**Executive Summary**
December 2023
EPA Contract Number: 68HERC22C0041
Title: Developmental Investigation of Recycled Color Mixed Glass in Engineered Soils
Principal Investigator: Richard Roark, RLA, Partner
Small Business: OLIN
EPA Contact: April Richards
Project Period: January 2022 – December 2023

**Research Topic**

OLIN, in partnership with Bottle Underground, E&LP, Andela Products, the Pennsylvania Recycling Markets Center, Circular Philadelphia, Craul Land Scientists, and the City of Philadelphia, has developed an engineered glass-based soil (GBS) and engineered process that repurposes city-wide waste bottle glass into a soil blend suitable for horticultural and green infrastructure projects. The project supports the EPA's goal to improve sustainable materials management to reduce landfill burdens and conserve materials and resources.

Recycling of solid waste materials, like glass, remains challenging to urban systems due to the costs of recycling in comparison to landfill disposal. Process costs for glass cullet are high, while products made from cullet have marginal commercial value. This makes glass recycling economically non-viable for most cities. Similarly challenging is food waste upcycling as soil compost: insufficient process or logistics infrastructure exists to take advantage of this readily developed resource at scale. A practical solution for converting local solid waste to local usable infrastructure effectively is therefore critical to improving use of these predominantly landfilled materials.

This project developed an engineered approach to converting glass waste and food compost into a soil product that can serve the needs of the city in urban development of green spaces and grounds beautification. The technology consists of an engineered soil, and an engineered process plan, that cities can implement to utilize pulverized glass, soil, and food compost amendment, to produce a clean, functional, soil product with demonstrated plant growth, and water draining potential like filtrating rain-garden soil blends. By reducing or potentially eliminating sand quantities with pulverized glass, the project addresses shortages of construction-grade sand, and the costs of sand use in soil preparations. This efficiency is further improved by facilitating on-site processing, and soil blending, improving the value for mixed-color, small-particle glass cullet.

As in Phase I, this Phase II proposal responds to the EPA Research Topic 5c: New applications for industrial non-hazardous secondary materials and food processing byproducts. The project also touches on topics that are of high importance according to the EPA's 2021-22 SBIR Solicitations, including: (1) Low impact construction materials and technologies to increase resiliency to disasters and recovery of materials generated from these incidents; (2) Innovative technologies that will improve the U.S. recycling system; and (3) Retrofit technologies to improve operation of stormwater management infrastructure.

**Project Description**

The team's Phase I and prior research into the horticultural performance and potential supply chain of recycled glass-based soil (GBS) support this product's viability as a substitute for mined sand; Phase II research addresses remaining technical questions and pilots a manufacturing and installation strategy.

Specifically, the research builds on previous laboratory and greenhouse research by testing the prototype GBS product's performance in two Pilot Site Installations, improving understanding of its effect on water flow and quality, and its suitability as a planting medium. The primary tasks performed are:

- Task 1: Pilot Project Design & Planning: Work with Philadelphia Water Department (PWD) and Philadelphia Parks & Recreation (PPR) to identify and design a site for a pilot field experiment testing the performance of GBS in green stormwater infrastructure.
- Task 2: Pilot Project Materials Production: Implement a glass-based soil manufacturing pilot locally. Facilitate collaboration between local material processing businesses and PPR to begin pilot production of the GBS prototype. Source and process prototypical glass-sand component. Blend GBS prototype at PWD pre-approved soil blending facility.
- Task 3: Pilot Project Installation: Install a pilot field experiment testing the performance of GBS in green stormwater infrastructure, while providing a public amenity and supporting the City's hurricane recovery.
- Task 4: Pilot Project Monitoring & Analysis: Continuously monitor the pilot field site for 12 months to assess GBS performance in terms of water flow and quality, and plant health; perform statistical analysis of compiled data.
- Task 5: Phase II Technical Plan: Produce an expanded Technical Plan that builds upon Phase I analysis, extending the range of study to cover the state of Pennsylvania. Identify logistical opportunities and challenges related to glass-sand production in smaller municipalities and in peri-urban contexts. Analyze opportunities for public-private collaboration in GBS manufacturing.
- Task 6: Reporting and Communication: Make all study findings available to the public through OLIN's web-based platforms (website, social media and professional networks) and through industry publications and conferences. Search out additional opportunities for public dissemination through city partnerships.

The Pilot Project located at 2400 Kelly Drive in Philadelphia, PA retrofitted an existing stormwater bioretention basin damaged during Hurricane Ida. The final installation contains approx. 1,900 square feet of Green Stormwater Infrastructure soil at a depth of 24 inches. All glass used in the basin was collected by Bottle Underground from Philadelphia residents and businesses and pulverized by Andela Products. The basin is divided into two halves: one side matching typical Philadelphia Water Department specifications (control) and the other side using the glass-based soil (GBS) mix developed in Phase I. Five commonly specified herbaceous plant species were installed as plugs in random distribution throughout the basin. Water flow and water quality monitoring systems were installed in the existing basin outlet structure and soil moisture sensors were installed in the glass-based soil and in the control soil.

To measure bioretention function, the team divided the stormwater basin into four zones for their data collection. Monitoring was conducted to determine how GBS soil mix impacted the water quality and water quantity functions of the bioretention system. Data was collected over a 12-month period. Specific research questions included:

- Does the GBS soil mix impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen?
- Does the GBS soil mix impact the runoff release rate from the outlet control system?
- Are there additional parameters of interest based on the pilot study's results?

- Are there design modifications necessary for bioretention systems using the GBS soil mix?

To measure plant performance and soil health, the team established a total of ten test plots for data collection (five on each side), specifically to measure vegetative cover and plant height. Specific research questions included:

- Does the GBS mix impact vegetative cover?
- Does the GBS mix impact plant growth or transpiration rates? If yes, is this impact the same across species?
- Does the GBS mix impact the presence of microorganisms and microarthropods?
- Does the GBS mix contain higher levels of metal concentrations when compared to the control?

Additionally, the Phase II Technical Planning Package, building upon the work completed in Phase I, analyzes the potential for a network of Philadelphia-based small businesses to partner with the City to manufacture GBS locally and proposes a waste diversion and manufacturing system that can be replicated by any municipality.

Finally, with the assistance of Andela Products, Circular Philadelphia, Bottle Underground, and the Pennsylvania Recycling Markets Center (RMC), the team developed a Commercialization Plan which provides critical information for prospective businesses that want to produce an environmentally, socially, and economically sustainable product used in the landscape architecture, grounds beautification, and green infrastructure sectors.

**Summary of Research Findings**

Monitoring and analysis indicate that the glass-based soil media did not adversely impact the water quality or water quantity performance of the bioretention system. This analysis was used to answer the research questions:

- Does the GBS mix impact water quality design targets for pH, temperature, total suspended solids, and dissolved oxygen? No, the GBS soil mix did not impact the ability of the system to meet water quality standards for effluent. Dissolved oxygen results were inconclusive.
- Does the GBS mix impact the runoff release rate from the outlet control structure? No, the GBS soil mix did not adversely impact runoff release rate. The system performed as well or better than a theoretical model counterpart in terms of flow rate leaving the system. Soil infiltration was higher and soil less compacted in the glass-based media. These results indicate that the change in media did not impact the hydrologic function of the bioretention system.
- Are there additional parameters of interest based on the pilot study's results? Monitoring of additional water quality constituents, such as metals, may be beneficial to better understand water quality function.
- Are there design modifications necessary for bioretention systems using the glass-based soil mix? No, the GBS mix appears to be a suitable substitution without additional design or installation requirements.

Monitoring and analysis indicate that the glass-based soil media had little to no adverse impact on the plant growth of plants in the bioretention system. This analysis was used to answer the research questions:

- Does the GBS soil mix impact vegetative cover? No, despite sample means being lower in most months in glass-based soil, there is no statistical evidence suggesting that glass-sand reduced vegetative cover. For the glass-based soil test plots, mean cover began slightly lower and ended slightly higher, suggesting that, if glass-sand did influence plant growth, it shifted the timing.
- Does the GBS soil mix impact plant growth? If yes, is this impact the same across species? When comparing mean plant height by species, some species demonstrated slightly lower mean height. For three species, height differences in mean growth were statistically significant.
- Does the GBS mix impact the presence of microorganisms and microarthropods? No, in fact samples of the GBS mix showed a higher fungal biomass.
- Does the GBS mix contain higher levels of metal concentrations when compared to the control? Yes, metal concentrations were elevated in the GBS mix. All recorded levels were well below the Pennsylvania Department of Environmental Protection standard limits for residential soils.

**Conclusions**

Phase II Pilot Project outcomes have demonstrated the long-term horticultural and hydraulic viability of GBS. Results of the study indicate that the GBS did not adversely impact the water quality or water quantity performance of the bioretention system. Minor decreases in plant height are noted, while vegetative cover is similar across soil treatments. Metal concentrations in GBS is higher than levels is the control soil, but all concentrations fall below drinking water limits. Commercialization analysis demonstrates that GBS can compete with conventional sand-based topsoil and that a bona fide market for GBS exists.

**Commercialization**

This Phase II Pilot Project provides proof of concept for glass-based soil (GBS) commercialization in Philadelphia. In so doing, it supports the growth, not only of the small business grantee (OLIN) but also, two other local small businesses: Bennett Compost and ReMark Glass/Bottle Underground (BU), a local specialized glass material recycler. The successful pilot installation demonstrates the efficacy of our engineering process, and encourages public and private entities to adopt the GBS specification, creating a demand for the new material and by extension, new demand for the glass-sand produced by BU and the food waste compost produced by Bennett. It will also decrease the (economic and environmental) costs of topsoil to the City of Philadelphia and improve the city's glass recycling rates. The proof of concept will make it possible to build new networks of public and private entities in other cities to implement similar plans.

Furthermore, the Commercialization Plan demonstrates that GBS will compete with conventional sand-based topsoil in medium and large-scale green stormwater infrastructure installations, such as rain gardens, detention ponds and low impact development tree planting trenches. Through extensive interviews with potential feedstock processors and suppliers, material specifiers, soil blending operations and potential end users located in the Philadelphia region, it has been determined a bona fide market exists for circular soils in the horticultural and green infrastructure industry sectors.

As a design and planning firm, OLIN sees planning and consulting services as an end product. OLIN will support public and private clients in implementing a glass diversion and soil processing system in their specific locations. To date, OLIN has installed GBS in a public park project and is additionally contracted to provide consulting services related to glass diversion and processing to a municipality. Competition, in

this context, is other design and planning firms or public entities that can provide similar services. To our knowledge, there are no competing firms or institutions that offer the expertise network and end-use specifications that meet local application needs, as well as technical manufacturing and commercialization plans in this sector. Therefore, the service that we are developing through this research is unique in our field and gives our firm a competitive advantage in localities that desire improved glass waste and food waste management systems.

**Project Team**

OLIN

Engineering & Land Planning Associates

Pennsylvania Recycling Markets Center

Andela Products

Craul Land Scientists

Circular Philadelphia

ReMark Glass and Bottle Underground

Bennett Compost

**Advisors**

Philadelphia Department of Parks and Recreation

Philadelphia Water Department