Comprehensive Examination

Mitigating the Impact of Superfund Sites and Pollution on Phoenix Residents

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ABSTRACT

This document is the written portion of Jennifer Weiler's comprehensive examination, submitted to the School of Arts, Media + Engineering in partial fulfillment of the requirements for the degree of PhD in Media Arts and Sciences at Arizona State University in April of 2016. Committee members comprise Todd Ingalls (chair), Dr. Stacey Kuznetsov, and Loren Olson.

This work examines the effects of current Superfund sites and other pollution on residents in the Phoenix area. It then describes specifics of different types of pollution and how they can be detected and combated by individuals. This also includes analysis of past grassroots efforts to combat pollution and the possibilities of citizen science collaborations between residents and researchers. The paper then proposes specific prototypes that could be implemented on a personal or community-wide scale to combat contaminant exposure, and then concludes with a timeline for future research and prototype implementation.

Keywords

Superfund, pollution, air-quality, DIY, analog-recording, air-filtration, ozone, oxidation, copper

INTRODUCTION

As industrial production and the human population continue to rapidly expand, the unfortunate chemical byproducts of manufacturing and machinery have started to become a serious health hazard to the people it was meant to serve. This is especially true in dense population centers, where there are extensive amounts of industrial activity, which cannot be mitigated by the local environment, since most of the natural ecosystem has been removed or reduced.

Currently, 81% of the population of the United States lives in urban areas, compared to 53% of the world's population [1][1]. Because many of these people live in urban areas in order to maintain economic security, it is imperative that they find ways to mitigate the potential health problems of prolonged pollution exposure without resorting to relocation.

Like many cities around the world, Phoenix is facing challenges protecting its residents from industrial pollution. Within the last 150 years, the Phoenix metropolitan area has gone from an agrarian farming community to a state capital with a population of over 4 million [2]. In part, this population boom has occurred due to government polices that made Phoenix a destination for industry and manufacturing in the decades after WWII [3]. These incentives included a low minimum wage, few industrial regulations, and potential work with the military air force base stationed in the area [4].

Unfortunately, the relative lack of regulations, unforeseen risks, and occasional industrial accidents led to several instances of massive environmental pollution, which placed both the local population and wildlife at risk of short and long-term health problems. The potential human exposure is exacerbated by Phoenix's rapidly growing population, which is pushing residential areas into previously unoccupied desert that many have been acceptable dumping grounds for hazardous materials [4]. While clean up efforts have been underway at many of these sites for decades, people in the area are still at risk of exposure from the still remaining chemicals [5]. In addition, there are concerns about unknown pollutants, which may not be detected until people begin to experience symptoms of related illnesses, which could take years or decades to develop [6]. While it is difficult to know for certain all pollutants that may be affecting a particular community, by mitigating the affects of known pollutants through increased detection and filtration, it may be possible to increase a community's overall health.

SUPERFUNDS

The Environmental Protection Agency's Superfund program is designed to diagnose, cleanup, and monitor sites within the United States that pose a threat to public health or the environment. The Superfund program was first established in December 1980, when the EPA was given the authority to clean up waste sites and spills that were not properly controlled by the state and local governments [7]. The new authority granted to the EPA was due to several large-scale environmental disasters, and increased awareness of the potential dangers of chemicals and toxic waste sites [6].

The EPA determines whether a polluted location is severe enough to be considered as a Superfund based on several factors, which are gathered by reviewing existing reports and documentation as well as an on-site inspection by an EPA official [8]. The danger posed by the site is analyzed by scoring the location based on the Hazard Ranking System (HRS), which determines whether the site is dangerous enough to qualify to be on the National Priorities List (NPL). The HRS scores the severity of a site based on the likelihood that a site has the potential to release hazardous substance into the environment, the toxicity of the waste involved,

[1] Typically, the population living in towns of 2,000 or more or in national and provincial capitals is classified as urban [1].

and the people or environment who could be affected by the release [9]. If a site scores high enough, it is placed on the NPL, where it is open to receive federal remedial (long-term) cleanup funds. However, in some cases the site is approached as a Superfund-Alternative (SA), where the EPA works with an independent group who has volunteered to take charge of the cleanup. This group can be a corporate entity or private citizens who have negotiated and signed an agreement with the EPA to perform the investigation and cleanup. The SA approach is rarely used and only accounts for a small percentage of Superfunds [10].

Current Superfund Sites in Phoenix

Within Maricopa County, there are currently five federal Superfund sites that are still going through cleanup and monitoring [5]. All five locations were first designated as Superfund sites in the eighties and speak to Phoenix's large industrial growth that occurred in the decades following WWII [3].

Indian Bend Wash Superfund Site: Industrial solvents containing volatile organic compounds contaminated groundwater in the Scottsville area. Some residents experienced upper respiratory tract and eye irritation, kidney dysfunction, and neurological effects after drinking well water.

Phoenix-Goodyear Airport Superfund Site: Military Aircraft chemicals entered the airport's drainage channels, contaminating the groundwater and soil. There were no perceived human health risks, since the groundwater is not connected to drinking sources. However, endangered species in the area could be threatened.

Hassayampa Landfill: Hazardous waste deposited at the landfill contaminated groundwater, air, and soil. The area is surrounded by undeveloped desert, but several thousand acres of farmland is irrigated by water near the site [5].

Motorola Inc. Superfund Site: The Motorola plant, the Honeywell facility, and possibly other industrial sites spilled and leaked chemicals into the area, contaminating the groundwater, soil, and air. Recently, state officials have chosen to stop studying instances of cancer and birth defects related to the Superfund due to limitations in the cancer registry [11].

Williams Air Force Base: Organic solvents, paint strippers, petroleum spills, metal plating wastes, hydraulic fluids, pesticides and radiological wastes contaminated groundwater and soil around the base [5].

While pollutants can spread in unforeseen ways, the locations and descriptions of Phoenix Superfunds can give us a strong indication of what areas and people are at the greatest risk.

Local water contamination is most likely to affect people who acquire their drinking water from wells or other local sources. For example, in the case of the Indian Bend Wash Superfund Site, it was specifically people who drank well water in the Scottsville area who became ill [5]. Fortunately, the majority of residents in the Phoenix area get their water from the Phoenix Water Services Department, whose water largely comes from the Salt, Verde, and Colorado rivers. Before the water is pumped to residents, it is treated in a four-stage purification process, composed of screening, coagulation, filtration, and disinfection [12]. While there are always risks, the tap water delivered to Phoenix residents has consistently met or exceeded all federal and state drinking water standards [12][13].

Although air pollution can travel large distances, people who live close to the source of the contamination are most likely to suffer the worst repercussions. For most Superfund sites caused by industrial pollution, the working class families who live near the factories are often the most at risk. In Phoenix, planning choices in the decades after WWII put factories and production centers near dense, low-income communities [4].

Current Brownfield Sites in Phoenix

The EPA defines a brownfield as a property whose expansion, redevelopment or reuse may be complicated by the presence of a pollutant or contaminant. Examples of potential brownfield sites include abandoned gas stations, old factories, airports, landfills, old dry cleaners, and junkyards [14]. Begun in 1955, the brownfields program is designed to allow local governments and communities to work together to prevent, analyze, and clean these sites [15].

One of the larger-scale brownfield projects in the Phoenix area was propelled by the construction of the light-rail system. Because large numbers of people would be using the light-rail for daily travel, the EPA chose to assess selected properties within 100 feet of the 13-mile Light Rail Corridor. In the 2004 report justifying the four hundred thousand dollars that would be spent assessing possible hazardous substances and petroleum spills, the EPA stated that the light-rail transportation was needed to meet the anticipated growth of the city in coming years [16]. It also lists Phoenix as a federally designated Enterprise Community, meaning that some residents and businesses are eligible for tax credits, lower utility rates, and grants aimed at stimulating the economy to alleviate the strain on lower and middle class families [17].

Other Pollution in Phoenix

Not all pollution affecting the residents of Phoenix can be tied to a specific site or accident. Unfortunately, much of the contaminants affecting the people of Phoenix are the result of the everyday actions of its citizens. Phoenix is currently rated 12th worst metro area in air quality nationwide, based on its unhealthy levels of ozone and particle pollution [18].

While researching pollution in Phoenix, I was able to speak to Katelyn Parady, who dealt with the problems of pollution in Phoenix while she was a PhD student in ASU's School of Human Evolution and Social Change. Ms. Parady, who focused on the affects of pollution in certain neighborhoods in south Phoenix, noted that the industrialization of Phoenix was not uniform. Overwhelmingly, the factories and large roadways are centered in low-income, minority neighborhoods, which results in those communities disproportionately facing the health affects of pollution. In addition, she stated that many members of the community expressed concern about the health effects of pollution, since there were an unusually high number of children in the area who were suffering from asthma and other respiratory ailments.

TYPES OF POLLUTION

The EPA's Hazard Ranking System categorizes four different pathways for determining pollution: ground water, surface water, soil exposure, and air [9]. Ground water and surface water are considered separate, since ground water primarily affects drinking water, while surface water can also affect sensitive environments and the food chain. Since this paper focuses specifically on the human effects of pollution, ground water and surface water are combined into one category.

Soil

Soil contamination largely affects the land close to the source of the pollution. If the land is part of a wildlife preserve or will be used to grow crops, there is risk of contaminants in the soil entering the food chain and eventually being consumed by humans or endangered species. Depending on the location of the contamination, soil pollution that is water-soluble can leach into the groundwater and travel away from the original site [19]. In addition, the Phoenix area is known for occasional dust storms that could redistribute soil contaminants.

Because soil is not consumed daily by Phoenix residents, any contamination will not have as direct an effect on the health of the local population.

Water

Due to Phoenix's subtropical desert climate, which is characterized by its high temperatures and lack of precipitation, there is a need for special attention focused on the quantity and quality of the city's water supply [20].

Common Water Pollutants

Water pollution can vary heavily based on the local ecosystem and the nature of any industrial production in the surrounding area. However, there are some common contaminants that are known to carry severe risk or detriment to human health. Whether naturally occurring or a product of human negligence, it is imperative that communities stay vigilant against materials that could transform a human necessity into a health hazard.

Microorganisms: There are many bacteria and viruses that naturally exist of water bodies that could make the water unsafe for human consumption. While the EPA recommends criteria to limit pathogens in water, state and tribal governments have the discretion to set their own water quality standards [6].

Nitrates: Nitrogen is a commonly occurring element that is naturally present in both the atmosphere and soil. As part of the nitrogen cycle, aerobic bacteria will convert soil ammonia into nitrates, which are beneficial to plants [21]. However, high concentrations of nitrate in groundwater are often an indicator of the presence of fertilizer or human/animal wastes [22]. Additionally, high nitrate levels in drinking water can cause blue baby syndrome, in which parts of the body, including hands, feet, and mouth, may turn blue due to decreased ability of blood to carry oxygen [23]. In the past, activists have attempted to tie nitrates more closely to biological waste in order to raise public consciousness to the potential dangers of exposure. British water chemist Edward Frankland had hoped to combat the 19th century public's apathy towards nitrate pollution by measuring contamination in units of "previous sewage contamination," a term that would cause a clear association between fecal matter and nitrates. Not all nitrate pollution is caused by sewage, but unless the actual source of the nitrates can be determined, it is very difficult to distinguish whether the nitrates originated from body waste [24].

Heavy Metals: Heavy metals are defined as metallic substances of higher atomic weight, including cobalt, copper, mercury, lead, and cadmium. While some heavy metals are beneficial in trace amounts, all can cause serious illness if they are over accumulated in the human body [25]. Often, lead and other heavy metals leach into tap water due to problems in service lines and home plumbing. Because of this, the risk of lead exposure can vary wildly between houses using the same water source [13].

Chlorinated Solvents: Byproducts of manufacturing, chlorinated solvents were specifically mentioned in several of the Phoenix Superfund sites. While chlorine can be used to rid water of dangerous microorganisms, unregulated chlorinated solvents of unknown chemistry could cause serious health risks. Most notably, residents near the Indian Bend Wash Superfund Site who drank well water contaminated by chlorinated solvents suffered from a range of serious health repercussions, including problems with respiration, kidney function, and neurological function [5].

Detecting Contaminants

Unfortunately, in many cases hazardous materials are first detected when residents become ill and undergo medical testing. This was seen recently in Flint, Michigan, where the first testing proving a definitive problem in lead levels was done through blood tests on children, despite the fact that residents had been complaining about their water quality for months [26]. By then, many residents had already been exposed to levels known to cause irreversible damage [27].

In order to determine any contamination in water, it is important to analyze water as it comes out of the tap, since many water containments, including lead and other heavy metals, can leach into the water from service pipes [26]. In order to get comprehensive results on any water contaminants, it is recommended to send water samples to a professional lab for testing [28][29]. There are some tests that can be done on site, but the materials and processes required for them may be beyond the skill set of the average resident. For example, one test for lead requires sodium rhodizonate and de-ionized water [30]. Many contaminants are difficult to test for because they do not chemically react many stimuli in a way that is observable by the naked eye [29][31].

It is possible to test for the overall "dirtiness" of water by using a filter to check for contaminant buildup, but the results would also represent the harmless substances that are in water, such as calcium and magnesium. While these are responsible for lime buildup in sinks and showers and reduced soap effectiveness, they pose no health threat and would give misleading indications of the amount of dangerous contamination in the water [32].

Solutions

There are chemical solutions capable of extracting dangerous materials from water, but when used improperly they can also cause damage to human health. For example, EDTA (Ethylenediaminetetraacetic acid) has been able to remove 95-97% of lead from contaminated materials [33]. In cases of acute lead poisoning, EDTA has been intravenously administered in order to bind to heavy metals in the bloodstream so that the kidneys can filter them out. However, EDTA may cause side effects ranging from low blood sugar to organ damage, seizures, and death [34]. Because of these potential health risks, it seems ill advised for residents concerned about lead in their water to attempt to filter it with EDTA without professional scientific or medical supervision.

Instead of chemically treating their tap water, many residents would likely find it less labor intensive and more effective to install one of the many commercially available types of water filters. In addition to the protective measures of a water filter, Phoenix residents may already be using filters for reasons such as taste and temperature. Many Phoenix residents complain about an odd taste to their water. The City of Phoenix 2010 Water Quality Report attributed this "musty" taste to algae that grows in the canals during the late summer and fall, which results in a lingering taste even after the algae is removed during the filtration process [12]. In addition, temperatures in Phoenix can easily top 100 degrees Fahrenheit during the prolonged summer season, which can result in a lack of cool running water available for residents [35]. In order to get cooler drinking water, many residents choose to store their water in a refrigerator before consuming it, which could encourage residents to use a container with a filter as a storage device.

In the case of the Indian Wash Bend Superfund Site, it was individual wells that were being polluted with chemicals [5]. However, if there were ever a case where a household hooked up to the main water utility found dangerous substances in their water, it would be extremely helpful to the larger community that they report the problem quickly. While the contamination could be limited to that one residence, having a warning system in place would enable others in the area to check their own water before they are exposed to additional pollutants.

Air

Like many large population centers, Phoenix is set in a flat valley surrounded by more rugged geography. Because of this, air and air pollution can become trapped over the metro area. This is not helped by the Phoenix metropolitan area's rapidly growing population, which reached over 4 million in 2015, nearly doubling its population in twenty-five years [2]. Phoenix has become the 6th largest city in the United States, but at the cost of being the 12th worst metro area in air quality [36][18].

Common Air Pollutants

The EPA defines the two most dangerous types of air pollution as particle pollution and ozone. Particle pollution is tiny solid and liquid particles that originate from sources like car exhaust and other industrial production [18]. There are two kinds are particulate matter, the first being "inhalable coarse particles," which are found near roadways and some industries, are between 2.5 and 10 micrometers in diameter. The second kind, "fine particles", are less than 2.5 micrometers in diameter and can be categorized as the smoke and haze emitted by factories and fires [37].

Ozone, the most widespread air pollutant, is created when sunlight interacts with car exhaust and other emissions [18]. Stratospheric ozone, located six to thirty miles above the Earth's surface, is formed through the interaction of ultraviolet radiation and oxygen, and helps protect the Earth from ultraviolet radiation. Ground level ozone, on the other hand, is largely formed from photochemical reactions between volatile organic compounds and nitrogen oxides, both of which are largely formed by industrial activity [38]. Because ozone is not water-soluble, the respiratory tract has a hard time filtering it out of inhaled air. Once deep inside the lungs, ozone starts to oxidize organic tissue, causing damage to the lung tissue and blood vessels [38].

Detecting Contaminants

The EPA measures six air pollutants - Carbon Monoxide, Lead, Nitrogen Oxide, Volatile Organic Compounds, Particulate Matter, and Sulfur Dioxide – at the county level across the United States [39]. However, even within a small area there can be large discrepancies in air pollution, so it would be beneficial for people to be able to measure contaminants in their local air.

To analyze air, there are commercially available air pollution detectors, as well as DIY instructions of how to build a pollution detector with gas sensor and Arduino parts [40]. In addition, there are materials, including fabrics, which are sensitive to pollution and will, over time, will show the results of being exposed [41]. While these materials do not give the instant results that electronic pollution detectors can provide, they can present a clear, visual explanation of the effect of pollution, which may convey the presence of contaminants more compellingly than numbers on a screen.

Solutions

For most types of air pollution, dust masks are not effective. The paper masks are designed to trap large particles such as sawdust, but are ineffective against fine particles and ozone [42]. The EPA provides a daily air quality forecast, which can notify residents of current levels of several local pollutants, and can predict when certain pollutants will be unusually high [43][44]. During these times, those concerned about pollution can avoid it by staying indoors. By tracking daytime pollution, which likely corresponds to the amount of nearby traffic and industrial activity, residents can avoid going out when contaminants are relatively high.

While most industrial pollutants are released into the outdoors, many people are exposed to worse air quality while indoors, due to the buildup of particles from building materials, household products, and organic matter. To combat this, the EPA recommends isolating or sealing off materials that release contaminants, improving ventilation, and using an air cleaner [45].

COMMUNITY PARTICIPATION

The goal of this research to is help individuals deal with the affects of pollution, and as such it is imperative that the information is presented in such a way as to encourage residents' investment and participation.

Measuring and Conveying Environmental Threats

Scientists are researchers are often outsiders to the communities they are attempting to help, and thus may purposely or accidentally exclude the local residents from the process of discovering, monitoring, and combating pollution. Often, when government bureaucracy or a private corporation is coordinating cleanup efforts, non-scientists are often excluded from risk-assessment and "cost and benefit" analysis, despite the fact that they are often the ones who will be most directly affected by potential health hazards [20].

When researchers are from a DIY background or working for an independent lab, there may be additional levels of distrust from the community. These largely stem from concerns that the researchers may be engaged in irresponsible or secretive practices, and these suspicions have only increased with the growing public awareness of potential threats such as bioterrorism [46].

Despite these obstacles, there has been a long history of attempting to engage citizens in the scientific discourse related to public health. During the 1800s, when communities were first becoming aware of the potential health hazards of manufacturing and dense urban living, many of the attempts to increase quality of sanitation focused on spreading awareness of dangerous substances in the water supply and informing the population of good health practices to reduce the spread of disease [20][24]. After the 1930s, the focus of community health switched to prioritizing the immunization and health of the individual "host" as opposed to the "environment," since the latter was seen as harder to control [20]. While this makes sense for some communicable diseases, it is unfortunately not possible to immunize people to the affects of pollution, and thus the personal approach to medicine leaves the underlying cause of many sicknesses in modern society unaddressed.

Another way that common research methods fail to take into account the real life concerns of people is the method and limitations of data collection. If a potential health problem cannot be measured or categorized, it is unlikely that it will be understood or mitigated [47]. Recently, the government stopped attempting to determine cancer cases connected to the Motorola Superfund site due to difficulties in correctly tracking cases. Because the canceled study was set up to track cancer cases in the area around the site, they would not be adding cases of people who had lived in the area but moved away before developing cancer, and would be including cases of people who had recently moved to the area and developed cancer unrelated to Superfund exposure [11]. Because the government feels it cannot accurately track the damage caused by the Superfund site, they choose not to track it at all, which results in both researchers and residents being in the dark about the potential dangers of the site. As a result, there is reduced likelihood that any damages will be properly assessed and addressed.

In addition, the health standards the government sets can be misleading, as the standard of acceptable levels of pollution varies by nation. While the World Health Organization does put out guidelines of known risks of certain contaminants, it acknowledges that each country is in charge of its own health standards, and that those standards will vary according to how that nation chooses to balance health risks, technological feasibility, and economic considerations [48]. As a result, citizens cannot always count on the government standards of what is "safe" to truly be so, which further underlines the need for individuals to take an active role in protecting their health.

Encouraging Community Involvement

One of the most powerful and effective ways to encourage community involvement in a project is to promote research that reflects the preexisting concerns of that community [20]. Often, the community's concerns are based on their particular circumstances, and can vary wildly between areas of the same city. For example, in downtown Phoenix, only 3% of residentially zoned areas directly border industrial zoning, compared to 35% of neighborhoods in South Phoenix [49]. As a result, the residents of the two areas likely have very different levels of concerns as to the presence of industrial pollution, and their suggestions for remedying the problem.

Fortunately, when it comes to dealing with pollution, there are already official avenues for the community to become involved in the process. In order to allow for community participation, the EPA allows qualified community groups to apply for grant money to hire an independent technical advisor, which encourages both community initiative and independent oversight outside of the government [10]. Community members also have power as consumer citizens, wherein they have some choice over what kinds of products and industries are encouraged based on how they spend their money [50]. However, this process has to occur on the macro-scale, and is not likely to result in fast, substantial changes on the local level.

It is also possible that members of the community are aware of potential dangers but may be unable to find accessible ways of addressing the problem. In such a case, it should be the goal of those outside of the community to provide opportunities for residents to help themselves. If the goal of the research is to encourage individuals in affected communities to engage in a new behavior, the community members should be part of the group initiating and designing the research that is meant to help them [51][52][46].

Designing for Community Involvement

A common theme when trying to encourage community involvement is the need to present information in ways that the user finds easily accessible [51][52]. Often, this takes the form of using physical or analog objects, which the user can interact with in a way that they cannot with a completely digital item [51][52][53][54].

Furthermore, using sensors that exist naturally in the environment can help encourage a higher level of understanding of the interconnectivity of the causes and results of disturbances to the community. For example, by monitoring natural sensors, such as fish and bee behavior, many hobbyists are able to spot a problem before it appears on digital sensors [54]. On the other hand, parts of the environment can be coopted to help gather additional information. In London, air pollution sensors are being placed in tiny backpacks and strapped to trained pigeons, which then fly specific routes over the city to record air pollution [55]. The information gathered by the pigeons is then used to spread public awareness about London's air quality, in hopes that public pressure will force lawmakers to pass new environmental regulations.

PROTOTYPING SOLUTIONS

While the genesis of this project focused specifically on Superfund sites, we have chosen to focus on broader pollution problems that have the potential to effect all residents in the Phoenix region, regardless of their geographic position relative to specific polluters. In addition, the decision was made to focus on air pollution, since air is something that affects everyone in the community, and the current air pollution in Phoenix is notably bad when compared to other parts of the country [18].

In order to encourage community participation and personalize the potential affects of contaminants, there was emphasis placed on making potential prototypes that would be easy for residents to use and understand the results of. While digital tools can be extremely useful for precise measurements, the number data they provide could prove obtuse to someone who is not familiar with pollution standards or does not understand the potential harm of different contaminants. Instead, this project has focused on analog pollution detectors, since a visible physical reaction to the presence of potentially dangerous particles will likely make a more lasting impression on the user [6].

Air Particle Pollution Sensing

In order to create an affordable analog pollution detector, it is necessary to utilize materials that is relatively inexpensive and could clearly display a physical alteration after being exposed to pollution. An EPA report on the effects of pollution on fabrics found that synthetic fabrics, particularly nylon, are the most sensitive to pollution due to the hydrophobic nature of the fibers and their electrostatic charge, which will attract air particles [56]. In addition, nylon is listed as being highly sensitive to ozone, which causes the fabric to loose strength and elasticity [41].

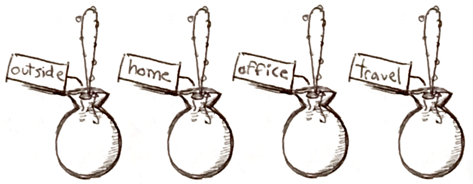

Figure 1. Personal Pollution Recorder Design. A series of small balls covered in nylon located in multiple locations the user regularly visits in order to gauge relative buildup of air pollution.

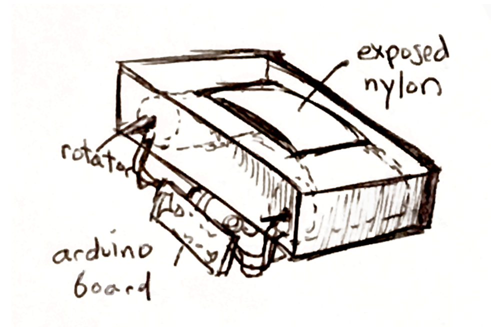

Figure 2. Air Quality Daytime Tracking. A simple mechanism that uses an Arduino controlled rotor to expose different parts of a nylon fabric to air pollution during different times of the day. Would be useful in determining the best times to be outdoors to avoid excess air contamination.

Personal Pollution Recorder

Small analog pollution recorders could prove useful in allowing individuals to better track where they are being exposed to the most pollution during the day. Each recorder would be a piece of nylon fabric wrapped around a Ping-Pong ball or ball of Styrofoam attached to a string or keychain (fig. 1). A person could be given several to place in various locations where they spend time (such as in their living room, backyard, or place of work), and carry one with them at all times. In addition, one recorder would be sealed in a plastic bag to avoid all air pollution. By comparing the amount of air particle damage on the nylon over several days or weeks, the user would be able to better determine where they are exposed to the most pollution. This would also offer insight to how they could best address the quality of the air they breathe. For excessive indoor air pollution, this may mean investing in better air filters or minimizing use of appliances that generate air particles [45]. If the problem is mostly stemming from outdoor pollution, this could mean limiting time outdoors or changing their daily schedule avoid times with higher air pollution, such as rush hour [42].

Air Quality Daytime Tracking

Air pollution can vary wildly in a single location depending on the time of day, especially in areas near factories or streets with heavy traffic [18]. One way that people living in these areas can avoid exposing themselves to extra air contamination would be to schedule their routine to avoid going out during the times with heaviest air pollution. However, in order to do that, they must be able to determine the general degree of air pollution at different times.

One way to detect changing air contamination throughout the day would be to expose different parts of a sheet of nylon to the air. To do so, one would need to construct a simple ardunio-controlled mechanism that would turn a rotator to expose different parts of the fabric at different times. The system could be programed to automatically roll the fabric back to its starting position overnight, and then repeat the process the next day. This way, the machine could be left unattended to build up visible contamination over several days or weeks (fig. 2).

Figure 3. Pollution for good: design for a small contraption that mixes ozone pollution with hydrogen gas to produce enough water to keep a small desert plant alive.

Based on the air quality of the area, the resulting pattern of discoloration in the fabric could show uniform pollution throughout the day or a definite spike in particles in the air at certain times. In addition, by comparing the results from several nearby locations, it may be possible to create an hour-by-hour mapping of the relative pollution in different areas within a community.

Challenges with Detecting Dangerous Air Pollution

As previously mentioned, there are many types of air pollution, and their relative danger to humans is based largely on their size. The smaller the particle, the easier it is for it penetrate deep into the lungs, causing greater damage to the lung tissue and possibly entering the bloodstream [18][37]. While nylon’s charged surface attracts both large and small particles, it is likely that larger particles will more visibly dirty the fabric due to their greater size. Because of this, nylon may give misleading examples on the presence of dangerous pollution, as a piece of fabric exposed to large, less-dangerous particles may appear dirtier than one exposed to smaller particles [56].

In addition to the discoloration, nylon is also noted to loose elasticity in the presence of ozone. However, the “stiffness” of the fabric may be difficult to visually determine, especially if the nylon is purposely shaped around an object [41].

Ozone Sensing

In hopes of creating a detector that could accurately record the presence of a specific dangerous pollutant, the focus of the research switched to finding materials that could visually show the presence of ozone. As one of the leading causes of Phoenix’s overall air pollution problem, ozone is something that affects all residents of the Phoenix Metropolitan area [36]. Ozone’s danger comes from its volatile nature, as it will easily chemically react with other molecules causing potential damage to organic tissue [38]. However, because it is so reactive, ozone can also combine with many other compounds in the environment, many of which can transform it into a harmless or helpful substance. By exposing ozone to certain materials, it may be possible to induce chemical reactions that reduce the presence of the dangerous substance within a local area.

Oxidizing Agent

Because ozone is composed of three unstably linked oxygen atoms, the most obvious means of transforming it into a benign substance is to get it to give up its third oxygen atom and revert back to O_2, which is regular oxygen that we are able to breathe. This process of donating oxygen atoms is called oxidation, and can be catalyzed by bringing ozone into contact with several different types of materials [57][58][59].

Of all the potential molecules that ozone can interact with, hydrogen gas appears to produce the most positive result. By oxidizing the hydrogen gas, the two molecules combine to form oxygen and water, which are both extremely beneficial to human health:

$O_3 + H_2 => O_2 + H_2O$

However, hydrogen gas is highly flammable, and as such should not be sprayed cavalierly into the air or used as a widespread solution to ozone pollution. However, it would be possible to create small installations using hydrogen gas that display the possible benefits of turning ozone into oxygen and water. For example, the water produced by the reaction may be enough to keep a small desert plant alive (fig. 3). Such a system could display the possibility of using a pollutant to create water in a desert environment, and thus help people to revaluate their preconceptions about how pollution can affect our lives.

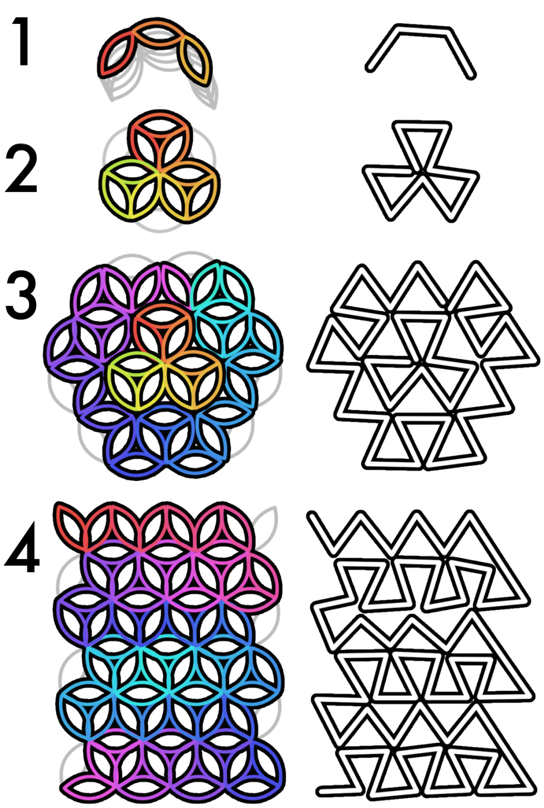

Figure 5. 1: (left) One cut and folded section as viewed from the side and (right) visualization of how the different folded sections are connected. 2: a small ring of connected sections. 3: large ring of folded sections. 4: rectangular space filled with connected folded sections.

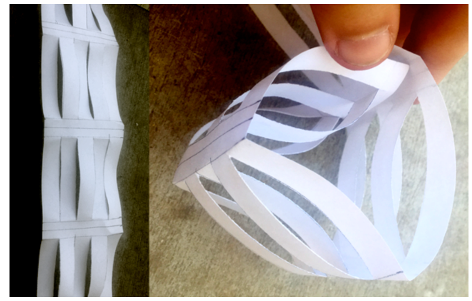

Figure 4. Left: slits cut into paper. Right: paper folded into shape to minimize size while maximizing surface area.

Two other atoms that can also be oxidized by ozone but are not flammable are copper and iron [41]. When copper is oxidized, it absorbs a single oxygen atom, turning the ozone (O_3) molecule into an oxygen (O_2) molecule. In contrast, when iron is oxidized, it absorbs the entire ozone molecule, meaning that it will not create additional oxygen, but will remove dangerous ozone from the atmosphere:

$O_3 + 2Cu => O_2 + Cu_2O$

$2Fe + O_3 => Fe_2O_3$

When iron becomes oxidized it changes from a reflective grey color to a matte red (a process which is often colloquially referred to as “rusting”) [41]. Pure copper, which is a shining orange-bronze color, will darken to black-brown, and then turn a pale green when completely oxidized [67]. Both of these changes are visible with the naked eye, and do not require advanced or expensive tools to measure changes.

In order to decrease the amount of ozone being consumed by residents of Phoenix, it could be useful to install iron and copper installations around the city to absorb the ozone. Because ozone is formed by combining volatile organic compounds (which come from chemical plants and gasoline pumps) and nitrogen oxides (which come from power plants, industrial furnaces, and motor vehicles), it would likely be most effective to have the installations placed near roadways and factories, where they could absorb the newly formed ozone before people are exposed to it [38].

Other particles, such as water, which always has some mix of unattached oxygen and hydrogen atoms in it, can also act as oxidizing agents. However, given the low amount of humidity and precipitation in Phoenix, the vast majority of oxidation that will occur will be the result of the city’s oversupply of ozone [35][57].

To allow the installations to be reusable, it is possible to use heat and hydrogen gas to remove the extra oxygen atoms from the iron and copper. The hydrogen and oxygen combine to form water, leaving the metal purified and capable of absorbing more ozone out of the atmosphere [60]:

$Fe_2O_3 + 2H_3 => 2Fe + 3H_2O$

$Cu_2O + H_2 => 2Cu + H_2O$

Folding Architecture

The goal of the iron and copper sculptures is to be able to absorb as much ozone as possible relative to their total mass. In order to do this, they should have as much surface area exposed as possible. One means of achieving this goal is to use iron and

Figure 6. Foil cut into portable trinket.

copper foil, which are both commercially available [61][62]. The foil can then be cut to further increase its surface area, and then folded in order to decrease its overall size, making the overall piece compact but with a large amount of exposed surface that can react to ozone while at the same time being aesthetically pleasing (fig. 4) [63][64]. In addition, these designs open up possibilities to be scaled for large installations or pocketsize items depending on the concerns of the user (fig. 5)(fig. 6).

In order to help people create designs to fill a particular space, we would supply them with tools to make the visualization and implementation process easier. These could exist as both low and high-tech solutions. To help people visualize the shapes that can be created using segments triangles (fig. 5), it would be useful to supply them with triangle-based graph paper to plot out ideas (fig. 7). For more complex ideas, a computer program could generate options of what type of shapes could fill up a specific area, instructions for how to cut those shapes, and information about how much material would be needed.

Other Metal-Based Materials

In addition to foil, there are other versions of these metals that may also prove effective as part of sculpture installations. Copper and iron are also available in mesh form, which would have an even greater surface area than the foil [63][65]. However, the structural integrity of the mesh after being cut could prove questionable, which would limit what kinds of sculptures, could be created with it. In addition, the mesh may be so thin that its structural integrity could be compromised by the oxidation, causing it to break or disintegrate and thus not be reusable.

Also, there is also a copper paint available that contains real pieces of copper [66]. If this paint is able to successfully react to ozone, it could be an interesting alternative that could allow users to paint whatever objects they have available, or create complex 3D printed objects that are too complex to fold by hand [64].

TIMELINE

Looking forward, this research is focused on further development of specific designs to create foil artifacts that can withstand the outdoor environment of Phoenix for extensive periods while performing their tasks of absorbing ozone from the atmosphere. While the potential objects produced by this project are scalable for both personal use and large-scale installations, in the immediate future this research is focused on continued development and testing of the foil, mesh, and paint materials to ensure that the oxidation will occur. There will also be a focus on getting feedback from Phoenix residents as to their thoughts on the potential effectiveness of these installations, as well as their general concerns about the degree and types of pollution in the Phoenix Metropolitan area.

Development

Over the summer, we will develop several more designs for creating cutout shapes to fill areas of specific size. In order to prototype more advanced models, we plan to use the aid of computer algorithms to create both designs and instructions for constructing more advanced forms.

Additionally, we will be developing a program that can record and analyze the amount of oxidation that occurs on a specific sheet of metal, so that it will be possible to precisely determine the relative effectiveness of different materials when they are being tested.

Testing

In order to ascertain the effectiveness of different available materials (iron and copper foil, mesh, and paint), we will invest in a small sample of all three and expose them to an outdoor ozone rich environment in order to observe the rate at which they oxidize. Depending on the speed of oxidation, the initial testing could take a few weeks to a few months. This experiment will also help determine the affects of oxidation on the structural integrity of materials. Ideally, the foil, mesh, and paint are able to maintain their shape without cracking or disintegrating.

This experiment should also test for possible user interaction problems with the installations. For example, since ozone is partly produced by chemicals emitted from vehicles, it was suggested to place these objects near the road where they can most efficiently absorb the ozone. However, if the metallic shine of the material causes a glare that could inhibit the ability of drivers to see clearly, the location of the installations would obviously have to be reconsidered.

After the initial experiment is complete, and the materials have been partially oxidized, we will attempt to use heat and hydrogen gas to reverse the oxidation process, thereby allowing the pieces to oxidize several times without needing to be discarded and replaced. Due to the highly flammable nature of hydrogen gas, this experiment will likely be conducted with the assistance of someone with experience working with combustible materials in an area that can contain and extinguish any potential fire.

Community Involvement

In order to gauge community interest in this approach to pollution detection, we would like to setup several workshops to allow people to experiment with the materials and proposed uses, and get feedback about the positive attributes and potential pitfalls of the prototype. In addition to the workshops, we hope to encourage

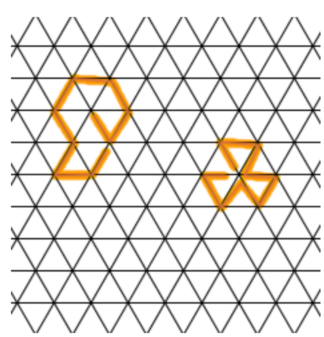

Figure 6. triangle graph paper to plot ideas

residents to create and record their own results using these materials and techniques, either in large installations or small mobile pieces.

These workshops should be completed after the further development and testing, so that we have a clear understanding of any physical limitations of the materials before introducing the project to residents in the area. As such, these workshops should probably take place during the next academic year, assuming that all material testing can be completed over the summer. In addition, since we will be supplying the materials for the workshop, including iron and copper foil, we will likely need additional time to request funding, since the materials needed for this workshop can become expensive if we are interested in possibly creating larger installation pieces.

In order to create greater interest for this project, we hope to plug in to existing nature and gardening communities. These groups are composed of local residents who have some level of interest in health and nature, and are confortable with the slower results of gardening. Some examples of gardening communities in the Phoenix area are *Growing Together Phx*, *The Micro Farm Project* and *Arizona Community Gardens* [68][69][70]. In the future, we envision people monitoring and sharing their results through both social media groups and community events, in a similar matter to how gardening communities will share information about their resulting produce. By doing this, we will hopefully gain a broad net of information about the differences in ozone pollution in different areas and during different times.

Long Term Data Gathering

Although all residents of the Phoenix Metropolitan Area are affected by air pollution, different areas of the city could be dealing with varied degrees of contamination. The locations of polluters, such as industrial centers and freeways, may cause certain communities to be at greater risk. To test whether this is true, identical foil sculptures will be placed in different neighborhoods within the Phoenix Metropolitan Area. Since the pieces will be small, this can be accomplished by asking individuals within the community to place the objects outside of their homes. By showing the buildup of air quality over a period of weeks or months, it is possible to obtain an accurate reading of the overall pollution in the community, instead of potentially inaccurate readings from only a specific time of day. If the results do show disparate affects of pollution, it may help spur awareness and action to cleanup the most affected neighborhoods.

Since the problem of ozone is present in all industrial areas, we would like to develop an online presence in order to inform individuals around the globe to the potential benefits of this project. In doing so, we would encourage residents who have used these techniques to document the work they had made and the results that oxidation has on the works over time. This would allow us to share the results of our research and keep track of the work of individuals who have embraced our solution. In addition, it would also allow us to find out the comparative effectiveness of the metal foil in different climates. For example, an area with high humidity or lots of rain may cause the foil to oxidize faster, making it a less effective metric of ozone presence in those areas.

If this project is successful, the online community will become active by the end of fall and will continue for years to come.

Evaluation

The success of this project will need to be evaluated in several steps. To begin, it is necessary to insure that the materials used will oxidize within a matter of weeks or months. In addition, the testing needs to establish that the materials have noticeable visible variety in the rate of oxidization when exposed to different levels of pollution. By comparing results from pieces placed in different areas of the city, we should see a noticeable difference in the rate of oxidation.

The workshops with members in the community will help us gauge general interest in the area and determine if this is a viable community-based project. Once members of the community are introduced to this approach to record pollution, we will be able to track how successful the information collection is by monitoring online updates as well as observing attendance and participation at the monthly get-togethers of the gardening communities. Ideally, through a mix of online presence and local interaction, we will be able to spread interest in this research to people throughout the Phoenix Metropolitan Area.

CONCLUSION

As individuals, we have very little control over the current industrial production and regulations that result in the levels of pollution we are exposed to. However, in order to help insure health and longevity, residents near polluted sites must find ways to mitigate the potential damage of prolonged exposure. In the Phoenix area, there are several superfund sites that have poured dangerous materials into the local environment that could still affect residents living near the site decades later. In addition, the everyday air contamination caused by local industry has caused Phoenix to have one of the worst air pollution records in the country. Unfortunately, it is very difficult to detect most particles using widely available materials, while others are difficult to filter out without the use of professional equipment. In addition, the division between pollution experts and the residents of areas affected by pollution can lead to distrust and uncertainty as to the best way to address the current risks of exposure.

This report has focused on proposing analog solutions to pollution detection and reduction. The first example, nylon fabric, could be used to attract and display air pollution. However, since nylon attracts all types of air particles, not just dangerous ones, it may have limitations as a means of detecting and mitigating pollution. To specifically target ozone, a molecule that forms at ground level as a result of industrial activity and can cause serious health damage due to its unstable, destructive nature, this paper has proposed using materials that would be easily oxidized to either trap the ozone or turn it into oxygen. By using iron and copper foil, it is possible to create lightweight structures that offer plenty of surface area for ozone to oxidize while still maintaining a physical structure. These pieces provide a visual example of the presence of ozone while simultaneously helping to neutralize the potential health threat. By using hydrogen gas to return the metal foil to its original state, these pieces can be used several times.

Going forward, we hope to create workshops to better access community interest and set up installations of copper and iron foil in public areas to measure the presence of ozone. Hopefully, this project will make people more aware of the physical affects pollution that exists around them while also working to mitigate potential harm.

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