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Perspective

Meeting the Water and Sanitation Challenges of Underbounded Communities in the U.S.

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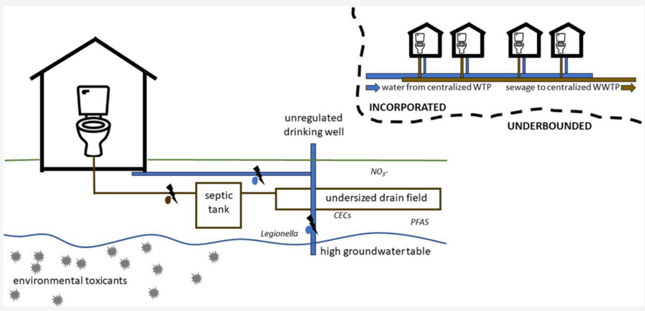
ABSTRACT: Water and sanitation (wastewater) infrastructure in the United States is aging and deteriorating, with massive underinvestment over the past several decades. For many years, lack of attention to water and sanitation infrastructure has combined with racial segregation and discrimination to produce uneven access to water and wastewater services resulting in growing threats to human and environmental health. In many metropolitan areas in the U.S., those that often suffer disproportionately are residents of low-income, minority communities located in urban disadvantaged unincorporated areas on the margins of major cities. Through the process of underbounding (the selective expansion of city boundaries to exclude certain neighborhoods often based on racial demographics or economics), residents of these communities are disallowed municipal citizenship and live without piped water, sewage lines, and adequate drainage or flood control. This Perspective identifies the range of water and sanitation challenges faced by residents in these communities. We argue that future investment in water and sanitation should prioritize these communities and that interventions need to be culturally context sensitive. As such, approaches to address these problems must not only be technical but also social and give attention to the unique geographic and political setting of local infrastructures.



KEYWORDS: *water and sanitation infrastructure, disadvantaged unincorporated communities, environmental justice, participatory process, sociotechnical design, sustainable solutions*

■ INTRODUCTION

While water and sewer services have been lauded as one of the greatest public health accomplishments in modern U.S. history,[1] communities across the country continue to fight for access. Meehan et al.[2] identify an estimated 471 000 households (1.1 million individuals) lacking a piped water connection, 73% of which are located in urban areas close to a networked supply. One of the most vulnerable segments of this population that suffers chronic water and sanitation insecurity (recognized broadly as access that is unreliable, inadequate, or unaffordable[3]) are residents of urban disadvantaged unincorporated (i.e., not governed by its own municipal corporation but by a county or township) communities.[4,5] These are typically low-income, minority neighborhoods with high residential density located on the edge of city limits, where decades of municipal underbounding have led to wide-scale disinvestment in public infrastructure.[6,7]

Underbounding is a form of gerrymandering through city-county annexation covenants that excludes certain communities—often African-American, Hispanic, and Native American—from the benefits of municipal citizenship, including access to clean water and adequate sanitation.[8,9] This practice has also resulted in greater exposure to unwanted development and land use, which concentrate environmental pollutants and contaminants in these communities (e.g., brownfields, poor air quality, contaminated groundwater), raising residents' health risks and lowering property values.[10,11] Underbounding also exposes many residents of these communities to unsafe drinking water and inadequate sanitation infrastructure and prevents access to meaningful participation in planning and decision making.[12] Notably, underbounded communities have unique challenges compared to other disadvantaged minority communities in urban areas because they often lack the same type or level of infrastructure regulation and political representation.[13]

With the recent passing of an historic bipartisan infrastructure deal, the U.S. Congress is poised to make "the largest investment in clean drinking water and wastewater infrastructure in American history."[14] This effort, combined with the White House's Justice40 proposal that would direct 40% of the benefits of federal investments toward addressing the climate crisis to communities with environmental justice challenges, will likely make available vast new resources to address chronic water and wastewater infrastructure problems. Yet, for underbounded communities, solutions to these challenges cannot be merely technical (e.g., provide access to centralized systems) but must also be sensitive to cultural context. We contend that solutions must emphasize holistic and participatory approaches that give attention to both social dynamics and systems dynamics, as well as ensuring equitability by codesigning solutions with community residents. In this commentary, we outline some of the key water and sanitation challenges in underbounded communities and identify three priorities for new investments aimed at tackling these problems.

■ CHALLENGES

Disadvantaged unincorporated communities are pervasive throughout the world. In the United States, these include (but are not limited to) *colonias* inhabited by Latino/a/x residents in the Southwest and especially along the U.S.–Mexico border,[15,16] Black and African-American neighborhoods in the Southeast and Midwest,[5,17] and many Native American communities throughout the country.[18,19] While these groups share similar water and sanitation challenges,[20] those that are underbounded in urban areas have unique characteristics.[21] In addition to their metropolitan setting, underbounded communities are often predominantly inhabited by people from minoritized races and ethnicities, have high residential densities, large proportions of renters, aging housing stock, and lack critical infrastructure due to their unincorporated setting.[22] Moreover, as Anderson[4] has pointed out, underbounded communities rely on only one tier of local government—the county—while disadvantaged urban neighborhoods within municipalities have access to both city and county resources. As such, compared to their municipal counterparts, underbounded communities have less opportunity for economic growth because of their alienation from services, such as water and sewer, even though they are often relatively close to connections to these systems.

Water. The distinctive socioeconomic and historical characteristics of underbounded communities have led to a wide range of water and sanitation challenges. For example, many residents of these communities have no choice but to rely on water contaminated by industrial wastes that pose a health threat or is undrinkable due to discoloration or foul odors. Since the 1970s, property values and corporate taxes have generally increased in inner cities, making unincorporated urban areas attractive for industries producing hazardous wastes.[10] Environmental contaminants (e.g., arsenic, lead, nitrate, pesticides) from these industries, as well as from nonindustrial sources, for instance, agriculture or residential landscaping, make their way into groundwater, contaminating private drinking wells these communities depend on.[22−27] Compounding this problem, drinking wells in unincorporated areas are usually not regulated after initial construction,[28,29] and property owners are often unaware of the dangers and the need to regularly test their water,[30] or if aware, are unable to afford it.[31] In some communities, this is a problem for medium-scale, community-wide systems, such as those that service low-income housing complexes, since residents often have limited information about their water systems.[2] Two studies of underbounded communities in North Carolina, for instance, report that well water users often determine water quality through taste and smell rather than laboratory testing because they cannot afford it and are unable to detect colorless and odorless contaminants.[32,33] Users also reported being unaware of where to get testing equipment, uncertain about how to use it, and concerned about time and cost associated with testing. Moreover, where low-cost testing services are available, such as through local health departments in some states, people are often unaware of the service.

Sanitation. Similar to their rural counterparts, residents of underbounded communities often rely on on-site wastewater treatment, such as septic systems,[34] which typically consist of a septic tank that delivers primary treatment followed by a drain field that provides additional attenuation and treatment via discharge to the vadose zone. Because properties in these communities are typically very small, drain fields are often not sized properly for the intended use of the system. In some communities, soil conditions can also be inadequate for the design of conventional drain fields.[35] Research also shows that underbounded communities often experience fluctuations in the numbers of people residing in individual homes such that, at times, higher residential density can overwhelm the capacity of the septic system, leading to failure.[36] Small lot size can also lead to well water contamination when the well and drain field are too close.[37] In a study of 20 domestic wells in communities served by septic systems, researchers found evidence of elevated wastewater compounds, including nitrate and PFAS (per-and polyfluoroalkyl substances).[38] New research demonstrates that the presence of human-associated viral and bacterial fecal indicators, as well as pharmaceuticals, personal care products (e.g., prescription drugs, stimulants, and cosmetics), and other contaminants of emerging concern, are detected in private wells and released into the environment through on-site wastewater treatment systems, which were not designed to handle these types of emerging contaminants.[39−41] While on-site wastewater treatment systems serve almost 20% of U.S. households,[42] there is much less research or oversight focused on the occurrence, fate, and improved treatability of emerging organic chemicals in such systems compared with more mechanized and centralized facilities.[43] Finally, drain fields can also be inundated by stormwater, as some underbounded communities, especially in the Southeast, are located in active flood zones.[44] In these settings, stormwater can mobilize contaminants, such as heavy metals and PFAS from brownfields or oil and pesticides from roads and parking lots into surface- and groundwater sources.[45] Stormwater may also introduce wastewater to water sources through cross connections, overflows, and leakage from broken and aged sewers.[46,47] Following a sustained flooding event in Louisiana, for instance, researchers measured bacteria in private wells, detecting gene markers of *Legionella* spp., *L. pneumophila*, and *Naegleria fowleri* in 40 homes.[48]

Inadequacies in Existing Solutions. One solution to some of these challenges that is often proposed is to connect residences in underbounded communities to small centralized systems. However, there are a range of socioeconomic challenges with this approach, including problems with sustainability of small systems in terms of operation and maintenance costs, lack of professional staff and certified operators, funding challenges for upgrades driven by increased regulatory requirements, incentivizing property owners to connect, and affordability of the service by households.[6,49−51] In short, simply creating separate infrastructure to serve underbounded communities may just add additional challenges to already under-resourced communities. More research is needed on these challenges to better understand barriers to adoption and the capital and recurring cost structures needed to incentivize property owners and to make the connection and service affordable over the long-term.[52,53] Research on an underbounded community in North Carolina, for example, revealed how financial cost plays a significant role in how residents perceive their choices concerning municipal water supply.[6] In another study (in California), research identified federal funding resources as instrumental in facilitating the process for residents of underbounded communities.[54]

In some cases, underbounded communities are partially or fully serviced by existing centralized systems or have potential access to those systems, as interlocal agreements between municipalities and unincorporated areas sometimes allow for a shared water or sewer service provision through extraterritorial jurisdiction. However, since utilities normally maintain responsibility for delivering water or sewer service only to the property, problems that arise "after the meter" (e.g., curb stop) are the property owner's responsibility, which can make it difficult for renters to address problems. Since much of the housing stock in underbounded communities is aging and inadequate, many residents with homes connected to centralized systems perceive or experience water quality problems, as well as plumbing problems.[55] The Flint, Michigan crisis revealed the inadequacy in municipal water quality across the U.S. with regard to lead and how this problem can be amplified by poor housing infrastructure.[56−59] High levels of lead in drinking water, for instance, occur through corrosion within aging on-site plumbing, including service connections, lead service lines, galvanized steel, lead solder joints, and aerators.[60] Current municipal water quality standards may also be inadequate as aging pipes within households are contributors to lead in water.[61] For example, following the lead crisis in Washington, DC, researchers identified lead service lines as a unique risk factor for elevated blood lead levels regardless of whether municipalities meet U.S. EPA water standards or use treatment, such as chloramine with orthophosphate or chlorine.[62−65] Additionally, the corrosion of household plumbing was listed as one of the reasons for elevated exposure to lead in children from North Carolina.[26] In short, simply connecting homes in underbounded communities to new or existing centralized systems is not necessarily a viable solution in all cases and thus other approaches need to be developed that take into account the unique social, political, economic, environmental, and technological settings.

APPROACHES

We propose three key approaches to address water and sanitation challenges in underbounded communities: participatory process, sociotechnical design, and sustainable solutions. Figure 1 highlights the positive benefits of each approach.

Participatory Process. While recognizing and accounting for the unique social and cultural characteristics of underbounded communities can produce more meaningful and locally relevant solutions, these interventions will not be sustainable if they are not equitable.[66−68] Solutions, therefore, must emerge from within the populations they serve (e.g.,

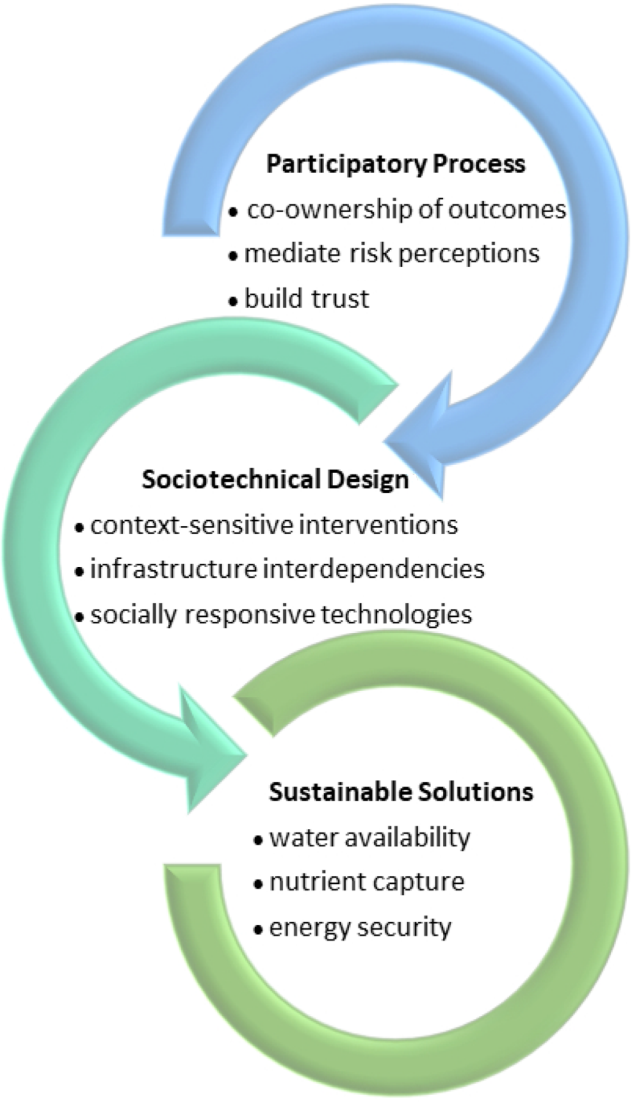


Figure 1. Proposed interventions and their benefits for addressing water and sanitation challenges of underbounded communities.

stakeholders) and must make room for authentic participation in decision-making processes to engender shared values of representativeness, transparency, accountability, and accessibility. A participatory process, for example, reframes the relationship with stakeholder groups by shifting power and resources in the structure of collaboration so they are more equitably shared.[69,70] Schensul[71] proposes several key factors that define participatory processes, including engagement involving long-term commitments, addressing authentic needs of affected communities, being rooted in local culture and history, being attentive to power dynamics, being multivocal and holistic in approach, involving reciprocal learning between the organization and stakeholder groups, balancing local and authoritative knowledge, and establishing plans for long-term sustainability. Environmental justice advocates for underbounded communities are increasingly calling for more of these types of "bottom up" approaches to action and change,[72] while realizing the increased burdens on community residents that add to the "third shift" on top of work, household labor, and family care especially among women.[73] Some barriers for community participation can be overcome by providing services to participants (e.g., meals,

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transportation, childcare services), and also by scheduling meetings at facilities with which partners are already familiar.[74] While environmental engineering research on water and sanitation challenges increasingly relies on citizen science models of participation,[75,76] public engagement within this context is often for purposes of sample collection and typically does not involve deeper-level participation in designing interventions, including decision making. Community-based participatory methods, for example, have been widely and effectively used for research in the fields of health sciences, and there is an opportunity to expand its use for environmental engineering research.[77]

Recent outcome-driven studies employing participatory approaches to research on water and sanitation insecurity highlight three important benefits of increased community involvement, especially with regard to decision making. First, by sharing decision making with local residents, participatory processes not only promote buy-in but also provide opportunities for co-ownership of interventions and their outcomes. Lehigh et al.,[78] for example, report on a participatory redevelopment project in an underbounded community near Tampa, Florida, aimed at addressing water, sanitation, and other challenges. They found that deep levels of community engagement and a sense of ownership in developing outcomes were achieved when their group equally valued both local and authoritative ("expert") knowledge. Second, participatory processes can provide a better understanding of how perceptions of risk differ across stakeholder groups. For example, in a recent review of household water insecurity in the global north, Meehan et al.[20] identify that techno-scientific approaches to meeting regulatory standards treat risk as an empirical phenomenon, which often contrasts with residents' perceptions of risk that are informed by cultural values, local beliefs, and personal experiences. They argue that, in some cases, water may be perceived as unclean but not necessarily unsafe, while in other cases, treated water, though safe to drink, may not be seen as drinkable water.[79,80]

Finally, participatory processes provide a greater awareness of the ways in which trust is an intervening factor between knowledge and acceptance of water and sanitation interventions as well as water quality more generally. For example, in a recent cross-cultural study, Stotts et al.[81] found that trust in the water authority correlated positively to attitudes about wastewater reuse. Work in water management has also shown the importance of trust in relations between water managers and communities,[82,83] as well as the relationship between trust, knowledge, and power.[84−86]

Sociotechnical Design. Water and sanitation security will not be realized through simple technology transfer to underbounded communities.[87] Social science research has convincingly demonstrated how economic inequalities, structural racism, political interests, health disparities, environmental legacies, and other factors can intersect to influence technology adoption, use, and sustainability.[88] Moreover, research shows that water and sanitation problems in underbounded communities are often interdependent with other resource challenges, such as food security,[89] housing infrastructure,[20] and stormwater management and transportation.[90] Recognizing these complex dynamics, solutions to the challenges articulated in the previous section need to account for the diverse character, demographics, and histories of underbounded communities.[89] The challenge is how to design "precision interventions" that are adaptive and sensitive to local social, cultural, and historical difference. Following the precision public health movement,[91] these approaches seek to provide context-sensitive solutions to specific populations by taking into account their unique human and environmental health contexts rather than more general one-size-fits-all solutions. Such sociotechnical approaches are especially important for underbounded communities because these neighborhoods often emerge as outcomes of racial power dynamics that shape, or in some cases determine, the nature of residents' lives and livelihoods.[54]

Novel research at the nexus of society and technology provides yet unrealized opportunities for integrating user experience and sociodemographic context into technology design and use. Water quality monitoring sensors and IoT (Internet of Things) smart sensors, for instance, may be useful for real-time pollution detection at the household scale for identifying contamination in private water wells or for predicting and mitigating risks of contamination incidents. Some research has been conducted on continuous or intermittent monitoring of certain physical and chemical parameters used to detect water contaminants,[92] and technologies have been developed for point-of-use sensors that detect health-relevant contaminants such as lead,[93] arsenic,[94] and nitrate.[95] However, more work is needed to scale these technologies up to market, and to make them portable, rapid, specific, sensitive, and cost-effective detection techniques that can be used in resource-limited settings and with limited technical capacity of the operator.[96] In addition to water quality monitoring, point-of-use (POU) and point-of-entry (POE) filters, such as water filters in refrigerators, faucet-mounted filters, pitcher-style filters, under-the-sink reverse osmosis systems, and whole-house filtration systems are relatively effective, but their efficacy is variable with regard to different contaminants and they can differ greatly in cost and maintenance.[97,98] Research is also needed on the sociotechnical factors surrounding the installation, use, and maintenance of these systems as well as the responsibilities for households using these technologies compared to those on centralized water and sewer systems. What new institutional arrangements might be needed to foster equitability? Mulhern et al.,[99] for example, examined experiences and perceptions of low-income, racially diverse households in North Carolina served by private wells regarding adoption and use of undersink activated carbon block POU filters. They found a lack of knowledge and skills for installing and maintaining the filters were barriers to adoption and that outreach and support programs were needed to provide technical assistance and financial support. Furthermore, these systems are typically designed to treat potable municipal water and are thus not necessarily appropriate for the treatment of other water sources used by some underbounded communities, such as groundwater or nonpotable surface water. McLaughlin et al.[100] found that POU chlorination is very effective at treating water under controlled conditions, such as in a laboratory, but when human factors such as improper storage and chlorine dosing are involved, the effectiveness decreased and water quality risks remained. In these cases, sociotechnical design must take into account local knowledge and user experience to improve the effective use of these technologies.

Recent research on systems dynamics modeling in environmental engineering represents a promising avenue for future development of sociotechnical design to improve environmental health, including water treatment.[101−103] For example,

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Walters and Javernick-Will[104] examined the dynamic interactions of social, technical, financial, institutional, and environmental factors of rural water infrastructure in Nicaragua that prevent water treatment and delivery systems from adapting to the complex interactions of these factors. Using causal loop diagramming, the researchers were able to detect the critical areas of factor interaction by identifying dominant feedback mechanisms that influence water system functionality. Another recent study, by Cannon et al.,[105] developed quantitative system dynamics models to identify the effective strategies to improve performance of community-managed water systems. The effective strategies identified were not technological solutions but instead service and maintenance practices including "professionalization of the service provider" and "preventative maintenance".

Sustainable Solutions. Working with underbounded communities to design sustainable solutions (i.e., those with characteristics that preserve the renewability of the resource and equitable access to it)[106] to water and sanitation insecurity offers many opportunities to transition to a green economy and combat the effects of climate change. The reuse of water and the recovery of resources (e.g., water, energy, and nutrients) from wastewater are two strategies, in particular, that can help provide water and sanitation service while also protecting human and environmental health and addressing other linked challenges, such as food and water insecurity and the high cost of energy. The lack of adequate stormwater infrastructure in underbounded communities, for example, provides the opportunity to design and develop new technologies and systems that can capture and treat stormwater and rainfall runoff for reuse as irrigation for household or community gardens or for potable use,[107] thus addressing food and water security issues.[108] This will become especially important for urban agriculture as the global shift in population becomes further urbanized. In many countries outside the U.S., greywater from certain household activities, such as washing dishes or clothes, is diverted from the sanitary sewer system and treated for reuse onsite.[109−112] However, in many states in the U.S., this practice falls into a regulatory gray zone, and more research is needed to improve the design and management of point-of-use treatment technologies as well as their health risks in underbounded communities and equity issues surrounding these technologies. Developing new, context-sensitive strategies for reducing inequities in water provision for underbounded communities will result in reduction of social costs and economic inefficiencies due to time spent acquiring water or disposable income devoted to purchase of water.[113,114]

On-site sanitation value chains provide another opportunity for transition to a green economy since they are prevalent in underbounded communities. These systems include containment, waste removal, transport, treatment, and disposal or reuse, with each step providing opportunities for integrating new technologies and strategies (e.g., behavioral change), which can lead to the recovery of water, energy/heat, and nutrients.[115] However, we need to improve our understanding of the design and operation of conventional versus resource recovery-based sanitation systems in these settings, especially at the household and community scales.[116,117] For example, anaerobic digesters at the household scale are prevalent globally and allow for the harvesting of nutrients, and organic materials from the digestate can be used as a fertilizer or soil amendment for community gardens.[118] However, many digesters operate under conditions that are not destructive to all human pathogens,[119] and their high cost (especially for biogas harvesting and use) often limits adoption. Community participation during the design and development processes is, therefore, essential for situating these technologies in underbounded environments, especially with regard to low cost, ease of use, low maintenance, and independence from energy sources.[120,121]

Finally, urban sanitation requires a high level of technical, managerial, and financial competency because of the interconnected nature of infrastructure covering personal choices made at the household level with a broader connection to the management of excreta that provides both public health and environmental protection. Even though a community might have adequate infrastructure, residents may not have access to safe and affordable drinking water if their water provider lacks the technical-managerial-financial capacity to operate the system.[122] Overall, sustainable technologies and practices offer opportunities to broaden the scope of urban design and retrofit redevelopment while protecting human and environmental health and reducing financial burdens of residents in underbounded communities.[123]

CONCLUSIONS

Residents of underbounded communities in the U.S. are often subject to unique overlapping water and sanitation challenges that jeopardize human and environmental health. The three urgent priorities for approaches we propose here are aimed at making solutions to these challenges more equitable, context-sensitive, and sustainable. Moreover, these approaches align with the U.S. Environmental Protection Agency's 2022−2026 strategic plan,[124] which seeks to embed environmental justice into regulatory oversight. Some of the interventions driven by the proposed approaches are undoubtedly relevant for unincorporated rural areas as well, though more research is needed in these settings to better understand needs and constraints. With expanding resources for infrastructure improvements for underserved populations on the horizon, these approaches should be integrated into future redevelopment priorities, plans, and projects.

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Notes

The authors declare no competing financial interest.

Biography

Dr. E. Christian Wells is Professor of Anthropology and Director of the Center for Brownfields Research & Redevelopment at the University of South Florida, where he served previously as the Founding Director of the Office of Sustainability and as Deputy Director of the School of Global Sustainability. He is an environmental anthropologist whose research investigates the drivers of WaSH (water, sanitation, and hygiene) insecurity, critical infrastructure transitions, and the socioeconomic and environmental legacies of land use. He is a Fellow of the American Association for the Advancement of Science and currently serves as President of the Florida Brownfields Association, the state's largest nonprofit advocacy organization dedicated to brownfields redevelopment and environmental justice.

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