Potential Best Practices for Environmentally Friendly Noise Walls

White Paper | December 2019

Hillsborough MPO
Metropolitan Planning for Transportation

CONTENTS

SECTION 1: EXECUTIVE SUMMARY

As urban populations and the amount of highway drivers increase, traffic related noise continues to place a burden on properties adjacent to the roadway. In addition to noise, community members in these neighborhoods are also affected by vehicle emissions and other traffic-related pollutants. Transportation agencies have become increasingly aware of such issues and as a result, have put great efforts into attenuating both. To reduce noise levels, noise walls are typically recognized as the most effective method by the Federal Highway Administration (FHWA). Noise walls are generally capable of reducing noise levels by 5-10 decibels (dBa) for nearby properties. Since the dBa scale is logarithmic, achieving a 10-dBa decrease in noise is the same as cutting noise levels in half. Furthermore, noise walls can provide other visual and environmental benefits, which is why they have become such a common practice around the country. The design and construction of noise walls provides opportunities to improve the sustainability of transportation projects by addressing the social, economic, and environmental concerns of the implementing agencies and community members. Throughout this White Paper, the term sustainability is used to reflect the balancing of social, environmental, and fiscal objectives over a long-time horizon:

- The social benefits of noise walls include their primary purpose as noise attenuators, but this paper also recognizes the potential for noise wall design elements to address other potential societal benefits such as providing healthier air, improving privacy, and contributing to community identity,
- The environmental benefits of noise walls include improved air quality and energy generation, depending on selected design elements, and
- The fiscal considerations associated with noise walls revolve around the affordability of the design elements that provide social and environmental benefits, as well as the direct or indirect economic benefits such as property tax revenue that can be associated with those benefits.

Sound barriers have been used around the world, and extensive literature exists documenting their effects and identifying best practices. Substantial research on sound barriers have been conducted in the United States as well as abroad in nations such as the Netherlands, Denmark, Germany, England, and Australia. The topics covered include policy and regulations around noise and vibration impacts, the effectiveness of different noise attenuation materials and designs, innovative abatement strategies, and general practices for roadside noise barriers. Issues of noise and air pollution are the same for affected communities, but the ideas and methods to alleviate the effects vary in nature. This White Paper analyzes global best practices for environmentally friendly noise walls and offers recommendations for the transferability of lessons learned globally to applications in Hillsborough County, particularly considering the planning and design processes used by the Florida Department of Transportation (FDOT). This White Paper defines "potential best practices" as a continuum of practices, programs, and policies that range from emerging, promising, and leading to those best practices that have been extensively evaluated and proven effective, as indicated in Figure 1 (Spencer et al., 2013). A challenge exists in defining a bright line between established best practices and emerging, promising, and leading practices; a limiting definition might argue that best practices are defined by current noise wall regulations. Yet, as the public health industry demonstrates, the continuum of practices is in a constant state of flux. The upshot of this white paper is that noise walls can be effective in providing a range of community benefits beyond noise reduction, yet the current regulatory environment inhibits the application and evaluation of potential best practices, requiring innovative partnerships and funding to both achieve, and document, the greatest environmental benefits.

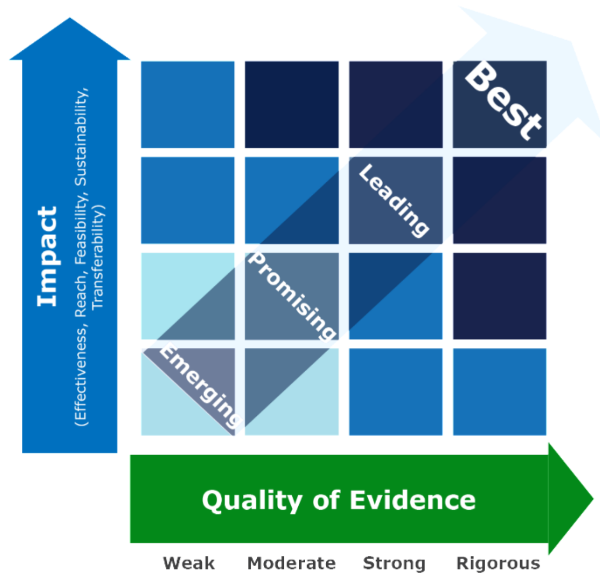

Figure 1. Continuum of Practices (*Source: Centers for Disease Control*)

NOISE WALLS CAN DO MORE THAN ATTENUATE NOISE

This evaluation revealed improvements can be made in each of the areas listed above. Various types of noise barriers and materials achieve different levels of noise attenuation. Solid concrete walls are the most common, providing reliable noise reduction at the most economic price. However, other materials and designs can achieve broader goals. New technological innovations or greening aspects can be integrated into the design with the intention of improving air quality. Alternative noise wall designs may increase pollutant dispersal abilities while others absorb or break down harmful pollutants themselves. Impacts on roadside environments can be minimized with living barriers and other landscaping considerations. Including native and self-sustaining species adapted for the local environment enhances the physical appearance, minimizes maintenance, and provides additional social and environmental benefits.

The same design characteristics used to improve air quality will have lasting effects on the health of adjacent neighborhoods. Noise walls reduce roadside air pollution concentrations by up to 50 percent, reducing associated risks such as cardiovascular or respiratory illnesses. Special considerations should be given to disadvantaged community members along the area that are disproportionately burdened by impacts of traffic noise and pollution. Inhabitants within 200 meters of a busy roadway are exposed to the highest concentrations of air pollution and are often society's most vulnerable populations. Since barriers will be additions to their communities, the residents should be able to easily participate in the decision-making processes. This paper also addresses the concern to minimize disturbance from construction processes.

Other technological advancements offer chances to generate electricity as well as attenuate noise. Agencies have experimented with incorporating solar panels to produce renewable energy. Others have attempted to make small wind turbines powered by vehicular turbulence a feasible addition. Both methods provide opportunities to harness the benefits of private-public partnerships that ultimately improve local communities. Proactive thinking regarding landscaping can result in numerous environmental and health benefits.

REGULATORY "SILOS" CAN HINDER BEST PRACTICES IMPLEMENTATION

An analysis of FDOT's current practices found the focus of noise barrier design has remained on better modeling noise impacts/benefits independent of other environmental benefits. This focus is a result of continued federal regulatory focus on noise reduction for sensitive receptors as the sole criterion regarding barrier cost-effectiveness, and therefore funding eligibility. As the industry's knowledge base increases over time, so too has the consideration of a wide range of environmental effects on the surrounding community. However, both federal and state funding regulations have limited the degree to which noise walls have become accepted practice. This White Paper describes the best practices in noise wall treatments pertaining to the following areas of interest: noise attenuation, air quality, public health, disadvantaged populations, energy generation, landscaping and aesthetics, and construction impact mitigation. This paper also suggests opportunities for advancing these practices within the current regulatory environment.

This White Paper discusses sustainable practices that are applicable to noise walls throughout Florida. These practices include strategies to reduce air pollution, generate electricity, and enhance roadside environments. Case studies also introduce the use of non-typical materials to reduce the project's carbon footprint. The contents of this White Paper are intended to assist FDOT and local communities by providing information on innovative strategies that merge noise abatement with sustainable practices.

FINDINGS AND OPPORTUNITIES

The memorandum provides several recommendations for noise wall implementation generally divided into two categories: one category focused on lessons learned for noise attenuation purposes and another set considering the potential for cross-disciplinary benefits beyond the primary noise attenuation purpose. For further pursuit within both categories the paper proposes establishment of an interagency

Noise Wall Working Group to collaboratively explore opportunities to advance the types of practices described in the following pages.

SECTION 2: PURPOSE AND SCOPE

The purpose of this White Paper is to describe best practices for the design of environmentally friendly noise walls. The paper is based on a review of academic studies and industry sources for national and global noise wall design practices and an assessment of the applicability of the identified design applications for the Florida context.

The bulk of this paper identifies best practices for the design of noise walls that have been most successful in achieving broad environmental goals. In addition to literature research using key word searches, the following other resources were scanned: the Transportation Research Board database (TRID), professional associations (such as the Institute of Transportation Engineers, National Association of City Transportation Officials, etc.), and various FHWA sites. FDOT District 7 staff provided helpful context from their local experience and guidance requested through the Department's participation in the American Association of State Highway and Transportation Officials (AASHTO) Noise Work Group.

Based on this research, the White Paper identifies completed and planned projects involving environmentally friendly noise walls and notes key features, descriptions, and characteristics. In addition, the White Paper research assessed the noise wall applications to identify demonstrated project success in achieving environmental goals and innovative project elements.

Based on the practices identified through literature research, the White Paper describes and clarifies the environmental benefits achieved or expected from the best practices. This includes answering the following questions, where supporting information is available:

- What makes this project truly successful from an environmental perspective? What are the estimated environmental benefits?
- What are the best practices that were employed for project success? What challenges were faced in the implementation of the noise wall application?
- What are the lessons learned?
- What is the applicability of the noise wall application in the Florida context?

SECTION 3: EFFECTS OF BEST PRACTICES

Roadside noise barriers, acoustical barriers, sound walls, noise walls and sound barriers are all synonyms for any physical structure placed between noise sources and noise-sensitive receptors. These 'obstructions' may serve a multitude of purposes in addition to noise attenuation, and in recent decades have been used to help achieve broader environmental goals. Noise barriers have become an increasingly common component of road infrastructure as communities have grown around highways and new roads are constructed near neighborhoods. This section discusses existing best practices for noise wall designs that attenuate noise, improve air quality and public health, address the concerns of disadvantaged populations, and even generate energy.

3.1 - NOISE ATTENUATION

Traffic noise is reported to be the most common source of noise affecting urban populations, and this trend will likely continue as both urban population and road traffic increases. Sources of traffic noise are vehicle motors, vehicular exhaust systems, and tires interacting with road surfaces. The diagram in Figure 2 shows how noise generation is affected by vehicle speed, traffic volume, and the type/size of vehicles.

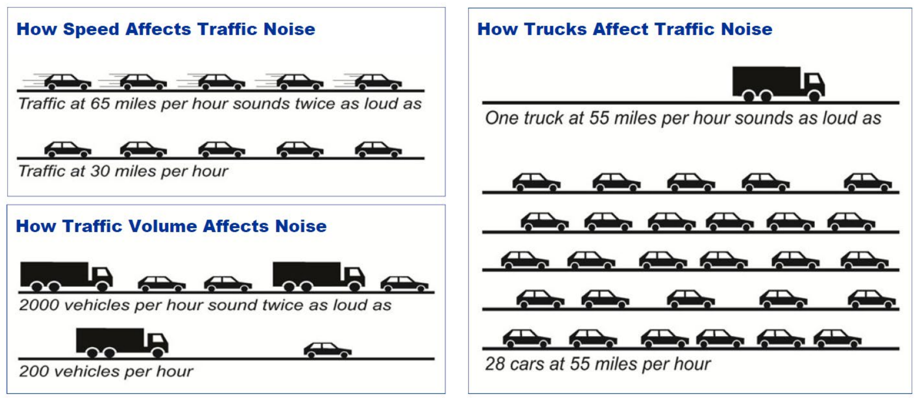

Figure 2: Diagram showing how noise levels are influenced by speed, number of vehicles, and type of vehicle. *(Source: PennDOT*)

Literature shows there are numerous problems resulting from traffic noise. Although the level of noise generated by vehicular traffic is not high enough to directly damage ear functions, long-term noise exposure has been linked to physical stress and health problems. Stressors such as annoyance, communication interferences, sleep disturbance, and reduced efficiency at completing tasks can induce physical problems such as high blood pressure, insomnia, and fatigue (Bluhm et al., 2004; Griefahn et al., 2000; Ohrstrom and Skanberg, 2004).

While it is possible to begin addressing the problems at their sources, the most common solution for reducing traffic noise is to construct roadside sound barriers. The Federal Highway Administration has a vast amount of resources on noise barriers covering the topics of abatement, acceptance criteria, design and construction, inventory, and research. Their research has shown noise barriers can reduce the measured acoustic noise by as much as half if it is designed properly by following current best practices.

Design guidelines ensure that the height and length of the barrier are sufficient to minimize sound that gets diffracted over the edge. To achieve a 5-dBa reduction, the barrier must be taller than the line-of-sight (each additional meter in height reduces sound by approximately 1.5-dBa) and four times the length of the distance between barrier and receiver (FHWA (d), 2017). Two basic, yet effective noise barriers are noise walls or earthen berms, with each having their own advantages and disadvantages. Common materials for walls include concrete, steel, aluminum, timber, safety glass, and acrylic. Most existing walls are constructed out of precast concrete due to its relatively low price and maximum noise reduction properties. Berms are an alternative to walls that simply consist of earthen materials and offer opportunities for natural landscaping. For design considerations, the slope of berms should be no more than 2H:1W (WSDOT, 2016). Therefore, the extra space requirements can often rule out the option of berms where there are right-of-way constraints. Any of these treatments (noise walls, earth berms, or combinations of the two) are appropriate solutions to effectively mitigate noise impacts. However, the choice of which to use depends on the local context, particularly the right-of-way constraints for using berms.

A 2004 pilot study in Japan described an innovative strategy to reduce noise at the receptor. Along National Route 43 in the Hyogo Prefecture, existing noise walls did not reduce ambient traffic noise to allowable limits. In response, the Hyogo National Highway Office decided to build an additional noise barrier in front of an elementary school adjacent to the roadway. The 4.5-meter wall would have been surmounted with speakers that generated anti-phase sounds, reducing noise levels by about 4-dBa in experimental stages (JPS, 2004). The speakers contained microphones that picked up traffic noise and emitted a noise that counteracted and eliminated some of the noise from reaching the school. However, the article published by *Japan for Sustainability* (2019) which discussed this project was published prior to the construction, and as of October 2019, Japanese officials have yet to report their conclusions on monitored effectiveness or the durability of the devices. This study proposes an innovative strategy to reduce noise impacts, but the technology currently available is most effective at reducing noise at the receptor.

3.2 - AIR QUALITY

Air quality is a function of a variety of characteristics of both the natural environment (related to climatologic elements such as topography and prevailing winds) and built environments (including stationary and mobile emissions sources). Within the Tampa Bay region, the Hillsborough Environmental Protection Commission reports on air quality non-attainment areas per standards maintained by the US Environmental Protection Agency. In 2018, two non-attainment areas for lead and sulfur dioxide, in the vicinity of industrial land uses including the CSX Yeoman Yard and in East Tampa, were redesignated as achieving attainment.

Heavy vehicular activity on major highways and interstates also generates concentrated air pollutants. Traffic related pollutants emitted by motor vehicles include greenhouse gases or particulate matter, which can be further broken down to include ultrafine particulates (UFP), black carbon, nitrogen and sulfur oxides, hydrocarbons and carbon monoxide (Brugge et al., 2007). The areas within 200 meters of major highways are often identified as pollution zones where people are much more likely to be exposed to the harmful pollutants.

Projects including field studies, laboratory experiments, and computer simulations have been conducted to link the exposure to traffic-related air pollutants to health problems. Short-term exposure can exacerbate existing health conditions and long-term exposure can greatly increase the risk of developing diseases and early mortalities (Pope and Dockery, 2012). Ultrafine particles of hydrocarbons and metals (iron and nickel) pose serious health risks to some of the most vulnerable community members: children, teenagers, the elderly, and those with pre-existing conditions. Environmental justice issues must also be noted because vulnerable, low-income or minority communities also tend to live alongside busy roads (Rowangould, 2013). The American Lung Association has compiled research concluding these populations are more likely to be faced with the onset of childhood asthma, impaired lung function, poor cognition, adverse birth outcomes, dementia, and others such as cardiovascular and respiratory diseases and chronic obstructive pulmonary disease [COPD] (ALA, 2018). To mitigate the effects of air pollution at the receptor, building designers can take extra steps to increase the quality of indoor air. Renovations to clean and reseal air ducts, adding new windows, and installing air-intake systems with maximum ability to capture particulates will help protect their vulnerable inhabitants.

Roadside noise walls also serve as barriers to air pollution. Studies have demonstrated the ways in which this occurs and the effectiveness of dispersion by the walls. Brechler and Fuka (2014) conducted a study which determined that noise barriers affect the dispersion of highway pollutants in three ways. Models display that walls increase vertical dispersion, induce vertical mixing (in the air cavity behind the wall), and loft emissions above the barrier itself (Brechler and Fuka, 2014).

Furthermore, research led by Hagler et al. (2011), analyzed the vertical distribution effects of near-road pollutant concentrations from sounds barriers of different heights. The results of this study are shown in Figure 3, concluding that a 3 meter barrier (described has half-height) reduced downwind concentrations by roughly 20%, and an 18 meter barrier (described as 3x height) reduced concentrations by as much as

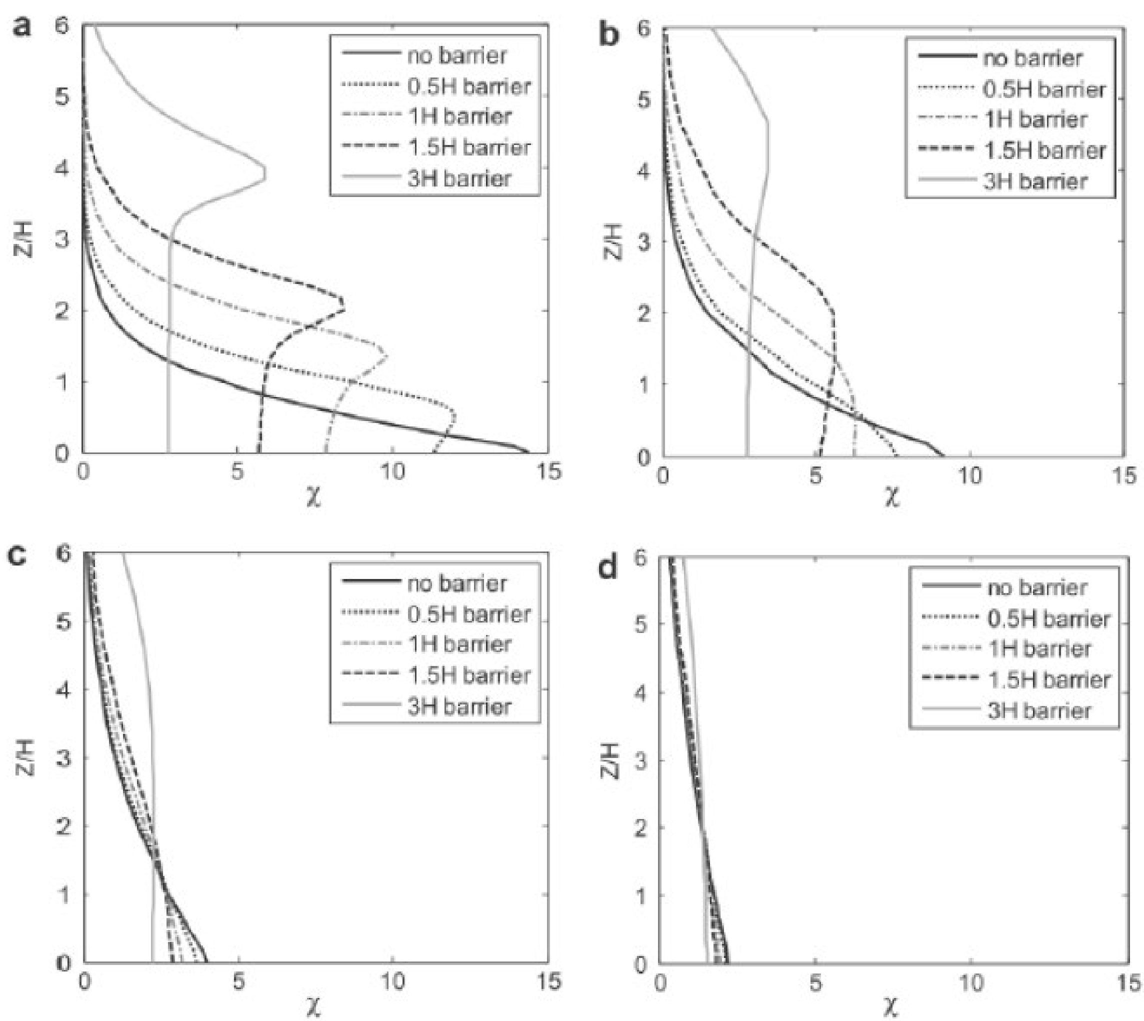

Figure 3: Vertical distribution of near-road pollutants of sound barriers of various heights, Vertical distribution of normalized concentrations (χ) at 20 m/3.3H (a), 50 m/8.3H (b), 150 m/25H (c), and 300 m/50H (d) from the edge of the roadway under perpendicular winds, for barriers of 3 to 18 m (9.8 to 59 feet) compared with a no-barrier scenario. The barrier is located 9.5 m (approximately 31.2 feet) from the road edge (*Source: Hagler et al., 2011*).

70% compared to no barrier at all (Hagler, et al., 2011).

A 2016 study by Baldauf et al. highlighted the influence of noise walls: downwind concentrations of pollutants were reduced by up to 50 percent behind the barrier. These reductions extended up to 300 meters from the road (984 feet), with the highest reductions within the first 50 meters (164 feet) of the road. This finding suggests that road barriers produce a gradient of air quality improvement with the greatest improvement benefiting the same sensitive receptors that noise walls are designed to protect.

Dense foliage by itself has also been shown to be effective in reducing pollutants with canopies over 16 feet (five meters) in height to sufficiently intercept most mobile source pollutants (EPA, 2016). The benefits of foliage can provide additional air quality improvements when combined with sound barriers. The California Air Resources Board (CARB) has developed a landscaping model for design practitioners based on research by Paulson et al. (2017) showing that addition of foliage (trees or tall bushes) that extend substantially above an adjacent noise wall is effective in reducing downwind pollutants, particularly during calm wind periods. In the case of height restricts or limitations for sound walls, taller trees can be incorporated into the landscape design, as shown in Figure 4. These findings have been incorporated into landscaping design guidance for vegetative barriers both with and without sound walls (SAQMD, 2017).

In recent years, technological innovations have produced walls that are more capable of reducing the amount of traffic pollutants reaching nearby communities. The underlying concept has been to integrate designs which absorb pollutants, which has been done by using porous barriers or catalytic coatings. The SmogStop Barrier (produced by a partnership between Western University, the University of Guelph, and the UK company GRAMM Barrier Systems) uses a "two-pronged approach" to enhance dispersion. Utilizing aerodynamics, this wall functions to generate wind vortices and enhance vertical mixing. The main proponents are two walls with a patented photocatalytic coating in which air flow is funneled between, breaking down harmful pollutants such as nitrous oxides and volatile organic compounds (VOCs) into harmless gases and water. Currently used along some stretches of highway in Ontario, field studies have supported their claims that the SmogStop can reduce traffic emissions by 58 percent and nitric oxide and nitrogen dioxide levels by 37 percent before reaching downwind neighborhoods, however further supporting research will be necessary (GRAMM Barriers, 2018). Similarly, a project conducted by EU-LIFE titled the Sound and Particle Absorbing System (SPAS) used particulate filters in the form of installable panels to remove air pollutants.

Figure 4: Trees that mature to a height taller than the height of the barrier act as a vertical extension, improving the capability to reduce air pollutants. (*Source: Matthew Murray Landscape Design)*

The results of this study were mixed, concluding that particulate matter (PM) concentrations were reduced, but the extent of the reduction is dependent on wind direction and pressure. The pollutants must be blown into the filter and field tests revealed the pressure generated by passing trucks was enough to overcome the filter resistance, however passing cars generated insufficient pressure (Schulte and Venkatram, 2013).

3.3 - PUBLIC HEALTH/CHRONIC DISEASE RATES

The effects of traffic-related air pollution on the public health of nearby communities are well documented (ALA, 2018; Brugge et al., 2007; Pope and Dockery, 2012; & Rowangould, 2013). Adverse health impacts from vehicular emissions can be addressed at the source (vehicles and roadways), at the receptor (buildings and neighborhoods), and in between. The research paper authored by Pope and Dockery included an insightful analysis and the section below provides valuable help with closing the gap in scientific knowledge about PM exposure and chronic cardiovascular disease:

> *Long-term PM exposure has been associated with increased cardiovascular mortality, various blood markers of cardiovascular risk, histopathological markers of subclinical chronic inflammatory lung injury, and subclinical atherosclerosis. Short-term exposures have been associated with cardiovascular mortality and hospital admissions, stroke mortality and hospital admissions, evidence of pulmonary and systemic inflammation and oxidative stress, altered cardiac autonomic function, arterial vasoconstriction, and more. There has also been substantial research exploring potential biological mechanisms or pathophysiological pathways that link PM exposure and cardiopulmonary disease and death. (Pope and Dockery, 2012)*

Due to near-road populations having greater exposure to harmful pollutants, there are subsequent economic impacts when medical treatment is necessary. Multiple studies have suggested communities with elevated levels of pollutant exposure coincide with more emergency doctor visits and hospital admissions (Zhang and Batterman, 2014). Market impacts occur as a result of changes in labor productivity (due to absence of work for illness) as well as increased health expenditures (OECD, 2016). The cost of treating patients affected by air pollution poses a burden on stakeholders including insurance companies and employers in addition to the patients themselves. Along the same lines, public programs such as Medicare/Medicaid may benefit substantially if air quality is improved in problematic areas, such as within the first few hundred meters of busy roadways (Romley et al. 2010). Although noise barriers will not be a feasible solution to improving city or region-wide air quality, they can decrease pollution levels of nearby properties, reducing the number of incidences requiring hospital care.

Figure 5 shows the percentage of Hillsborough County residents with asthma, obtained from the Hillsborough County Health Atlas. The prevalence of asthma appears higher in the general vicinity of I-4 and I-275. This observation does not mean that asthma is directly related to vehicular exhaust; correlation does not imply causation. A number of environmental and economic relationships have contributed over many years to the pattern of asthma sufferers. Nevertheless, the correlation does indicate the sensitivity of communities in these portions of the County to health concerns.

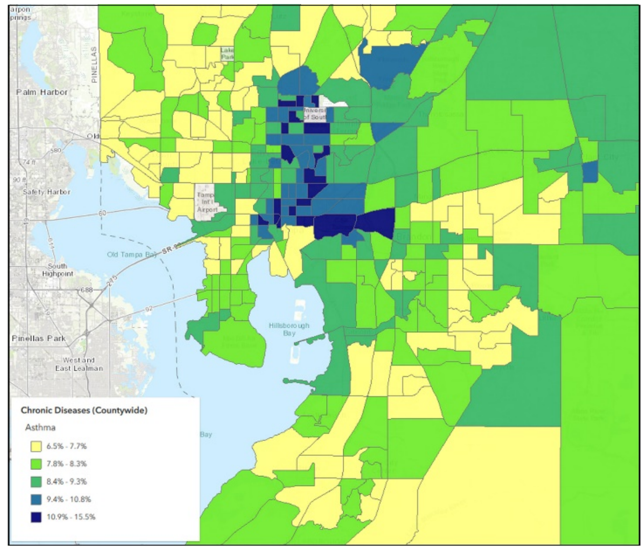

Figure 5. Percentage of Hillsborough County Population With Asthma. (Source: Hillsborough MPO Health Atlas)

Another risk to take note of is lead contamination. Although lead is a naturally occurring element, it is also a pollutant that was emitted by vehicle exhaust until lead additives to gasoline were phased out in 1978. Nevertheless, lead contamination is still present in soils along many long-standing roadways and can become airborne when disturbed by roadway maintenance activities. High concentrations of this heavy metal can be toxic if consumed or inhaled, with the risk heightened for communities with urban gardens alongside congested or heavily trafficked highways. Pediatric lead poisoning is a common occurrence, as children are more vulnerable to exposure. The effects can lower intelligence and slow neurological development but can often be prevented by taking simple steps such as checking the property's history, testing the soil, and taking extra gardening precautions (Moss, 2018). The consumption of lead-contaminated produce is rarely the cause of poisoning but blocking dust (which may contain lead particles) is another benefit to be considered when adding barriers between highways and near-road communities.

3.4 - CONCERNS OF DISADVANTAGED POPULATIONS

The level of noise pollution is dependent on several factors such as number, type, and speed of vehicles, the material of the road, and time of year. Despite this variability, disadvantaged populations frequently deal with traffic noise and other nuisances associated with proximity to highways. Regarding noise, Nega et al. (2013) studied the Twin Cities Metro Region and found the association between "noise levels and household income, median household value, the percentage of non-white residents, and the percentage of the population less than 18 years of age". As with noise, Shrestha et al. (2016) concluded that communities with higher socioeconomic vulnerabilities were disproportionately burdened with PM and nitrous oxide (NO_2) pollutants. Similarly, Chakraborty (2009) analyzed the Tampa Bay area and highlights the correlation between areas with high concentrations of vehicular air pollutants and the locations of predominantly in low-income communities.

It is debatable whether the relationship between adverse traffic impacts and disadvantaged populations is caused by intentional planning or market forces. Instances of both causes have been well documented and analyzed in recent years. Some cases show that highways, interstates, and expressways have been constructed nearby or through disadvantaged communities due to the cost of land and inequities in the ability to influence decision makers across urban areas. Others show that market forces were at play when new communities were built near the roads because the land was cheaper, making the housing stock more affordable. Either way, low-income and minority populations are often the ones affected by inequalities associated with noise and pollution exposure.

Attention should be given to addressing the issues of environmental justice. Fortunately, there are many opportunities for public participation throughout the process of designing and constructing sound barriers. Before making any decisions, stakeholders need to be identified and included in discussions. The final decisions on the characteristics of the wall, the features of its design, and whether the community wants a noise wall will be influenced by the participation of those that will be directly and/or indirectly affected. Some neighborhoods may want a sound wall to attenuate traffic noise, but there may also be groups of people adamantly opposed for several reasons: a wall may make them feel isolated or may block their view. If decisions have been made to move forward with concrete barriers, there are a variety of patterns and textures that community members can add that will create a local identity and a sense of place around/for the barrier.

3.5 - ENERGY GENERATION

Although the main function of a sound barrier is to attenuate traffic noise, interest has been growing in deploying photovoltaic systems to generate electricity as well. Energy usage is increasing as urban areas expand throughout the country and many see it necessary to meet growing demands with renewable sources. Dual-purpose photovoltaic noise barriers (PVNBs) offer a partial solution to producing energy in areas while reducing the effects of highway traffic noise.

There is great potential in the state of Florida and throughout the US to implement PVNBs at a large scale. A case study from Wadhawan and Pearce (2017) made the following conclusions: (1) there is no inherent tradeoff between using solar panels and the effective sound abatement of noise walls, (2) the total potential for power generation from existing noise barriers across the country ranges from 7-9 GW, (3) national implementation can produce 700 GW hours per year, enough to sufficiently power over 50,000 households, 4 national savings can total more than $66 million in annual electricity savings through the use of this method. Uncertainty with this calculation is credited to soil and shading losses, which can be minimized by using different directional orientation and mountings, such as cassette (f) and zigzag (e) configurations shown in Figure 6. According to the FWHA, the most common approach to PVNBs globally is to retrofit an existing noise wall with a top-mounted PV system as it offers the highest surface area per linear meter of noise wall (FHWA (b), 2017). Advancements have increased the appeal of PVNBs: costs for installation have declined in recent years and trials have assured the safety and low maintenance of PVNBs as well (FHWA (b), 2017). Additional benefits can be gained as widespread usage of photovoltaic systems becomes more common. This evolution suggests that less electricity will need to be generated by burning conventional fossil-fuels, offsetting pollution that may impact human health and the environment (Prehoda and Pearce, 2017). Researchers Gu et al. (2012) determined that the payback period to offset the construction costs of PVNB installations to be 5.4 years. The barrier they analyzed used 8-kilowatt peak (kWp) along 360 meters of barrier beside a Chinese metro line and factored in savings from air quality improvements from avoiding emissions (Gu et al., 2012).

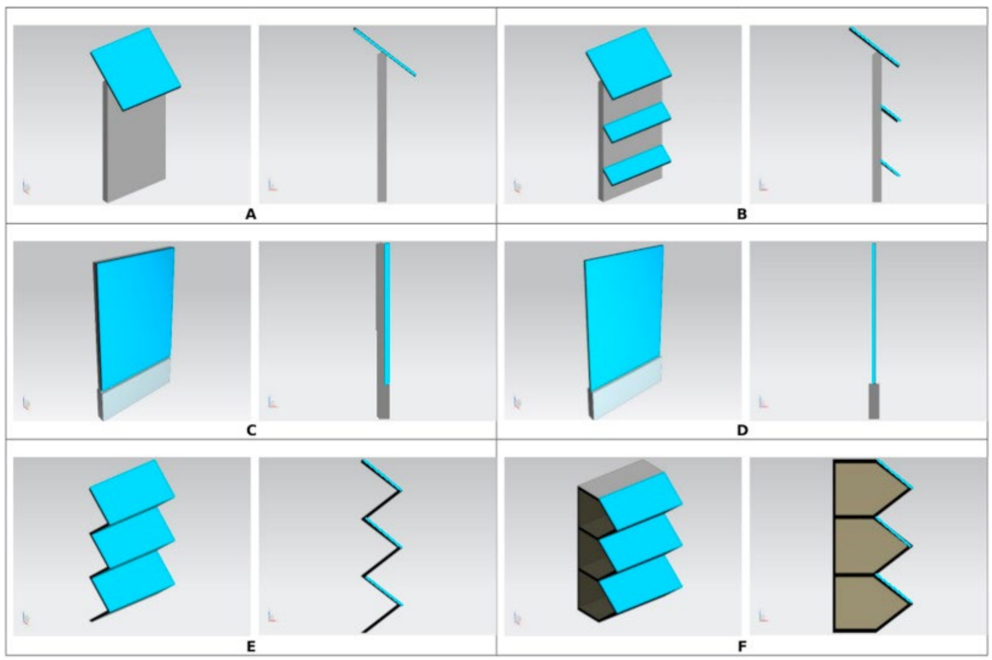

Figure 6: Various configurations of photovoltaic noise barriers: a) top mounted, b) top and side shingles, c) covering the vertical surface, d) bifacial surfaces, e) zigzag configuration, and f) cassettes. (*Source*:*Wadhawan and Pearce (2017).*

When considering retrofitting or designing noise walls to support PVNBs, the leading agency must consider the angle at which the panels are set. Wadhawan and Pearce (2017) show that panels tilted at a 30-degree angle capture the most solar irradiation, although this should be calculated with details of the local latitude and weather conditions. Regarding the implementation of PVNBs, there are three identified impediments to implementing utility-purposed, large scale photovoltaic systems. First, literature reviews have shown the U.S. lacks progressive governmental policies supporting large scale use compared to other countries (Mabee et al. 2011; Moosavian et al. 2013; Solangi et al. 2011). Secondly and along the same lines, there are insufficient financing options (Alafita and Pearce 2014; Overholm 2015). Finally, Margolis and Zuboy (2006) discussed the difficulty of overcoming established energy systems, and that some communities hold a poor perception of the aesthetics of PV systems (Margolis and Zuboy, 2006).

Another electricity-generating option open to further research involves traffic powered wind turbines. Turbines that have been designed to be small, efficient, and powered by low speeds have been placed around the country alongside arterial roadways with high speed moving vehicles. Using the turbulence of passing cars, a windmill is rotated to turn kinetic energy into mechanical energy. This is small-scale energy generation and is limited to powering streetlights or signs over highways. However, since noise walls are placed a distance away from the road, turbines may not receive adequate turbulence and therefore may not be the most feasible or reasonable addition to invest state or federal funds into.

3.6 - CONSIDERATIONS FOR LANDSCAPING AND AESTHETICS

The main goal of a noise wall is to reduce noise to an acceptable level. These walls can be constructed with a variety of materials, obviously creating a variety of possible appearances. The design process should recruit the assistance of interdisciplinary professionals, including planners, landscape architects, highway engineers, acoustic engineers, and structural engineers from the beginning to ensure that each element is being achieved. This section focuses on the visual quality of landscapes, and the importance of creating a barrier that is visually appealing to the community in which it stands.

Stakeholder input into noise wall design is important to both address the community context and manage expectations regarding the benefits and limitations of the final product. The FHWA has reported that complaints have included a restriction of views, a feeling of confinement, a loss of air circulation, a loss of sunlight and lighting, and poor maintenance of the barrier. Motorists have sometimes complained of a loss of view of scenic vistas and a feeling of being "walled in" when traveling and others have complained poor visual designs "seem out of place, visually oppressive, and overly dominant" when compared to the surrounding environment (FHWA (d), 2017). In areas where viewsheds are important from either perspective (towards or away from the roadway), acrylic walls may be an appropriate solution, although a scan of state DOTs (El-Rayes, 2018) indicated that the high cost and associated maintenance with acrylic barriers makes them a solution only where their visual benefits are paramount.

The most effective way to get the public involved is through public meetings or citizen groups. These events offer a chance to educate community members on noise abatement principles, methods, and benefits/adverse impacts. They also provide the opportunity for the community to give their input on what type of barrier, what materials, and what colors/patterns they would like to see. After all, the noise wall will be a noticeable addition to their environment and should reflect the desires of residents that will view it on a daily basis.

From a design standpoint, noise walls can either blend in with the surroundings or stand out as a visible addition to the neighborhood. To achieve the latter, an increasingly common method is to design a structure that acts as a piece of artwork as well. Examples exist all around the world0in Australia, the Sound Tube over Melbourne's CityLink Tollway is a multi-purpose project that is used to mitigate noise pollution and act as an iconic piece of local infrastructure. The flashy artistic component was not an initial function; enhancements were made later by adding controllable, alternating LED lights to the structure. Starting as the sunlight fades, different colors and themes illuminate the highway for drivers passing through while minimizing the noise to surrounding apartments. In terms of noise abatement, tunnel structures are one of the highest ranked types in social and technical performance that an agency can consider (Oltean-Dumbrava and Miah, 2016). For another example in Australia, manufacturing company Hebel takes pride that their sound barriers along Sydney's M4 Motorway (as seen in Figure 7) are also designed to reduce the monotony of long stretches of roadways. Fragmented into multiple sections, each wall is painted a separate color that links to the surrounding landscape and creates an identity and a sense of place (Hebel, 2017).

To help the wall harmonize with its surrounding, rustic materials or colors found in nature can be used to give the wall a natural sentiment. Likewise, landscaping with native plants in available space provides numerous benefits. According to the Florida Department of Environmental Protection (FDEP), even in dense urban areas, landscaping in tight spaces helps improve the site's appearance, connect the area back to the natural environment, improve human health and well-being, create micro-habitats, slightly mitigate the effects of urban heat islands, and can even assist with stormwater management (FDEP, 2006). The same document authored by FDEP staff lists and discusses nine Florida-friendly landscaping principles: putting the right plant in the right place, efficient watering, appropriate fertilization, mulching, attraction of wildlife, responsible management of yard pests, recycling yard waste, reduction of stormwater runoff, and waterfront protection (FDEP, 2006).

Figure 7: A Hebel sound barrier of autoclaved aerated concreate mounted on a highway overpass. *(Source: Hebel)*

The creation of living barriers is another method promoting sustainable practices by directly integrating vegetation into the designs. Behind noise reduction, the secondary function of a green/vegetated noise barrier is a mitigative measure to reduce the visual impacts. Creating a forested strand to reduce noise is possible, but the measured noise reduction is limited, and the trees/shrubs used must be sufficiently dense, tall, and wide. However, meeting these criteria, especially in urban areas, is difficult and often impractical (FHWA (d), 2017). With living structures, the entire structure can consist of hardened soil and vegetation or it can have a wired net frame such as a trellis to support vegetation separated from the structures itself.

However, for noise abatement purposes, solid barriers are the most effective (recommended) compared to vegetative barriers because of the non-continuity allowing sound and pollutants to make their way through the openings. As shown in Figure 8, incorporating greening to a solid noise barrier has advantages such as softening the hard structure's appearance and purifying the air. This trellis approach separating natural plant material from the load-bearing infrastructure provides an opportunity to achieve air quality and aesthetic benefits while reducing maintenance concerns associated with plants burrowing directly into walls or pillars. This concept can be applied to a variety of vertical infrastructure, although care must be taken to ensure the ability to conduct periodic inspections and maintenance of the infrastructure behind the trellis.

Figure 8: Two applications of trellises produced by Greenscreen, a manufacturer of modular trellis systems. The photo on the left includes a trellis mounted along the side of the Houston Memorial Hospital, and the right photo covers a barrier (*Source: Greenscreen*)

Another innovative way to leverage the environmental benefits of a noise wall is to fuse noise abatement and stormwater retention. District Seven is currently exploring plans to harvest rainwater to ease landscape maintenance and make the process more cost-effective. The concept is to create a gravity-fed system that will provide reliable irrigation for tree establishment and supplemental watering during droughts on highway overpass side slopes. Rainwater is siphoned from an overpass catch basin to a cistern that uses gravity in place of pumps and controllers to supply water directly to the roots of trees, shrubs, and ground cover. During the dry season, water trucks will be able to replenish the cisterns if the area lacks enough rainfall. This system could be applied to offer reliable irrigation for a landscaped noise wall that is both water and energy efficient. More importantly, it demonstrates innovative thinking in advancing best practices, a concept explored further in Section 4.

Maintenance and accessibility are two important considerations in noise wall design. Access points may be necessary for a variety of reasons, including structural or landscaping maintenance or emergency access. Regarding the maintenance on noise barriers along highways, topics that need be considered include the availability of replacement parts, access for extended stretches of barriers, deterioration (from moisture, ultraviolet light exposure, graffiti/vandalism, and loss of painted coatings), landscaping, and litter. The FHWA also identifies snow as a considerable factor but this does not pose a sufficient threat within Florida. To address concerns over access, existing solutions from the FHWA and various state departments of transportation have used overlapping barriers, access doors, removable panels for utilities personnel. For instances where the fire department requires or desires access, techniques may include installing hose couplers, panel mounted valves, or small covered openings (FHWA (d), 2017),

3.7 - CONSTRUCTION IMPACT MITIGATION

During the construction phase for highways and noise walls alike, workers may need to use certain techniques or take special actions to address and reduce the noise they produce. In the Construction Noise Handbook, the FHWA has identified various methods of mitigating construction noise. Special provisions include setting time constraints, using the quietest practical equipment, attending training programs, and including incentives/disincentives for participation (FHWA (e), 2017).

As with general noise nuisances, there are opportunities to mitigate construction noise at different points from the source, along the path, and at the receiver. Managing noise at the source can be done by using less noisy machinery, adequate muffler systems, enclosures, temporary walls, and utilizing existing features like berms/noise barriers (FHWA (a), 2017). If the project site is adding a sound barrier in addition to road construction, there is the option to construct the barrier first to minimize sound disturbance as the remaining construction continues. The FHWA has identified that controlling noise at the receiver's end should be used as a last alternative, as the other methods include techniques that are more effective. Acoustical window treatments, such as interior or exterior glass sashes, temporary interior clear vinyl curtains, or full acoustical window installation have been implemented successfully (FHWA (a), 2017). Due to the multitude of construction-related factors and the advantages/disadvantages of each option, an individual evaluation should be done before a selection is made.

Construction project managers should take each option into consideration when determining which is best suited for their project. Other considerations to be included are "the amount of reduction needed, local noise ordinances, length of construction period, cost and effectiveness of control strategies, the feasibility of each mitigation measure, any problems with implementing the measure, and the practicality of each method" (FHWA (a), 2017).

SECTION 4: CHALLENGES FOR CURRENT FUNDING AND IMPLEMENTATION

Current noise walls and noise abatement measures may use federal funds as long as the following requirements are met: (1) a traffic noise impact has been identified, (2) the noise abatement measures will reduce the traffic noise impact, and (3) the overall noise abatement benefits are determined to outweigh the overall adverse social, economic, and environmental effects and the costs of the noise abatement measures. (FHWA (e), 2017). One challenge faced by communities in the United States arises from the threshold for noise levels requiring noise abatement. The FHWA requires that measures must be taken to address excessive noise if the levels exceed 67 dBa in residential areas or where schools, hospitals, and places of worship exist, whereas the World Health Organization's noise value is set at 55 dBa (FHWA (f) 2019; WHO 1999). As a result of these standards, communities in the US are left to deal with higher levels of noise before regulations require abatement considerations. In conjunction with forecasted noise levels, a noise wall will only be implemented if both reasonable and feasible. The criteria by which FDOT considers a noise barrier to be feasible and reasonable are outlined in Chapter 18 (Highway Traffic Noise) of the Project Development and Environment Manual. For instance, areas in which houses are spread apart may have high noise levels that could be mitigated by a wall, but the additional length needed to adequately reduce the noise level may impede on the project's reasonability.

State and federal regulations divide noise walls into two types. Type I projects are required to mitigate increased noise resulting from highway construction or reconstruction. As this is a required mitigative measure, federal funds can be used to cover most of the costs. Type II projects are those that are built independently from highway construction. Type II projects are retrofit noise walls that are *not* a DOT requirement, therefore making the standards to receive federal funding much more restrictive. Policy initiatives such as BUILD Grants have been an additional source of funding for noise walls. In 2018, a BUILD Grant was awarded in Louisiana's St. Tammany Parish to cover $25,000,000 of the total $36,000,000 needed for the I-12 widening and rehabilitation project, which included the construction of a sound barrier to reduce the anticipated noise levels (USDOT, 2018). Any landscaping around noise walls, however, is funded by both the state and the local jurisdiction. Per Section 334.044 (26) of the 2019 Florida State Statutes: "No less than 1.5 percent of the amount contracted for construction projects shall be allocated by the department for the purchase of plant materials" that enhance the roadside environment.

The FDOT stormwater harvesting initiative discussed in Section 3 demonstrates a proactive and progressive approach to furthering best practices, bridging the gap between allowable costs and actual costs. A similar approach could be pursued to develop noise wall designs that surpass minimum requirements and offer multiple benefits to the environment or local community. Such innovative pilot projects can also inspire third party contributors to participate in the project.

Another gap FDOT is attempting to bridge is between the project funding sources. Noise walls are typically funded by state/federal funds. In Florida, these funds are not applicable to barriers not deemed reasonably/feasibly priced. Noise barriers designed to have additional benefits may cost more up front, but this opens the door to third party funding. It can be offset by county or city partners that are willing to financially contribute, or noise walls have an opportunity to be funded by tax increment financing (TIF). TIFs are a method of public financing used as a subsidy for infrastructure projects. Pursuing TIF-funded projects may provide opportunities for communities to build noise walls that may not have been built without funding assistance. Local governments may consider that the benefits of noise walls may include the effect of an increased tax-base independent of a formal TIF. Ozdenerol et al. (2015) used traffic noise mapping to show traffic related nuisances have a negative effect on housing values. The researchers identified trends showing that housing values depreciate as traffic related nuisances increase. Noise walls can increase housing values, and consequentially, property tax revenue, providing local governments a direct interest in partially funding noise walls to offer a return on investment. Additionally, project sponsors can seek funding for noise walls with special design features that improve air quality. The Federal Transit Administration offers funding for projects that improve air quality in areas that are determined to be current/former nonattainment areas in which the standards for ambient air quality for ozone, carbon monoxide, and particulate matter are not met (TDOT, 2019). Consideration should be given to innovative technologies such as catalytic coatings and absorptive materials as discussed in Section 3.2. These techniques may be considered as experimental pilot projects, for which Congestion Management and Air Quality (CMAQ) funding can cover 80 percent of project costs, leaving the remaining 20 percent of capital costs to be matched by local governments, who often are also required to assume maintenance responsibilities.

SECTION 5: OPPORTUNITIES

The range of opportunities and improvements in noise wall design and construction is encouraging. Two types of initiatives should be considered to focus available resources on promoting noise wall design; one focused on process and the second on technical matters.

From a process perspective, the MPO should consider developing a Noise Wall Implementation Strategic Plan that would identify opportunities to bridge funding gaps for desired noise wall design elements not eligible for federal funding. The Strategic Plan would ideally be developed through collaboration in a Noise Wall Working Group of representatives of state, regional, and local agencies involved in environmental quality for transportation projects, and consisting of two geographic components:

- A statewide component to leverage emerging tools and lessons learned from FDOT Central Office, FDOT Districts, and MPOs; particularly regarding success stories and lessons learned statewide and innovative practice successes through similar groups such as the AASHTO Noise Work Group
- A regional component to identify both technical and geographic areas of greatest need within Hillsborough County, identify and cultivate technical and funding champions and innovative funding sources including third party contributions and federal grant opportunities.

From a technical perspective, FDOT could collaborate through the Noise Wall Working Group to review and consider changes to noise wall guidelines and processes. The concepts of sustainability described in the literature can be incorporated into both design and process components to help reinforce the synergies and tensions among the societal, environmental, and fiscal elements of noise barrier treatments. The literature suggests several recommendations for advancing potential best practices in planning and designing noise walls that may provide a useful starting point, including consideration of both the primary purpose of noise attenuation and the secondary pursuit of cross-disciplinary benefits.

For the purposes of noise attenuation:

- Dark colors are strongly discouraged and light, neutral colors are highly recommended.
- If constructing an earth berm, paving the top for a pedestrian/bike paths should be avoided as the material will reflect noise from that surface
- If conditions exist to create limits on the height on noise walls, research finds that incorporating a T-top design is equivalent to adding one meter in height of a straight wall.
- Planting at the base of a noise wall can help the wall's height appear less imposing.
- Depending on the length of the barrier and the need for future maintenance, doorways or gates can be incorporated at reasonable intervals to provide access to either side for both pedestrians and wildlife. To minimize and reductions to the noise walls acoustic performance, an additional parallel barrier in front of the access point which is several times the length of the opening should be installed.
- Brick noise walls are generally less effective than concrete walls, considering total project costs and feedback from contractors and suppliers; bricks can be considered for decorative purposes if they provide context-sensitive value offsetting costs.
- For concrete noise barriers, using the same color and texture for each segment is recommended to reduce costs and ease production processes.

Considerations for exploring additional community benefits beyond noise attenuation include:

- For aesthetic and air-purifying purposes, plant-based greening should be incorporated into noise wall design wherever practical, considering external partnerships for maintenance. As one option, a wire cage can act as a trellis to keep plants away from the wall surface.
- Landscaping with native species should prioritize at-grade planting as opposed to (but not ruling out) planting on the slope of a berm or directly on the barrier. This provides more soil volume, better moisture retention, and more space facilitating sustainable plant growth and allowing greater flexibility when selecting plant species and spatial design. FDOT should continue to prioritize landscaping with native species that connect the project back to the local environment, create micro-habitats, and offer additional environmental benefits.
- Landscape architects should be consulted to select native species that provide habitat opportunities, are low-maintenance, and are best for phytoremediation and carbon-sequestration.
    - Phytoremediation is the practice of plants to remove harmful contaminants in soil, air, or water through accumulation in root systems and plant tissues and is accepted as an environmentally friendly and cost-efficient method to decontaminate brownfield or other contaminated sites (Ansari et. al., 2018).
    - The USDA Forest Service defines carbon sequestration as "the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through

photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils (USDAFS, 2016).

- Oltean,-Dumbrava and Miah (2016) analyzed the sustainability of various types of barriers. The results are based of performances are shown below, some of which can be seen in the photos/diagrams in Figure 9.
  - The top five overall structures: earth barrier (mound/berm), gabions (wire cage filled with graded stones), steel support structure and concrete panels, self-supporting concrete/brick system, and steel support structure and transparent modules.
  - Top five social performances: earth barrier, tunnel with transparent panels, green barrier (containing vegetation), steel and transparent modules, and gabions.
  - Top five technical performances: tunnel-concrete structure, earth barrier, tunnel-steel structure, gabions, and steel support structure and timber panels.

Top five environmental performances: steel and concrete panels, steel and transparent modules, steel and plastic panels, self-supporting concrete/brick system, and gabions.

Figure 9: Various types of noise walls. Each is made of different materials, offering not only a different look, but different levels of noise attenuation and prices for construction and maintenance. (*Sourced by photo)*

The Noise Wall Working Group would provide an appropriate forum for further review and collaboration on the opportunities described in this technical memorandum.

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