies. RHA hopes this paper will serve as a useful tool for local and regional respiratory health stakeholders to make engaged and informed policy discussions on the impact of climate change on persons living with lung disease in Chicago, Illinois, and the Midwest.

II. MAJOR ISSUES IN RESPIRATORY HEALTH

a. Extreme Weather Events

Extreme weather events are on the rise. Data from the National Atmospheric Administration's National Climatic Data Center shows, "a statistically significant increasing trend of about 5% per year in the frequency of billion-dollar disasters."[3] This trend has been occurring since 1980 (and is adjusted for inflation).[4] Extreme weather events can include heat waves, cold waves, floods, and droughts, all of which can have negative consequences for persons living with respiratory disease.

i. Heat Waves

People with chronic lung disease are disproportionally vulnerable to increases in average temperature. According to the U.S. Global Change Research Program (USGCRP), "heat is already the leading cause of weather-related deaths in the United States. More than 3,400 deaths between 1999 and 2003 were reported as resulting from exposure to excessive heat."[5] This statistic is likely to get worse. If greenhouse gas emissions increase, heat-related deaths in Chicago could increase by as much as 120 percent by 2080.[6] If such emissions are not reduced, it has been projected that by 2050, heat waves like the one in Chicago in July 1995 that killed more than 700 people could occur as frequently as every two years.[7] Below are projected mortality estimates for Chicago, based on a six million person population. Even under a lower greenhouse gas emission scenario, mortality is likely to increase. However, under a higher greenhouse gas emission scenario, heat-related deaths will jump by several hundred percent between 1975 and the end of this century.

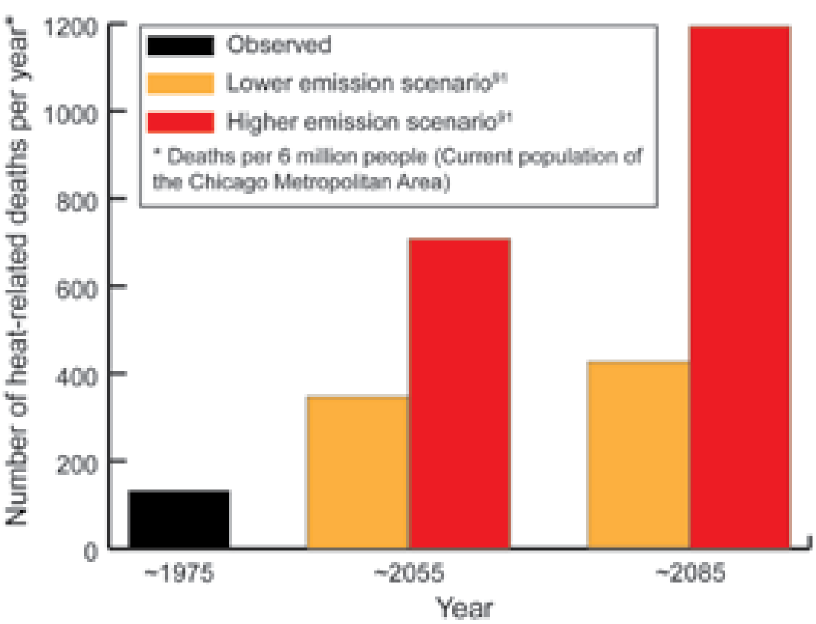

Figure 1. *Projected increase in heat-related deaths in Chicago, averaged for each over a 30-year period around 1975, 2055, and 2085. These numbers would actually be substantially higher, as this presumes a population of 6 million people in the Chicago Metropolitan Area.*

U.S. Global Change Research Program. (2009) Global Climate Change Impacts in the United States. Second U.S. National Climate Assessment, pg. 90.

Chicago is likely to get warmer due to climate change. Even under scenarios that assume lower levels of greenhouse gas emissions, Chicago is projected to become significantly hotter. According to a 2010 study projecting future heat waves and accompanying mortality in Chicago, "[b]ased on its average summer heat index values, by the end of the century, Chicago would be expected to feel more like Atlanta, GA, does today under lower emissions, and like Mobile, AL, under higher."[8] In their Second National Climate Assessment, the USGCRP shows the entire Midwest getting progressively warmer and having more days above 95°F, based on a scenario in which heat-trapping gases continue to rise.[9] Nationally, extreme summer heat will become more common as well, with temperatures that would have ranked in the hottest 5 percent of recorded summertime temperatures between 1950-1979 now projected to occur at least 70 percent of the time by 2035-2050.[10]

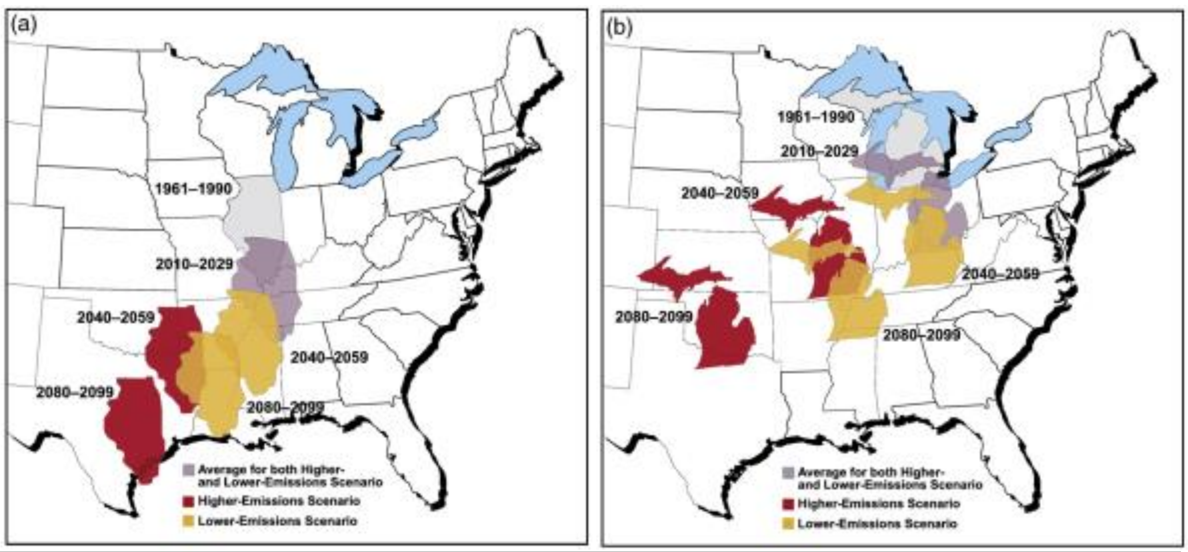

Figure 2. *Climate projections for Illinois and Michigan based on higher and lower plausible greenhouse gas emissions scenarios. Note that both states have already moved substantially south for the 2010-2029 time period, indicating that both Illinois and Michigan are already averaging warmer annual temperatures than they did in 1961-1990.*

Hayhoe, K., Sheridan, S., Kalkstein, L., & Greene, S. (2010). Climate change, heat waves, and mortality projections for Chicago. *Journal of Great Lakes Research, 36*, 65-73.

For people with respiratory issues, rising temperatures and the associated heat waves can pose problems beyond those affecting all citizens. For example, extreme heat events can cause people with chronic obstructive pulmonary disease (COPD) to hyperventilate, causing dyspnea or shortness of breath.[11] Breathlessness can be extremely problematic for people with COPD. For example, a 2009 study on excessive heat and respiratory disease found that "elderly patients with COPD may be unable to dissipate excess heat through circulatory adjustment, and exposure to extreme temperatures increases their risk of developing pulmonary vascular resistance . . . ."[12] Practically, this means that extreme temperatures make it more difficult for people with COPD to cool off, as their bodies may have difficulty pushing blood through their circulatory system quickly enough to dissipate heat adequately.

In extreme events, these are symptoms from which it can be difficult to impossible to recover. Indeed, a 2008 study of heat-related mortality found that "exacerbations of chronic pulmonary disease are strong risk indicators of heat-related mortality" and that persons living with chronic pulmonary disease were at "extremely high risk" of heat-related mortality.[13]

ii. Extreme Cold Events

In spite of hotter summers, Chicago is not likely to see more pleasant winters. In Chicago:

> [W]inter precipitation is expected to increase as temperatures warm, maintaining the total amount of snowfall at similar levels to that observed historically over much of the coming century. Thus, although summers may feel like the South, winters are expected to feel more like those of northern Ohio or central Pennsylvania do today, with no significant reduction in snow or ice.[14]

For people with lung disease that can be exacerbated by extreme cold, such as people living with asthma or COPD, there may be some reprieve in the form of warmer temperatures; however, hazardous winter conditions, including heavy snow and ice, which can make it difficult for individuals with impaired mobility to leave the house or reach medical attention, will continue to persist.

iii. Flooding

Floods in the Midwest are likely to become more common in the future, as anthropogenic (originating in human activity) climate change brings heavier and more frequent extreme precipitation events.[15] A 2008 study modeling precipitation shows, "an increased frequency of very heavy and moderate precipitation at the expense of light and heavy precipitation."[16] Expounding on this, the Third National Climate Assessment notes: "Generally, annual precipitation increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls. This tendency towards more intense precipitation events is projected to continue in the future."[17] While some areas, particularly the American West, are experiencing increasing drought as the result of climate change, the Second National Climate Assessment notes that "during the past 50 years, the greatest increases in heavy precipitation occurred in the Northeast and the Midwest."[18] A 2010 study on extreme weather events in Chicago specifically suggests that extreme precipitation events in Chicago will increase by the end of the century, particularly in the fall and spring.[19] The heaviest rainfalls are the events that cause the most flooding, so as heavy precipitation events rise, so too will floodwaters.

Flooding can affect people with asthma and allergies via heavier levels of molds and fungus growth in previously flooded areas. These effects are exacerbated by the difficulty in completely mitigating post-flood mold growth. The immediate effects of flooding can also pose a serious threat to persons with chronic respiratory disease. Floods can limit access to support networks, healthcare providers, and medical supplies like oxygen deliveries. For people with a chronic respiratory disease like COPD, this can pose a substantial threat. It can be difficult for these individuals to evacuate due to mobility issues or medical supply requirements. As stressful events, floods may also trigger adverse effects in people with respiratory illnesses precisely when access to emergency care is especially difficult. Flooding is also addressed in the section "Aeroallergens" below, as one of the biggest effects of flooding for individuals with respiratory issues may be the spread of molds and fungi in previously flooded areas.

iv. Droughts

Droughts are also projected to increase as summers become "progressively hotter and drier" due to climate change.[20] Because "very heavy and moderate" precipitation events are rising "at the expense of light and heavy precipitation," droughts are more likely to fill in the spaces between precipitation events.[21] Drought can exacerbate many issues associated with particulate matter, as dusty or dry conditions, more frequent wildfires, and dry soil and vegetation, "increase the number of particulates that are suspended in the air, such as pollen, smoke, and fluorocarbons."[22] Increased airborne particulate matter is relevant to people living with respiratory issues, from allergies to asthma to COPD. During a drought, the risk of coccidioidomycosis (valley fever) is also increased, as people inhale more fungal spores from dry, disrupted soil.[23, 24] Coccidioidomycosis is a respiratory fungal infection that can cause influenza-like symptoms such as fever, chest pain, and coughing; people with compromised immune systems (such as individuals with COPD) are particularly susceptible.[25, 26] While most coccidioidomycosis infections occur outside of the Midwest, people visiting the Southwest – long seen as a haven for those living with respiratory conditions – can easily contract the disease.

b. Wildfires

i. Increases in Wildfire Occurrence

Globally, average temperatures are expected to rise over the next century under every emissions scenario.[27] Locally, "both Illinois and Michigan summers are expected to become progressively hotter and drier, particularly under higher emissions."[28] This trend is expected to cause more wildfires both regionally and globally, as "earlier snowmelt dates correspond to increased wildfire frequency."[29] An increase in droughts, extreme heat events, and longer warm-weather seasons will also contribute to a rise in wildfire frequency and severity.[30] A 2013 study of climate change and wildfires notes: "Current climate change models are in agreement that there will be increased fire weather severity in the future. This is anticipated to increase both fire occurrence and severity, resulting in larger fires and more area burned . . . ."[31] Likewise, a 2014 study of large wildfires in the western United States found "significant, increasing trends in the number of large fires and/or total large fire area per year."[32]

Postulations that these wildfires are caused by some alternative to climate change, such as changes in land use, are unlikely. For example, Westerling et al. (2006) examine western wildfires over the last several decades and explain:

> Large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.[33]

In other words, climate change appears to be having a larger influence on fire prevalence than for example, logging or past fire suppression policies.

ii. Broad Geographic Effect of Wildfires

Although individual wildfires are typically geographically isolated and local phenomena, the smoke produced by wildfires affects a much larger swath of the population than wildfires themselves. A 2013 Natural Resources Defense Council (NRDC) analysis shows: "about two-thirds of the United States – nearly 212 million people – lived in counties affected by smoke conditions in 2011. And climate change will make matters worse, as hotter temperatures and longer dry seasons in summer create conditions that can lead to more frequent wildfires."[34] Notably, Illinois had no wildfires within its borders in 2011, but almost 12 million Illinoisans spent a week or more living in areas with medium/high-density smoke conditions during that same year.[35] In 2011, one forest fire in far northern Minnesota – approximately 600 miles from Chicago— created a smoke plume heavy enough to be covered by the Chicago media and ultimately result in the National Weather Service issuing a special weather statement for the Chicago area. Smoke was heavy enough in some parts of Chicago to cause eye irritation and affect breathing, resulting in health advisories. It also generated several calls to area fire departments by worried residents in fear their building was on fire.[36]

iii. Health Hazards of Wildfire Smoke

Although wildfires occur sporadically and are geographically distant from many Americans, the consequences of wildfire smoke on respiratory health cannot be ignored. A California study analyzing respiratory issues related to a series of wildfires in California in October 2003 found that "wildfire-related $PM_{2.5}$ led to increased respiratory hospital admissions, especially asthma. . . . "[37] Bronchitis, bronchiolitis, and COPD hospital admissions also increased during and shortly after this spate of wildfires.[38] Likewise, meta-analysis on bushfires and wildfires "suggests that there is a modest association between bushfire smoke and respiratory health."[39] A 2011 study also reinforces that "increases in . . . PM_{10} were associated with increased odds of respiratory physician visits and hospital admissions. . . ."[40] Similarly, a 2012 study associated smoke exposure with "increases in self-reported symptoms, medication use, outpatient physician visits, emergency room visits, hospital admissions, and mortality."[41] These increases were most strongly associated with outcomes related to asthma.

Compounding the issue, wildfire smoke appears to be worse for respiratory health than similar concentrations of typical ambient air particulate matter. A 2009 study analyzing air samples from central and northern California during a series of wildfires in the last week of June 2008 found, "concentrations of PM were not only higher during the wildfire episodes, but the PM was much more toxic to the lung on an equal weight basis than was the PM collected from normal ambient air in the region."[42] This may be due to the increased percentage of soluble materials (such as metal ions or organic solvents from partially combusted biomass) in wildfire smoke as compared to ambient PM.[43, 44, 45]

c. Particulate Matter (2.5 and 10)

i. What Constitutes Particulate Matter

Unlike most other airborne pollutants, particulate matter (PM) is a confusing amalgamation of many different substances with variable sizes, chemical makeups, and effects on public health. The term "particulate matter" is a catch-all term for solid and liquid particles suspended in the air. Generally, discussions of particulate matter of concern to lung health break it into two groups by size: PM_{10}, which is particulate matter below 10 micrometers in size, and $PM_{2.5}$, which is encompassed in PM_{10} but only includes the fraction that is 2.5 micrometers or smaller.[46] PM_{10} is inhalable, while $PM_{2.5}$ can get further or deeper into the lungs due to the smaller size of the particles. For this reason, $PM_{2.5}$ is often considered more damaging or worse for lung health.[47] Both PM_{10} and $PM_{2.5}$ can be made up of many different substances, including soil dust, sea salt, black carbon, organic carbons, nitrates, and sulfates.[48] Of these, sulfates, nitrates, organic carbons, and elemental carbon are generally smaller than 2.5 micrometers in diameter.[49] There are also important gaseous particulate matter precursor pollutants, such as nitrogen oxides (NO_X), sulfur oxides (SO_X), ammonia, and hydrocarbons, which can form particulate matter in the atmosphere downwind of where they are emitted as gases.[50]

While particulate matter comes in various sizes, agencies like the EPA have focused more attention on reducing $PM_{2.5}$, based on the greater associated health impacts and the greater number of people exposed to high concentrations.[51] PM_{10} tends to be more often a local area concern, falling out of the atmosphere over fairly short distances.[52] $PM_{2.5}$ components, on the other hand, can travel much further from emission sources and affect a much broader area. What's more, gaseous $PM_{2.5}$ precursor emissions can travel hundreds of miles before combining to create $PM_{2.5}$ constituents like nitrates and sulfates.[53]

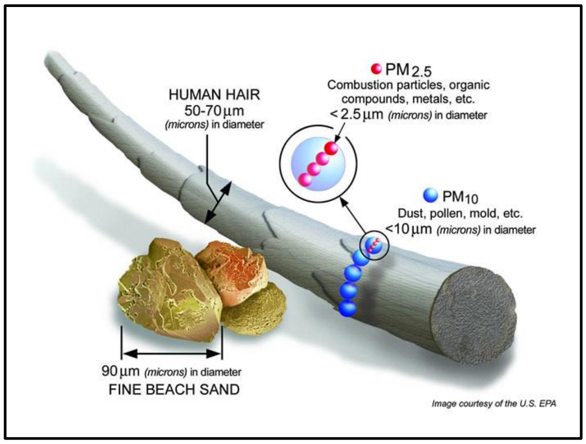

Figure 3. *The size of particulate matter, showing fine beach sand and a human hair for scale.*

U.S. Environmental Protection Agency. Particulate Matter website. Retrieved from [http://www.epa.gov/airquality/particulatematter/graphics/pm2_5_graphic_lg.jpg.](http://www.epa.gov/airquality/particulatematter/graphics/pm2_5_graphic_lg.jpg)

ii. Trends in Particulate Matter

Particulate matter is not composed of one chemical, and is not even uniform from one geographic area to another, due to regional differences in emissions of $PM_{2.5}$ precursors. Sulfates, for instance, are a primary player in pollution in the southeast U.S., but play a minimal role in the northwest, largely because the coal power plants which are the largest sources of sulfur dioxide are almost completely absent. Therefore, trends in particulate matter caused by climate change can vary widely.

1. Trends in Past Particulate Matter

The Intergovernmental Panel on Climate Change (IPCC) states that aerosol optical depth (AOD, an indicator of the total particulate matter in the air) has actually been decreasing over Europe and the eastern United States since the mid-1990s, probably as a result of more stringent regulations for $PM_{2.5}$ precursor sources such as coal-fired power plants and diesel engines, and is also decreasing over the North Atlantic Ocean.[54] Ground-level monitored particulate matter trends back up this finding by showing downward trends in Europe and North America since the mid-1980s.[55] The IPCC gives "robust evidence from around 200 regional background sites" indicating downward trends over the last two decades of $PM_{2.5}$ and sulfate in Europe and the USA.[56] However, the IPCC also finds that AOD has increased over eastern and southern Asia since 2000 and "in the 2000s dust-related AOD has been increasing over the Arabian Peninsula."[57] Much of this is related to the increasing industrialization of Southeast Asia and desertification throughout the Arabian Peninsula (as well as the Middle East, Turkey, China, and sub-Saharan Africa).

2. Trends in Future Particulate Patter

There are several different models that show particulate matter decreasing globally in the future. For example, Tagaris et al. (2007) combined the effects of climate change and emissions reductions to yield an averaged 23% decrease in $PM_{2.5}$ over the United States and forecast that "organic carbon will be the dominant component of $PM_{2.5}$ mass in the future" based on reductions in sulfate, nitrate and ammonium $PM_{2.5}$ components.[58] Likewise, Racherla and Adams (2006) suggest fine particulate species will decrease "by 2 to 18% because of increased wet deposition loss rates associated with increased precipitation."[59]

However, these studies are confounded by more recent data. Ebi and McGregor (2008) state: "More stringent emissions controls for ozone, $PM_{2.5}$, and other pollutants can be expected with the growing body of evidence of the adverse health impacts of these air pollutants. Therefore, the extent to which climate change affects air quality will depend partially on ongoing regulatory control of ozone and $PM_{2.5}$."[60] Ayres et al. (2009) note, "although mitigation policies may result in reductions in particle emissions at the local level, desertification and a higher frequency of forest fires may increase transboundary transport of particles."[61]

The IPCC's most recent report only assesses changes in particulate matter based on climate change, without considering potential future environmental health policy-based reductions in sulfate, nitrate, or other components of PM covered under the Clean Air Act.[62] In this scenario, polluted regions will experience regional feedbacks that increase peak ozone and $PM_{2.5}$, but the failure to account for changes in emissions of PM essentially negates these findings.[63]

Given this uncertainty, it is important to focus on the public health benefits of policy-driven PM reduction in concert with the effects of climate change on PM. As a 2008 literature review on climate impacts on air quality found, "efforts to mitigate climate impacts by reduced fossil fuel combustion also will often result in co-benefits from reduced direct health impacts of air pollution."[64]

iii. Speculation of Particulate Matter in the Midwest

1. NO_X and Nitrates

The term "nitrate" typically refers to ammonium nitrate. Ammonium nitrate is a common fertilizer, and is produced in the atmosphere from ammonia and nitrogen oxides (NO_X). The EPA regulates nitrogen dioxide (NO_2), a nitrate precursor and proxy for a variety of nitrogen oxides.[65] NO_X can come from many sources, but one large source is fossil-fueled power plants. Power plant emissions, "increase substantially during heat waves, when air conditioning use peaks."[66] In fact, "weekday emissions of NO_X from selected power plants in California more than doubled on days when maximum daily temperatures climbed from 75°F to 95°F in July, August, and September of 2004."[67]

This is problematic for individuals with asthma, because "NO_2 can enhance the allergic response to inhaled allergens, and NO_2 concentrations in ambient air are also reportedly associated with cough, wheezing and shortness of breath in atopic subjects."[68] Lower atmospheric concentrations of NO_2 yield fewer asthma exacerbations, fewer allergic responses among individuals with asthma, and higher respiratory capability among individuals with compromised respiratory systems. As described in the following section, NO_X emissions (including NO_2) are also critical to summertime ozone formation, which also contributes to asthma exacerbation.

While atmospheric nitrates in the Midwest have decreased significantly over the last decade – due in large part to the regulation of NO_X by the EPA[69] – large parts of the planet are expected to see increases in nitrate precursor emissions in the future, and "nitrate aerosols are expected to become more important. . . ."[70] This makes it likely that strict future regulation of NO_X , and in particular NO_2, will continue to be necessary in order to protect the respiratory health of people in the United States and around the globe.

One interesting caveat regarding the role of nitrate in the atmosphere is that nitrate has a high albedo in the atmosphere. Therefore, it plays a role as a global warming damper rather than a driver. This is because "nitrate is a strongly scattering aerosol and in some spectral regions, its scattering properties are even greater than those of sulfate aerosols."[71] That being said, a 2007 study on nitrate aerosols on the future atmosphere notes, "this impact is still small compared to greenhouse gas forcings, therefore, the main role nitrate will play in the future atmosphere is as an air pollutant . . . and . . . reaching pollution levels like sulphate aerosols."[72]

2. SO_X and Sulfates

The term "sulfate" generally refers to ammonium sulfate. Commonly used as a fertilizer, ammonium sulfate is produced when sulfur dioxide and ammonia are available in the atmosphere. Atmospheric sulfates in the Midwest have decreased significantly over the last decade or two, due primarily to the regulation of sulfur dioxide (SO_2) from fossil fuel combustion sources by the EPA.[73] Much of this reduction has been related to requirements of the acid rain program and subsequent programs targeting large SO_2 sources like coal-fired power plants; reduction requirements targeting coal power plant emissions were phased in beginning in 1995.[74] More recently, the sulfur content in diesel fuel has also been controlled. In 2006, ultra-low sulfur diesel fuel was phased in for all highway diesel vehicles.[75] Between 2007 and 2012, ultra-low sulfur diesel was also phased in for non-road, locomotive, and marine engines.[76] The effects of these regulations are two-fold, as ultra-low sulfur diesel puts less sulfur into the air and allows for diesel particulate filters to remove more organic and black carbon particulate matter from engine exhaust without the corrosion caused by high sulfur concentrations.

In 2014, the EPA announced regulations on gasoline that will phase in during 2017 and which will cut sulfur standards by sixty percent over the next three years.[77] EPA actions will also result in sulfur reductions at power plants. EPA's Mercury and Air Toxics rule is also expected to bring future reductions in SO_2 as it uses SO_2 as a proxy for toxic hydrochloric and hydrofluoric acid gases, and strategies to reduce those toxic gases will also capture and prevent the release of significant SO_2 emissions.[78] This is a boon for lung health; however, much like nitrate, sulfates have a high atmospheric albedo, and work as a global warming damper to some extent. Ironically, cleaning the air to prevent illness and deaths could allow more solar energy to reach the surface of the earth, increasing the impacts of global warming and necessitating even more urgent reductions in global warming pollutants.

3. Black Carbon

Black carbon is particulate matter that is formed when fuels such as fossil fuels and biomass are burned but do not combust completely, thereby leaving residual material. In the northern hemisphere, the production of black carbon is dominated by the burning of fossil fuels.[79] In the southern hemisphere, the burning of biomass takes center stage. Unlike nitrates and sulfates, black carbon is a strong greenhouse driver, "increas[ing] cloud and atmospheric heating. . . ."[80]

Black carbon is unique, in that it is very short-lived for a greenhouse driver. Although black carbon accounts for about as much climatic forcing as half of all atmospheric CO_2, it typically resides in the atmosphere for less than a week.[81] Hypothetically, halting black carbon emissions could make a significant dent in global warming within a matter of weeks. As Jacobson (2002) finds, "any emission reduction of fossil-fuel (f.f.) particulate BC [black carbon] plus associated organic matter (OM) may slow global warming more than may any emission reduction of CO_2 or CH_4 for a specific period."[82] In other words: "eliminating all f.f. BC+OM could eliminate >40% of net warming (>15% of total warming before cooling is subtracted out) within 3-5 years if no other change occurred. Reducing CO_2 emissions by a third would have the same effect, but after 50-200 years."[83] This is because "black carbon is likely the second most important individual climate-forcing agent in the industrial era, following carbon dioxide."[84]

However, substantial reductions in black carbon have not been implemented and black carbon emissions in the Midwest have remained stagnant for the last decade.[85] This is a loss on two fronts, as black carbon (and organic matter) reductions would "not only slow global warming but also improve human health."[86] Because black carbon is a component of particulate matter, can get deep into airways, and has such a short atmospheric residence time, regulations on black carbon could present an almost immediate benefit both to climate change and to public health.[87, 88] Therefore, lowering black carbon levels would ultimately ease the burden on asthmatics and people with COPD or other respiratory diseases. At the same time, the warming reduction available through the regulation of black carbon could help offset warming caused by reductions in nitrate or sulfate.[89]

The case for reducing black carbon, then, is a pretty easy one to make. There are immediate public health benefits in reducing particulate matter, of which black carbon is a component. With significant cuts in black carbon emissions, the portions of global warming driven by black carbon could be swiftly and significantly mitigated, allowing carbon dioxide reductions to phase in more slowly. Finally, reductions in black carbon can be achieved through straightforward methods, such as reducing slash-and-burn forest management and adding particulate filters to vehicles and power plants.[90]

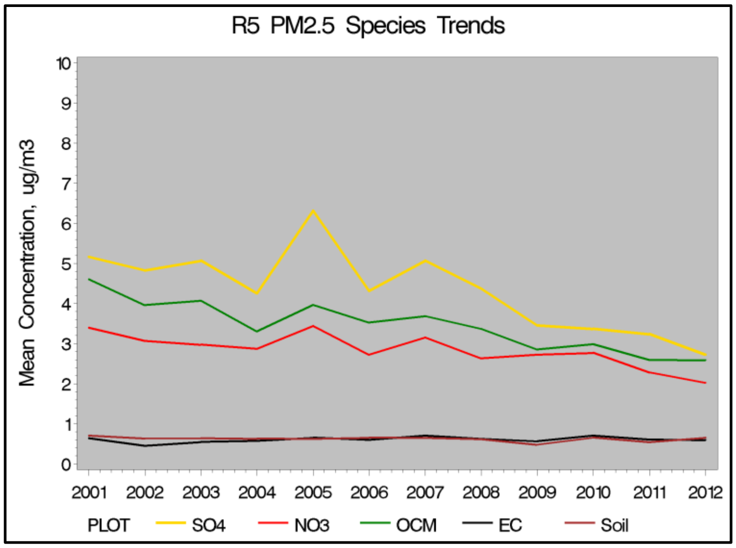

Figure 4. *This chart shows trends in particulate matter in the Midwest. Note that sulfates, nitrates, and organic carbons all seem to show decreases, while elemental carbon (sometime also referred to as black carbon) and soil have not changed much over time.*

Source: Lake Michigan Air Directors Consortium

d. Aeroallergens

Aeroallergens can be particularly problematic for those with allergic asthma, or for those whose respiratory health is already compromised by COPD, lung cancer, or other respiratory issues. For individuals with allergic asthma, days with high pollen or mold counts can make it difficult to go outside or engage in normal activities. A 2012 study on the effects of climate change on allergic disease notes:

> The influence of climate change on allergy is unpredictable, as there are various items on both sides of the scale. However, preliminary suspicions by clinical experts indicate that the scale is tipped toward increasing allergies and allergic airway disease, but depending on regions as climate change will have different effects in different regions.[91]

Common aeroallergens include both pollen and mold, and both seem to demonstrate a response to changing temperatures and atmospheric CO_2 levels caused by climate change.[92] With higher volumes pollen being produced over pollen seasons longer in duration, allergic symptoms could worsen and thereby trigger more asthma attacks.[93]

i. Increases in Pollen Volume

As atmospheric CO_2 and temperatures increase, a number of plants seem to be producing more total pollen in a season. Over a decade ago, researchers were already noting an increase in seasonal volume of allergenic pollen types throughout western Europe.[94] For example, Spieksma et al. (2003) note statistically significant increases of airborne birch (Betula) and oak (Quercus) pollen both in Leiden, Netherlands and in Derby, United Kingdom, with oak pollen also displaying a statistically significant increase in Brussels, Belgium. Every station investigated by Spieksma et al. (2003) showed a statistically significant increase in stinging-nettle (Urtica) pollen as well.[95] The trends in this study utilize a minimum of 20 years of data, and rising birch, oak, and stinging nettle pollen suggests that these increases are not confined to just a few species of pollen-producing plants.

More recently, Rogers et al. (2006) investigated the effects of altered CO_2 levels on ragweed pollen production, reporting that "under conditions that simulate future levels of atmospheric CO_2 and increased temperature . . . one effect – increased production of allergenic pollen – could strongly effect the significant proportion of the population with pollen allergies as climate change progresses."[96]

ii. Lengthening Pollen Season

Rising temperatures also seem to be lengthening the pollen season and causing earlier flowering dates for certain plants. Researchers investigating the western United States have noticed "three spring indicators — lilacs, honeysuckles, and streamflow . . . — [have] exhibit[ed] trends toward earlier spring timing since the mid-1970s."[97] A 2002 study of British plants likewise noted, "the average first flowering date of 385 British plant species has advanced by 4.5 days during the past decade compared with the previous four decades," and added, "these data reveal the strongest biological signal yet of climate change."[98] In addition, a 2011 study found that the "duration of the ragweed (Ambrosia spp.) pollen season has been increasing in recent decades as a function of latitude in North America."[99]

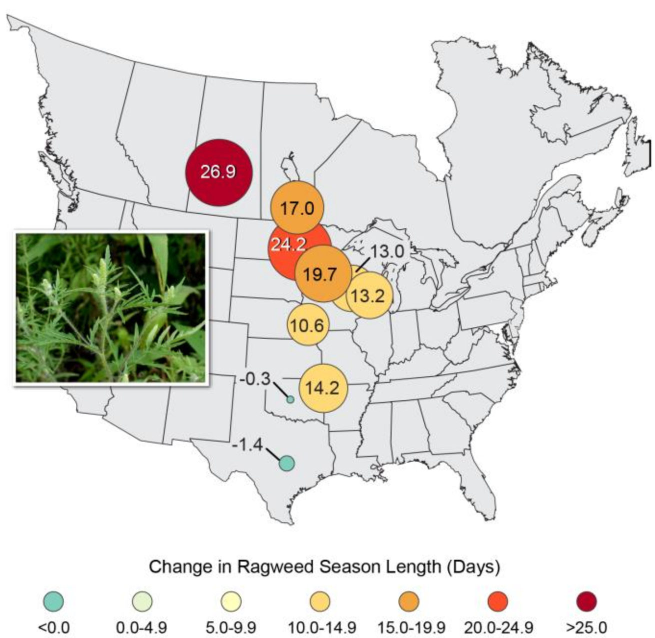

Figure 5. *This figure, from the Third National Climate Assessment and utilizing data from Ziska et al. 2011, shows the change in ragweed season length throughout the interior of North America from 1995 to 2011. This is in response to rising temperatures in the area.*

U.S. Global Change Research Program. (2014) Global Climate Change Impacts in the United States. Third U.S. National Climate Assessment.*, pg 223.*

A lengthened pollen season, coupled with an increase in the total quantity of pollen produced by plants in a season, has the potential to pose significant risks for many individuals. Either issue could exacerbate existing respiratory problems, and the two combined have the potential to increase sensitization, even in individuals who currently have no respiratory issues.[100]

iii. Increased Allergenicity

There is limited research on allergenicity changes in pollen under the effects of climate change. However, a six-year study at the Duke University Free-Air CO_2 Enrichment experiment demonstrates: "elevated atmospheric CO_2 in an intact forest ecosystem increases photosynthesis, water use efficiency, growth, and population biomass of poison ivy. The CO_2 growth stimulation exceeds that of most other woody species. Furthermore, high-CO_2 plants produce a more allergenic form of urushiol."[101] Urushiol is the rash-inducing allergen in poison ivy, poison oak, and poison sumac – the reason that all these plants start with the word "poison." While the urushiol in poison ivy is not an aeroallergen (and requires contact with the skin) these results suggest that the allergenicity of some plants may also increase with rising atmospheric CO_2 levels.[102]

iv. Pollen and Thunderstorms

Climate change appears to be driving an increase in the occurrence of severe weather events, such as thunderstorms. Climate models show that the future will hold more frequent severe thunderstorms, as the convective available potential energy increases due to our warming planet.[103] This is of concern to respiratory health because thunderstorms have been linked to asthma exacerbations.[104, 105] While asthma exacerbations can be due to a number of stressors, including increased ozone from lightning, thunderstorm-asthma is tied specifically to pollen allergies. D'Amato et al. (2007) explains:

> [T]here is evidence that under wet conditions or during thunderstorms, pollen grains may, after rupture by osmotic shock, release into the atmosphere part of their content, including . . . components that can reach lower airways inducing asthma reactions in pollinosis patients. The thunderstorm-asthma outbreaks are characterized, at the beginning of thunderstorms by a rapid increase of visits for asthma in general practitioner or hospital emergency departments.[106]

Essentially, thunderstorms break pollen grains apart into smaller, more easily inhalable pieces. Those pieces can penetrate further into the lungs, causing asthmatic events. Therefore, with an increase in the occurrence of thunderstorms, a corresponding increase in doctors' appointments and emergency room visits for asthma may result.

v. Pollen and Other Airborne Particulates

More and more research suggests that pollen has a substantially larger effect in the presence of other respiratory irritants. NRDC analysis shows that "110 million Americans live in areas with both ragweed and ozone problems" and individuals with respiratory health issues can have such issues exacerbated by either.[107] Most importantly, the two in conjunction (ragweed pollen and ozone increases) have more significant effects than either respiratory stressor alone. A 2006 study finds ambient particulate matter carrying allergens, like pollen and latex, adsorbed to the surfaces of particles.[108] This allows allergens to get into airways on the surface of other pollutants.[109] Furthermore, a 2010 study contends that urban air pollution causes damage to the tissues of the lungs, resulting in more severe allergic responses when exposed to aeroallergens.[110]

vi. Mold and Fungus

The relationship between climate change and mold or fungus is a bit more difficult to ascertain than the relationship between climate change and pollen; nevertheless, environmental changes driven by climate change (particularly changes in temperature and humidity over geographical areas) have the potential to affect the growth and allergenicity of mold and fungus. According to a 2008 study on the impacts of climate change and CO_2 on fungal spores, "predicted levels of atmospheric CO_2 change will not directly impact fungal processes in the environment. However, other climate change parameters that result from elevated CO_2, such as increased temperatures or changed precipitation regimes, may have pronounced effects on fungal abundance and/or activity."[111] Changes in leaf litter biomass can additionally increase the spore production of allergenic fungi.[112]

As with plant produced allergens, there is some evidence that fungi are becoming more allergenic over time. A 2013 study tested the common allergenic fungus Aspergillus fumigatus at a variety of CO_2 levels and found that rising atmospheric CO_2 levels are causing this common fungus to become substantially more allergenic.[113] This effect may taper as CO_2 levels continue to rise, but more research is necessary. That being said, for individuals already suffering from airborne mold or fungus allergies, this effect has the potential to harm respiratory health.

1. Increases in Temperature and Humidity

Over the next century, Chicago's climate is projected to grow consistently warmer, increasing the average temperature, humidity, and incidence of heat waves.[114, 115] These increases in temperature and humidity "will increase problems for those with allergies and asthma."[116] Unless dehumidification measures are undertaken, increased humidity will increase dampness in buildings, which, "appears to increase the risk for a number of health effects such as cough, wheeze, asthma, airways infections, tiredness, and headache."[117] While the driving mechanism behind these health effect increases is unclear, the association between building dampness and respiratory issues is a robust one.

Increased temperature and heat waves are also likely to encourage more use of air conditioning in buildings. Because air conditioners require maintenance to keep filters clean and avoid excessive condensation in or around the unit, increases in air conditioner usage may increase the incidence or prevalence of indoor allergens including mold and fungus.[118]

2. Increases in Mold and Fungi Resulting from Flooding

As discussed in the "Extreme Weather Events" section above, in addition to general warming, the Chicago region is likely to see an upswing in the number of extreme weather events, such as severe precipitation events and associated flooding like that seen in April of 2013.[119] Any increase in flooding frequency or duration can lead to mold growth. For example, "after Hurricanes Katrina and Rita made landfall on August 29 and September 24, 2005, respectively, large sections of New Orleans (Orleans Parish) and the three surrounding parishes (Jefferson, Plaquemines, and St. Bernard) were flooded for weeks, leading to extensive mold growth in buildings."[120] In fact, a study investigating airborne mold concentrations in flooded New Orleans homes after Hurricanes Katrina and Rita found that ten of the 13 samples (77%) taken within the flooded area of New Orleans were in the 99th percentile of historical spore concentrations and thus classified as "very high."[121] The study concludes, "the high concentrations of mold measured indoors and outdoors in the New Orleans area are likely to be a significant respiratory hazard that will be important to monitor over time."[122] Not only will increased extreme precipitation events lead to more flooding, but that flooding is liable to cause extensive mold and fungal growth and serious respiratory hazards.

Additionally, such flood damage is difficult to remediate successfully and may result in heightened airborne mold and fungus concentrations even after floodwaters have receded and homes have been cleaned. A Colorado study investigating homes that were cleaned and reoccupied after a large flooding event found that "when compared to large literature databases, culturing from air samples collected in houses reclaimed from flood damage had significantly higher airborne microorganism levels than in houses where no flood damage had occurred—in many cases this difference was between two and three orders of magnitude."[123] The difficulty in remediating flood damage can cause long-term problems for individuals with respiratory issues, increasing the hazards associated with floodwater-damaged homes (mold and fungal growth) for extended periods of time after flooding.

3. Toxigenic Molds and Climate Change

Toxigenic molds are molds that can produce toxins. There is an immense variety in toxigenic molds and they can produce all manner of symptoms. Some toxigenic molds can cause digestive issues, liver disease, seizures, psychosis and possibly even cancer.[124] In the indoor air environment, connections between many of these illnesses and mold exposure have been lacking.[125] However, some varieties of mold, such as relatively common Stachybotrys chartarum (i.e., "black mold"), have been associated with respiratory distress, as well as asthma development.[126] A 2004 Institute of Medicine report found "sufficient evidence to link indoor exposure to mold with upper respiratory tract symptoms, cough, and wheeze in otherwise healthy people; with asthma symptoms in people with asthma; and with hypersensitivity pneumonitis in individuals susceptible to that immune-mediated condition."[127]

Increased climatic variability in countries with commercial agriculture is causing the formation of more toxigenic molds, including Fusarium, which is linked to respiratory disease.[128] This is because "climate change is resulting in more extreme rainfall and drought events."[129] The confluence of extreme precipitation events punctuating longer, drier periods exacerbates issues in two ways. As one study on mycotoxins notes: "Alternating drought and flooding may contribute to mycotoxin production. Drought weakens the seed kernels of plants, allowing greater fungal contamination. Flooding causes moist conditions that promote fungal growth."[130] This allows for greater fungal contamination in grains and seeds used for food, which can affect wide swathes of the country and world, even if the original fungal contamination is isolated to a specific area.

e. Diseases

Vector-borne diseases are diseases that are transmitted by an organism, such as insects (ticks and mosquitoes are common vectors) and rodents (rats or mice, typically). Common examples of climate impacts on vector-borne diseases include the encroachment of dengue fever back into the American South as more areas become hospitable to dengue-transmitting mosquitoes, the spread of Lyme disease in North America as summers lengthen, and the appearance of the chikungunya virus (spread by mosquitoes) in the Caribbean and southern Europe.

While the public health effects of climate change on vector-borne diseases, generally, are substantial and well-documented,[131] there are relatively few concrete links between climate change and vector-borne *respiratory* disease. Nevertheless, the warmer, wetter weather likely to be seen in the Midwest and other parts of the United States is cause for concern. While there is no "smoking gun" linking climate change to vector-borne respiratory diseases, there are nevertheless a number of warning signs.

For example, a 2000 study links the 1991-1992 occurrence of the El Niño-southern oscillation (ENSO) and related increased precipitation with a 1993-1994 outbreak of hantavirus cardiopulmonary syndrome (HCPS) in the Four Corners states in the American Southwest.[132] Following this outbreak, a significant attempt was made to educate the public about the risks and prevention of hantavirus infection from rodents urine and droppings.[133] In spite of this public education push, the ENSO event of 1997-1998 was followed by another increase in HCPS in 1998-1999, particularly in areas with above-average rainfall.[134]

Likewise, a 2005 study of the Greater Philadelphia Metropolitan Area found a link between increased rainfall and occurrences of legionellosis 6-10 days (the incubation period of Legionella bacteria) later.[135] Legionellosis is a term for diseases caused by Legionella species, including Legionnaires' disease, Pontiac fever, and other cases of pneumonia. Studies posit that this increase in legionellosis is due to contamination of water sources with Legionella bacteria and sediment after increased rainfall, which reduces the effectiveness of chlorination.[136]

Outbreaks related to weather conditions such as these should be monitored moving forward, as they may increase with a changing climate that favors warmer, wetter conditions in the Midwest with increased occurrence of severe rainfall events.

f. Ozone

Climate change has the potential to increase ozone levels above where they would otherwise be, making progress toward controlling ozone smog more difficult even as health standards are tightened based on medical evidence and need. Without action to address precursor emissions, ozone pollution in cities like Chicago will continue to get worse. Given no changes in anthropogenic emissions, ozone levels in 50 eastern US cities would increase between now and the middle of the century due to the effects of global warming, and "cities that already experience elevated ozone levels under the current climatic conditions are predicted to exhibit the largest increases in ozone in the projected future climate scenario."[137] Areas such as Chicago would expect higher 1-hour and 8-hour maxima for ozone, as well as more National Ambient Air Quality Standards exceedance days/summer for ozone in the future.[138] Another assessment covering Chicago predicts that the number of summer ozone exceedance days will increase three- to eight-fold from current numbers, based on current precursor emissions and a variety of global climate scenarios.[139] This means that not only will Chicago's ozone levels increase, but there will be more Ozone Action Days where the city will have to advise citizens to conserve energy, limit their time spent outdoors, and limit their use of motors.

However, basing expected future ozone levels on current ozone precursor emissions may not be an accurate predictor of future ground level ozone levels. The EPA in conjunction with states has historically regulated ozone precursor emissions. Implementation of programs and policies aimed at reducing ozone have decreased the allowable levels of ozone precursors like nitrogen oxides and volatile organic compounds (VOC) over the years.[140] This course of action is likely to continue as lower concentrations of ozone are deemed unsafe by the EPA, the ozone NAAQS is tightened, and subsequent programs and policies require further ozone precursor reductions.[141] As recently as October 2015, the EPA tightened the ozone NAAQS to 70ppb.[142] In addition, the EPA's Clear Air Scientific Advisory Committee has noted that: "Some healthy individuals have been shown to have clinically relevant responses [to ozone], even at 60 ppb" and "children and adults with asthma are at increased risk of acute exacerbations on or shortly after days when elevated ozone concentrations occur, even when exposures do not exceed the NAAQS concentration of 75 ppb."[143]

i. A Brief Look at the Formation of Ozone

Ozone is a colorless gas found in the air, formed by electrical discharges and complex chemical reactions involving gases emitted both by natural processes and by many human activities and industries. Oxides of nitrogen (NO_X) and many reactive hydrocarbon compounds are key ingredients that interact in the atmosphere, ultimately forming an excess of ozone gas as a by-product.

In Illinois, the vast majority of NO_X is emitted from mobile emitters (such as automobiles, aircraft, and locomotives) and fossil fuel combustion (including industrial boilers, electricity generation, and commercial or institutional fuel combustion). Changing mobile emissions (through tighter federal tailpipe standards, vehicle fleet turnover, increased use of electric vehicles, and greater use of transit and non-motorized modes of transportation), as well as reducing fossil fuel combustion electricity generation, would be expected to reduce the ozone concentrations.

Interestingly, ozone can also be produced through electrical discharge.[144] Lightning is the primary cause of this production. In the middle and upper troposphere, summer lightning is the dominant producer of NO_X and O_3 and plays a small role in increasing monitored global background ozone levels, as some ozone from the upper troposphere diffuses down to ground-level.[145] In the lower troposphere, anthropogenic emissions play the dominant role, but lightning contributions can get as high as approximately 20% of the O_3 budgets in the summer.[146] Current data shows that thunderstorms are becoming more frequent, because the warming planet creates more convective available potential energy.[147] There is limited evidence that cloud-to-ground lightning in urban areas is also on the rise, as urbanization encourages the formation of thunderstorms and density of lightning flashes.[148, 149, 150] This increase may be due to urban heat islands, aerosol concentration, or both.[151] Thus, as the prevalence of thunderstorms and cloud-to-ground lightning increases with climate change, ozone concentrations could also increase where people live.[152]

ii. Where Ozone is Headed Globally – Background Levels

In recent decades, surface ozone worldwide has been on the rise, but that rise has begun to taper. The IPCC's Fifth Assessment Report (2013) states, "European surface ozone… more than doubled by the end of the 20th century. There is medium confidence from more widespread measurements beginning in the 1970s that surface ozone has increased at most (non-urban) sites in the [Northern Hemisphere] (1 to 5 ppb per decade)."[153] On the whole, surface ozone increased throughout the Northern Hemisphere over the 20th century, although it may not have increased over the Southern Hemisphere. However, that rise is coming to a halt in the eastern USA and western Europe. In these regions, "surface ozone … has leveled off or is decreasing."[154] This is likely related to a decrease in human industry generated ozone precursor emissions across Europe and North America and directly connected to active air pollution control policies begun in the 1970s, which have become progressively stronger.

Globally, scenarios assuming future low emissions of greenhouse gases show a decrease in surface ozone, while scenarios assuming high greenhouse gas emissions show an increase in surface ozone. For instance, the following maps from the USGCRP Assessment 2 show "projected changes in ground-level ozone (a component of smog) for the 2090s, averaged over the summer months (June through August), relative to 1996-2000, under lower and higher [greenhouse gas] emissions scenarios."[155]

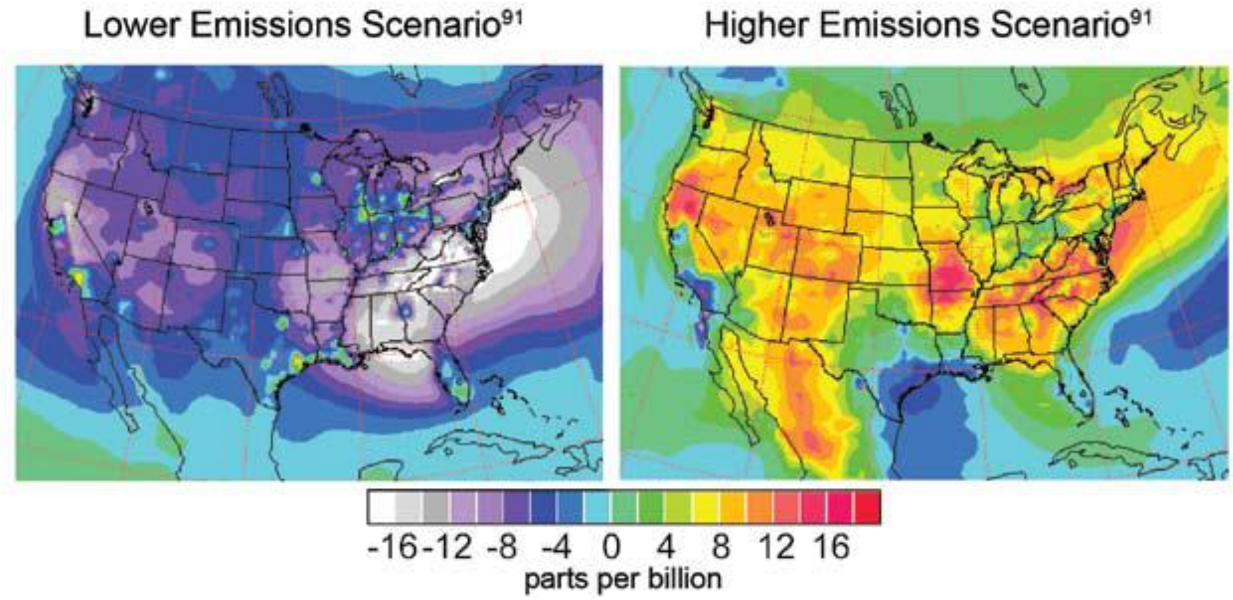

Figure 6. *Projected changes in summertime ground-level ozone for the end of the century (2090s), relative to the turn of the century (1996-2000). The scenario on the left shows projections for lower greenhouse gas emissions, based on the IPCC SRES B1 scenario. The scenario on the right shows projections for higher greenhouse gas emissions, based on the IPCC SRES A2 scenario.*

U.S. Global Change Research Program. (2009) Global Climate Change Impacts in the United States. Second U.S. National Climate Assessment.

While longer-term projections like these are somewhat uncertain, a recent study by Pfister et al. (2014) on future summertime ozone showcases the likely results of similar scenarios in the next few decades.[156] Pfister et al. (2014) contrast current anthropogenic emissions with scenarios in which emissions of nitrogen oxides and volatile organic carbons are reduced 60% to 70%, with interesting results.[157] A future with the current levels of emissions leads to a 70% increase in days with ozone above 75 ppb (an unhealthy level) by the year 2050. If nitrogen oxides and volatile organic carbons are reduced by 60% to 70%, however, ozone levels across the country would be reduced, and days over 75 ppb would drop to under 1% of the current total.[158]

Unfortunately, there is a lack of clarity on what will actually happen to future ozone levels, compounded by debate about what level of ozone is safe for human health. Several different drivers are likely to affect ozone levels moving forward. For instance, the IPCC states with high confidence that global warming will decrease background surface ozone.[159] This is because a warmer, wetter climate will actually enhance "ozone photochemical destruction in the lower troposphere" or break down ozone faster, offsetting ozone accumulations to some extent.[160] If levels of ozone precursors remained constant, this would lead to a lower background level of ozone.

On the other hand, many climate models suggest that this decrease would be rendered irrelevant due to higher atmospheric methane (CH_4) levels. Through a somewhat convoluted process, methane can oxidize in the atmosphere, creating formaldehyde and eventually yielding carbon monoxide (CO) and other byproducts. If enough NO_X is present, it can combine with the CO to create tropospheric ozone. According to the IPCC, higher levels of methane could raise ozone levels as much as 8 ppb (25% of the current global average) by 2100.[161] The IPCC performed a meta-analysis of a number of scenarios exhibiting different methane emissions to draw this conclusion. The higher the levels of methane in the atmosphere, the higher future ozone levels are projected to be. Models that accounted for changes in vegetation due to changes in temperature and atmospheric composition have shown a smaller total rise in ozone levels, but still show levels increasing in several parts of the world, including the Midwest and much of the eastern United States.[162] Atmospheric methane levels are on the rise, and have been for several decades. In 2012, atmospheric methane concentrations were 1,826 ppb, more than double pre-industrial levels.[163]

iii. Where Ozone is Headed Locally

An abundance of research demonstrates that rising temperatures and rising surface ozone in urban areas go hand in hand. For example, Jacob and Winner (2008) look at the Northeast and contrast the hottest summer (1998) with the coolest summer (1992) between 1980 and 2006.[164] They find that the hottest summer "experienced a record high number of exceedances" of ozone standards, and the coolest summer "had a low number of exceedances," with 1998 exceedances being a factor of 10 greater than 1992 exceedances.[165]

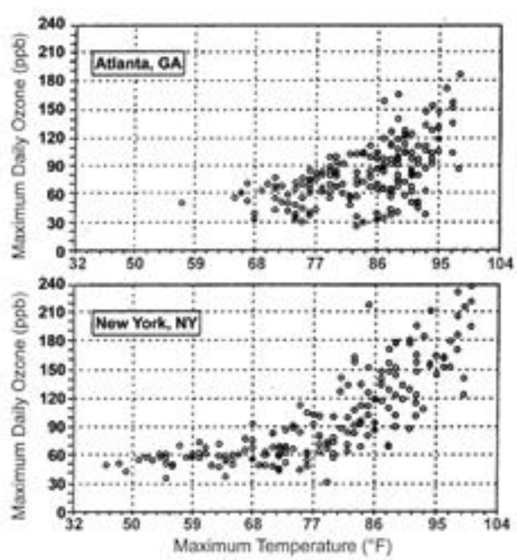

Figure 7. *These graphs from the USGCRP Assessment 2 plot temperature and ozone against each other and show clearly that rising ozone accompanies rising temperatures in cities as far apart as Atlanta, GA and New York, NY.*

U.S. Global Change Research Program. (2009) Global Climate Change Impacts in the United States. Second U.S. National Climate Assessment.

According to the IPCC's most recent report, "observational and modelling evidence indicates that, all else being equal, locally higher surface temperatures in polluted regions will trigger regional feedbacks in chemistry and local emissions that will increase peak levels of ozone and $PM_{2.5}$ (medium confidence)."[166] This bodes poorly for Chicago and other larger urban centers that struggle to keep their daily ozone maxima below current health standards. Although maximum ozone standards have decreased over the years in the Midwest, anticipated progress toward cleaner air may be eroded by these regional feedbacks.

For instance, Sheffield et al. (2011) predict "an increase in regional summer ozone-related asthma emergency department visits for children aged 0-17 years of 7.3% across the New York City metropolitan region by the 2020s [as compared to the 1990s]."[167] This study looked at individuals aged 0-17 around the New York City metropolitan region and found that, under a variety of scenarios, ozone-related asthma emergency department visits rose. All tested scenarios for the New York City metropolitan region showed increases ranging from 5.2% to 10.2% in ozone-related emergency department visits. Given this information, it appears more important than ever to lower ozone precursor emissions, since population redistribution and current ozone precursor emission levels (which could still increase in the medium term) could lead to increased ozone-related emergency department visits, as could rising asthma prevalence.[168] According to the CDC, asthma prevalence in the United States grew 15% between 1999 and 2009, and "the number of people diagnosed with asthma grew by 4.3 million from 2001 to 2009."[169, 170]

## III.	POLICY INITIATIVES AND THE PUBLIC HEALH RESPONSE TO CLIMATE CHANGE

Climate change has long been viewed by the public as primarily an environmental issue, rather than a health issue. Even as recently as March 2015, surveys indicate that less than half of American adults would describe climate change as a health issue.[171] Health has only recently begun to be addressed as a priority climate change issue. While most directors of local health departments already believe that climate change is affecting their communities, survey data shows that most feel that they lacked the expertise and resources to protect their communities.[172] Given these shortfalls, even when climate change has previously been addressed by public health practitioners, interventions have often gravitated towards adaptation more than prevention, such as the CDC's B.R.A.C.E. (Building Resilience Against Climate Effects) Framework, designed to help local health officials build strategies and programs to respond to climate change in their communities.[173]

2015 has seen an encouraging flurry of proactive public health activity addressing climate change. In April 2015, President Obama announced a series of initiatives to reframe climate change as a public health priority and to ultimately protect the public from the health impacts of climate change.[174] As part of these initiatives, the White House recently convened a summit known as the National Dialogue on Climate Change and Health, featuring diverse public health voices ranging from the American Public Health Association, to the U.S. Surgeon General, to United Farm Workers.[175] In response to this summit, a coalition of 14 national public health organizations issued a formal declaration affirming the public health community's commitment to addressing climate change as a public health issue.[176] In addition, a coalition of deans from 30 different medical, public health and nursing schools responded by committing to educating their students on the health effects of climate change.[177]

In June 2015, the prestigious medical journal, *The Lancet*, published a report stating that climate change "threatens to undermine the last half century of gains in development and global health," but that "tackling climate change could be the greatest global health opportunity of the 21st century."[178] Among the top strategies for tackling climate change the report recommends include reducing our reliance on fossil fuels, particularly by swiftly phasing out coal from the global energy mix.[179] The report also recommends that cities' increase development of energy-efficient buildings, bike and pedestrian-friendly transportation routes, and green space to reduce urban air pollution and greenhouse gasses, which could lower chronic disease rates, including respiratory disease.[180] One study detailed in the Lancet report found that in the U.S., improved health outcomes from such emission mitigation measures would outweigh the costs of such policies by more than ten times over.[181]

Likewise, the U.S. EPA published a report in June 2015 stating that a global agreement to phase out greenhouse gas emissions would prevent upwards of 70,000 premature deaths each year in the U.S. by the year 2100.[182] The report found that reducing our reliance on fossil fuels would alone prevent 57,000 premature deaths from poor air quality annually.[183] Up to 12,000 annual extreme heat and cold-related deaths in major U.S. cities could also be prevented under such a greenhouse gas mitigation scenario.[184] Public policy solutions to swiftly reduce greenhouse emissions and improve public health have been proposed and continue to be developed both locally and federally. The U.S. EPA has already set standards to reduce greenhouse gases and increase fuel efficiency from vehicles, both light duty and heavy duty. Light duty vehicles are currently responsible for nearly 60 percent of U.S. transportation-related greenhouse gas emissions.[185] Light-duty vehicle standards proposed in 2012 are projected to cut six billion metric tons of greenhouse emissions over the lifetime of vehicles sold between 2012-2025.[186] Likewise, the first phase of the standards to cut carbon emissions and reduce petroleum use among heavy duty vehicles is currently in the process of being implemented; the second phase of this program was introduced earlier this year and proposes to introduce performance-based standards beginning in model year 2021 and continuing through model year 2027.[187] These heavy-duty vehicle standards have the potential to cut one billion metric tons of greenhouse gases.[188]

Similarly, in mid-2015 the U.S. EPA finalized a rule to drastically limit greenhouse gas emissions from the largest sources of those emissions – fossil-fuel-fired power plants. Fossil-fuel-fired power plants are a leading driver of climate change and are responsible for 39 percent of the total carbon emissions in the U.S. Known as the Clean Power Plan, the EPA's proposed rule would reduce emissions from U.S. power plants by 30 percent by 2030.[189] A recent study by the Harvard School of Public Health estimates that a power plant carbon standard would prevent up to 2,100 premature deaths, and 760 hospitalizations from conditions including respiratory diseases between 2020-2030 in Illinois alone, in large part by substantially reducing levels of fine particulate matter and ground-level ozone.[190]

Figure 8.

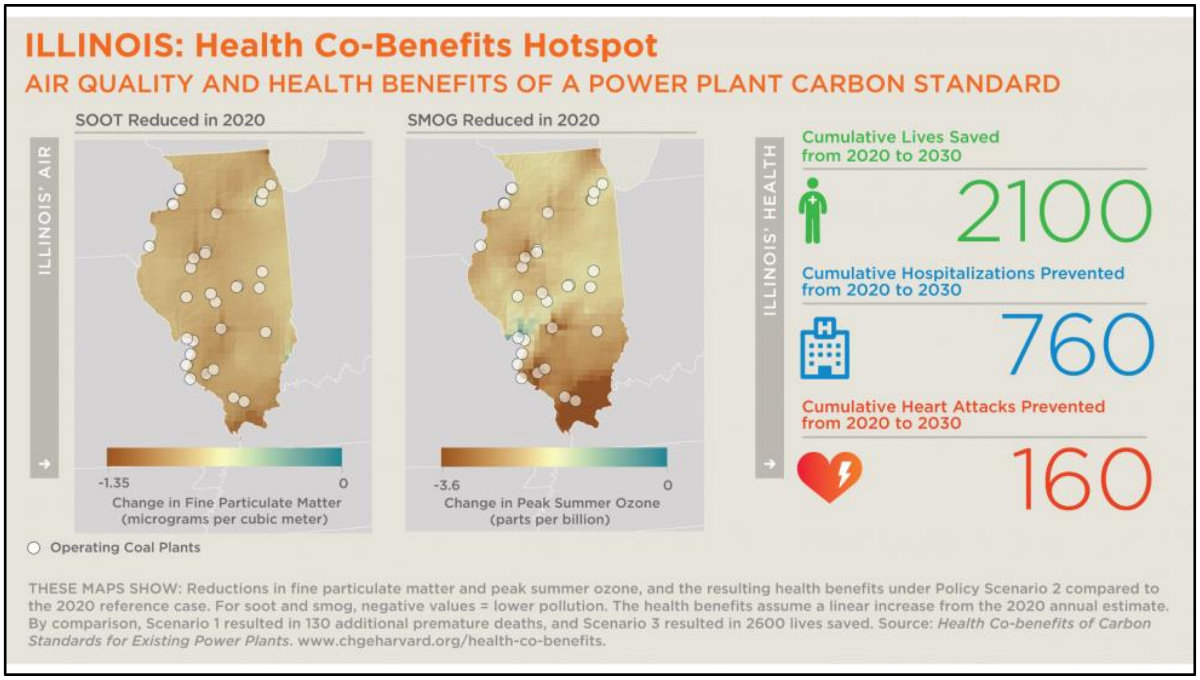

Image Source: Harvard T.H. Chan School of Public Health, Center for Health and the Global Environment. (2014) Infographics: Health Co-Benefits of Carbon Standards for Existing Power Plants. Retrieved from http://www.chgeharvard.org/resource/infographics-health-co-benefits-carbon-standards-existing-power-plants.

IV. CONCLUSION

As the climate warms, changes both drastic and subtle will affect the lives of people living with lung disease. Increasingly, extreme summertime heat waves will increase morbidity and mortality among the most vulnerable people first. People living with chronic lung disease who already face daily challenges with medication, mobility, stress regulation, and access to care, among other needs related to living with chronic illness, are more susceptible to those dangers than individuals living without such challenges. Unfortunately, increasingly unstable and extreme winter weather may not offer safe harbor the other end of the year. Warming has already increased extreme rainfall events in number and size, presenting immediate and secondary dangers from flooding. More extreme, deeper droughts may increase air pollutant burdens, ranging from exposure to more dust and more smoke, to breathing more ozone smog. Allergy triggers will also likely increase with the projected changes in climate, driven by increases in pollen, potential increased exposure to mold and fungi, and weather-related effects that can increase allergenicity of such triggers.

Such changes present the risk of hindering the steady progress that has been made in reducing air pollution and reducing the threat to public health through regulatory action at the federal, state and local levels. Reports from U.S. and international agencies, as well as reports from many organizations, have documented numerous other health threats that are expected to increase with a warming climate. Clearly, climate change is escalating a number of health challenges that will become increasingly problematic for people living with lung disease and other chronic conditions, as well as those living without constant health challenges. Across the Midwest, climate changes driven by global warming will increasingly disrupt weather patterns, raising the number of extreme events as time marches forward.

Doing nothing to reduce the greenhouse gas emissions we collectively continue to inject into the atmosphere will only make future climate disruption worse. While greenhouse emissions already in the atmosphere will continue to warm the planet and disrupt the climate many years into the future, reducing the emissions our activities create going forward will ensure that we do not create a situation that would bring even more extreme and dangerous climate disruptions. Simply put, we must begin to reduce these emissions.

While the scope of the effort to reduce emissions, as well as a full analysis of specific strategies aimed at reducing greenhouse gases is beyond the scope of this white paper, it is hoped that the impact of climate change on lung health inspires the reader to explore and understand those policy options, and ultimately, to support prudent efforts to reduce greenhouse gas emissions in order to protect human health and well-being.

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