

MESH Magazine

University of San Diego

Issue 8

Summer 2026

Beyond the Turning Point

Exploring how research, collaboration, and community action are shaping more sustainable, resilient, and equitable futures





BEHIND THE RESEARCH

10 RESEARCHERS.

10 DIRECTIONS.

ONE TURNING POINT.

Neriah Foye · Aerospace Repairability

Davenj Bradley · Circular Economy

Obed Yeboah · Water & Environmental Justice

Micky Elnahas · Sustainable AI

Kristen Werner · Zero Waste

Alexandra Drobny · Renewable Energy

Alexandra Causey · Collaborative Governance

Alicia Jackson · Community Trust

Celina Rong · Watershed Restoration

Mackenzie Anderson · Food Recovery



MESH · SUMMER 2026, Volume VIII

A NOTE FROM THE EXECUTIVE DIRECTOR

Dear Readers,

It is an honor and a pleasure to help introduce you to Volume 8 of our MESH Magazine! While every MESH cohort is unique, this one has a special place in my heart because I had the privilege of meeting some of these students in-person while in San Diego last May.

At that moment, students had already been marinating on their Capstone topics for almost two years (or sometimes more), but they were only just beginning the real work of distilling their broad topics of interest into the focused, nuanced, empirically-grounded investigations and arguments that you will find in the following pages. Now, just a few months later, this cohort has gone 'beyond the turning point' in many ways of its own: skeletal curiosities have become full-blooded interrogations; cautious observers have become active creators of new knowledge, and disparate themes and topics have re-emerged as a coherent whole.

This process has been arduous for all and painful for some, but I'd like to think that this struggle is no more -- and certainly no less -- than a symptom of learning and growth. And indeed, on the subject of turning points and the inevitable terrors of liminality, I think of the following insight from Chögyam Trungpa: "We are always in transition. If you can relax with that, you'll have no problem."

From one turning point to the next, and beyond and beyond -- I offer my gratitude to these students and to the MESH Mentors, faculty, and administrators who make this program possible. May we all relax into the many transitions that this moment demands of us so fiercely.

**Dr. Willy Oppenheim, MESH Capstone Lead
Executive Director**

the time when pages, cups of the
the subconscious mind, stories untold
my fading memories, lost archives.

A NOTE FROM THE CO-EDITORS

Dear Readers,

A turning point changes the way we see what comes next. It challenges us to question what we have accepted, rethink what is possible, and decide what kind of future we want to create. Beyond the Turning Point begins there.

Across these pages, ten researchers take on sustainability from completely different directions, from aerospace, AI, and renewable energy to environmental justice, waste, water, food recovery, and community resilience. Different questions. Different communities. Different approaches. Yet each project pushes beyond simply identifying a problem and asks what can be done differently.

Together, these stories move from rethinking sustainability to confronting existing systems, building resilience through collaboration, and turning research into action. They reflect the curiosity, challenges, growth, and purpose that shaped our time in the MESH program and remind us that research has the power to reach far beyond the page.

We invite you to question what exists, challenge what can be better, and carry these ideas beyond the page as we shape what comes next.

The turning point is only the beginning. What we create beyond it is up to all of us.

With gratitude,

Neriah Foye, Kristen Werner, & Davenj Bradley

Co-Editors, Beyond the Turning Point

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**Beyond Reusability: Repairability as a Sustainability Design Philosophy for Reusable
Aerospace Systems**

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Abstract

Reusable aerospace systems have transformed spaceflight by allowing spacecraft and launch vehicle components to operate across multiple missions rather than being discarded after a single use. However, reusability alone does not establish long-term sustainability. Reusable systems still require inspection, maintenance, repair, refurbishment, replacement materials, energy, labor, and other resources between missions, raising an important engineering question about what allows these systems to remain operational efficiently over time. Although aerospace research extensively addresses material durability, thermal protection, lifecycle impacts, maintainability, and systems engineering, repairability is often treated as a response to damage rather than as a consideration built into the design process.

This research examines repairability as a sustainability design principle for reusable aerospace systems and explores how decisions involving advanced aerospace materials, lifecycle thinking, and systems engineering influence the ability to inspect, repair, refurbish, and return aerospace systems to service throughout their operational lives. Through a literature-based synthesis of aerospace engineering, lifecycle assessment, systems engineering, and sustainability research, the study identifies relationships among material performance, maintenance requirements, resource use, operational readiness, and long-term system performance. These relationships support a conceptual framework in which repairability is considered earlier in engineering design rather than primarily after damage occurs.

The findings suggest that the sustainability of reusable aerospace systems depends not simply on whether a vehicle can be reused, but also on how effectively it is designed to remain operational across repeated missions. Positioning repairability as a design principle expands the evaluation of aerospace sustainability beyond reusability alone and provides a foundation for future research in repairable thermal protection systems, lifecycle modeling, maintenance optimization, and sustainable aerospace design.

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Introduction

Sustainability has become an important consideration as reusable spacecraft continue changing aerospace engineering. Unlike expendable launch vehicles designed for a single mission, reusable spacecraft are expected to complete multiple flights while maintaining safe and reliable performance. Making that possible requires more than designing a vehicle that can survive launch and reentry. Engineers must also consider what happens between missions, including inspection, maintenance, repair, refurbishment, and the resources required to return a spacecraft safely to service.

My research initially focused on advanced aerospace materials and how improvements in durability, thermal resistance, and structural performance could extend the operational life of reusable spacecraft. However, the literature revealed a broader engineering challenge. Research on lifecycle assessment by [Dominguez Calabuig et al. \(2024\)](#) and [Wildermuth et al. \(2024\)](#), NASA's systems engineering framework ([NASA, 2016](#)), and systems thinking described by [Meadows \(2008\)](#) demonstrates that material performance cannot be separated from the engineering decisions that determine how a spacecraft is inspected, maintained, repaired, and sustained throughout its operational life. These relationships shifted the focus of this research from identifying materials capable of surviving repeated missions to examining how reusable aerospace systems are designed to remain operational over time.

Repairability grew as an important connection among these areas of research. In this study, repairability refers to the intentional consideration of inspection, accessibility, maintenance, repair, refurbishment, and return-to-service requirements during the design and operation of reusable aerospace systems. Although repair is commonly associated with maintenance after wear or damage occurs, the ability to perform those repairs efficiently is influenced by decisions made much earlier in the engineering process. Material selection, component accessibility, inspection requirements, structural configuration, and replacement strategies can determine how easily a reusable system can be restored for another mission. This research therefore examines repairability as a design principle rather than solely as a response to damage. From this perspective, the sustainability of reusable aerospace systems depends not only on whether a spacecraft can fly again, but also on how it is designed to support continued operation across repeated missions. Examining repairability in this way provides an opportunity to connect material performance, lifecycle consequences, and systems-level engineering decisions while expanding the discussion of aerospace sustainability beyond reusability alone.

Problem Statement

Reusable aerospace systems are designed to operate across multiple missions, but their long-term sustainability depends on more than the ability to recover and reuse a vehicle. Each mission introduces inspection, maintenance, repair, refurbishment, testing, and resource demands that influence how efficiently the system can remain operational over time. Aerospace research has addressed many of these challenges through advanced materials, thermal protection systems, damage tolerance, nondestructive inspection, maintainability, maintenance and repair, lifecycle management, and systems engineering. This existing research demonstrates that the engineering requirements needed to support repeated operation are already an important part of reusable aerospace design.

The gap addressed in this research is therefore not an absence of attention to inspection, maintenance, or repair. Aerospace research has established methods for evaluating damage, improving maintainability, supporting maintenance and repair activities, and reducing the operational demands associated with reusable systems. Design-for-maintainability research also demonstrates that factors such as accessibility, visibility, assembly and disassembly, and maintenance time can be considered during the design process rather than only after a system enters operation as demonstrated by [Lockett et al., \(2012\)](#) and [Lockett and Arvanitopoulos-Darginis, \(2017\)](#). Research on reusable thermal protection systems similarly shows that inspection, maintenance, repair, and replacement requirements can influence the operational demands associated with repeated flight.

What remains less developed is the connection between these existing engineering practices and the broader sustainability of reusable aerospace systems. Maintainability, inspection, material durability, repair processes, lifecycle impacts, and systems performance provide important knowledge about keeping aerospace systems operational, but these areas are not always evaluated together through repairability as a sustainability design principle. As a result, the ability to reuse a vehicle can be evaluated separately from the resources, labor, downtime, replacement requirements, and design decisions that determine what is required to sustain that reuse across multiple missions. Addressing this gap requires moving beyond the question of whether an aerospace system is reusable and examining how it is designed to remain reusable. Positioning repairability as a sustainability design principle provides a way to evaluate how advanced aerospace materials, lifecycle thinking, maintainability, inspection and repair requirements, and systems engineering interact across repeated operation. Rather than replacing existing aerospace approaches to maintainability or repair, this research builds on them by examining how these engineering decisions can be brought together within a broader framework for the long-term sustainability of reusable aerospace systems.

Purpose Statement

The purpose of this research is to examine repairability as a sustainability design principle within reusable aerospace systems. Through a literature-based synthesis of advanced aerospace materials, lifecycle thinking, systems engineering, and sustainability research, the study examines how repairability can influence engineering decisions across the operational lifecycle of reusable spacecraft. The resulting conceptual framework organizes the relationships among these areas to illustrate how decisions involving materials, inspection, maintenance, repair, refurbishment, and system integration can collectively influence long-term sustainability. Rather than proposing a new repair technology, the framework provides a way to evaluate repairability as an engineering consideration that begins during design and continues throughout the operational life of a reusable aerospace system.

Research Question

This study is guided by the following research question:

How can repairability function as a sustainability design principle within reusable aerospace systems, and how is it shaped by advanced aerospace materials, lifecycle thinking, and systems engineering?

This question shifts the focus from whether reusable aerospace systems are inherently sustainable to the engineering conditions that influence their ability to remain operational across repeated missions. It also provides the foundation for examining repairability across material performance, lifecycle decisions, and systems-level engineering rather than treating repair as an isolated maintenance activity.

Thesis Statement

Repairability should be incorporated as a sustainability design principle throughout the design and operational lifecycle of reusable aerospace systems because the ability to sustain reuse is shaped by more than a vehicle's capacity to survive multiple missions. Material selection, accessibility for inspection and repair, maintenance requirements, refurbishment demands, and systems-level decisions influence the resources, downtime, and replacement needs required to return a vehicle to service. When these factors are considered together, repairability provides a way to connect engineering design with long-term lifecycle performance. Therefore, the sustainability of reusable aerospace systems depends not only on whether a vehicle can be reused, but also on how effectively it is designed to be inspected, repaired, maintained, and returned to service across repeated missions.

Significance of the Study

The significance of this research lies in expanding how sustainability is considered within the engineering of reusable aerospace systems. Reusability can reduce the need to manufacture new hardware for every mission, but the long-term benefits of reuse are also influenced by what is required to keep that hardware operational. Inspection, maintenance, repair, refurbishment, replacement components, resource use, and operational downtime all contribute to the demands associated with returning a reusable vehicle to service. Considering these factors during design creates an opportunity to evaluate sustainability not only through the number of times a vehicle can be reused, but also through the engineering requirements necessary to sustain that reuse.

Positioning repairability as a sustainability design principle brings greater attention to decisions that can influence a reusable aerospace system long after initial development. Material selection affects not only thermal and structural performance but also inspection and repair requirements. Component accessibility can influence the time and effort required for maintenance, while refurbishment and replacement strategies can affect resource use and operational availability. Evaluating these relationships earlier in the engineering process may help identify tradeoffs between immediate technical performance and the longer-term requirements of maintaining a reusable system across multiple missions.

This research also establishes a conceptual foundation for future empirical investigation. The framework developed here can be evaluated and refined through lifecycle modeling, maintenance and refurbishment data, repairable thermal protection system research, material-level repair studies, and comparisons of reusable aerospace architectures. Future research could also examine measurable relationships among repairability, turnaround time, replacement frequency, resource consumption, lifecycle impacts, and operational performance. Developing evidence in these areas could help determine when designing for repairability produces meaningful sustainability benefits and where tradeoffs may limit those benefits.

What the Literature Reveals About Sustainable Aerospace Engineering

Research on sustainable aerospace engineering spans several areas that influence the design and continued operation of reusable systems. Studies of reusable launch vehicles examine the environmental and operational implications of repeated flight, while advanced materials research focuses on durability and performance under demanding thermal and mechanical conditions. Lifecycle assessment expands the evaluation beyond individual missions by considering impacts across development, manufacturing, operation, maintenance, and end of life, while systems engineering provides a structure for understanding how decisions across these stages interact. Research on inspection, maintenance, and repair further demonstrates that keeping a reusable system operational introduces engineering requirements that extend beyond its ability to survive multiple flights.

Taken together, these areas reveal a broader question about what makes reuse sustainable over time. Material durability, lifecycle performance, maintenance requirements, and system integration are not independent concerns; decisions in one area can create consequences elsewhere in the system. The literature review therefore examines these relationships progressively, beginning with the distinction between reusability and sustainability before considering reusable aerospace systems, advanced aerospace materials, lifecycle thinking, systems engineering, and repairability. This progression provides the foundation for examining repairability as a sustainability design principle within reusable aerospace systems.

Sustainability Beyond Reusability

Reusability is often associated with sustainability because recovering and reusing aerospace hardware can reduce the need to manufacture replacement systems for every mission. However, the literature demonstrates that the ability to reuse a spacecraft does not automatically produce sustainable outcomes. [Dominguez Calabuig et al. \(2024\)](#) show through lifecycle analysis that rocket exhaust emissions, propellant selection, manufacturing, refurbishment, and operational decisions continue to influence environmental performance even when launch vehicles are reusable. [Wildermuth et al. \(2024\)](#) similarly demonstrate that meaningful comparisons among launch systems require evaluation across development, production, launch, operation, and end of life rather than focusing on reuse or mission performance alone. Together, these studies challenge the assumption that reusability can serve as sufficient evidence of sustainability and demonstrate the importance of evaluating what is required to support reuse throughout a system's lifecycle.

Lifecycle thinking provides a way to examine these broader consequences. [ISO 14040](#) establishes a framework for evaluating environmental impacts across the full life of a product rather than concentrating on a single stage such as manufacturing or operation. Applied to reusable aerospace systems, this perspective draws attention to how decisions made during design and development can continue influencing resource use and environmental performance during operation, maintenance, refurbishment, and eventual end of life. Sustainability therefore cannot be evaluated at a single point in time but must account for how engineering decisions accumulate across the lifecycle of the system.

Systems thinking further demonstrates why these decisions cannot be evaluated independently. [Meadows \(2008\)](#) explains that the behavior of a system is shaped by relationships among its components, meaning that an improvement in one area can create consequences elsewhere. In reusable aerospace systems, a material selected for greater thermal performance may improve flight capability while introducing additional inspection or repair challenges. Similarly, a design intended to reduce mass may lower fuel requirements while making damaged components more difficult to access or replace. These tradeoffs demonstrate why individual improvements do not necessarily translate into greater sustainability at the system level.

[NASA's systems engineering framework](#) reinforces this perspective by connecting design, testing, operations, maintenance, and sustainment across the lifecycle of an aerospace system. [Abson et al. \(2017\)](#) similarly describe sustainability leverage points as opportunities where changes to the structure of a system can create broader effects than isolated improvements. Applied to reusable aerospace systems, these perspectives suggest that stronger materials, cleaner manufacturing, or repeated vehicle use represent only individual parts of a larger sustainability problem. The resources required between missions, the management of damage, the useful life of components, and the ability to restore a system without extensive replacement also influence the long-term benefits of reuse.

These relationships establish an important distinction between reusability and sustainable reuse. Reusability describes the capability of a system to operate across multiple missions, while sustainable reuse requires consideration of what is necessary to maintain that capability over time. This distinction creates the foundation for examining repairability as a design principle because the ability to inspect, maintain, repair, and restore a reusable system is influenced by engineering decisions made throughout its lifecycle.

Reusable Aerospace Systems

Reusable aerospace systems represent a major shift from traditional expendable launch architectures because they are designed to recover and operate portions of a vehicle across multiple missions. However, the engineering challenges associated with reusable systems extend beyond successfully recovering hardware after flight. Repeated operation introduces requirements involving structural durability, thermal protection, propulsion performance, inspection, maintenance, reliability, and the ability to prepare a vehicle safely for another mission. These requirements have been part of reusable launch vehicle development for decades.

[The National Research Council's evaluation of NASA's Reusable Launch Vehicle program](#) illustrates this history. Development efforts during the 1990s focused on technologies including reusable cryogenic tanks, composite primary structures, advanced thermal protection systems, propulsion, avionics, and more operable vehicle systems. The program evaluated technologies not only for technical performance but also for characteristics such as producibility, operability, weight, robustness, and multi-flight reliability. These priorities demonstrate that achieving reuse has long required engineers to consider what happens to a vehicle across repeated operations rather than focusing only on whether individual components can survive another flight.

The engineering demands of reuse also create relationships among vehicle design, operations, and long-term performance. A component capable of surviving repeated missions may still require extensive inspection or maintenance between flights, while a high-performing material may introduce additional challenges when damage occurs. Similarly, increasing the number of times hardware can be reused does not necessarily reduce the resources required to support each additional mission. Reusable aerospace systems must therefore be evaluated not only according to flight capability but also according to the operational requirements that make continued reuse possible. This distinction is important for sustainable aerospace engineering. Reusable systems create opportunities to extend hardware life and reduce repeated manufacturing, but those benefits depend partly on how efficiently vehicles can be maintained and returned to service. Examining reusable aerospace systems from this perspective shifts attention toward the engineering decisions that support continued operation and provides the foundation for considering how material selection, lifecycle planning, and repairability influence sustainable reuse.

Advanced Aerospace Materials

Advanced aerospace materials play an important role in the performance and longevity of reusable aerospace systems. Unlike expendable vehicles, reusable spacecraft must withstand demanding thermal, mechanical, and environmental conditions across multiple missions. Thermal protection systems are one of the clearest examples because they must protect the vehicle during atmospheric entry while continuing to perform safely after repeated exposure. Material selection therefore affects more than whether a spacecraft can survive a mission. It can also influence how the vehicle is inspected, maintained, repaired, and prepared for future flights. The development of thermal protection materials shows how long engineers have been working to improve the performance of reusable aerospace systems. [Rasky \(1992\)](#) examined advanced ceramic matrix composites for thermal protection applications, demonstrating the early interest in materials capable of performing under extreme temperatures. [Glass \(2008\)](#) later explored ceramic matrix composites for thermal protection systems and hot structures, showing how these materials could support high-temperature aerospace applications. More recent research demonstrates how much this field has continued to develop. [Mitchell and Tiley \(2024\)](#) describe thermal protection systems that include high-temperature alloys, refractory metals, ceramics, ceramic matrix composites, ultra-high-temperature ceramics, carbon-carbon composites, and other materials designed for demanding aerospace environments. This range of materials also demonstrates why material selection cannot be based on a single performance characteristic.

Durability is an important part of this discussion, but durability does not mean that a material will remain unchanged across every mission. Repeated thermal cycling, oxidation, mechanical loading, impact, and surface degradation can affect material performance over time. These conditions make repeated use different from simply surviving one successful mission. Engineers must also be able to understand how materials change after exposure, determine whether damage has occurred, and decide whether a component can safely remain in service. For reusable systems, the question becomes not only how well a material performs during flight, but also what happens to that material after the vehicle returns. Ceramic matrix composites help illustrate this challenge. Their ability to withstand high temperatures while maintaining relatively low weight makes them valuable for aerospace applications where conventional materials may face thermal limitations ([Glass, 2008](#)). However, improving thermal performance does not eliminate concerns about inspection, damage, joining, maintenance, or repair. As material systems become more advanced, understanding their condition after repeated use can become just as important as their initial performance. A material that survives extreme temperatures may still create operational challenges if damage is difficult to identify or if repairing the material requires extensive time, specialized processes, or replacement of larger components.

This distinction between durability and repairability is important to the larger argument of this research. Durability describes how well a material resists degradation or damage, while repairability considers what happens when degradation or damage does occur. A highly durable material may reduce how often repairs are needed, but it does not automatically make those repairs easier. In the same way, extending the life of a component may provide sustainability benefits, but those benefits can be reduced if inspection, maintenance, or repair requires large amounts of labor, energy, replacement material, or operational downtime. Material performance and repairability are therefore connected, but they are not the same engineering objective.

Manufacturing decisions add another layer to this relationship. Additive manufacturing has created new opportunities for producing aerospace components with complex structures while giving engineers greater control over material use and component design. [Shen et al. \(2025\)](#) examine additive manufacturing of aerospace composites and show how material selection, manufacturing processes, design, and final component performance are closely connected. This is relevant to reusable aerospace systems because the way a component is manufactured can influence not only its initial performance but also how it is maintained, replaced, or potentially repaired later in its lifecycle. Additive manufacturing may also create new possibilities for replacement and repair by allowing components to be reproduced from digital designs or redesigned to improve future performance. However, these possibilities must still be evaluated alongside material properties, manufacturing reliability, qualification requirements, energy use, and the ability to inspect and certify components for aerospace service. A manufacturing method should not be considered sustainable simply because it can reduce material waste or produce more complex structures. Its value depends on how those advantages affect the performance and resource demands of the larger system over time.

Looking across this literature reveals an important tradeoff. Materials with greater thermal resistance, lower weight, or longer service lives can improve vehicle performance, but those improvements can also create different inspection, manufacturing, maintenance, and repair requirements. The strongest material in one category may not produce the strongest outcome across the entire lifecycle. For reusable aerospace systems, material selection therefore becomes

a lifecycle decision as much as a performance decision. Advanced materials remain necessary for extending the capabilities and operational lives of reusable aerospace systems, but their contribution to sustainability depends on more than how long they can survive. Engineers must also consider what happens when those materials begin to degrade, how damage can be identified, whether repairs are possible, what resources those repairs require, and when replacement becomes necessary. Looking at materials this way connects advanced material performance directly to the larger question of repairability and creates a natural transition from designing systems that can survive repeated missions to designing systems that can be sustained throughout them.

Lifecycle Thinking in Aerospace Engineering

Lifecycle thinking expands the evaluation of reusable aerospace systems beyond what happens during an individual mission. Instead of focusing only on launch, flight, or reentry performance, a lifecycle perspective considers how decisions made during design and manufacturing continue influencing a system during operation, inspection, maintenance, repair, refurbishment, and eventual end of life. This perspective is important for reusable systems because their sustainability depends on what occurs across repeated missions rather than the performance of a single flight.

[ISO 14040](#) provides one of the primary frameworks for evaluating environmental impacts across the lifecycle of a product or system. The framework considers stages ranging from raw material acquisition and production to use and end-of-life management. Within reusable aerospace systems, this approach creates a broader way to evaluate engineering decisions. A material that reduces vehicle mass, for example, may improve performance during flight but require energy-intensive manufacturing or specialized maintenance later in its lifecycle. A component designed to survive multiple missions may reduce replacement needs but still require frequent inspection or refurbishment. Lifecycle thinking makes these relationships more visible by considering impacts across stages rather than evaluating each decision separately.

Research from aviation maintenance also demonstrates why design and operation cannot be treated as completely separate phases. [Lee et al. \(2008\)](#) examined product lifecycle management within aviation maintenance, repair, and overhaul and showed how information created throughout a product's lifecycle can support maintenance and operational activities. Their work is useful to this research because it demonstrates that decisions and information developed during design continue to matter after an aerospace system enters service. Inspection, maintenance, repair, and overhaul are not disconnected from the original design of a system; they are influenced by choices made much earlier in its lifecycle. This relationship becomes even more important when a system is intended for repeated use. Every additional mission can introduce new maintenance requirements, material degradation, inspections, repairs, replacement components, and resource demands. Extending the physical life of a spacecraft or component can reduce the need for repeated manufacturing, but longer service life does not automatically mean lower lifecycle impacts. If maintaining that system requires increasing amounts of labor, energy, replacement materials, or extensive refurbishment between missions, some of the benefits associated with reuse may be reduced. Lifecycle thinking therefore provides a way to examine

not only how long a reusable system remains operational, but also what is required to keep it operational.

Circular economy research adds another perspective to this discussion by focusing on how products and materials can remain useful for longer periods of time. [Kirchherr et al. \(2017\)](#) demonstrate that circular economy approaches extend beyond recycling and include strategies involving reuse, repair, refurbishment, remanufacturing, and extending the useful life of products and materials. [Bocken et al. \(2016\)](#) similarly connect circularity to decisions made during product design, including strategies intended to slow resource loops by extending product life. These ideas are relevant to reusable aerospace systems because reuse itself represents only one way of extending the value of a system. Repair and refurbishment can also influence how long components remain useful and how much new material or replacement hardware is required throughout operation. Applying circular design concepts to aerospace systems requires care because spacecraft operate under safety, reliability, and performance requirements that differ from many commercial products. A component cannot remain in service simply because repairing it would conserve resources. Engineers must determine whether repair can restore the component to the level of performance and reliability required for future missions. This creates an important balance between extending useful life and maintaining mission safety. Repairability should therefore not be understood as repairing every damaged component indefinitely, but as creating engineering options for inspection, repair, refurbishment, or replacement when those options are technically appropriate.

End-of-life decisions are also part of lifecycle sustainability. Eventually, reusable aerospace components reach a point where continued operation or repair is no longer practical. Decisions involving replacement, decommissioning, material recovery, recycling, or disposal can influence the total resource and environmental impacts associated with the system. End-of-life planning can include material recovery, recycling, and other strategies intended to preserve value after aerospace components leave service. Considering these outcomes earlier in design can help connect decisions about material selection and component architecture with what happens at the end of their useful lives. Looking across lifecycle management and circular design literature reveals that reuse is only one stage within a much larger process. A reusable aerospace system moves through repeated cycles of operation, inspection, maintenance, repair, and refurbishment before eventually reaching end of life. Decisions made at the beginning of that lifecycle can influence what is possible at every stage that follows. Lifecycle thinking therefore strengthens the case for considering repairability during design because the ability to maintain or restore a system later depends in part on choices made before the system ever enters service.

From this perspective, repairability becomes one way of connecting early engineering decisions with long-term operational consequences. Designing for repair does not guarantee that every component will or should be repaired, but it allows inspection, maintenance, refurbishment, replacement, and resource requirements to be considered before damage occurs. This expands the evaluation of reusable aerospace systems from how many missions a vehicle can complete to how those missions are supported throughout the entire lifecycle.

Systems Engineering as an Integrative Framework

Systems engineering provides a way to bring the different parts of reusable aerospace design together rather than evaluating materials, maintenance, lifecycle impacts, and operational performance as separate concerns. Reusable aerospace systems contain many interconnected components and requirements, meaning that a decision intended to improve one part of the vehicle can influence performance elsewhere. This becomes important for sustainability because improving an individual technology does not necessarily improve the long-term performance of the entire system. [NASA's systems engineering framework](#) approaches aerospace development as a lifecycle process that extends from stakeholder expectations and technical requirements through design, verification, validation, operation, maintenance, and eventual disposal. This structure demonstrates that engineering decisions made during early development continue influencing later stages of a system's life. Requirements involving materials, component configuration, accessibility, inspection, reliability, and maintenance can therefore affect what becomes possible once a reusable vehicle enters operation.

For repairability, this relationship is important because the ability to repair a system is not determined only after damage occurs. A component may be technically repairable, but its location within the vehicle may make it difficult to access. A material may have an available repair method, but inspecting the damaged area or verifying the repair may require extensive disassembly. A design may improve aerodynamic or structural performance while making replacement of a damaged component more difficult. These examples demonstrate how repairability can depend on decisions made across several engineering areas rather than on a single repair process. Systems thinking helps explain why these relationships matter. [Meadows \(2008\)](#) describes systems as collections of interconnected elements whose behavior is shaped by the relationships among them. From this perspective, changing one part of a system can create effects elsewhere, including outcomes that were not originally intended. Within reusable aerospace systems, decisions involving mass, material durability, thermal protection, component accessibility, maintenance requirements, and operational turnaround can interact in ways that are difficult to understand when each factor is evaluated independently.

A lightweight material, for example, may reduce vehicle mass and improve flight performance while creating more complicated inspection or repair requirements. Increasing the durability of a component may extend its useful life but require a manufacturing process that uses more energy or makes the component harder to replace. Designing components for easier access may support faster maintenance but introduce structural, thermal, or mass tradeoffs elsewhere in the vehicle. None of these decisions can be evaluated through sustainability alone or technical performance alone. They require engineers to consider how benefits and tradeoffs move across the larger system. This is also where leverage points become useful. [Abson et al. \(2017\)](#) describe leverage points as places within systems where changes can influence broader system behavior. [Leventon et al. \(2021\)](#) extend this discussion by emphasizing the importance of understanding how a system is defined, what outcomes are being pursued, and how interventions may affect the larger system. Applied to reusable aerospace engineering, this perspective raises an important question: whether considering repairability earlier in design could influence multiple lifecycle outcomes rather than addressing repair only after a component has been damaged.

Repairability could influence several connected areas of a reusable system. Designing components with inspection and repair in mind may affect accessibility, maintenance time, replacement needs, resource use, operational downtime, and the useful life of materials and components. However, these benefits cannot be assumed. Improving repairability in one area may create additional mass, complexity, cost, or design constraints elsewhere. Systems engineering provides a way to evaluate these tradeoffs and determine whether a repairability decision improves the performance of the larger system rather than simply making one component easier to repair. This distinction is important because repairability should not become another isolated design objective. If engineers optimized only for ease of repair without considering safety, reliability, mass, thermal performance, structural requirements, cost, and mission objectives, the result could create new problems elsewhere in the vehicle. The value of repairability comes from considering it alongside these requirements and evaluating where it can support long-term system performance without compromising mission needs.

Viewing repairability through systems engineering therefore changes its role within reusable aerospace design. Instead of treating repair as an activity that begins when damage is discovered, repairability can be considered earlier as one of the requirements that influence design decisions across the lifecycle. Systems engineering provides the structure for understanding those relationships, while systems thinking helps reveal the tradeoffs and feedback that can occur among them. Together, these perspectives support the evaluation of repairability not as an isolated maintenance function, but as a design principle whose value depends on how it affects the reusable aerospace system as a whole.

Repairability and Long-Term Sustainability

The literature on advanced materials, lifecycle thinking, systems engineering, and aerospace maintenance shows that repairability exists within a much larger set of decisions that determine how reusable aerospace systems remain operational over time. Materials influence how damage occurs and what repair methods are possible. Lifecycle decisions determine how inspection, maintenance, repair, refurbishment, and replacement affect the resources required throughout repeated use. Systems engineering connects these requirements with safety, reliability, performance, mass, cost, and mission objectives. Aerospace maintenance and inspection research adds another important piece by showing that accessibility, inspection requirements, maintenance time, and the ability to evaluate damage can also be influenced during design. Looking across these areas together shows why repairability cannot be understood only as the act of fixing a damaged component.

Repairability begins before damage occurs. Decisions involving material selection, component architecture, accessibility, joining methods, inspection requirements, available repair processes, and replacement strategies can determine whether a damaged component can be restored efficiently once a vehicle enters operation. This means that two components with similar performance during flight may create very different challenges after damage occurs. One may be accessible, inspectable, and repairable with limited disruption to the larger system, while another may require extensive disassembly, specialized equipment, or complete replacement. From a sustainability perspective, those differences matter because they influence the labor, materials, energy, time, and replacement hardware required to support continued operation.

Research on design for maintainability provides direct evidence that these concerns can be addressed before an aerospace system enters service. Lockett and colleagues developed aircraft design methodologies that evaluate maintainability during the design process rather than waiting until maintenance activities begin. Their work considers factors such as accessibility, assembly and disassembly, visibility, ergonomics, and maintenance task time as characteristics that can be evaluated using computer-aided design tools ([Lockett et al., 2012](#); [Lockett & Arvanitopoulos-Darginis, 2017](#)). This literature is important to the repairability argument because it demonstrates that the conditions affecting later maintenance are not completely fixed after a vehicle is built. Engineers can evaluate some of those conditions while the system is still being designed.

Product lifecycle management research provides a similar connection between early engineering decisions and later operational requirements. [Lee et al. \(2008\)](#) demonstrate that information generated throughout the product lifecycle continues to support maintenance, repair, and overhaul after an aircraft enters service. Design and maintenance are therefore not completely separate stages. Decisions made during development can influence the information, processes, and options available to maintenance teams later in the lifecycle. For reusable aerospace systems, this supports considering repair requirements before repeated operation begins rather than addressing them only after damage occurs. Inspection introduces another part of this relationship. [Esquivel and Seibold \(2004\)](#) examined nondestructive evaluation methods for inspecting reusable launch vehicle components beneath thermal protection systems. Their work identified both the capabilities and limitations of different inspection methods and emphasized the need to understand inspection requirements unique to reusable launch vehicles. This is important because repair cannot begin with the repair process itself. Damage must first be detected, located, and evaluated. If a component is difficult to access or if the surrounding material system makes damage difficult to identify, the ability to repair that component becomes connected to the way the larger vehicle was designed.

Thermal protection systems provide one of the clearest examples of how these issues affect reusable spacecraft. Reusable thermal protection must survive extreme conditions while also supporting the inspection and maintenance needed between missions. Earlier reusable launch vehicle development identified reducing thermal protection maintenance and inspection requirements as an important requirement for improving vehicle turnaround. The Space Shuttle also demonstrated the operational challenges created by thermal protection tiles that could be damaged and required careful inspection and replacement between missions. [Pace and Maji \(2008\)](#) connected these maintenance demands with the cost of reusable spaceflight and examined whether alternative high-temperature materials could support less maintenance-intensive thermal protection systems. These examples show that material performance, inspection, maintenance, and reuse have already been connected within aerospace engineering even when they have not been framed specifically through sustainability.

Current aerospace practice continues to show that thermal protection is managed across more than the flight portion of a mission. [NASA's thermal protection capabilities](#) include design, analysis, testing, manufacturing, installation, repair, removal, and replacement of thermal protection components. This reinforces the idea that reusable material systems exist within an operational cycle rather than functioning only during launch or reentry. The ability to repair or replace thermal protection is therefore already part of aerospace practice; the question for this

research is how those activities can be considered earlier and evaluated through a sustainability perspective.

Research on sustainable maintenance, repair, and overhaul extends the discussion beyond technical maintainability by connecting maintenance activities with resource efficiency, waste reduction, component life extension, and long-term operational performance. These relationships matter because maintenance is one of the processes that makes continued reuse possible. A reusable vehicle may avoid the need to manufacture an entirely new system for every mission, but maintaining that vehicle still requires resources. Inspection equipment, replacement materials, repair processes, labor, energy, testing, and operational downtime all contribute to the larger demands associated with reuse. Improving the sustainability of reusable aerospace systems therefore requires attention not only to how many times hardware can be reused, but also to what is required between those uses.

Design-for-repair literature outside aerospace adds another useful perspective. [Roskladka et al. \(2025\)](#), writing within the context of repairable electronic products and the circular economy, identify accessibility, modularity, product architecture, repair information, and tool availability as factors that can influence whether products can be repaired. These principles cannot be transferred directly into aerospace systems because spacecraft operate under much stricter safety, reliability, performance, and verification requirements. However, the underlying design question remains useful: whether decisions made before a system enters service create or limit the options available when damage eventually occurs.

This difference between maintainability and repairability is also important. Maintainability addresses the broader ability to perform maintenance activities efficiently and effectively throughout operation. Repairability focuses more directly on what happens when damage, degradation, or failure requires a component or system to be restored. The two concepts overlap, but they are not interchangeable. Existing design-for-maintainability research provides an important foundation for repairability because accessibility, inspection, disassembly, maintenance time, and component configuration can influence whether repair is practical. Repairability builds on that foundation by asking how those decisions affect the ability to restore function while also considering their consequences across the lifecycle.

Repairability also cannot take priority over mission safety or technical performance. A component should not be made easier to repair if doing so creates unacceptable structural weakness, thermal risk, additional mass, or reliability concerns. Repairing a damaged component is also not automatically more sustainable than replacing it. Some repairs may require specialized materials, energy-intensive processes, extensive testing, or repeated intervention that makes replacement the more practical lifecycle decision. Repairability should therefore be understood as creating viable engineering options for restoring a system when repair is safe, effective, and appropriate rather than requiring every damaged component to remain in service indefinitely.

Circular design research strengthens this distinction. [Bocken et al. \(2016\)](#) describe product-life extension, repair, reuse, refurbishment, and related strategies as ways of slowing resource flows and preserving the value of products and materials for longer periods. Within reusable aerospace systems, these ideas suggest that extending useful life depends on more than recovering a vehicle after flight. The components within that vehicle must also support continued

operation. Repair and refurbishment can contribute to that goal when they reduce unnecessary replacement and preserve functional hardware, but their value depends on how they interact with the technical requirements of the system.

Looking across these areas reveals tradeoffs that become visible only when materials, maintainability, lifecycle thinking, and systems engineering are considered together. A more durable material may reduce repair frequency but make damage more difficult to detect or repair. A modular component may be easier to remove or replace but introduce additional interfaces, mass, or structural complexity. Greater access for inspection and maintenance may reduce turnaround time but require design changes elsewhere in the vehicle. A repair process that extends component life may reduce replacement material while increasing labor, testing, or energy requirements. These examples show why repairability cannot be evaluated through a single measure.

Instead, the value of repairability depends on its effects across the larger aerospace system. Relevant considerations may include damage frequency and severity, accessibility, inspection requirements, repair time, maintenance labor, resource consumption, replacement frequency, component life extension, operational downtime, reliability, and the ability to verify that a repaired component is safe for continued service. These factors also provide measurable outcomes for future research and could help determine when designing for repairability produces meaningful sustainability benefits and when those benefits are limited by other engineering requirements. Taken together, the literature does not suggest that aerospace engineering has ignored inspection, maintenance, or repair. In fact, research on maintainability, nondestructive evaluation, reusable thermal protection systems, aviation MRO, and lifecycle management demonstrates that many pieces of this problem already exist. The gap is narrower and more specific. These areas are not always evaluated together through the question of how repairability can function as a sustainability design principle within reusable aerospace systems. This research builds on existing engineering knowledge by bringing those relationships into a common framework rather than treating repairability as a completely new aerospace concern.

These relationships form the foundation for positioning repairability as a sustainability design principle. The framework does not assume that greater repairability will always produce greater sustainability. Instead, it proposes that repairability should be considered early enough in the engineering process for its benefits and tradeoffs to be evaluated alongside material performance, maintainability, inspection requirements, lifecycle impacts, safety, reliability, and mission objectives. From this perspective, repairability becomes part of the larger engineering question of how reusable aerospace systems can be designed not simply to survive multiple missions, but to remain supportable throughout them.

Concept	Common Emphasis in the Literature	Perspective Developed in This Capstone
Reusability	Ability to operate across multiple missions	Creates the opportunity for sustainable reuse but does not guarantee it
Sustainability	Environmental and lifecycle impacts	Depends on engineering decisions and resource demands across the system lifecycle
Advanced Materials	Thermal, structural, and performance requirements	Material performance should also be evaluated alongside inspection, maintenance, repair, and replacement requirements
Lifecycle Thinking	Evaluates impacts across stages of a system's life	Reveals how design decisions influence resource use, maintenance, repair, refurbishment, and end-of-life outcomes
Systems Engineering	Integrates technical requirements across the system lifecycle	Provides a structure for evaluating repairability alongside safety, reliability, performance, mass, cost, and mission requirements
Repairability	Commonly addressed through maintenance, repair, and maintainability practices	Considered as a sustainability design principle that can be evaluated before damage occurs and throughout the operational lifecycle

Building the Conceptual Framework

The relationships identified across the literature draw from several areas of engineering rather than a single theory or discipline. Research on advanced aerospace materials, lifecycle thinking, systems engineering, maintainability, inspection, repair, and maintenance each addresses a different part of the challenge of keeping reusable aerospace systems operational. When these areas are considered together, repairability provides a way to examine how decisions made during design can influence the options available throughout repeated operation.

Three areas form the foundation of the framework: advanced aerospace materials, lifecycle thinking, and systems engineering. Advanced materials determine many of the physical conditions that influence durability, degradation, inspection, and possible repair methods. Lifecycle thinking expands the evaluation of those materials and components beyond initial performance by considering what happens during manufacturing, operation, maintenance, repair, refurbishment, replacement, and end of life. Systems engineering provides the structure for evaluating these decisions alongside safety, reliability, mass, cost, performance, and mission requirements. Repairability operates across these areas by asking how early engineering decisions affect the ability to identify damage, access components, perform repairs or replacement, verify continued performance, and return the system to service. Maintainability and

inspection provide an important bridge within this framework. Existing aerospace research demonstrates that accessibility, visibility, assembly and disassembly, maintenance time, inspection methods, and other operational requirements can be considered during design. Repairability builds on this foundation but focuses more directly on the options available when damage or degradation requires intervention. A system may be maintainable without every component being repairable, and a technically repairable component may still create significant maintenance or inspection demands. Considering these relationships together allows repairability to be evaluated as part of a larger operational system rather than as an isolated response to damage.

The framework also recognizes that repairability does not move in only one direction. Designing for easier inspection or repair may reduce downtime or replacement needs, but it can also introduce additional mass, interfaces, manufacturing complexity, cost, or other engineering constraints. Material choices that improve durability may reduce repair frequency while making eventual repairs more difficult. Components designed for easier replacement may improve operational flexibility while creating different structural or resource requirements. These relationships make tradeoff analysis an important part of the framework. For this reason, the framework does not treat maximum repairability as the desired outcome. Instead, it asks whether repairability has been considered early enough for its benefits and tradeoffs to be evaluated alongside other engineering requirements. Depending on the component, mission, and type of damage, the most appropriate decision may involve repair, refurbishment, replacement, or retirement. The purpose is not to assume that repair is always the most sustainable option, but to avoid reaching the point of damage without having considered what options the design makes possible.

Repairability creates a relationship among design decisions, operational consequences, and lifecycle sustainability. Design decisions involving materials, architecture, accessibility, inspection, and component integration influence repairability. Repairability can then influence outcomes such as maintenance requirements, repair time, replacement frequency, resource consumption, operational downtime, component life, and return-to-service capability. These outcomes contribute to the larger lifecycle performance of the reusable aerospace system and can also provide feedback for future design decisions. This creates a continuing relationship rather than a linear process. Information gained through inspection, maintenance, repair, and repeated operation can reveal how materials and components actually perform in service. Those findings can inform later design changes, material selection, repair strategies, and future vehicle development. In this way, repairability connects decisions made before flight with information generated after flight, allowing lessons from repeated operation to contribute to future engineering decisions.

Bringing these relationships together positions repairability as a sustainability design principle within the larger engineering system. It does not replace existing approaches to maintainability, inspection, lifecycle assessment, or systems engineering. Instead, it brings these areas together around a specific question: what engineering decisions make it possible to sustain reuse when materials and components experience damage, degradation, or changing performance over time? By asking that question during design rather than only after damage occurs, the framework provides a structure for evaluating how repairability may contribute to the long-term sustainability of reusable aerospace systems.

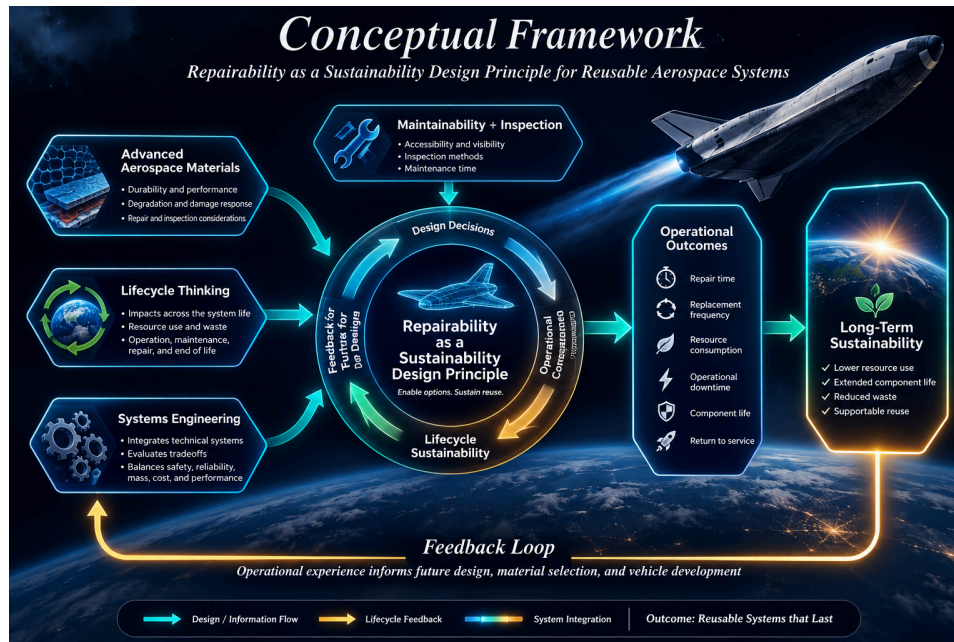


Figure 1
Conceptual Framework for Repairability as a Sustainability Design Principle in Reusable Aerospace Systems

This conceptual framework illustrates how advanced aerospace materials, lifecycle thinking, systems engineering, and maintainability and inspection contribute to the consideration of repairability during reusable aerospace system design. Repairability influences operational outcomes including repair time, replacement frequency, resource consumption, operational downtime, component life, and return-to-service capability. These outcomes contribute to long-term sustainability while creating a feedback loop through which operational experience can inform future design decisions, material selection, and vehicle development. The framework emphasizes that repairability is not treated as an isolated maintenance activity or as an objective to be maximized independently, but as a design principle evaluated alongside lifecycle and systems-level requirements. Figure created by Neriah Foye.

Research Design

This research uses a literature-based conceptual research design to examine how repairability can function as a sustainability design principle within reusable aerospace systems. The study draws from research across advanced aerospace materials, lifecycle assessment, systems engineering, maintainability, inspection, maintenance and repair, circular design, and sustainable aerospace engineering. Rather than testing a specific technology or collecting primary data from aerospace professionals, the research brings these existing areas of knowledge together to examine relationships that are relevant to the long-term sustainability of reusable systems. A literature-based design was appropriate because the research question extends across several areas of aerospace engineering that are often addressed through different technical perspectives. Material research provides evidence about durability, degradation, thermal performance, and damage response. Maintainability and inspection research addresses

accessibility, damage detection, maintenance requirements, and operational support. Lifecycle research provides methods for considering resource use and impacts across repeated operation, while systems engineering provides a structure for evaluating relationships and tradeoffs among technical requirements. Examining these areas together made it possible to investigate reparability without treating it as an isolated maintenance activity.

Epistemologically, this study takes an interpretive and systems-oriented approach, recognizing that knowledge about sustainable reusable aerospace systems is developed by examining relationships, tradeoffs, and patterns across multiple bodies of engineering evidence rather than isolating a single technical variable. The research process involved identifying literature that addressed reusable aerospace systems and the engineering conditions that influence their continued operation. Sources included peer-reviewed journal articles, technical reports, aerospace engineering publications, standards, government and institutional reports, and foundational literature related to systems thinking and sustainable design. Priority was given to sources that contributed directly to understanding material performance, inspection, maintainability, repair, lifecycle impacts, system integration, and the operational demands associated with reuse. Sources from aviation maintenance, circular design, and other engineering fields were also included when they provided concepts that could be evaluated within the more demanding safety and performance requirements of aerospace systems.

Although this study did not generate primary experimental data, it is empirically grounded in published technical evidence, including lifecycle assessment results, reusable thermal protection research, nondestructive evaluation studies, maintainability analyses, material-performance research, and documented operational requirements from aerospace systems. These sources provide the evidence base used to evaluate the relationships proposed in the conceptual framework. The literature was examined for recurring relationships rather than only summarized by topic. As the research developed, several connections became increasingly important: material durability did not necessarily determine ease of repair; the ability to inspect or maintain a component could be influenced during design; extending component life could reduce replacement while introducing other resource or operational demands; and improving reparability could create tradeoffs involving mass, complexity, cost, reliability, or performance. These relationships helped move the analysis from separate discussions of materials, lifecycle thinking, and systems engineering toward a broader examination of how those areas interact.

Reparability became the central concept connecting these relationships. Existing aerospace research already addresses maintainability, inspection, nondestructive evaluation, repair, thermal protection maintenance, and operational turnaround. The research design therefore did not begin from the assumption that reparability or related practices were absent from aerospace engineering. Instead, the analysis examined how existing engineering knowledge could be brought together and considered through the additional question of long-term sustainability. The conceptual framework was developed from this process of comparison and synthesis. Advanced aerospace materials, lifecycle thinking, and systems engineering became the three primary areas of the framework, while maintainability and inspection provided an important connection between design decisions and later operational requirements. Reparability was then positioned across these areas to examine how early engineering decisions can influence repair options, resource demands, component life, operational downtime, and return-to-service

capability. The framework represents the relationships identified through the literature rather than a model that has been experimentally validated.

This research design also recognizes an important limitation of conceptual research. The relationships identified in the literature can support the development of a framework, but they cannot establish that designing for greater repairability will always improve sustainability. The value of repairability depends on the component, material, vehicle architecture, mission requirements, type of damage, available repair process, and tradeoffs created elsewhere in the system. For this reason, the framework is intended to organize these relationships and identify areas for future testing rather than predict a single outcome for all reusable aerospace systems.

Selecting and Synthesizing the Literature

The literature for this research was selected to capture the different engineering areas involved in sustaining reusable aerospace systems over time. Searches were conducted using Google Scholar, Scopus, Web of Science, and the NASA Technical Reports Server. Search terms included combinations of *reusable aerospace systems*, *reusable spacecraft sustainability*, *reusable launch vehicles*, *aerospace lifecycle assessment*, *thermal protection systems*, *advanced aerospace materials*, *ceramic matrix composites*, *aerospace maintainability*, *design for maintainability*, *nondestructive evaluation*, *aerospace inspection*, *maintenance*, *repair*, and *overhaul*, *repairability*, *systems engineering*, *circular design*, and *design for repair*. Additional search terms were used as new connections within the literature became relevant to the research question.

Sources were selected based on their relevance to the research question rather than their connection to a single discipline. Priority was given to peer-reviewed research and technical literature addressing reusable aerospace systems, material performance and degradation, thermal protection, inspection, maintainability, repair and maintenance, lifecycle impacts, and systems-level engineering decisions. NASA and other government or institutional publications were included when they provided technical information, engineering frameworks, standards, or historical evidence relevant to reusable aerospace systems. Foundational research in systems thinking, lifecycle assessment, circular design, and sustainability was also included when it provided concepts needed to interpret the aerospace literature.

The research also extended beyond spacecraft-specific literature when other engineering fields provided useful concepts for the analysis. Aviation maintenance, repair, and overhaul research was included because it provides an established body of knowledge on the relationship between design decisions and long-term maintenance requirements. Circular design and design-for-repair literature provided additional perspectives on product-life extension, accessibility, modularity, repair, refurbishment, and replacement. These concepts were not treated as directly interchangeable with spacecraft engineering. Instead, they were considered within the stricter safety, reliability, verification, material, and mission requirements of aerospace systems. The literature was first organized around the major areas most closely connected to the research question: reusable aerospace systems, advanced aerospace materials, lifecycle thinking, systems engineering, and repairability. Further review showed that maintainability, inspection, nondestructive evaluation, maintenance and repair, and operational turnaround were also

necessary to understand the larger problem. This changed an important part of the research direction. Rather than treating repairability as something missing from aerospace engineering, the literature showed that many of the practices that support repairability already exist within aerospace maintainability, inspection, maintenance, repair, and reusable vehicle operations.

From there, the synthesis focused on the relationships, differences, and tradeoffs across these areas rather than summarizing each source independently. Materials research was compared with maintenance and inspection literature to examine the difference between material durability and the ability to identify and respond to damage. Lifecycle and circular design research were considered alongside aerospace maintenance to examine how repair, refurbishment, and replacement can affect component life and resource demands. Systems engineering literature provided a way to examine how these decisions interact with safety, reliability, mass, cost, performance, and mission requirements. Tradeoffs were also important to the analysis. A design decision that supports one sustainability objective can create additional demands elsewhere in the system. Greater durability may reduce replacement frequency without making a component easier to repair. Easier access may support inspection and maintenance while introducing mass or structural constraints. Repair may extend component life while requiring additional labor, energy, materials, or testing. Considering these tradeoffs helped prevent repairability from being treated as an automatic sustainability benefit and instead placed it within the larger set of engineering decisions required to sustain reuse.

Through this comparison, repairability became the central concept connecting the different areas of the research. The literature did not show that aerospace engineering has overlooked maintenance, inspection, or repair. It showed an opportunity to examine how these established practices relate to advanced materials, lifecycle impacts, and systems-level tradeoffs when sustainability becomes part of the design question. These relationships were then used to develop the conceptual framework for evaluating repairability within reusable aerospace system design. Because this research is conceptual and literature-based, the selection and synthesis process was intended to develop an informed engineering framework rather than provide an exhaustive systematic review of all available aerospace literature. The framework reflects the evidence and relationships examined in this study and provides a foundation that can be tested, expanded, or refined through future empirical research and application to specific reusable aerospace systems.

Literature Analysis and Concept Development

The literature was analyzed by comparing how different areas of research addressed the engineering requirements involved in repeated aerospace operation. Rather than applying a formal coding or thematic analysis procedure, I examined the sources for recurring relationships, differences, tradeoffs, and areas of overlap that could help answer the research question. This approach allowed the analysis to move beyond summarizing individual sources and toward understanding how different engineering decisions influence the ability to sustain reuse over time. The analysis began with three areas that had consistently shaped the research: advanced aerospace materials, lifecycle thinking, and systems engineering. Within the materials literature, I examined how durability, thermal performance, degradation, damage, and material selection affect repeated use. Lifecycle literature expanded the analysis to include manufacturing,

operation, inspection, maintenance, repair, refurbishment, replacement, and end of life. Systems engineering provided a way to examine how these decisions interact with safety, reliability, mass, cost, performance, and mission requirements.

Maintainability and inspection provide important connections among these areas. Aerospace research on design for maintainability showed that accessibility, visibility, assembly and disassembly, and maintenance time can be considered during design. Research on nondestructive evaluation and thermal protection systems added the need to detect, locate, and evaluate damage before decisions about repair or replacement can be made. Aviation maintenance and repair literature further demonstrated how information and decisions from earlier lifecycle stages continue to influence operational activities after a system enters service. The sources were then compared across these areas to identify where their engineering concerns intersected. One of the clearest relationships was the difference between durability and repairability. A material may survive demanding conditions for an extended period without necessarily being easy to inspect or repair once damage occurs. Another relationship involves component accessibility: a repair method may technically exist, but the location or configuration of the component can determine whether using that method is practical. Similar comparisons revealed connections among repair time, replacement frequency, resource consumption, operational downtime, component life, and return-to-service requirements.

Tradeoffs were considered throughout the analysis because the literature did not support treating repairability as an automatic sustainability benefit. Increasing accessibility may support inspection and repair while introducing additional mass or structural constraints. Greater material durability may reduce repair frequency while creating more difficult repair requirements when damage does occur. Repairing a component may extend its useful life while requiring additional energy, labor, materials, or testing. These comparisons showed that the value of repairability depends on how it affects the larger system rather than on whether a component can simply be repaired. These relationships were used to develop the conceptual framework presented in this study. Repairability became the central concept because it connects decisions made during design with the consequences of damage and degradation during operation. Advanced materials, lifecycle thinking, and systems engineering form the main structure of the framework, while maintainability and inspection help connect design decisions with later operational requirements. The framework also includes feedback from operational experience because information gained through inspection, maintenance, repair, and repeated use can inform future material choices, component designs, and vehicle development.

The analysis ultimately shifted the research question away from whether repair exists within aerospace engineering and toward how existing engineering practices can be evaluated together through sustainability. Aerospace research already provides substantial knowledge related to maintainability, inspection, damage evaluation, maintenance, and repair. The conceptual contribution of this research is bringing those areas into conversation with material performance, lifecycle impacts, and systems-level tradeoffs to examine repairability as a sustainability design principle for reusable aerospace systems.

Strengthening the Research Process

Several steps were taken throughout the research process to strengthen the quality of the analysis and avoid relying too heavily on a single source, discipline, or perspective. Because this study brings together literature from different areas of aerospace engineering and sustainability, sources were compared across fields and used according to the type of evidence they provided. Peer-reviewed research formed the primary scholarly foundation, while NASA and other technical or government publications provided engineering guidance, historical information, and evidence related to reusable aerospace systems. Standards and foundational literature were used to support lifecycle, systems, and sustainability concepts.

Comparing multiple sources was also important when evaluating major claims. Conclusions about reusable aerospace systems were not based only on sustainability literature, just as conclusions about repairability were not based only on design-for-repair research. Material science, thermal protection, maintainability, inspection, maintenance and repair, lifecycle management, and systems engineering literature were considered together when the research question crossed those areas. This helped identify where different bodies of research supported one another and where their assumptions or priorities differed. Source selection also required attention to the context in which the research was produced. Concepts from aviation maintenance, circular design, and repairable products were useful for understanding accessibility, maintenance, repair, refurbishment, component life, and resource use, but they were not assumed to transfer directly to reusable spacecraft. Aerospace systems operate under demanding thermal, structural, safety, reliability, and verification requirements. When concepts from outside spacecraft engineering were included, they were therefore interpreted within those constraints rather than presented as direct solutions for aerospace design.

The analysis also included evidence that challenged assumptions made earlier in the research process. A broader review of aerospace literature showed that inspection, maintainability, nondestructive evaluation, repair, and operational support are not new concerns within aerospace engineering. Instead of continuing with the assumption that these areas had been overlooked, the research question was refined to examine how existing engineering practices could be connected more directly to sustainability through repairability. This helped narrow the research gap and prevented the conceptual framework from being built on an inaccurate description of existing aerospace practice. Tradeoffs and evidence that complicated the proposed relationship between repairability and sustainability were also included. Repair can extend component life and reduce replacement in some situations, but it can also require additional labor, materials, energy, testing, or downtime. Designing for greater accessibility can support maintenance while creating constraints involving mass, structure, or component integration. These competing outcomes were included because the purpose of the framework is not to prove that repairability is always sustainable, but to provide a way to evaluate when and how it may contribute to sustainable reuse.

Finally, the claims made in this study were kept within the limits of the available evidence. The conceptual framework represents relationships supported through the literature reviewed in this research, but it has not been experimentally tested or validated on a specific reusable aerospace vehicle. Conclusions are therefore presented as a conceptual contribution and

a foundation for future investigation rather than as proof that a single repairability strategy will produce the same outcome across all reusable aerospace systems.

Ethical Considerations

Although this study did not involve human participants or the collection of primary data, ethical considerations remained important throughout the research process. The main responsibilities involved accurately representing existing research, distinguishing between evidence and interpretation, acknowledging limitations, and avoiding claims that extended beyond what the literature could support. This was important because the study brings together research from several engineering areas to develop a conceptual framework rather than testing repairability directly on a reusable aerospace system.

Care was taken to represent the existing aerospace literature accurately, including evidence that challenged assumptions made earlier in the research process. Aerospace engineering already contains substantial work on maintainability, inspection, nondestructive evaluation, maintenance, repair, thermal protection systems, and lifecycle management. Presenting repairability as if these practices were absent would have overstated the research gap and misrepresented the field. The resulting framework therefore extends and synthesizes existing engineering knowledge rather than replacing established aerospace practices. The use of research from outside spacecraft engineering also required careful interpretation. Concepts from aviation maintenance, circular design, and design-for-repair literature contributed useful perspectives on accessibility, component life, refurbishment, repair, and resource use. However, these concepts were not assumed to transfer directly to reusable aerospace systems. Differences in safety requirements, operating environments, material performance, reliability, verification, and mission objectives were considered when applying ideas from other fields.

Safety is also an important ethical consideration when discussing repairability in aerospace engineering. Extending component life or reducing material replacement may support sustainability, but these goals cannot take priority over vehicle reliability, mission requirements, or human safety. A component should not remain in service simply because repair uses fewer resources than replacement. Any repair would need to restore the level of performance and reliability required for continued operation and meet the appropriate engineering and verification requirements. For this reason, the framework does not assume that repair is always preferable to replacement. Similar care was taken when discussing sustainability benefits. Repairability may reduce replacement needs, extend component life, or support more efficient maintenance in some applications, but repair itself also requires resources. Labor, energy, replacement materials, specialized equipment, inspection, testing, and operational downtime can influence whether repair produces a meaningful lifecycle benefit. The study therefore avoids treating repairability as automatically sustainable and instead considers it as one engineering option whose benefits and tradeoffs must be evaluated within the larger system.

Finally, all sources used in the study are credited to their original authors and organizations, and the conceptual framework is presented as the interpretation developed through this research. The framework has not been experimentally validated and is not intended to prescribe specific repair decisions for operational aerospace vehicles. Its purpose is to provide a

foundation for examining how repairability can be considered alongside materials, lifecycle impacts, maintainability, safety, reliability, and systems-level requirements when evaluating the long-term sustainability of reusable aerospace systems.

Repairability as a Sustainability Design Principle

The analysis supports positioning repairability as a sustainability design principle within reusable aerospace systems. This does not mean that repair is new to aerospace engineering or that existing approaches to maintainability, inspection, and maintenance are insufficient. Instead, the literature shows that many of the engineering conditions that determine whether repair is possible are established long before damage occurs. Material selection, component accessibility, inspection requirements, system architecture, joining methods, maintenance planning, and replacement strategies can all influence what options remain available once a reusable vehicle begins operating across multiple missions.

This changes how repairability can be understood within sustainable aerospace engineering. When repair is treated mainly as an operational response, attention begins after a component has experienced damage or degradation. Considering repairability during design moves that question earlier in the lifecycle. Engineers can ask how damage will be identified, whether affected components can be accessed, what repair methods may be available, how a repair can be verified, and when replacement would be more appropriate. These decisions do not guarantee that a component will be repaired, but they determine whether repair remains a realistic option when intervention becomes necessary.

The analysis also shows that repairability is different from durability and maintainability even though the three are closely connected. Durability affects how well a material or component withstands repeated exposure and how frequently intervention may be required. Maintainability addresses the broader ability to perform maintenance activities efficiently throughout operation. Repairability focuses on the ability to restore function after damage or degradation occurs. A durable component may still be difficult to repair, while a maintainable system may contain components that must be replaced rather than restored. Keeping these concepts separate makes it possible to evaluate what each one contributes to continued operation.

Repairability becomes relevant to sustainability when these design decisions are connected to their consequences across the lifecycle. Repairing a component may extend its useful life, reduce replacement, and preserve material already invested in the system. It may also affect maintenance time, energy use, labor, testing requirements, and operational downtime. In other situations, replacement may require fewer resources or provide a safer and more reliable outcome than repair. The sustainability value of repairability therefore comes from preserving the ability to evaluate these options rather than assuming that repair itself is always the preferred outcome.

This finding also expands the meaning of reusable design. A vehicle can be technically reusable while still requiring extensive work between missions. Repeated flight may involve inspection, replacement, refurbishment, testing, and repair before the vehicle can safely return to service. Reusability describes the capability to operate again, but it does not explain the engineering

effort required to maintain that capability. Repairability adds another question to reusable design: what has been built into the system to support continued operation when wear, damage, or degradation occurs?

The answer cannot be separated from systems-level tradeoffs. Increasing accessibility may make inspection or repair easier while adding mass or limiting other design choices. Selecting a more durable material may reduce repair frequency while making eventual repairs more difficult. Modular components may support replacement while introducing additional interfaces or structural complexity. These relationships show why repairability should not be maximized independently. Its value depends on how it interacts with safety, reliability, performance, mass, cost, resource use, and mission requirements.

For this reason, repairability as a sustainability design principle is best understood as a design consideration rather than a predetermined solution. Its purpose is to make the consequences of future damage and degradation visible earlier in the engineering process. Instead of waiting until a component fails or becomes damaged to determine what can be done, engineers can consider those possibilities while materials, components, and system architectures are still being selected and developed.

This perspective also creates a stronger connection between design and operational experience. Inspection, maintenance, repair, and refurbishment generate information about how materials and components perform under actual repeated use. That information can reveal damage patterns, difficult-to-access components, repair limitations, maintenance demands, and unexpected resource requirements. Feeding these lessons back into future designs allows repairability to change as engineers gain a better understanding of how reusable systems behave across their operational lives.

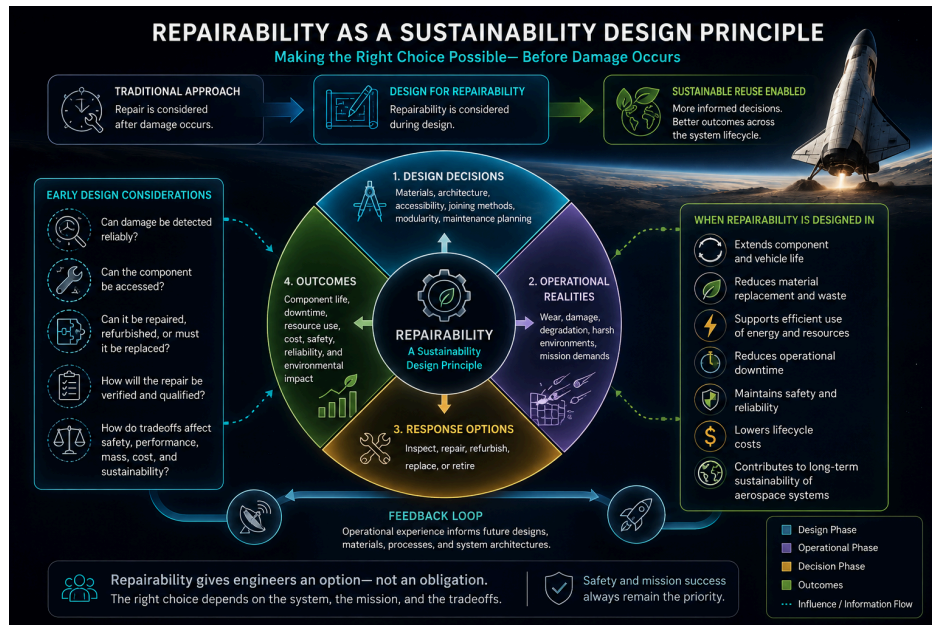


Figure 2
Repairability as a Sustainability Design Principle

This figure illustrates how considering repairability during early aerospace system design can influence the options available after wear, damage, or degradation occurs. Design decisions involving materials, architecture, accessibility, joining methods, modularity, and maintenance planning shape the ability to inspect, repair, refurbish, replace, or retire a component during operation. These decisions can influence component life, resource use, operational downtime, cost, safety, reliability, and other lifecycle outcomes. The feedback loop represents how information gained through operation, inspection, maintenance, and repair can inform future materials, processes, and system designs. Repairability is presented as an engineering option rather than an obligation, with safety, reliability, mission requirements, and systems-level tradeoffs remaining central to the final decision. Figure created by Neriah Foye.

The central finding is not that reusable aerospace systems should simply be made easier to repair. It is that repairability should become part of the engineering conversation early enough for its lifecycle consequences and tradeoffs to be evaluated before they are locked into the design. When considered alongside advanced materials, lifecycle thinking, maintainability, inspection, and systems engineering, repairability provides a way to connect the technical ability to reuse aerospace hardware with the larger challenge of sustaining that reuse over time.

Sustainability Beyond Reusability

Reusability and sustainability are closely connected, but they are not interchangeable. Reusability describes the ability of a vehicle or component to operate across multiple missions, while sustainability requires a broader evaluation of what is needed to make those repeated missions possible. Recovering and flying hardware again can reduce the need to manufacture an entirely new system for every mission, but repeated use also introduces inspection, maintenance,

repair, refurbishment, testing, replacement, energy use, and other operational demands. The sustainability of a reusable aerospace system therefore depends not only on whether it can fly again, but on what is required for it to continue doing so. A vehicle capable of completing many missions may appear more sustainable when reuse is measured mainly by the number of flights completed or the amount of hardware preserved. That picture becomes more complicated when the resources required between missions are included. Frequent replacement of damaged components, extensive inspection, long refurbishment periods, specialized repair processes, or increasing maintenance demands can reduce some of the resource benefits expected from reuse. The number of times a system can operate is important, but it does not provide a complete picture of its long-term sustainability.

Thermal protection systems provide a clear example. Their ability to survive the extreme conditions of atmospheric entry is necessary for vehicle reuse, but survival alone does not determine what happens between missions. Damage must be identified, evaluated, and addressed before another flight. Depending on the material and system design, this may involve inspection, localized repair, removal and replacement, testing, or refurbishment. A thermal protection system can therefore support technical reusability while still requiring significant resources and operational effort to prepare the vehicle for continued use. Advanced materials create similar questions. Increasing durability can extend component life and reduce how often replacement is necessary, but durability alone does not account for inspection requirements, repair difficulty, manufacturing demands, or what happens when the material eventually reaches the end of its useful life.

One material may provide an advantage because it lasts longer, while another may be easier to inspect, repair, replace, or recover. Looking at these outcomes together provides a more complete understanding of whether a material actually supports sustainable reuse. The longest-lasting material will not always create the best lifecycle outcome. The time and resources required between missions also matter. Reusable aerospace systems move through repeated cycles of flight and ground operations, and the work required during those periods influences how effectively reuse can be sustained. Inspection time, maintenance labor, repair requirements, component replacement, testing, and return-to-service activities can affect both vehicle availability and resource use. Reducing unnecessary demands between missions can strengthen the benefits of reuse, as long as those reductions do not compromise safety or reliability.

Many of the conditions that influence these outcomes are established before the vehicle ever enters service. Decisions involving materials, component architecture, accessibility, inspection, maintenance, repair, and replacement can shape what will be required later in the lifecycle. Sustainability therefore becomes part of the engineering process rather than an outcome that can only be measured after a reusable system has already been designed and operated. No single engineering decision can guarantee sustainable reuse. A lighter material may improve flight performance while introducing different manufacturing or repair demands. A more accessible component may reduce maintenance time while creating mass or structural tradeoffs. Repair may preserve material and extend component life in one situation, while replacement may provide a safer or less resource-intensive option in another. What matters is how these decisions interact across the larger system and what they require over time.

Sustainable reuse can therefore be understood as more than the ability to operate hardware again. It includes the ability to support repeated operation while considering the resources, maintenance, repair, replacement, performance, safety, and lifecycle consequences required to make that operation possible. This does not reduce the importance of reusability. It expands the question from whether a system can be reused to how that reuse is sustained over time. Within this broader view of sustainable reuse, repairability preserves another engineering option when damage or degradation occurs. It does not make a reusable system sustainable by itself, and it does not mean that repair should always be selected over replacement. Its value comes from allowing the consequences of future intervention to be considered during design and evaluated alongside other lifecycle and system requirements. Sustainability beyond reusability therefore means designing not only for another mission, but also for the decisions, resources, and engineering work required across the missions that follow.

Repairability as the Connecting Principle

Repairability connects advanced aerospace materials, lifecycle thinking, and systems engineering because decisions in each area influence what happens when a reusable system experiences damage or degradation. Materials determine how components respond to repeated thermal, mechanical, and environmental conditions. Lifecycle thinking extends those decisions across manufacturing, operation, inspection, maintenance, repair, refurbishment, replacement, and end of life. Systems engineering provides a way to evaluate these requirements alongside safety, reliability, performance, mass, cost, and mission objectives. Repairability brings these areas together around a practical question: what options remain available when a material or component can no longer continue operating in its current condition?

The connection begins with material selection. Advanced aerospace materials are selected to meet demanding performance requirements, but those choices also influence how damage can be detected, evaluated, and addressed later. A material may provide excellent thermal resistance or structural performance while requiring specialized inspection or repair methods. Another material may have different durability limitations but provide more practical options for maintenance or replacement. Looking at materials through repairability adds another consideration to material selection without reducing the importance of performance. The question becomes not only how a material performs under expected conditions, but what the system allows engineers to do when that performance begins to change. Lifecycle thinking extends this question beyond the material itself. Damage can lead to several possible outcomes, including continued operation, repair, refurbishment, replacement, or retirement. Each option carries different requirements for labor, energy, materials, testing, time, and other resources. The decision that restores a component to service may not always be the decision with the lowest lifecycle impact, and the option that preserves the most material may not always provide the safest or most practical outcome. Repairability connects these choices by making the consequences of future intervention part of the lifecycle discussion before the intervention is actually needed.

Systems engineering provides the structure needed to evaluate these choices because repairability cannot be considered independently from the rest of the vehicle. Making a component easier to access may support inspection and repair while affecting mass, structural

design, thermal protection, or component placement. Changing a joining method may improve disassembly while creating different reliability or manufacturing requirements. Adding modularity may simplify replacement while increasing the number of interfaces within the system. Repairability therefore becomes useful only when its benefits and tradeoffs are evaluated alongside the requirements that determine whether the overall system can perform its mission safely and effectively.

Maintainability and inspection strengthen the connection between these three areas. Before a component can be repaired, engineers must be able to determine its condition, locate damage, understand whether intervention is necessary, and access the affected area. A technically available repair method has limited value if the damage cannot be reliably detected or if reaching the component requires extensive disassembly. In the same way, an easily accessible component does not automatically create a repairable system if the material cannot be restored to the required level of performance. Repairability depends on these conditions working together. This creates an important sequence within reusable operation. Material and system design influence how damage occurs and whether it can be identified. Inspection provides information about the condition of the component. Engineers can then evaluate whether continued operation, repair, refurbishment, replacement, or retirement is appropriate. That decision affects resource use, maintenance time, operational downtime, component life, and return-to-service requirements. Those outcomes become part of the lifecycle performance of the system and can provide information for future design decisions.

Repairability therefore connects decisions made at different points in time. Choices made during early design affect options that may not be needed until years later, while information collected during operation can influence the next generation of materials, components, and vehicles. A repair that repeatedly requires extensive disassembly may reveal an accessibility problem. Frequent replacement of the same component may point to a material or design limitation. Inspection results may identify damage patterns that were not fully anticipated during development. These experiences can then be used to improve later designs rather than treating each maintenance or repair event as an isolated problem. The connection also works across different measures of performance. Technical performance asks whether a component can meet its required function. Operational performance considers what is required to keep that component available for service. Lifecycle performance expands the evaluation to include the resources and consequences associated with maintaining that capability over time. Repairability does not replace any of these measures. It provides a point where they can be considered together when damage or degradation creates the need for an engineering decision.

For reusable aerospace systems, this is what makes repairability more than a maintenance concern. It connects material behavior with operational decisions, operational decisions with lifecycle consequences, and lifecycle consequences with future system design. The value of the principle is not simply that damaged hardware can be repaired. Its value comes from creating a clearer connection between how reusable systems are designed, what happens to them during repeated operation, and what is required to keep them safely and effectively in service over time.

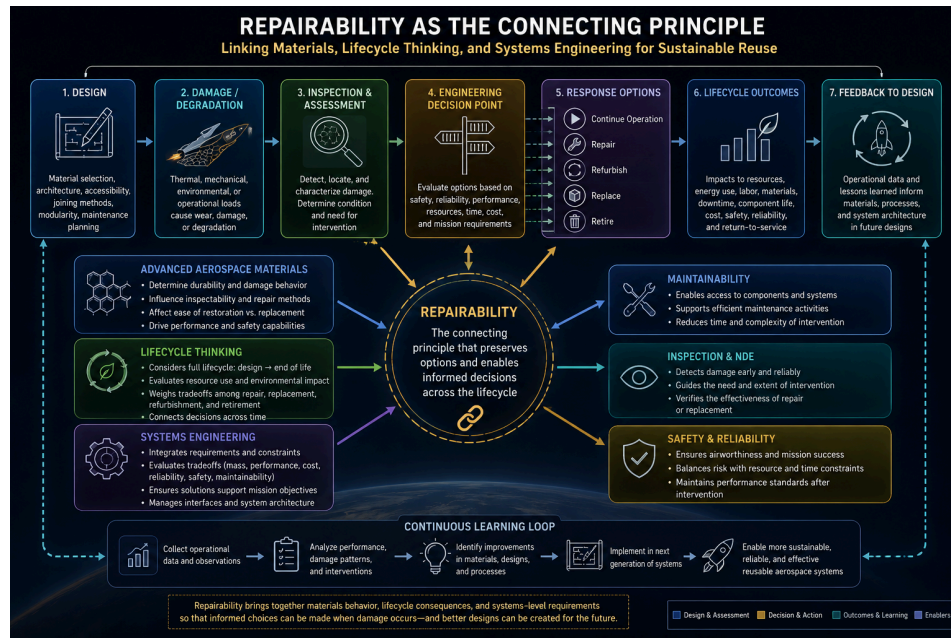


Figure 3
Repairability as the Connecting Principle in Reusable Aerospace Systems

This figure illustrates how repairability connects advanced aerospace materials, lifecycle thinking, and systems engineering across the operational life of a reusable aerospace system. The process begins with design decisions that influence how materials and components respond to damage or degradation, followed by inspection and assessment to determine whether intervention is necessary. Repairability supports the engineering decision process by preserving options for continued operation, repair, refurbishment, replacement, or retirement based on safety, reliability, performance, resource demands, cost, and mission requirements. Maintainability and nondestructive evaluation support access, damage detection, and verification throughout this process. Lifecycle outcomes, including resource use, operational downtime, component life, and return-to-service requirements, provide feedback that can inform future materials, processes, component architectures, and system designs. The continuous learning loop demonstrates that repairability connects decisions made before damage occurs with lessons gained through repeated operation, allowing future reusable aerospace systems to be designed using knowledge gained throughout the lifecycle. Figure created by Neriah Foye.

An Integrated Conceptual Framework

The integrated framework brings together the relationships among advanced materials, lifecycle thinking, systems engineering, maintainability, inspection, and repairability within the larger challenge of sustainable reuse. Advanced aerospace materials, lifecycle thinking, and systems engineering form the foundation of the framework, while maintainability, inspection, and repair connect design decisions with the realities of repeated operation. These areas do not function independently. Decisions made in one area can change the requirements, limitations, and options available in another. At the center of the framework is repairability as a sustainability design principle. Its role is not to make repair the preferred response to every form of damage or

degradation. Instead, repairability preserves the ability to make informed decisions when intervention becomes necessary. Depending on the condition of the component and the requirements of the mission, the appropriate response may be continued operation, repair, refurbishment, replacement, or retirement. Considering these possibilities during design allows engineers to evaluate what each option may require before those decisions are limited by choices that have already been built into the system.

Advanced aerospace materials provide the physical foundation for these decisions. Material properties influence durability, damage behavior, thermal and structural performance, inspection requirements, and available repair methods. Lifecycle thinking expands the evaluation by considering what those material and design choices require during manufacturing, repeated operation, maintenance, repair, replacement, and end of life. Systems engineering then provides the structure for evaluating these choices alongside safety, reliability, performance, mass, cost, resource use, and mission objectives. Repairability connects the three by focusing attention on what happens when continued operation requires some form of intervention. Maintainability and inspection support this connection by determining whether the condition of a component can be understood and whether intervention is practical. Damage must be detected and evaluated before engineers can determine the appropriate response. Components must also be accessible enough for inspection, maintenance, repair, or replacement to occur. These conditions show why repairability cannot be evaluated only by asking whether a technical repair method exists. The larger question is whether the system has been designed in a way that allows damage to be identified, decisions to be made, and the selected response to be completed and verified safely.

The framework also places lifecycle outcomes directly into the engineering decision process. Repair time, replacement frequency, maintenance labor, energy and material use, operational downtime, component life, cost, reliability, and return-to-service requirements can all change the value of a repairability decision. A repair that extends component life may support sustainability in one application but require enough additional resources or testing to make replacement more appropriate in another. The framework does not assign a universal value to repair. It provides a structure for evaluating the consequences of the available options. Another important part of the framework is feedback from operation to design. Reusable aerospace systems generate information every time they are inspected, maintained, repaired, refurbished, or returned to service. Repeated damage in the same location may point to a material or design limitation. Difficult access may reveal that maintenance requirements were not fully addressed during component integration. A repair that performs successfully across multiple missions may provide information that supports future material or design choices. Operational experience can therefore become an input for future engineering rather than remaining only a record of what happened after flight.

This feedback makes the framework continuous rather than linear. Design influences operation, operation produces information, and that information can influence future design. Over time, this creates an opportunity to improve not only individual repair processes but also the materials, architectures, inspection strategies, maintenance requirements, and engineering decisions that determine how reusable systems are supported. Repairability becomes part of a learning process across generations of aerospace systems. The integrated framework also provides a clearer way to understand sustainable reuse. Reusability establishes that a vehicle or component can operate again. Sustainable reuse asks what is required to preserve that capability

across repeated missions and whether those requirements create acceptable technical, operational, and lifecycle outcomes. Repairability contributes to this goal by connecting the consequences of future damage with decisions being made during design, when engineers still have the greatest ability to shape the options available later.

Repairability does not replace durability, maintainability, lifecycle assessment, or systems engineering. Instead, it connects these existing areas around the long-term support of reusable aerospace systems. Its contribution is the integration of material behavior, inspection and maintainability, repair and replacement options, lifecycle consequences, systems-level tradeoffs, and operational feedback within a sustainability-focused design perspective. This provides a foundation for evaluating not only whether aerospace hardware can be reused, but how engineering decisions can support that reuse safely, effectively, and sustainably over time.

Implications for Aerospace Engineering

The findings suggest that damage, inspection, maintenance, repair, and replacement should not be viewed only as problems that begin after a reusable vehicle enters service. Many of the conditions that determine what engineers can do later are established much earlier through decisions involving materials, component architecture, accessibility, joining methods, inspection requirements, and system integration. Considering these conditions during design gives engineers more opportunity to understand their long-term consequences before the available options become limited.

For materials engineering, advanced aerospace materials should be evaluated through more than their ability to survive demanding operating environments. Thermal resistance, structural performance, durability, mass, and other performance requirements remain essential, but what happens to a material throughout repeated use also matters. Engineers can consider how damage will be detected, whether localized repair is possible, what equipment or processes would be required, how a repair could be verified, and what happens when repair is no longer appropriate. These questions add another layer to material selection when different materials meet performance requirements but create very different inspection, maintenance, or repair demands. Inspection and nondestructive evaluation are closely connected to these decisions. Repairability has limited value if damage cannot be reliably identified or characterized. Considering inspection during design can improve the ability to monitor component condition throughout repeated operation and provide the information needed to decide between continued use, repair, refurbishment, replacement, or retirement. Not every component can be equally accessible or easy to inspect, especially within the constraints of an aerospace vehicle. Identifying these requirements earlier, however, can help engineers understand where design choices may create challenges once the vehicle enters service.

Maintainability adds another connection between design and repeated operation. Accessibility, assembly and disassembly, component placement, and maintenance time can influence how efficiently a reusable vehicle is supported between missions. Repairability extends this discussion by asking what happens when routine maintenance is no longer enough and damage requires more significant intervention. A material or component may be technically repairable, but that advantage becomes much smaller if completing the repair requires extensive

disassembly, specialized processes, long periods of downtime, or difficult verification procedures. Repairability also creates a systems engineering question because its requirements and tradeoffs cross disciplinary boundaries. Improving access to a component may support inspection and repair while affecting mass or structural configuration. Simplifying replacement may introduce additional interfaces. Extending component life through repair may increase inspection, testing, or verification requirements. These decisions cannot be evaluated through repairability alone. They have to be considered alongside the safety, reliability, performance, cost, and mission requirements of the larger vehicle.

Lifecycle evaluation can provide a more complete picture of these decisions by including more of what happens between missions. Repair frequency, replacement frequency, maintenance labor, inspection requirements, refurbishment, material and energy inputs, operational downtime, and component life all contribute to what is required to sustain repeated operation. Including these activities can help identify situations where the expected benefits of reuse are strengthened by longer component life or more efficient maintenance, as well as situations where resource-intensive support requirements reduce those benefits. What happens during operation can also improve future designs. Inspection results, maintenance records, recurring damage, repair histories, replacement patterns, and turnaround requirements provide information about how materials and components actually perform under repeated use. A component that repeatedly experiences the same type of damage may point to a material or design limitation. A repair that consistently requires extensive disassembly may reveal an accessibility problem. A successful repair strategy may provide information that can improve future material selection or component design. Using these lessons creates a direct connection between operational experience and the development of future reusable systems.

None of these implications mean that aerospace engineers should maximize repairability across every component or choose repair whenever damage occurs. Safety, reliability, performance, and mission success remain essential. In some situations, replacement or retirement will be the better engineering decision. Considering repairability earlier simply allows those options and their consequences to be evaluated intentionally instead of waiting until damage occurs and discovering that the design has already limited what can be done.

For aerospace engineering, the broader implication is a shift from designing only for repeated flight toward designing with the full requirements of repeated operation in mind. Reusable vehicles must not only survive missions; they must also be inspected, maintained, repaired or refurbished when appropriate, verified, and safely returned to service. Bringing repairability into those decisions creates another connection between advanced materials, operational experience, lifecycle consequences, and systems-level engineering. Over time, this approach could support reusable aerospace systems that are not only capable of flying again, but are designed with greater awareness of what it takes to keep them flying.

Looking Forward

This final chapter brings together the major findings of the research and considers what they mean for the long-term sustainability of reusable aerospace systems. It reflects on the role of repairability as a sustainability design principle, the importance of considering what is required

to sustain reuse across repeated missions, and the engineering tradeoffs identified throughout the study. The chapter also addresses the limitations of this research and identifies opportunities for future work to test, refine, and apply the conceptual framework within aerospace engineering.

Summary of Findings

This research examined how repairability, advanced aerospace materials, and lifecycle thinking can contribute to the long-term sustainability of reusable aerospace systems. Reusability alone does not provide a complete measure of sustainability. A vehicle may be capable of flying multiple missions while still requiring significant inspection, maintenance, repair, refurbishment, testing, replacement, and other resources between flights. Sustainable reuse therefore depends on both the ability to reuse aerospace hardware and what is required to keep that hardware safely operational over time.

Repairability also begins much earlier than the repair itself. Material selection, component architecture, accessibility, inspection requirements, joining methods, maintainability, and replacement strategies can influence the options available when damage or degradation occurs. By the time a component requires intervention, many of those options may already be limited by decisions made during design. Considering repairability earlier gives engineers the opportunity to think about those future conditions while they can still influence the design. The research also helped separate durability, maintainability, and repairability. These concepts support continued operation in different ways, but they are not interchangeable. Durability describes how well materials and components withstand repeated use. Maintainability addresses how effectively maintenance can be performed throughout operation. Repairability focuses on what can be done when damage or degradation requires a component to be restored. A component can be highly durable but difficult to repair, just as a system can be maintainable while still containing components that must be replaced rather than restored.

Repairability becomes a sustainability question when those decisions are followed across the lifecycle. Repair can extend component life and reduce replacement in some situations, but it can also require additional labor, materials, energy, inspection, testing, and time. Replacement may be safer, more reliable, or less resource-intensive in other situations. The goal is not to make repair the preferred outcome. It is to make sure that repair, replacement, refurbishment, continued operation, and retirement can be evaluated as engineering options rather than assuming that one decision will always produce the most sustainable result.

These decisions also cannot be separated from the larger aerospace system. Repairability interacts with safety, reliability, mass, structural requirements, performance, cost, accessibility, and mission objectives. Improving one area can create new requirements somewhere else in the vehicle. Systems engineering provides a way to understand those tradeoffs and evaluate repairability without allowing it to override the requirements that determine whether the vehicle can perform safely and effectively. The literature also clarifies a more specific research gap. Aerospace engineering has already developed substantial knowledge related to maintenance, inspection, nondestructive evaluation, repair, maintainability, thermal protection systems, and operational support. The opportunity is not to introduce repair as a new aerospace concern, but to connect these existing areas more directly with advanced materials, lifecycle consequences, and

sustainability. Repairability provides a way to make that connection by focusing on how design decisions influence the options and resource demands associated with continued operation.

This supports the use of repairability as a sustainability design principle within reusable aerospace systems. It does not mean designing every component for maximum repairability or choosing repair whenever damage occurs. It means considering future damage, inspection, repair, refurbishment, replacement, and retirement early enough for those possibilities to influence engineering decisions. The framework organizes these relationships while leaving room for the safety, performance, lifecycle, and systems-level tradeoffs that determine which option makes sense. The larger finding is simple: sustainable reuse requires more than designing aerospace hardware to fly again. It requires understanding what will be needed to inspect, maintain, restore, verify, and safely return that hardware to service throughout its operational life. Connecting repairability with materials, lifecycle thinking, maintainability, inspection, and systems engineering provides a foundation for designing reusable aerospace systems not only for the next mission, but with greater awareness of what it will take to support the missions that follow.

Contributions to Aerospace Engineering

The main contribution of this research is not the introduction of repair, maintainability, or inspection into aerospace engineering. These areas are already well established within aerospace research and practice. The contribution is bringing them into a broader sustainability discussion and examining how repairability can connect decisions involving advanced materials, lifecycle consequences, repeated operation, and systems-level tradeoffs. This creates a different way to think about what it means to design a reusable aerospace system for long-term use. Bringing these areas together makes it possible to follow repairability from early design decisions through repeated operation. Advanced aerospace materials, lifecycle thinking, and systems engineering each address different parts of that process, while maintainability and inspection connect early decisions with what becomes necessary once the vehicle is in service. Repairability sits across these areas because the options available after damage or degradation are shaped by decisions made throughout the system. Looking at the problem this way keeps repairability connected to the safety, reliability, performance, resource, and mission requirements that shape aerospace design.

The distinction between reusability and sustainable reuse is also important. Reusability establishes that aerospace hardware can operate again, but it does not describe everything required to make another mission possible. Inspection, maintenance, repair, refurbishment, replacement, testing, and return-to-service activities continue between missions and can influence the resources required throughout the operational life of a vehicle. Bringing these activities into the sustainability discussion expands the evaluation of reuse beyond the number of times a vehicle or component can fly. Durability, maintainability, and repairability support continued operation in different ways. Improving one does not automatically improve the others. A component may be highly durable but difficult to repair, while a maintainable system may still contain components that require replacement rather than restoration. Recognizing these differences makes it easier to evaluate what each contributes to the long-term support of reusable aerospace systems without treating them as interchangeable.

Repairability as a sustainability design principle builds on these distinctions. It does not mean that every damaged component should be repaired or that greater repairability will always create a more sustainable system. It means considering future intervention early enough for continued operation, repair, refurbishment, replacement, or retirement to remain part of the engineering decision process. Thinking about these possibilities during design connects sustainability with choices being made before damage occurs instead of treating sustainability only as an outcome evaluated later in the lifecycle. Operational experience can feed directly into future aerospace design. Inspection results, maintenance demands, repair histories, recurring damage, replacement patterns, and return-to-service requirements provide information about how materials and components perform across repeated missions. A recurring repair problem may reveal limitations in accessibility or component architecture, while repeated damage may point to a material or design issue. Successful repair strategies can also provide information that supports future material selection, inspection planning, and component development. In this way, what engineers learn during operation can influence the design of future reusable systems.

These contributions are conceptual rather than experimentally validated, but they provide a foundation for more focused aerospace research. The relationships identified in this study can be tested using specific materials, components, thermal protection systems, vehicle architectures, maintenance records, lifecycle data, or reusable aerospace programs. Future research can also develop measurable ways to determine when repairability supports sustainable reuse and when safety, reliability, resource demands, or other engineering requirements make replacement or retirement the better decision. The contribution of this research can therefore be understood as a shift in the question being asked. Instead of focusing only on whether aerospace hardware can be reused, this research asks what engineering decisions make that reuse supportable across repeated missions and throughout the lifecycle. Repairability provides one way to connect those decisions with materials, maintenance requirements, operational experience, resource demands, and systems-level tradeoffs. The goal is not simply to make reusable systems last longer, but to better understand what it takes to support them throughout the repeated missions they were designed to complete.

Limitations

This research has several limitations that shape how the findings should be interpreted. Because the study is literature-based and conceptual, the relationships among repairability, advanced aerospace materials, lifecycle thinking, maintainability, inspection, and systems engineering were not tested experimentally or applied to a specific reusable aerospace vehicle. The findings provide a foundation for further investigation, but they cannot establish that a particular repairability strategy will produce the same sustainability outcome across different aerospace systems. The breadth of the research also limited how much technical detail could be given to individual materials, components, or subsystems. Reusable aerospace systems include highly specialized materials, structures, propulsion systems, thermal protection, avionics, manufacturing processes, and maintenance requirements that operate under very different conditions. Repairability for a thermal protection system may look very different from repairability for a structural component or propulsion system. Examining these relationships across the larger system was useful for understanding how the pieces connect, but applying them in practice will require more focused research at the material, component, and subsystem levels.

Access to operational data was another limitation. Detailed information about recurring damage, inspection findings, repair frequency, maintenance labor, component replacement, refurbishment, turnaround time, and the resources required between missions is not always publicly available for reusable aerospace programs. Without consistent operational data, this research could not quantitatively compare the lifecycle consequences of different repair and replacement decisions. More complete data would make it possible to measure how repairability affects resource use, component life, downtime, cost, and other outcomes across repeated missions.

Some of the literature used in this study also comes from outside spacecraft engineering, including aviation maintenance, repair and overhaul, lifecycle assessment, circular design, and design for repair. These areas provide useful ways to think about accessibility, inspection, maintenance, component life, refurbishment, and resource use, but their requirements cannot be transferred directly to reusable aerospace systems. Spacecraft operate under demanding thermal, structural, safety, reliability, verification, and mission conditions. Concepts drawn from other fields would therefore need to be evaluated within aerospace-specific applications before becoming design requirements or operational practices. Sustainability adds another layer of complexity because it can be measured through environmental, economic, operational, and technical outcomes.

This research focused on how repairability can influence resource use, component life, maintenance and repair demands, replacement, operational downtime, and continued reuse. It did not conduct a complete lifecycle assessment, calculate a carbon footprint, develop an economic model, or measure the environmental impacts of a specific vehicle. As a result, the study cannot determine that repair will have a lower overall lifecycle impact than replacement in every situation. The lack of primary data also limits the stakeholder portion of the research question. Interviews with aerospace engineers, materials specialists, maintenance professionals, manufacturers, and other stakeholders were not conducted, so this study cannot determine directly how different groups evaluate repairability or which tradeoffs they would prioritize in practice. Published research provides evidence about existing engineering approaches and technical concerns, but direct stakeholder research could reveal differences between design priorities, operational experience, organizational requirements, and sustainability goals that the literature alone cannot fully capture.

These limitations define where the current research ends and where the next stage can begin. The relationships identified here still need to be tested within specific vehicles, materials, components, and mission environments. Repairability may provide meaningful sustainability benefits in some applications and limited benefits in others. Determining where those benefits exist will require aerospace-specific data, measurable performance indicators, lifecycle comparisons, and input from the engineers and other stakeholders responsible for designing, maintaining, and operating reusable systems.

Recommendations for Future Research

Future research should move from the conceptual relationships identified in this study toward testing repairability within specific reusable aerospace applications. Applying the ideas to individual materials, components, subsystems, or vehicle architectures would make it possible to determine where repairability provides measurable benefits and where other engineering requirements limit its value. Thermal protection systems provide a strong starting point because they experience repeated exposure to extreme conditions and require inspection, maintenance, repair, or replacement throughout operation. Structural components, propulsion systems, and other reusable hardware could provide additional cases for comparison. Developing measurable indicators of repairability would be another important step. Repairability cannot be evaluated only by determining whether a component can technically be repaired. Future studies could measure factors such as damage detectability, accessibility, repair time, labor requirements, material and energy inputs, specialized equipment, verification requirements, operational downtime, component life after repair, and return-to-service performance. These measures could help distinguish between a repair that is technically possible and one that provides a practical lifecycle advantage.

Lifecycle comparisons are also needed to determine when repair produces a meaningful sustainability benefit. Future research could compare repair, refurbishment, replacement, and retirement under the same operating conditions and evaluate the resources required by each option. This could include material consumption, energy use, maintenance labor, testing, replacement frequency, downtime, cost, and component life across multiple missions. Combining these measures with lifecycle assessment could provide stronger evidence about when extending the life of a component reduces overall impacts and when replacement may provide the better outcome. Operational aerospace data would strengthen this work even further. Maintenance records, inspection findings, recurring damage patterns, repair histories, replacement frequency, turnaround time, and component performance across repeated missions could be used to test whether the relationships identified in this study appear in actual reusable systems. Longitudinal data would be valuable because the consequences of design decisions may not become visible after a single mission. Following materials and components across repeated cycles of operation, inspection, intervention, and return to service could show how repairability changes throughout the useful life of a system.

Stakeholder research should also be revisited. Interviews or other primary research with aerospace engineers, materials specialists, systems engineers, maintenance and inspection professionals, manufacturers, and sustainability specialists could examine how repairability is understood across different areas of aerospace practice. These perspectives could identify which repairability measures are most useful, where design and operational priorities conflict, and what barriers prevent repair and maintenance requirements from being considered earlier. Stakeholder research would also address the part of the research question that could not be examined directly in the current literature-based study. Future work could also investigate how repairability requirements might be incorporated into existing aerospace design and systems engineering processes. This could include determining where repairability should be considered during requirements development, material selection, preliminary and critical design reviews, verification planning, maintainability analysis, and lifecycle assessment. The goal would not be

to create a separate repairability process, but to determine where repair-related questions can be evaluated within engineering activities that already guide aerospace system development.

Another direction is the development of decision-support methods for comparing intervention options after damage occurs. A future model could combine technical condition, safety, reliability, repair time, resource requirements, lifecycle impacts, cost, and mission constraints to help compare continued operation, repair, refurbishment, replacement, and retirement. Such a method would need to preserve engineering judgment rather than reduce complex aerospace decisions to a single sustainability score, but it could make the tradeoffs among different options more visible. Research should also examine how information from repeated operations can be carried back into future design. Recurring damage, difficult inspections, unsuccessful repairs, frequent replacement, and long turnaround times can reveal limitations that may not have been fully understood during development. Successful repairs can be equally informative by showing which materials, architectures, inspection methods, or repair processes continue to perform reliably after intervention. Studying these feedback relationships could help determine how operational experience can improve the next generation of reusable aerospace systems.

Ultimately, the next step is to determine where repairability creates measurable value. The question is no longer simply whether aerospace components can be repaired, but when designing for repairability improves lifecycle performance without compromising safety, reliability, performance, or mission requirements. Answering that question will require technical testing, operational data, lifecycle comparisons, and input from the people who design, inspect, maintain, repair, and operate reusable aerospace systems.

Final Reflection

Completing this capstone changed the way I think about sustainable aerospace engineering. I began this research focused heavily on advanced aerospace materials and the role they could play in making reusable systems more sustainable. As I worked through the literature, the question became much larger than material performance alone. A reusable vehicle may be built from advanced materials and designed to survive multiple missions, but those capabilities do not tell us everything about what will be required to keep that vehicle operating throughout its lifecycle. Repairability gave me a way to connect many of the questions I was asking about materials, maintenance, inspection, lifecycle impacts, and systems engineering. It also pushed me to think differently about sustainability. Sustainability is not only about selecting better materials or reducing environmental impacts at one point in the lifecycle. It is also shaped by decisions about what happens when components wear, become damaged, require inspection, need repair, or eventually have to be replaced. Many of those outcomes are influenced by decisions made long before the vehicle ever experiences them.

One of the most important lessons from this research was learning to let the evidence change the direction of the argument. Aerospace engineering has already developed extensive knowledge related to maintainability, inspection, nondestructive evaluation, repair, and repeated operation. Recognizing that made the research stronger because the question was no longer whether aerospace engineering had considered these problems. The more meaningful question

became how these existing areas of engineering could be connected with sustainability and lifecycle thinking in a way that supports reusable systems over the long term. This work also reinforced how important tradeoffs are in engineering. Repair is not always better than replacement, durability does not automatically mean repairability, and the most sustainable option cannot always be identified by looking at one part of a system. Safety, reliability, performance, resources, cost, maintenance requirements, and mission objectives all have to remain part of the decision. That complexity is not a weakness in the idea of repairability; it is the reason repairability has to be considered within the larger engineering system.

My position as a researcher also shaped the questions I chose to ask. My academic background has encouraged me to approach aerospace sustainability through both technical performance and the broader consequences of engineering decisions. Throughout this project, I had to remain aware that sustainability is not defined only by what is technically possible. Decisions about materials, maintenance, cost, resource use, access to technology, and long-term space infrastructure are also influenced by institutional priorities, economic constraints, policy choices, and the organizations with the power to determine which technologies are developed and supported. Recognizing these influences helped me approach repairability not as a universally beneficial solution, but as an engineering principle whose value depends on the technical and social context in which decisions are made.

As reusable spaceflight continues to advance, I believe sustainable aerospace engineering will require us to think beyond whether a vehicle can simply fly again. We also have to understand what it takes to inspect, maintain, restore, verify, and safely return that vehicle to service across repeated missions. I hope this capstone contributes to that conversation by providing another way to think about repairability as a sustainability design principle and by creating a foundation that future research can test, challenge, and improve. More than anything, this project has changed the question I carry forward: not only can we build aerospace systems that are reusable, but how can we design them to remain supportable throughout the missions they are meant to complete?

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E-Commerce Packaging and the Circular Economy in Phoenix:

Tracing The Package in Reverse

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Abstract

The rapid expansion of e-commerce has transformed consumer behavior while simultaneously increasing the amount of packaging waste generated by online retail. Although previous research and studies have examined packaging materials, recycling technologies, and sustainable design, less attention has been given to how packaging waste affects local communities and environmental justice at the municipal or local level. This qualitative case study explores how e-commerce packaging waste influences environmental sustainability, public health, and environmental justice within the Phoenix metropolitan area. Using a combination of Photovoice, community observation, document analysis, and semi-structured interviews, this study examines the relationship between consumer convenience, municipal waste management, and circular economy initiatives. Findings suggest that while City of Phoenix has invested significantly in recycling infrastructure and sustainability planning, continued population growth, increasing e-commerce activity, and contamination of recyclable materials present ongoing challenges to most waste diversion efforts. Observations from downtown Phoenix and other areas further reveal that packaging waste is not distributed evenly across communities and frequently intersects with issues of housing insecurity, public health, and environmental justice. Rather than presenting packaging solely as a waste-management problem, this study argues that discarded materials represent opportunities for innovation through circular economy strategies emphasizing reuse, material recovery, and community partnerships. By integrating institutional data with lived experiences and visual documentation, this research contributes to broader conversations regarding sustainable urban development and demonstrates how local perspectives can inform more equitable approaches to resource management.

Keywords: E-commerce packaging; Circular Economy; Environmental Justice; Phoenix, Arizona; Municipal Recycling; Sustainable Packaging; Photovoice; Waste Diversion; Public Health; Qualitative Case Study

Looking Beyond the Front Door

Every week, millions of packages arrive on doorsteps across the United States. Consumers eagerly anticipate what's inside the box, yet few stop to consider what happens to the cardboard, plastic mailers, foam inserts, and protective packaging after the purchase has been opened. The transaction appears complete once the product is delivered, but the environmental story of the package has only begun.

According to recent market research, the global e-commerce packaging market continues to expand rapidly due to increasing online retail demand and consumer expectations surrounding convenience and delivery speed ([Towards Packaging, 2025](#)). Packaging and delivery statistics compiled by [Capital One Shopping](#) (2025) further demonstrate the extraordinary growth of package delivery volumes in the United States, reflecting how e-commerce consumption patterns continue accelerating nationwide. These trends illustrate not only the scale of consumer convenience, but the growing environmental impacts associated with cardboard waste, plastic, transportation air emissions, and disposal systems.

During the COVID-19 pandemic, recycling facilities within the region experienced approximately a [31% increase in cardboard recycling volume](#) between 2019 and 2020 as online shopping activity surged. This dramatic increase in packaging waste exposed challenges within municipal recycling infrastructure and highlighted the growing strain placed on local waste-management systems.

Living and driving through midtown, uptown or downtown Phoenix has fundamentally changed how I think about waste. Walking through my neighborhood, I routinely observe stacks of Amazon boxes beside apartment dumpsters, overflowing recycling containers, plastic mailers caught in desert landscaping, and discarded packaging accumulating in public spaces. These observations raised a question that eventually became the foundation of this research:

How does the growth of e-commerce packaging waste affect environmental sustainability, public health, and environmental justice within the Phoenix metropolitan area, and how might circular economy approaches help create more equitable and sustainable outcomes?

This question started to emerge not only from my academic interests but also from some of my professional and personal experiences. As an Environmental Health and Safety (EHS) professional, I've spent the last several years evaluating hazardous workplace environment risks, environmental compliance, and sustainability initiatives across multiple sectors and manufacturing operations. At the same time, I also operate a small e-commerce business and therefore participate in the very system or systems I seek to examine. This dual perspective per se places me in a very unique position: I am simultaneously a contributor to packaging waste and now a researcher attempting to understand its broader consequences.

While much of the public conversation surrounding e-commerce focuses on speed, convenience, and economic growth, comparatively little attention has been given to what happens after delivery. Each package requires raw materials, manufacturing, storage, transportation, and ultimately disposal or recovery. Although many packages and packaging materials are technically recyclable, successful recycling depends on consumer behavior, cross-contamination rates, municipal infrastructure along with market demand for recovered materials. Consequently, packaging waste represents more than an environmental and health issue it reflects the interconnected nature of production, consumption, public policy, and community well-being. Phoenix provides an especially compelling setting for this research.

As one of the fastest-growing metropolitan areas in the United States, the city continues to experience rapid residential development alongside increasing online consumer activity. According to the [U.S. Census Bureau](#), Phoenix has added tens of thousands of residents annually over the past several years, placing additional pressure on municipal infrastructure, including solid waste and recycling systems. Figure 1 illustrates Phoenix's significant population growth from approximately 1.5 million residents in 2015 to more than 1.8 million in 2025, providing context for the increasing volume of consumer packaging waste and the pressure on the region's solid waste and recycling systems.

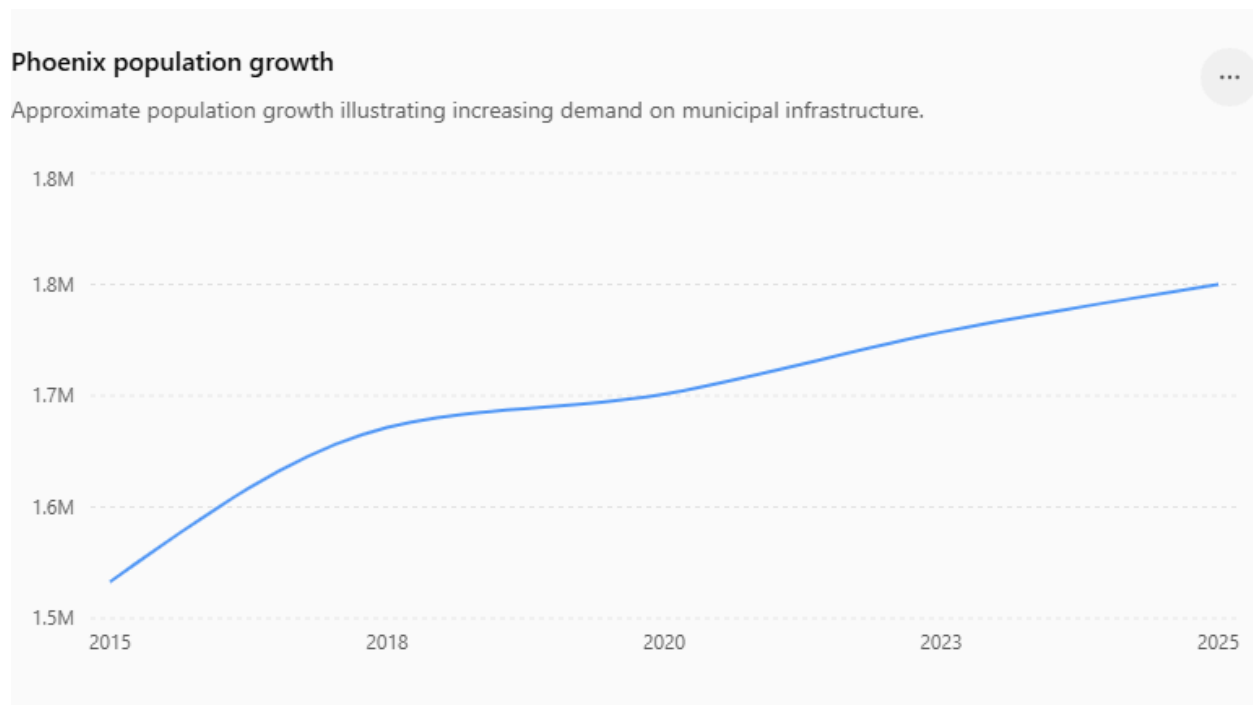


Figure 1. Population Growth – Source: (U.S. Census Bureau Population Estimates)

At the same time, the City of Phoenix has adopted ambitious sustainability goals through its [Climate Action Plan](#), including increasing waste diversion rates and advancing circular economy principles.

Despite these efforts, challenges remain. Recycling contamination continues to reduce the effectiveness of material recovery along with increasing volumes of cardboard and flexible plastic packaging complicate existing waste-management systems. Moreover, according to research these challenges are not experienced equally across all neighborhoods. Environmental justice scholars [pioneered by foundational work like Robert Bullard’s 1990 study on environmental racism and equity](#) have long argued that environmental burdens including waste facilities, pollution, and inadequate infrastructure often disproportionately affect lower-income communities and historically minority or marginalized populations. Packaging waste, therefore, should not be viewed solely as a technical waste management issue but also as a question of equity, public health, and environmental responsibility.

This study challenges the dominant narrative that packaging waste ends once consumers place materials in a recycling bin. Instead, it argues that discarded packaging continues moving through complex social, economic, and environmental systems involving municipal agencies, private businesses, sanitation workers, informal recyclers, community organizations, and residents themselves. Understanding these interconnected systems requires looking beyond

traditional waste-management metrics to examine how packaging is experienced within everyday life.

To explore these questions, this research employs a qualitative case study centered on the Phoenix metropolitan area. Through Photovoice, community observation, document analysis, and interviews with stakeholders representing government, sustainability organizations, academia, and industry, the study seeks to amplify multiple voices and perspectives surrounding packaging waste and identify opportunities for more sustainable resource management.

Rather than proposing a single solution, this research contributes to ongoing conversations regarding sustainability by highlighting opportunities to strengthen existing systems through collaboration, innovation, and a circular economy forward-thinking mindset.

Ultimately, the project argues that the future of sustainable packaging depends not only on better materials but also on reimagining the relationships among consumers, businesses, governments, and communities. Figure 2 illustrates this central idea or concept by visually depicting how sustainable packaging requires us to reverse the traditional "take, make, and dispose" mindset and instead examine the upstream decisions that shape waste before it reaches consumers.



Figure 2. This image represents reversing the lifecycle of consumer waste by tracing discarded materials back through the systems that produced them. Image created by Davenj Bradley (2026).

From Convenience to Circularity: What We Know and What We Still Need to Learn

The remarkable growth of e-commerce has fundamentally transformed retail, supply chains, and consumer expectations. Online shopping has become deeply integrated into everyday life, offering unprecedented convenience while generating increasing amounts of packaging waste. As a result, [packaging waste continues to contribute to landfill growth](#), greenhouse gas emissions (GHGs), resource depletion, and environmental concerns. Research indicates that waste systems create unequal social consequences amongst [African American communities](#) located near landfills, with many experiencing exposures to environmental hazards, air pollution, and other public health risks. The goal is to examine current studies regarding e-commerce packaging waste, sustainable packaging strategies, circular economy principles, environmental justice concerns, and public health implications.

Growth of E-Commerce and Packaging Waste

Researchers identify e-commerce as a contributor to increasing packaging consumption. According to a peer-reviewed article, [online retail](#) often requires layers of protective packaging compared to traditional packaging. Consider that products must withstand transportation, warehousing, sorting, and delivery, which increases usage of cardboard, plastic films, bubble wrap, and protective inserts.

The growth of online shopping accelerated significantly during the [COVID-19 pandemic](#), further increasing demand for packaging materials worldwide. While e-commerce may reduce certain environmental impacts associated with physical retail locations, studies suggest that packaging waste remains one of the most significant [sustainability challenges](#) within the sector.

Recent industry reports suggest that packaging waste will continue increasing alongside parcel delivery growth. It's estimated that e-commerce generated approximately [3.88 billion pounds](#) of plastic packaging waste in 2022 with projected increases through 2027. This reinforces concerns that current waste-management systems may struggle to keep pace with consumption and shipping demands. Industry data suggest that [online shopping packaging waste increased by approximately 14.6%](#) during recent years, highlighting the need for more sustainable packaging solutions.

Research also highlights the [complexity of evaluating packaging sustainability](#). A package that uses less material may lack adequate protection, resulting in product damage and additional costs. Conversely, highly protective packaging may generate unnecessary waste. This tension illustrates the challenge of balancing economic efficiency, product integrity, and environmental responsibility.

Although substantial literature documents the growth of packaging waste, relatively few studies examine how this waste streams affect specific communities and regional waste-management systems. Most research focuses on packaging design, materials engineering, and life-cycle assessment rather than social and environmental consequences. While the growth of e-commerce has transformed consumer convenience, it has also shifted attention toward how packaging materials are managed after delivery, leading to increasing interest in circular economy approaches.

Sustainable Packaging and Circular Economy

One dominant trend emphasizes sustainable packaging design as a primary solution to packaging waste challenges. Sustainable packaging typically refers to packaging systems that minimize environmental impacts throughout production, transportation, use, and disposal phases while maintaining product functionality. This brings me to what is called a Life-cycle assessment (LCA), which has become one of the most widely used methods for evaluating packaging sustainability. Life-cycle assessments examine environmental impacts associated with [raw material extraction](#), manufacturing, transportation, use, and end-of-life disposal. Through this approach, researchers compare alternative materials and packaging systems to determine their overall environmental performance.

Studies show that [material substitutions can significantly reduce](#) environmental impacts. For example, replacing petroleum-based plastics with biodegradable materials may decrease fossil fuel consumption and greenhouse gas emissions. However, researchers caution against viewing biodegradable or compostable materials as universal solutions and instead found that consumer [misunderstanding regarding disposal methods](#) often limits the effectiveness of biodegradable packaging. Also, small businesses may struggle to adopt preferable materials due to higher costs.

Challenges remain for e-commerce businesses who must balance sustainability with profitability and customer expectations are hard to ignore. The [Sustainable Packaging Coalition](#) identifies reduction, reuse, recycling, and renewable material sourcing as core principles of sustainable packaging systems. Likewise, [Zero Waste Europe](#) argues that waste is fundamentally a design problem and advocates upstream redesign strategies that eliminate waste before products enter the marketplace. These approaches are shifting attention away from [end-of-life disposal](#) options and more toward product and packaging development. I believe these perspectives complement (LCA) methodologies by emphasizing prevention rather than reactive.

The concept of the circular economy emerged as what some would say as an influential framework within sustainability research. Instead of the linear model "take, make, and dispose of," circular economy seeks to maintain materials within use cycles through reuse, repair, remanufacturing, and recycling according to [The Circular Economy](#). These principles have

encouraged the development of reusable packaging, closed loop, and material recovery systems. Now some argue that [circular systems can reduce resource extraction while minimizing waste generation](#). The [Environmental Protection Agency](#) notes that many communities pursuing zero-waste initiatives prioritize source reduction, material reuse, and community engagement alongside recycling efforts.

According to reports and research, [Dell Technologies \(2024\)](#) incorporated recycled plastics into product manufacturing and packaging systems through closed-loop material initiatives. Similarly, [Nike's Move to Zero](#) initiative seeks to reduce waste generation and increase recycled-material utilization throughout its supply chain.

[Sierra Nevada Brewing Company](#) provides another example of circular practices through composting, material recovery, and reuse initiatives that show how circular economy concepts can be applied by bigger companies at scale. Research suggests that [packaging should be viewed not as waste but as a resource stream](#). Despite enthusiasm for change, critics remain uneven and argue that circular economies rely heavily on technical solutions while overlooking social, political, and economic barriers. Furthermore, many circular [economy studies](#) emphasize national or global systems rather than local community impacts. The question of who benefits from circular initiatives and who bears environmental burdens remains unanswered. Although circular economy principles provide a framework for reducing waste, researchers increasingly recognize that environmental impacts are not experienced equally across all communities.

Environmental Justice and Public Health

According to research, [environmental justice](#) provides a lens through which to examine packaging waste and disposal systems. Environmental justice emerged in response to evidence that environmental burdens are frequently concentrated within low-income and communities of color. Pundits argue that [environmental inequities are not accidental](#) but often embedded within social, economic, and political systems. Waste management infrastructure frequently reflects historical [patterns of segregation](#), land-use planning decisions, and economic inequalities. These patterns contribute to air pollution, contaminated water, noise, odors, and other environmental burdens that extend beyond race and geography to include questions of gender, labor, and social equity. This report argues that waste-management systems and privatization practices often impose disproportionate burdens on [women, particularly within vulnerable communities](#). This suggests packaging waste should be analyzed not only through environmental or economic lenses but also through questions of social justice and community well-being. This aligns with Franklin's argument that technological systems must be evaluated by examining [who benefits from them and who bears their associated costs](#).

Recent studies show that packaging waste generated by affluent consumers often travels through disposal systems that [disproportionately affect lower-income communities](#). This shifts attention away from individual behaviors and more towards responsibility and accountability and offers valuable insights for understanding packaging waste, yet relatively few studies explicitly connect e-commerce packaging systems to environmental justice outcomes. As e-commerce continues to expand, understanding how waste generation intersects with community health and environmental burdens becomes more important.

Waste-management systems influence public health through multiple pathways. Landfills, transfer stations, transportation corridors, and industrial processing [facilities can contribute to air pollution, water contamination, odor exposure, and other environmental hazards](#). The World Health Organization (WHO) defines waste as [discarded material capable of creating environmental exposures through air, water, soil](#), and food pathways. This perspective assists in broadening traditional understandings of waste beyond visible trash, litter and landfill accumulation.

As materials break down over time, concerns regarding microplastic contamination and long-term environmental exposure continue to attract attention. These public health concerns reinforce the importance of reducing waste generation at its source rather than relying on disposal and remediation strategies. Studies have identified associations between proximity to waste facilities and adverse health outcomes, [including respiratory illnesses, stress-related conditions, and reduced quality of life](#).

Plastic pollution presents additional public health concerns. Researchers increasingly document the presence of [microplastics within ecosystems, food systems, and drinking water supplies](#). While long-term health effects remain under investigation, growing evidence suggests that [plastic waste may pose risks](#) extending far beyond visible litter and landfill accumulation. In comparison, little research examines e-commerce packaging as a distinct contributor to environmental health concerns. These studies suggest that packaging waste is not solely an engineering challenge but also a social and environmental justice issue requiring community-centered solutions.

Phoenix Research, Trends and Gaps

Urban growth introduces added challenges to waste management due to rapidly expanding metropolitan regions that generate large quantities of waste. Where I live in Phoenix, Arizona, the city and surrounding regions have experienced [substantial population growth over recent decades](#), increasing demand for housing, transportation, commercial development, and waste infrastructure. Climate challenges that include extreme heat and water scarcity, further

complicate efforts which mirror broader trends observed across rapidly growing metropolitan regions.

Local sustainability efforts emphasize waste diversion, recycling, heat mitigation, and circular resource management. The City of Phoenix's Zero Waste and Circular Economy Roadmap, Maricopa County sustainability programs, and Phoenix Public Works diversion efforts provide valuable local context for understanding how global packaging-waste trends manifest within the Phoenix metropolitan region. For instance, Zero Waste and Circular Economy Roadmap establishes goals of achieving [50% waste diversion by 2030](#) and zero waste by 2050.

These goals align with sustainability frameworks that reduce landfill dependence while maximizing the value of discarded materials. Together, the programs demonstrate how governments are integrating circular economy principles into long-term sustainability planning. While Phoenix has established ambitious waste diversion targets, Figure 3 provides a visual assessment of current residential recycling trends, highlighting both the progress achieved and the work that remains to meet the city's long-term sustainability objectives.

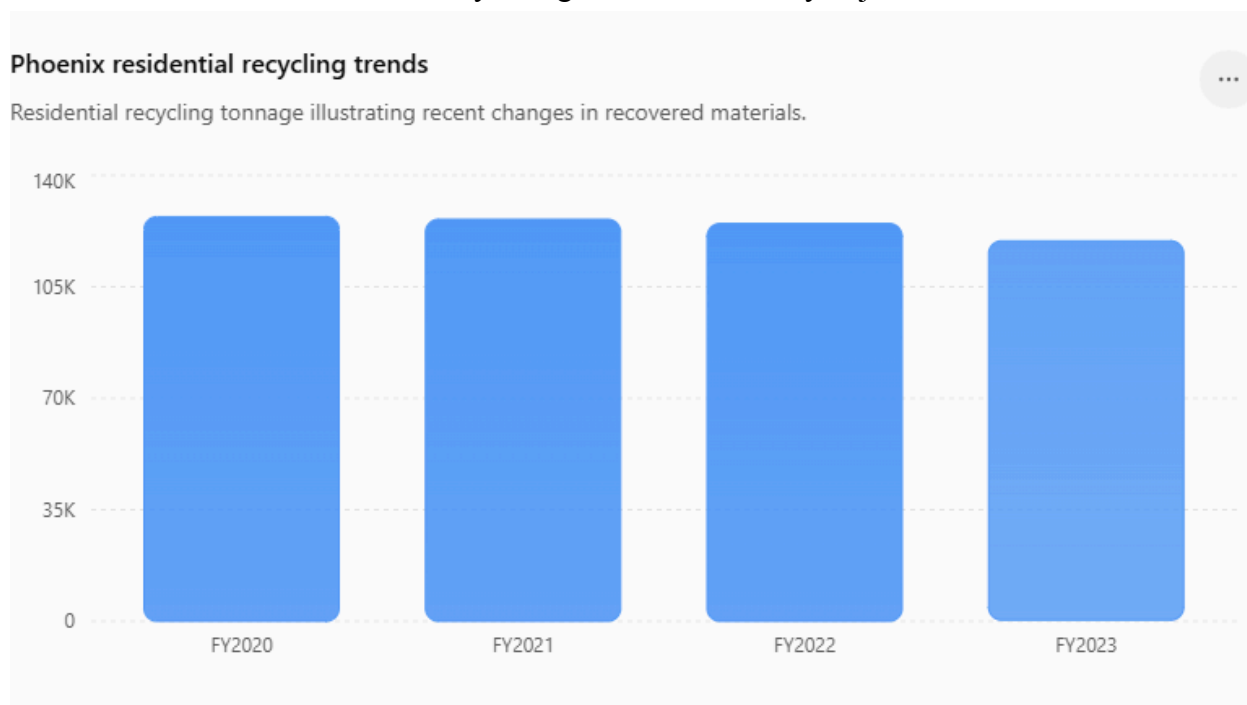


Figure 3. Annual Residential Recycling - Source: City of Phoenix Climate Action Plan Progress Report.

Local agencies in the Phoenix area have emphasized waste diversion and circular economy strategies as part of sustainability planning. While no research focuses specifically on e-commerce packaging waste within the Phoenix metropolitan region. Existing studies highlight waste-management trends rather than packaging-specific impacts. This gap presents an

opportunity for me to conduct localized research that connects global consumption patterns with regional environmental and social outcomes.

Some city officials argue reducing landfill dependence can lower greenhouse gas emissions and create opportunities through material recovery and reuse programs. Phoenix's Public Works Department serves more than [422,000 households](#) and has educational programs, recycling infrastructure, and business partnerships designed to increase diversion and reduce contamination in recycling. Phoenix has partnered with Arizona State University and community organizations to support projects such as the [Circular Plastics Micro-factory](#), which converts locally recovered plastics into new products while creating local employment opportunities.

Despite these efforts, significant challenges remain. Waste characterization studies continue to show substantial quantities of recyclable materials entering municipal landfills, suggesting barriers related to consumer input, contamination, and market demand for recovered materials. These local challenges reinforce findings within sustainability literature that technological solutions alone are insufficient without community engagement, policy support, and environmental justice considerations. Recent stakeholder insights from the City of Phoenix further illustrates this complexity.

During an interview response, Alyssa Knowles of Phoenix Public Works explained that cardboard generated through e-commerce remains one of the strongest and most desirable materials within the recycling market. In contrast, flexible plastic films, bubble mailers, and Styrofoam create far greater operational challenges because they are not accepted in Phoenix's curbside recycling program and frequently interfere with material recovery equipment. This distinction demonstrates that the environmental impacts of e-commerce packaging are not driven solely by increasing packaging volumes but also by the changing composition of packaging materials entering municipal recycling systems. Several dominant themes emerge across the board.

First, research emphasizes shifting trend amongst consumer demand and habits which resulted in a [31% increase in cardboard](#) waste using technological and material solutions. Sustainable materials, biodegradable alternatives, and improved recycling systems receive substantial attention yet often frame waste primarily as an engineering problem.

Second, circular economy frameworks are influencing packaging research. Third, environmental studies demonstrate that waste infrastructure disproportionately affects vulnerable communities.

There's also gaps due to very little research integrating packaging, environmental justice, public health, and community development into a single framework specifically as it relates to urban environments as stated in a recent [study](#).

Additionally, most of the literature framework evaluates national or global systems trends without considering the local community waste-related impacts. Finally, most studies focus on waste reduction without considering how recovered materials could support the community, including economic development, housing initiatives, and neighborhoods. For instance, a construction company in Columbia, has [“developed with blocks made from recycled plastic allows a house to be built in just five days and at considerably lower costs than usual methods”](#).

Building on this data the U.S. Census Bureau, [e-commerce now represents approximately one-sixth of all retail sales in the United States](#) and continues to grow annually. Every online purchase requires protective packaging, transportation, and distribution, creating environmental impacts that extend well beyond the point of delivery.

Much of the existing literature has focused on improving packaging materials through recyclable, biodegradable, or compostable alternatives. Researchers have also examined life-cycle assessments comparing different packaging types and transportation methods to reduce greenhouse gas emissions and material consumption. These studies consistently conclude that packaging design plays an important role in reducing environmental impacts but acknowledge that material innovation alone cannot solve broader waste-management challenges.

The circular economy has emerged as one of the most influential frameworks for addressing these concerns. Unlike the traditional linear economic model of "take, make, dispose," circular economy principles seek to maintain the value of materials through reuse, repair, remanufacturing, and recycling. The [U.S. Environmental Protection Agency defines a circular economy](#) as one that keeps materials in productive use for as long as possible while minimizing waste generation and conserving natural resources. Under this framework, packaging should be viewed not as disposable waste but as a valuable resource capable of re-entering the economy through recovery systems.

Although these concepts have gained considerable attention within academic research and industry sustainability reports, implementation remains largely uneven. Municipal recycling systems face increasing contamination rates, fluctuating commodity markets, and consumer confusion regarding acceptable recyclable materials. Phoenix illustrates these challenges well. While the city has invested in transfer stations, material recovery facilities, and ambitious waste diversion goals, cross-contamination continues to reduce recycling efficiency, highlighting the gap between recyclable design and actual material recovery.

Another important body of literature examines environmental justice in which scholars have demonstrated that environmental burdens such as pollution, waste facilities, and inadequate infrastructure which are rarely distributed equally across society. Communities experiencing

economic disadvantages often bear disproportionate environmental risks while receiving fewer environmental benefits. Despite extensive environmental justice research, relatively few studies explicitly examine e-commerce packaging waste through this lens.

This gap became increasingly apparent throughout my own observations in downtown Phoenix. Packaging waste was frequently visible in apartment complexes, public rights-of-way, and areas experiencing housing insecurity. Throughout my conversations with unhoused individuals suggested that discarded cardboard and aluminum often become valuable economic resources through informal recycling practices. These observations challenge my simple assumptions that packaging is merely discarded after consumption. Instead, materials continue moving through complex social systems that involve economic necessity, municipal infrastructure, and community resilience.

Photovoice methodology provides an important contribution to understanding these relationships. [Wang and Burris \(1997\) argue that photographs are not simply illustrations but forms of qualitative data](#) capable of revealing patterns and experiences that may otherwise remain invisible. By documenting packaging waste within everyday environments, Photovoice allows researchers to connect broader sustainability concepts with local lived experiences while amplifying perspectives that traditional quantitative methods may overlook.

Systems thinking further strengthens this analysis by recognizing that packaging waste cannot be understood in isolation. Consumer expectations, logistics networks, business decisions, public policy, recycling infrastructure, and environmental health all interact to shape how packaging moves through society. Viewing packaging solely as a disposal issue ignores these interconnected relationships and limits opportunities for systemic improvement.

Taken together, the literature suggests that technological innovations alone are insufficient to address the environmental impacts of e-commerce packaging. While sustainable materials and improved recycling technologies remain essential, equally important are questions regarding consumer behavior, municipal capacity, environmental justice, and collaborative governance. This study builds upon existing scholarship by integrating these perspectives within a single qualitative case study focused specifically on Phoenix. Rather than examining packaging solely through engineering or waste management metrics, it explores how packaging waste is experienced by communities, interpreted by stakeholders, and situated within broader discussions of sustainability, equity, and circular economy transitions.

Although previous research has examined e-commerce growth, recycling systems, and sustainable packaging independently, relatively little research has explored how these issues intersect within Phoenix using qualitative methods that incorporate community observations and stakeholder perspectives. This study addresses that gap through a Photovoice-informed

qualitative case study examining how e-commerce packaging waste influences sustainability, environmental justice, and circular economy opportunities within the Phoenix metropolitan area.

A Qualitative Exploration of Packaging Waste in Phoenix

This study employs a qualitative case study approach to examine how e-commerce packaging waste influences environmental sustainability, public health, and environmental justice within the Phoenix metropolitan area. This follows approaches used by Wang and Burris (1997) in Photovoice research and Creswell (2023) in qualitative case study methodology, emphasizing multiple data sources, triangulation, and thematic analysis. Because the research seeks to understand lived experiences, institutional responses, and community perceptions rather than establish statistical relationships, qualitative methods provide the flexibility necessary to explore the complexity of packaging waste as both an environmental and social phenomenon.

The study combines five complementary methods: a literature review, document analysis, Photovoice, community observation, and semi-structured interviews. Together, these methods provide multiple forms of evidence that allow findings to be compared across sources while strengthening the credibility of the analysis.

Positionality

Qualitative research requires acknowledging the researcher's relationship to the topic being studied. I occupy a unique position within this project. Professionally, I work in Environmental Health and Safety (EHS), where I routinely evaluate environmental risks, regulatory compliance, and sustainability initiatives.

Personally, I also operate a small e-commerce business, making me both a participant in and an observer of the packaging systems examined in this study. My positionality also extends beyond my professional and small business owner role. As a resident of Phoenix, I experience the city's rapid growth and changing waste streams firsthand through everyday observations in my own neighborhood. As a graduate researcher, I entered this project with both academic responsibilities and ethical obligations to accurately represent participant perspectives.

Rather than attempting to eliminate this perspective, I acknowledge it as a source of insight while remaining conscious of potential bias. Throughout the research process, observations were continually compared with academic literature, municipal documents, and stakeholder perspectives to ensure that conclusions were supported by multiple sources rather than personal experience alone.

Photovoice, Community Observation & Document Analysis

Attention was given to research examining e-commerce growth, packaging waste, circular economy principles, environmental justice, municipal recycling systems, and sustainable materials management. Municipal documents from the [City of Phoenix](#), the [U.S. Environmental Protection Agency \(EPA\)](#), the [Arizona Department of Environmental Quality \(ADEQ\)](#), and the [U.S. Census Bureau](#) were analyzed to establish a baseline understanding of Phoenix's recycling infrastructure, waste diversion goals, and population trends.

Photographs collected throughout downtown Phoenix documented packaging waste within apartment complexes, public access recycling stations, sidewalks, and residential neighborhoods. Photovoice served as the primary field methodology throughout this project. Rather than serving only as illustrations, these images became qualitative data that revealed recurring patterns in waste generation, disposal behavior, and recycling infrastructure.

Figure 4 provides a representative photovoice image captured during the study, illustrating how packaging waste accumulates within residential settings as qualitative evidence of disposal patterns observed throughout my research.



Figure 4. Overflow packaging waste in my apartment's interior hub. Photograph by Davenj Bradley, (June 2026)

Community observations were conducted throughout the research period by documenting locations where packaging waste accumulated and examining how residents interacted with recycling systems. Attention was given to apartment complexes, mixed-use developments, transfer stations, and public spaces where packaging materials were frequently observed.

Interviews

Interviews were conducted with stakeholders representing multiple perspectives on sustainability and waste management, etc. Participants included professionals working within municipal government, environmental management, recycling operations, sustainability organizations, and community development. Additional perspectives were gathered from Alyssa Knowles of the City of Phoenix Public Works Zero Waste Team through a structured email interview. Her responses provided valuable municipal insight regarding recycling operations, contamination trends, waste diversion programs, public education initiatives, and Phoenix's ongoing circular economy efforts.

Including both frontline operational personnel and municipal sustainability leadership strengthened triangulation by allowing findings to be compared across different levels of the City's waste management system. Figure 5 provides a visual representation of the interview process, demonstrating how direct engagement with community stakeholders contributed firsthand perspectives and contextual understanding to the research findings.

Figure 5. Interview conducted in downtown Phoenix with consent from participants. Photograph by Jaime Kistner (2026).

Moving beyond individual narratives, the interview matrix in Figure 5 transforms stakeholder experiences into collective knowledge by identifying common challenges, opportunities, and system-level solutions for addressing e-commerce packaging waste in Phoenix.

Participant	Stakeholder Group	Position / Perspective	Summary of Key Findings	Representative Quote	Primary Theme(s)	Evidence Source
Bill	Unhoused Community Member	Resident experiencing homelessness	Uses discarded cardboard and plastic mailers for shelter, insulation, and weather protection. Views packaging waste as both a survival resource and evidence of excessive consumer waste.	"The cardboard and plastic help keep us dry and out of the sun."	Environmental Justice, Waste, Social Equity	Interview
Sam	Unhoused Community Member	Resident experiencing homelessness	Frequently reuses Amazon boxes, plastic mailers, and other packaging materials for temporary shelter and storage. Noted increasing quantities of discarded packaging throughout Phoenix.	"Most of what we use comes from boxes people throw away."	Environmental Justice, Circular Economy, Waste	Interview
Anonymous	Municipal Transfer Station	Administrative Dispatch Clerk (3.5 years)	Reported significant increases in cardboard, plastic mailers, and Amazon packaging entering transfer stations. Identified contamination of recyclable materials as one of the greatest operational challenges. Recommended stronger collaboration among municipalities, businesses, and residents to improve recycling outcomes.	"The biggest issue is the segregation—or lack of it."	Recycling Infrastructure, Circular Economy, Waste Management	Interview
Apartment Manager	Multi-Family Housing	Community Property Manager	Observed substantial increases in cardboard and plastic packaging from online shopping. Reported overflowing recycling bins, contamination, pest issues, and increased maintenance costs associated with e-commerce packaging waste.	"We see far more boxes and plastic mailers than we did just a few years ago."	Convenience, Community Impact, Environmental Justice	Interview
Alyssa	City of Phoenix Public Works / Sustainability	Recycling & Diversion Program Representative	Explained the City's recycling goals, contamination challenges, public education initiatives, and ongoing investments in diversion programs. Emphasized that consumer behavior and proper source separation remain essential to achieving Phoenix's 2030 diversion targets.	"Improving recycling starts with residents placing the right materials in the right container." (Paraphrase if no direct quote was recorded.)	Municipal Sustainability, Recycling Infrastructure, Circular Economy, Public Education	Expert Interview



Figure 6. Interview Matrix. Summary of stakeholder interviews conducted as part of the Phoenix case study. The matrix synthesizes participant roles, key findings, representative quotations, and recurring themes related to e-commerce packaging waste, environmental justice, and circular economy opportunities.

A semi-structured interview guide was used during stakeholder interviews summarized in Appendix A.

Interview questions explored several common themes:

- Perceptions of e-commerce packaging waste
- Circular economy opportunities
- Environmental justice concerns
- Public education
- Community partnerships
- Recommendations for improving waste reduction

Data Analysis

Data collected through interviews, observations, photographs, and documents were analyzed using thematic analysis. Rather than focusing on numerical outcomes, thematic analysis identifies recurring patterns that emerge across multiple forms of evidence.

The first is environmental justice. Environmental justice emphasizes that environmental benefits and burdens are not distributed equally across society. This framework encourages examination of who benefits from e-commerce systems and who bears the environmental and social costs associated with waste generation and disposal. It also raises questions regarding power, equity, and access to healthy environments.

The second framework is the circular economy. Circular economy principles challenge traditional linear models of production and consumption. Instead of viewing packaging as disposable waste, circular economy thinking encourages viewing materials as resources that can remain in circulation through reuse, recycling, and recovery systems.

The third framework is systems thinking. Packaging waste does not exist in isolation. It is connected to consumer behavior, supply chains, public policy, business practices, waste infrastructure, and community health. System thinking allows me to understand how these interconnected systems shape environmental outcomes. Interview transcripts, observation notes, Photovoice images, and municipal documents were reviewed multiple times using manual thematic coding. Initial concepts were highlighted by hand and grouped into recurring categories such as consumer convenience, recycling contamination, environmental justice, infrastructure, and circular economy opportunities. These preliminary codes were then compared across interviews, observations, and published literature to identify patterns that appeared consistently across multiple sources. Rather than relying on software-assisted coding, themes were developed iteratively through repeated review of field notes and interview responses until five dominant themes emerged:

- Convenience drives consumption.
- Packaging continues its lifecycle after delivery.
- Phoenix possesses significant recycling infrastructure, but important gaps remain.
- Environmental justice influences how packaging waste is experienced.
- Circular economy principles provide opportunities for more sustainable systems.
- These themes organize the findings presented in the following section.

What Happens After the Package Arrives?

One of the most significant findings from this research is that packaging waste does not disappear once consumers open a package. Instead, it enters a complex system involving households, municipalities, recycling facilities, informal reuse, and ultimately either landfill disposal or material recovery. The primary dataset consisted of five stakeholder interviews, Photovoice observations collected throughout Phoenix, field notes, municipal documents, and supporting secondary data summarized in Appendix C.

Theme 1: Convenience Drives Consumption

Three of four interview participants independently described convenience as the primary driver of increasing packaging waste. Bill noted that discarded cardboard had become an everyday resource, while the apartment manager described a noticeable increase in overflowing recycling areas. These observations align with [previous studies showing that convenience contributes to increased packaging demand and material waste](#). Nearly every participant acknowledged that consumer expectations have shifted dramatically over the past decade. Fast shipping, free returns, and next-day delivery have become normalized expectations rather than premium services.

These conveniences, however, generate environmental costs that remain largely invisible to consumers. Every shipment requires cardboard, plastic mailers, labels, tape, cushioning materials, transportation fuel, warehouse infrastructure, and disposal systems. Photographs collected throughout downtown Phoenix consistently documented overflowing recycling bins and packaging waste associated with apartment complexes and multi-family housing. While these observations do not establish causation, they illustrate how increasing package deliveries contribute to visible changes within residential waste streams.

Theme 2: Packaging Has a Second Life

One unexpected finding involved the continued value of discarded packaging materials. Throughout community observations and informal conversations, I observed individuals collecting cardboard and recyclable materials for redemption or reuse. Packaging that most consumers viewed as waste often retained economic value for others.

This observation challenges the traditional linear view of consumption. Rather than ending with disposal, packaging frequently continues moving through informal recovery systems before eventually reaching recycling facilities or landfills.

The circular economy emphasizes precisely this principle: materials should retain value for as long as possible rather than becoming waste after a single use.

Theme 3: Phoenix Has Infrastructure, but Gaps Remain

Phoenix has invested substantially in municipal recycling infrastructure. The city currently operates transfer stations, materials recovery facilities, composting operations, and landfill management systems while pursuing ambitious waste diversion goals through its [Climate Action Plan](#). While Phoenix has developed substantial waste management infrastructure, Figure 7 reveals the importance of examining the spaces between consumption and recovery by connecting residential packaging waste generation with the facilities designed to manage these materials.



Figure 7. The map identifies major transfer stations, materials recovery facilities (MRFs), regional landfills, and apartment complexes where field observations of e-commerce packaging waste were conducted.

Yet infrastructure alone cannot guarantee successful recycling. Residential contamination rates remain significant, reducing the amount of recyclable material that ultimately becomes marketable commodities. [Phoenix waste diversion progress report](#). Interview findings from Alyssa Knowles of the City of Phoenix Public Works provided important context regarding these contamination challenges.

While previous interviews emphasized increasing cardboard volumes, Knowles explained that cardboard itself remains one of the strongest commodities in the recycling market. Instead, flexible plastic films, bubble mailers, Styrofoam, and LDPE plastic bags create the greatest operational challenges because they are not accepted in Phoenix's curbside recycling program and frequently become entangled in material recovery facility (MRF) equipment. This distinction demonstrates that the primary challenge is not simply the growing volume of e-commerce packaging, but the changing composition of packaging materials entering the waste stream. Figure 8 illustrates the gap between Phoenix's current waste diversion performance and its future sustainability targets, highlighting the challenges associated with increasing diversion rates within a rapidly growing metropolitan region.

Phoenix waste diversion progress

City waste diversion rates compared with the 2030 goal.

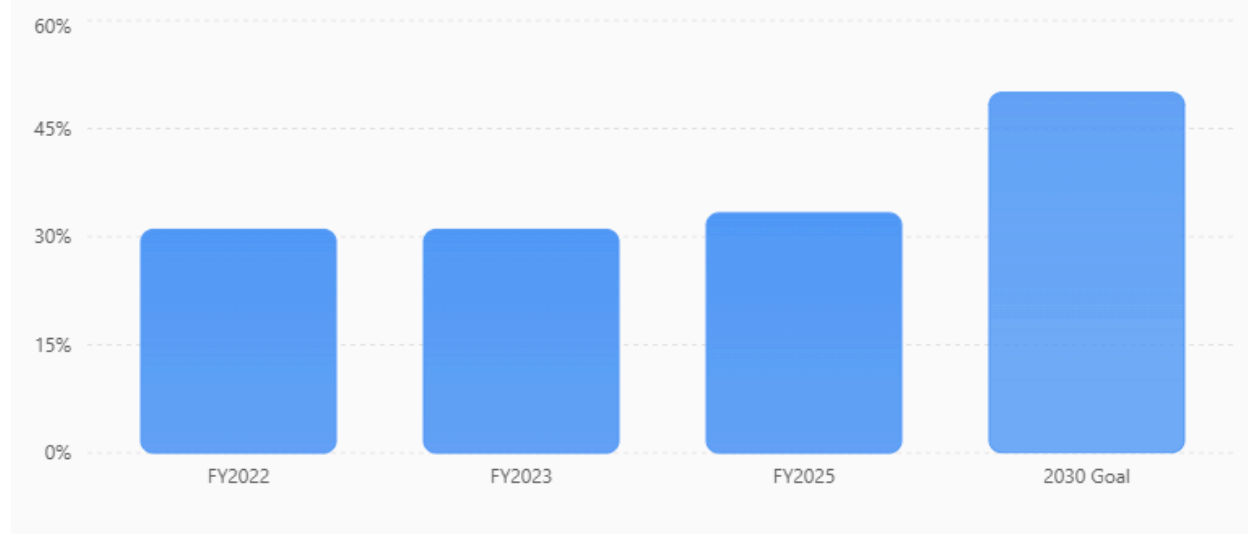


Figure 8. Outlines the city waste diversion rates compared with the 2030 goal and progress.

Phoenix's diversion rate has improved modestly, but the city remains well below its long-term goal of [diverting 50% of waste from landfills](#) as shown below. This gap illustrates that sustainable packaging requires improvements not only in recycling technology but also in consumer education, product design, and policy implementation.

Year	Rate
FY2022	31
FY2023	31
FY2025	33.3
2030 Goal	50

Theme 4: Environmental Justice Is Central to Conversation

Perhaps the most compelling finding emerged from examining packaging waste through the lens of environmental justice. Neighborhood observations suggested that discarded packaging accumulates most visibly in areas characterized by higher housing density, rental housing, and public gathering spaces.

Conversations with community members also highlighted how environmental burdens intersect with broader issues such as homelessness, heat exposure, sanitation, and access to public services.

Rather than existing independently, these issues form interconnected systems that influence health, neighborhood quality, and community resilience. Viewing packaging solely as a waste management issue therefore overlooks its broader social implications.

Theme 5: Circular Economy Opportunities

Rather than framing packaging waste exclusively as an environmental liability, participants frequently emphasized opportunities for innovation. Interview findings also highlighted several emerging initiatives already underway in Phoenix. Knowles described the City's Zero Waste Business Agreement, which partners with businesses to increase waste diversion while promoting innovative recycling services to residents. She also discussed the planned Resource Innovation Campus, a future circular economy business park intended to support companies developing solutions for harder-to-recycle materials. These initiatives demonstrate that Phoenix is already moving beyond traditional recycling toward broader circular economy strategies focused on innovation and public-private collaboration.

Potential strategies included:

- reusable shipping containers,
- improved packaging design,
- expanded producer responsibility,
- increased public education,
- local material recovery partnerships,
- stronger collaboration between municipalities and businesses.

Phoenix Survey Results: Public Perceptions of Sustainable Packaging

Through multiple studies, consumers expressed strong support for more sustainable packaging practices. Approximately **67% of consumers reported they would choose products packaged in environmentally friendly materials when available**, while **73% supported companies reducing unnecessary plastic packaging**. Additionally, **more than 60% of respondents indicated they were uncertain about which packaging materials could be recycled**, suggesting that confusion regarding recycling practices remains widespread.

These findings closely align with themes identified throughout this research. Interviews with Phoenix stakeholders including apartment management, municipal waste personnel, and unhoused community members identified increasing volumes of cardboard boxes, plastic

mailers, and contamination within recycling systems. The recurring issue of cross-contamination reported by participants may be partially explained by consumer uncertainty regarding proper recycling practices.

Phoenix and Young Adult Perspectives

Field observations and informal conversations conducted during this study suggested that many adults between the ages of **18 and 26** expressed mixed recycling behaviors. While many participants indicated support for sustainable packaging and environmental responsibility, their actual recycling practices varied considerably.

Overall, the survey findings reinforce the qualitative evidence collected throughout this capstone by demonstrating that improvements in packaging design, public education, and standardized recycling guidance remain critical components of advancing Phoenix's circular economy and reducing packaging waste.

These recommendations align closely with [EPA guidance promoting circular economy principles and sustainable materials management](#). Collectively, the findings suggest that improving packaging sustainability requires coordinated action among consumers, manufacturers, municipalities, and policymakers rather than reliance on recycling alone. Additional stakeholder and supplier interview summaries are included in *Appendix D*.

Recommendations, Future Research & Opportunities

Although this study contributes to understanding e-commerce packaging waste within Phoenix, several opportunities remain for future investigation. Longitudinal studies examining changes in packaging waste over time would help evaluate the effectiveness of municipal sustainability initiatives and circular economy policies.

Additional research should also explore consumer decision-making regarding online shopping, recycling behavior, and reusable packaging systems. Understanding behavioral influences may prove equally important as technological innovation. Future studies may also incorporate quantitative analyses of packaging generation rates, material composition, contamination trends, greenhouse gas emissions, and lifecycle assessments specific to metropolitan Phoenix.

Finally, expanding community participation through additional interviews with sanitation workers, neighborhood organizations, Indigenous communities, logistics providers, and policymakers would further strengthen understanding of how packaging waste affects different populations. The conversation surrounding sustainable packaging is still evolving. Continued interdisciplinary collaboration among engineers, environmental scientists, policymakers,

businesses, and community members will remain essential for developing more equitable and resilient systems. One important finding of this research is that Phoenix is not beginning from scratch.

The city has already invested heavily in recycling infrastructure, public education, landfill management, and long-term sustainability planning. Climate Action Plan goals call for increasing waste diversion while supporting broader circular economy initiatives.



Figure 8. Materials Recovery Facility at a Phoenix transfer station where recyclable materials, including cardboard, paper, plastics, and metals, are sorted for processing. Photograph taken by Davenj Bradley, June 2026

These efforts demonstrate meaningful institutional commitment to sustainability. However, observations conducted throughout this study indicate several opportunities for continued improvement.

Opportunity 1: Improve Public Education

Expanded educational campaigns focused specifically on e-commerce packaging could reduce contamination while improving recovery rates. Or even simple conversations amongst residents themselves is another avenue for public awareness and education. This recommendation is strongly supported by municipal stakeholders.

Knowles identified public education as one of Phoenix's most effective waste reduction strategies, citing school outreach programs, material recovery facility tours, social media campaigns, community newsletters, and partnerships with organizations such as Keep Phoenix Beautiful. These efforts suggest that improving recycling behavior may depend as much on consistent education as on technological improvements within recycling infrastructure.

Opportunity 2: Strengthen Circular Economy Partnerships

Municipal government cannot solve packaging waste independently. Partnerships with Amazon, UPS, FedEx, local retailers, universities, nonprofit organizations, and recycling companies could create innovative reuse and recovery programs that extend the life of packaging materials. Including but not limited to creating recycling bins for old plastic mailers, bubble wrap and cardboard at or near all parcel pickup locations.

Arizona's current policy environment relies heavily on voluntary partnerships rather than local regulatory mandates because state preemption limits municipal authority to prohibit certain packaging materials. As a result, collaboration among businesses, nonprofit organizations, municipalities, and universities becomes especially important for expanding recycling opportunities and advancing Phoenix's circular economy objectives.

Opportunity 3: Expand Packaging Data Collection

Phoenix currently reports overall recycling performance but does not publish detailed data specific to cardboard packaging generated through e-commerce. Improved material tracking would allow future researchers and policymakers to better understand packaging trends and evaluate the effectiveness of sustainability initiatives from a local and regional perspective instead of relying on national data.

Opportunity 4: Incorporate Environmental Justice into Waste Planning

Future planning efforts should continue evaluating how waste infrastructure, recycling access, and public education affect different neighborhoods. Including community voices within sustainability planning can improve trust while ensuring that environmental benefits are distributed more equitably. I definitely noticed that impoverished or marginalized communities were the worse areas observed.

Opportunity 5: Shift the Conversation

Perhaps the most important recommendation emerging from this study is conceptual rather than technical. E-commerce packaging should no longer be viewed simply as waste. Instead, it should be recognized as a resource whose value extends beyond its original purpose. This shift from disposal toward stewardship lies at the heart of the circular economy and offers perhaps the greatest opportunity for creating more resilient communities. Take my conversations with Bill and Sam as a primary example.

Beyond the Box: Rethinking Packaging

When I began this capstone, I thought I was studying cardboard boxes, plastic mailers, and shipping materials. As the research progressed, I realized the project was never really about packaging. It was about people.

It was about the delivery driver dropping off another package before sunrise. It was about the sanitation worker emptying overflowing recycling bins during a Phoenix summer. It was about municipal planners balancing sustainability goals with population growth. It was about businesses trying to meet consumer demand while reducing environmental impacts. It was about the unhoused individuals I met who often found value in materials that others viewed as worthless. And perhaps most importantly, it was about consumers including myself whose daily purchasing decisions quietly shape the environmental systems around us.

This study explored how e-commerce packaging waste influences environmental sustainability, public health, and environmental justice within the Phoenix metropolitan area. Through a qualitative case study combining literature review, document analysis, Photovoice, community observation, and stakeholder interviews, five interconnected themes emerged.

First, consumer convenience continues to drive unprecedented growth in packaging waste. While online shopping has improved accessibility and efficiency, these benefits are accompanied by increasing demands on municipal recycling and waste-management systems.

Second, packaging rarely completes its journey when it leaves the consumer's hands. Instead, discarded materials continue moving through formal recycling systems, informal reuse networks, transfer stations, material recovery facilities, and landfills. This extended lifecycle illustrates the complexity of modern consumption and reinforces the importance of viewing materials as resources rather than disposable waste.

Third, Phoenix has demonstrated meaningful leadership by investing in recycling infrastructure, Climate Action Plan initiatives, and ambitious waste diversion goals. However, observations throughout this research indicate that challenges remain. Population growth, contamination of recyclable materials, evolving packaging designs, and changing consumer behaviors continue to place pressure on existing systems.

Fourth, this research suggests that packaging waste should also be understood as an environmental justice issue. Waste is not experienced equally across communities. Neighborhood characteristics, housing density, access to recycling infrastructure, and broader socioeconomic conditions all influence how environmental burdens are distributed. Recognizing these inequities

broadens the conversation beyond engineering solutions to include questions of fairness, inclusion, and community well-being.

Finally, the findings demonstrate that circular economy principles offer a promising framework for reimagining packaging systems. Rather than focusing exclusively on disposal, circular economy thinking encourages communities to extend material life through reuse, repair, recovery, and collaborative partnerships. While recycling remains an essential component of sustainability, it should be viewed as one strategy within a broader system that prioritizes resource stewardship and waste prevention.

Perhaps the most significant lesson I learned throughout this project is that sustainability is rarely about finding one perfect solution. Instead, it requires understanding relationships. Packaging waste connects consumers to manufacturers, businesses to governments, neighborhoods to global supply chains, and environmental health to social equity. Every package tells a story extending far beyond the moment it arrives at a front door.

As both an Environmental Health and Safety professional and an e-commerce business owner, this research has challenged many of my own assumptions. Like many consumers, I once focused primarily on what arrived inside the package. Today, I find myself asking different questions. Who produced this packaging? Where will it go after I recycle it? Who manages it? Who benefits from the current system? Who bears its costs?

These questions do not produce simple answers. They do, however, encourage more thoughtful conversations about sustainability and our collective responsibility toward the communities we share.

Ultimately, this study argues that improving packaging sustainability requires more than stronger recycling programs or better packaging materials. It requires collaboration among governments, businesses, researchers, and residents to create systems that value materials, reduce waste, and promote environmental justice. By shifting our perspective from disposal to stewardship, Phoenix has an opportunity not only to manage packaging waste more effectively but also to serve as a model for other rapidly growing metropolitan areas seeking more resilient and equitable futures. One of the unexpected outcomes of this capstone has been recognizing how much my own perspective has changed.

As a child growing up in California, I remember saving shoe boxes, cardboard containers, and glass jars without realizing I was practicing a simple form of reuse. Years later, working in Environmental Health and Safety and operating an online business, I began viewing sustainability primarily through regulations, compliance, and operational performance. This project reminded me that sustainability is ultimately about people.

The photographs I captured throughout Phoenix and metro areas, the conversations I had with residents, municipal employees, and unhoused individuals, and the countless hours spent reviewing research all reinforced one simple realization: environmental stewardship begins long before waste reaches a landfill and continues long after a package has been delivered.

If this project contributes anything, I hope it encourages readers to pause before throwing away the next cardboard box or plastic mailer. Behind every package is an opportunity to rethink how materials move through our communities and how our individual choices collectively shape the future. That shared responsibility may be the most important takeaway from this research.

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Appendix A Interview Guide

Purpose

This semi-structured interview guide was used to collect qualitative data from community members, municipal employees, apartment managers, recycling professionals, and other stakeholders regarding e-commerce packaging waste in Phoenix, Arizona. Questions were adapted slightly depending on participant expertise.

Interview Guide

- How has e-commerce changed packaging waste in Phoenix?
- What challenges exist within current recycling systems?
- Which materials are most difficult to recover?
- How effective are current public education efforts?
- What opportunities exist for circular economy partnerships?
- How does packaging waste affect different communities?
- What policy changes would have the greatest impact?
- What role should manufacturers play in reducing packaging waste?
- Interview Questions for City of Phoenix Public Works
- Has the City observed an increase in packaging waste associated with e-commerce deliveries?
- What packaging materials create the most significant challenges for recycling operations?
- What percentage of residential recycling contamination involves shipping materials or related packaging?
- Are current recycling facilities capable of handling projected growth in packaging waste?
- What barriers prevent greater recovery and recycling of packaging materials?
- How is Phoenix pursuing its Zero Waste 2050 goals regarding packaging reduction?
- What recommendations would you make to policymakers seeking to reduce e-commerce waste?
- What role should manufacturers and retailers play in addressing packaging waste at the source?
- Are there neighborhoods or communities disproportionately affected by waste-management challenges?
- What future initiatives or innovations do you believe will have the greatest impact on packaging waste reduction?

Appendix B
Photovoice, Figures & Image Log

Figure	Date	Location	Description	Theme	Reflection
Photo 1	June 2026	Phoenix Apartment Complex	Overflowing recycling enclosure with boxes and plastic mailers	Waste	Demonstrates increasing packaging volumes and contamination.
Photo 2	June 2026	Transfer Station	Mixed cardboard and plastic contamination	Circular Economy	Highlights challenges with material separation.
Photo 3	July 2026	Apartment Mailroom	Large accumulation of parcels awaiting pickup	Convenience	Illustrates growth of e-commerce deliveries.
Photo 4	July 2026	Downtown Phoenix	Cardboard used as shelter by unhoused residents	Environmental Justice	Shows secondary reuse of packaging materials.
TABLE	July 2026	Interview Matrix	Stakeholder interview matrix	Research/Data	Highlights current challenges within area.
Photo 6	June 2026	Interview Photo	Stakeholder interview matrix	Environmental Justice	Highlights challenges and upside of waste.

Appendix C
Secondary Data Summary

Organization	Key Finding	Relevance to Phoenix
City of Phoenix	Zero Waste 2050 initiative emphasizes recycling and waste reduction.	Supports local sustainability goals.
Arizona State University	Research highlights circular economy and sustainable materials management.	Provides regional academic context.
Arizona PIRG	Supports reducing single-use plastics and improving recycling systems.	Reinforces community advocacy efforts.
EPA	Over 60% of consumers report confusion regarding recyclable materials.	Explains contamination challenges observed during interviews.
Sustainable Packaging Coalition	Approximately 67% of consumers prefer environmentally friendly packaging.	Demonstrates consumer demand for sustainable alternatives.
The Recycling Partnership	Approximately 73% support reducing unnecessary plastic packaging.	Aligns with recommendations from interview participants.
Arizona Forward	Promotes sustainable development and waste reduction initiatives across Arizona.	Supports statewide sustainability objectives.

Appendix D Supplier Interviews

Supplier & Stakeholder Interviews

Purpose

This appendix summarizes stakeholder interviews for my capstone project on e-commerce packaging waste and sustainability. It captures diverse perspectives from affected communities and waste stakeholders, highlighting perceptions, challenges, and opportunities for waste reduction and circular practices. These insights complement other research methods and inform recommendations for more sustainable, equitable waste management in Phoenix.

Note: Participant names have been anonymized or replaced with pseudonyms when requested to protect confidentiality. All interviews were conducted voluntarily, and quotations are presented as accurately as possible based on interview notes and participant responses.

Participant	Stakeholder Group	Position / Perspective	Summary of Key Findings	Representative Quote	Primary Theme(s)	Evidence Source
Bill	Unhoused Community Member	Resident experiencing homelessness	Uses discarded cardboard and plastic mailers for shelter, insulation, and weather protection. Views packaging waste as both a survival resource and evidence of excessive consumer waste.	<i>"The cardboard and plastic help keep us dry and out of the sun."</i>	Environmental Justice; Waste; Social Equity	Interview
Sam	Unhoused Community Member	Resident experiencing homelessness	Frequently reuses Amazon boxes, plastic mailers, and other packaging materials for temporary shelter and storage. Noted increasing quantities of discarded packaging throughout Phoenix.	<i>"Most of what we use comes from boxes people throw away."</i>	Environmental Justice; Circular Economy; Waste	Interview
Anonymous	Municipal Transfer Station	Administrative Dispatch Clerk (3.5 years)	Reported significant increases in cardboard, plastic mailers, and Amazon packaging entering transfer stations. Identified contamination of recyclable materials as one of the greatest operational challenges. Recommended stronger collaboration among municipalities, businesses, and residents to improve recycling outcomes.	<i>"The biggest issue is the segregation—or lack of it."</i>	Recycling Infrastructure; Circular Economy; Waste Management	Interview
Apartment Manager	Multi-Family Housing	Community Property Manager	Observed substantial increases in cardboard and plastic packaging from online shopping. Reported overflowing recycling bins, contamination, pest issues, and increased maintenance costs associated with e-commerce packaging waste.	<i>"We see far more boxes and plastic mailers than we did just a few years ago."</i>	Convenience; Community Impact; Environmental Justice	Interview
Alyssa	City of Phoenix Public Works / Sustainability	Recycling & Diversion Program Representative	Explained the City's recycling goals, contamination challenges, public education initiatives, and ongoing investments in diversion programs. Emphasized that consumer behavior and proper source separation remain essential to achieving Phoenix's 2030 diversion targets.	<i>"Improving recycling starts with residents placing the right materials in the right container." (Paraphrase if no direct quote was recorded.)</i>	Municipal Sustainability; Recycling Infrastructure; Circular Economy; Public Education	Expert Interview

Appendix E Cost & Data Analysis Charts

Purpose:

To provide supplemental quantitative data, comparison tables, and supporting graphics referenced throughout the capstone. These materials expand upon the findings discussed in the main text but are presented separately to maintain the magazine-style narrative of the paper.

Category	Percent
Containers & Packaging	28.1
Food Waste	21.6
Yard Waste	12.1
Paper	11.8
Plastics	12.2
Metals	8.8
Glass	4.2
Other	1.2

Table.1- Municipal Solid Waste Composition. Composition of municipal solid waste generated in the United States by major material category. Containers and packaging comprise the largest portion of the waste stream, highlighting the importance of improving packaging design, recycling systems, and circular economy strategies.

Source: City of Phoenix Climate Action Plan Progress Report.

Table 2. Sustainable Packaging Comparison

Material	Approximate Cost	Recyclable	Compostable	Carbon Impact
Corrugated Cardboard	Low	✓	✓	Low
Virgin Plastic Mailer	Low	Limited	✗	High
Recycled Poly Mailer	Moderate	✓	✗	Moderate
Compostable Mailer	High	✗	✓	Low
Molded Fiber Packaging	Moderate	✓	✓	Low

How Do Women in Obuasi Navigate the Impacts of Illegal Mining-Related Water Contamination
While Balancing Family Health Responsibilities and Livelihood Needs?

Shiley School of Engineering, University of San Diego

EHS-540-01: Capstone Project

Obed Yeboah



Caption:

Figure 1. Women in Nyanza Province, Kenya, walk each day to collect water for cooking, drinking, and cleaning, illustrating the daily burden of water collection experienced by many women in sub-Saharan Africa, including communities affected by illegal mining in Obuasi,

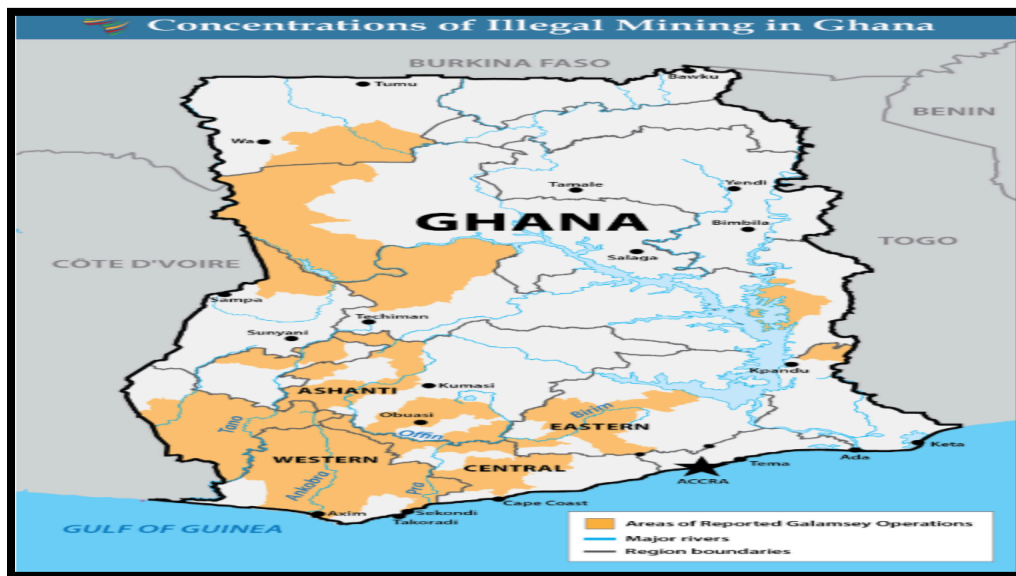
Ghana. Note. Photograph by Peter Bregg. From Water for Life: An African Photo Exhibit, by C. Smith and M. Notaras, 2011, Our World, United Nations University. [Water for Life: An African Photo Exhibit](#). Used under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License.

Abstract

Illegal mining (galamsey) has become one of Ghana's most pressing environmental and public health challenges, particularly in the Obuasi Municipality, where mining activities have degraded surface and groundwater through mercury contamination, sedimentation, and other pollutants. Women and children are disproportionately affected because women are primarily responsible for household water collection, food preparation, and caregiving. As access to safe water declines, they experience increased health risks, greater time burdens, and fewer opportunities for education and income-generating activities. Despite these impacts, limited qualitative research has examined how women navigate household water insecurity while balancing caregiving responsibilities and livelihood needs in mining-dependent communities.

This qualitative case study examines how illegal mining-related water contamination affects the daily lives of a household in Obuasi, Ghana. Guided by the theoretical frameworks of Feminist Political Ecology and Environmental Justice, the study explores the intersection of environmental degradation, gender inequality, and economic dependence on mining. Data were collected through a semi-structured interview with members of a single household and supplemented with document analysis of peer-reviewed literature, government publications, and reports from organizations addressing water quality, mining, and environmental governance in Ghana. These multiple sources were used to contextualize and interpret the family's lived experiences.

The study documents how illegal mining has reduced access to safe and reliable water, increased women's unpaid labor associated with water collection and household caregiving, and heightened concerns about the health impacts of contaminated water on children and families. The findings also illustrate how environmental degradation, limited livelihood opportunities, and weak environmental governance reinforce one another, creating conditions that disproportionately burden women in mining communities. By combining a household case study with environmental justice and feminist political ecology perspectives, this research contributes a contextualized understanding of how environmental contamination is experienced at the household level and highlights the need for stronger environmental governance, improved access to safe water, gender-responsive policymaking, and sustainable livelihood alternatives in Ghana's mining communities.



Caption: *Figure 2. Concentrations of illegal gold mining (galamsey) activities across Ghana, highlighting major hotspots in the Ashanti, Western, Eastern, and Central Regions, including the Obuasi area. Note. Adapted from Ghana's Illegal Gold Mining Crisis: A National Security*

Threat with Regional Implications, by E. Srem, 2026, Africa Center for Strategic Studies
(<https://africacenter.org/spotlight/galamsey-ghana-gold-mining-security/>). The map illustrates the geographic concentration of illegal mining activities and provides context for this study's focus on Obuasi in the Ashanti Region.

Introduction

Background of Study.

Access to safe drinking water remains one of the world's most significant environmental and public health challenges. [According to the World Health Organization \(WHO\)](#), approximately 2.2 billion people lack access to safely managed drinking water services worldwide. This challenge is particularly acute in Sub-Saharan Africa, where rapid population growth, inadequate infrastructure, climate variability, and environmental degradation continue to limit reliable access to safe water.

In Ghana, although access to basic drinking water services has improved over the past two decades, water quality remains a persistent concern, especially in mining communities. Illegal artisanal and small-scale mining, locally known as *galamsey*, has become a major contributor to the degradation of rivers, streams, and groundwater through mercury contamination, sedimentation, and the discharge of mining waste. Studies have documented elevated concentrations of heavy metals, including mercury and arsenic, in water bodies surrounding mining communities, posing serious risks to both ecosystem integrity and public health.

Obuasi Municipality in Ghana's Ashanti Region represents one of the country's most important gold mining districts. Alongside large-scale industrial mining, illegal mining activities have expanded considerably, placing increasing pressure on local water resources. As surface water

quality deteriorates, households face growing challenges obtaining safe water for drinking, cooking, sanitation, and other daily needs.

Women experience these impacts disproportionately. In many Ghanaian households, women are primarily responsible for collecting water, preparing food, caring for children, and maintaining household health. Consequently, environmental degradation extends beyond ecological consequences to influence gender roles, household labor, family health, and economic well-being.

Growing up in Ghana, I often heard family members describe rivers that once provided clean drinking water and supported farming activities. During conversations with my uncle, he recalled a time when streams near his community could be used safely for drinking, fishing, and irrigation. Today, many of those same water sources have become unsafe because of mining activities. These personal conversations deepened my understanding of the challenges facing mining-affected communities and reinforced my interest in examining how environmental degradation affects everyday household life. They also helped me recognize that the Donkor family's experiences reflect broader realities shared by many Ghanaian families.

Additionally, I observed many women and children walking long distances each day to collect water for their families. Those experiences shaped my understanding of water insecurity as both an environmental and social justice issue. They also motivated my interest in examining how illegal mining affects everyday life in communities where access to safe water has become increasingly uncertain.

This study argues that women in Obuasi are not passive victims of environmental degradation. Instead, they continually adapt to changing environmental conditions through household water

management, caregiving, economic decision-making, and community support. However, these adaptive strategies require significant personal sacrifice and should not substitute for effective environmental governance. The resilience demonstrated by mining-affected families reflects their determination to survive rather than evidence that current policies are adequate.

Literature Review

Illegal mining (galamsey) has become one of Ghana's most significant environmental, social, and public health challenges. While numerous studies have documented its effects on water quality, deforestation, and ecosystem degradation, growing evidence suggests that these environmental impacts are experienced unequally across society. Women, children, and economically marginalized households often bear the greatest burden because of their responsibilities for water collection, household management, and caregiving.

This chapter reviews existing scholarship on illegal mining and water contamination in Ghana while situating the study within the complementary theoretical frameworks of Feminist Political Ecology (FPE) and Environmental Justice (EJ). Together, these frameworks provide a lens for understanding not only the environmental consequences of galamsey, but also how social structures shape vulnerability, access to resources, and the unequal distribution of environmental risks.

[Operation Halt](#) is a military-led anti-illegal mining initiative established by the Government of Ghana to combat illegal mining activities, particularly along rivers and forest reserves. Although the initiative has resulted in arrests and the destruction of illegal mining equipment, critics argue that enforcement has been inconsistent and has failed to address the underlying economic drivers of galamsey.

Theoretical Framework

Feminist Political Ecology.

[Feminist Political Ecology](#) emerged during the 1990s through the work of scholars including Dianne Rocheleau, Barbara Thomas-Slayter, and Esther Wangari. The framework argues that environmental change cannot be understood independently of gender, power, and political-economic structures. Rather than viewing environmental degradation as affecting everyone equally, Feminist Political Ecology examines how women and men experience environmental change differently because of socially constructed divisions of labor, unequal access to resources, and differences in political power.

Within mining communities, women frequently assume responsibility for collecting water, preparing food, caring for children, and maintaining household health. When rivers become contaminated through illegal mining, these responsibilities become increasingly difficult and time-consuming. Consequently, environmental degradation creates additional unpaid domestic labor that disproportionately falls upon women. Feminist Political Ecology therefore provides an important framework for understanding how environmental change reinforces existing gender inequalities rather than affecting all community members equally.

Environmental Justice.

Environmental Justice developed from social movements in the United States during the 1980s and has since evolved into a global framework for understanding how environmental risks and benefits are distributed across populations. [Scholars such as Robert Bullard](#), often regarded as the father of Environmental Justice, demonstrated that disadvantaged communities are

disproportionately exposed to environmental hazards while possessing fewer political resources to influence environmental decision-making.

Within the Ghanaian context, Environmental Justice extends beyond pollution alone to include equitable access to safe drinking water, participation in environmental governance, and the fair distribution of both the benefits and burdens associated with natural resource extraction.

Although gold mining contributes substantially to Ghana's economy, communities such as Obuasi often experience environmental degradation without receiving comparable improvements in public infrastructure, healthcare, or water services.

Together, Feminist Political Ecology and Environmental Justice provide complementary perspectives. Feminist Political Ecology explains who performs the labor associated with environmental degradation, while Environmental Justice explains why these burdens are distributed unequally through broader political and institutional systems.

Illegal Mining and Water Quality Degradation.

Water contamination resulting from galamsey extends beyond ecological degradation. Declining water quality influences agriculture, household food security, sanitation, education, and community health. Consequently, water pollution should be understood as both an environmental problem and a social justice issue that disproportionately affects already vulnerable populations.

Health Impacts.

Women frequently serve as the primary caregivers for children and elderly family members. Consequently, exposure to contaminated water creates a dual burden whereby women face potential health risks themselves while simultaneously managing illness among other household members. This interaction between environmental exposure and caregiving responsibilities

illustrates why environmental contamination cannot be understood solely through toxicology but must also be examined through gendered household dynamics.

Gendered Water Labor.

Feminist scholars use the term reproductive labor to describe unpaid activities necessary to sustain households and communities, including water collection, food preparation, childcare, elder care, and maintaining household health. Although this labor is essential to family well-being, it is often invisible within formal economic systems and disproportionately performed by women. Environmental degradation increases the time and physical effort required for these responsibilities, thereby expanding women's unpaid workload without corresponding economic compensation.

Governance and Institutional Challenges.

Weak environmental governance is only one dimension of the problem. In many rural Ghanaian communities, patriarchal social structures continue to influence decision-making within households, local governance institutions, and community resource management. Although women are primarily responsible for collecting and managing household water, they are frequently underrepresented in leadership positions responsible for water governance and environmental planning. As a result, those most directly affected by water contamination often have limited influence over decisions concerning mining regulation, environmental remediation, or water infrastructure investment.

This exclusion reinforces environmental injustice by limiting opportunities for women to shape policies affecting their daily lives. Consequently, addressing water insecurity requires not only

stronger environmental enforcement but also more inclusive governance structures that recognize women's knowledge, lived experience, and leadership within mining communities.

Government Response to Illegal Mining.

In response to the rapid expansion of illegal mining, the Government of Ghana has implemented several enforcement initiatives, including Operation Halt, a joint military and law enforcement task force established to dismantle illegal mining operations and protect environmentally sensitive areas. While these initiatives have resulted in temporary reductions in illegal mining activity, researchers and community members have questioned their long-term effectiveness because mining frequently resumes once enforcement teams leave affected communities. Critics argue that enforcement strategies alone cannot resolve galamsey without simultaneously addressing unemployment, rural poverty, land tenure, and limited access to legal small-scale mining opportunities. This tension emerged clearly in the present study, where participants viewed alternative livelihood opportunities as essential to any sustainable solution.

Gaps in Literature

Most existing studies rely on environmental monitoring data, water quality assessments, or national policy analyses. Comparatively little research has documented how a single household experiences environmental degradation in everyday life or examined how women negotiate competing responsibilities for caregiving, water collection, and household survival within mining-affected communities. By foregrounding one family's lived experience, this study complements quantitative environmental research with qualitative insight into the human dimensions of illegal mining.

Methodology

Introduction.

This study employed a qualitative case study design to explore how illegal mining-related water contamination affects the lived experiences of a household in Obuasi, Ghana. Rather than measuring environmental contamination quantitatively, the research sought to understand how environmental degradation is experienced in everyday life through household water management, caregiving responsibilities, livelihood decisions, and perceptions of environmental change. Guided by the complementary frameworks of Feminist Political Ecology (FPE) and Environmental Justice (EJ), the study examined how gender, power, environmental governance, and economic dependence intersect within a mining-affected community.

Research Design.

A qualitative case study design was selected because it allows for an in-depth examination of a contemporary issue within its real-life context. This approach was appropriate because the study sought to understand the experiences of one household rather than produce statistically generalizable findings. A case study design enabled me to explore the complex relationships among environmental contamination, household decision-making, caregiving, and livelihood strategies while preserving the social and cultural context in which these experiences occurred.

Using a single household as the unit of analysis allowed for a detailed exploration of how illegal mining influences daily life in ways that are often overlooked in quantitative environmental studies. Rather than focusing solely on environmental indicators, this study prioritized the perspectives and experiences of individuals living with the consequences of water contamination.

Positionality.

As a Ghanaian and an environmental health and safety professional, I bring both personal and professional perspectives to this research. Growing up in Ghana, I witnessed women and children traveling long distances to collect water, particularly during periods when local water sources became unreliable. These experiences shaped my understanding of water insecurity as both an environmental and social justice issue.

My graduate education in engineering, sustainability and health further influenced my interest in examining the relationship between environmental degradation, public health, and community resilience. While my background provided cultural familiarity and facilitated rapport with participants, I remained mindful of the potential for personal experiences to influence data interpretation. Throughout the research process, I engaged in reflexive notetaking to critically examine my assumptions and ensure that participants' perspectives remained central to the analysis. Rather than attempting to eliminate subjectivity, this study acknowledges that qualitative research is inherently interpretive. Transparency regarding my background and analytical decisions strengthens the credibility and trustworthiness of the findings.

Study Setting.

The study was conducted in Obuasi Municipality, located in Ghana's Ashanti Region. Obuasi has long been recognized as one of Ghana's major gold-producing regions. Alongside industrial mining, the municipality has experienced a substantial increase in illegal artisanal and small-scale mining (galamsey), contributing to deforestation, land degradation, and contamination of rivers and streams used for domestic water supply.

The community provides an appropriate setting for examining how environmental degradation affects household water security because residents continue to depend on local water sources while navigating the economic opportunities and environmental risks associated with mining.

Participant Selection.

Purposive sampling was used to identify participants who possessed direct experience with the phenomenon under investigation. The primary participants were members of the Donkor family, a household residing in Obuasi that has experienced the effects of illegal mining on water access, household health, and livelihood decisions.

Although the interview centered on the experiences of the family's primary female caregiver, conversations also included perspectives shared by other household members regarding environmental change, employment, and household decision-making. Including multiple family perspectives provided a more comprehensive understanding of how water contamination influences family life.

The Donkor family was selected because their experiences reflected many of the broader social and environmental challenges identified within the literature while providing rich, detailed accounts of everyday life in a mining-affected community.



Caption:

Figure 3 Illegal gold mining (galamsey) continues to degrade forests and water resources in Ghana despite multiple government interventions. The figure illustrates the widespread environmental impacts that provide context for this study of illegal mining in Obuasi, Ghana.

Note. Adapted from Ghana's War on Illegal Mining Has Failed – We Set Out to Find Out Why, by G. Crawford and G. Botchwey, 2025, The Conversation

(<https://theconversation.com/ghanas-war-on-illegal-mining-has-failed-we-set-out-to-find-out-why-262644>). Used under the Creative Commons Attribution (CC BY) license.

Data Collection

Semi-Structured Interviews.

Data was collected through a semi-structured interview with members of the Donkor family.

Semi-structured interviewing provided sufficient flexibility to explore participants' experiences while maintaining consistency across key topics, including water access, health concerns, caregiving responsibilities, livelihood strategies, and perceptions of environmental governance.

The conversational nature of the interview encouraged participants to elaborate on issues that they considered most important, allowing unexpected themes to emerge naturally. Follow-up questions were used to clarify responses and encourage participants to provide examples from their daily lives.

Document Analysis.

To contextualize the interview findings, I conducted a document analysis of peer-reviewed journal articles, government publications, and reports produced by international organizations and non-governmental organizations. These documents included:

1. Ghana Water Resources Commission reports
2. Ghana Environmental Protection Agency publications
3. Ministry of Lands and Natural Resources documents
4. World Health Organization reports
5. Peer-reviewed studies, scholars examining illegal mining, water quality, environmental governance, and gender in Ghana

Rather than serving as primary data, these documents provided contextual information that supported interpretation of the household interview.

Data Analysis.

Interview transcripts and documentary evidence were analyzed using [Braun and Clarke's six-phase thematic analysis](#). This approach was selected because it provides a systematic yet flexible method for identifying patterns across qualitative data while remaining compatible with the interpretive perspectives of Feminist Political Ecology and Environmental Justice.

The analysis involved:

1. Familiarization with the data through repeated reading.
2. Initial coding of meaningful segments.
3. Development of preliminary themes.
4. Review and refinement of themes.
5. Definition and naming of themes.
6. Integration of themes into the final narrative.

Themes were developed inductively from participants' experiences while also considering concepts identified within the theoretical frameworks and existing literature.

Trustworthiness.

To enhance credibility, findings from the household interview were compared with peer-reviewed literature and official reports addressing illegal mining, water contamination, and environmental governance in Ghana. This triangulation strengthened confidence in the consistency of emerging themes.

Dependability was supported through documentation of analytical decisions throughout the coding process. Confirmability was enhanced through reflexive journaling, which allowed me to distinguish participants' perspectives from my own interpretations. Thick description of the study

setting and participant experiences supports transferability by enabling readers to determine the applicability of findings to similar mining communities.

Ethical Considerations.

Ethical principles of voluntary participation, informed consent, confidentiality, and respect for participants guided the study. Before the interview, participants were informed of the study's purpose, their right to decline participation, and their ability to withdraw at any time without consequence.

Because the Donkor family consented to the use of their family name within the context of this capstone, identifying information is presented with permission. Sensitive personal information not directly relevant to the research questions has been omitted to protect participant privacy.

Limitations.

Several limitations should be considered when interpreting the findings. First, the study focuses on a single household and therefore is not intended to represent the experiences of all mining communities in Ghana. Instead, the objective was to develop an in-depth understanding of one family's lived experience.

Second, documentary sources reflect the perspectives of researchers, government agencies, and international organizations, each of which may emphasize different aspects of illegal mining and environmental governance. To reduce potential bias, information was compared across multiple sources. Finally, qualitative research relies on participants' recollections and interpretations of past experiences. Although these accounts may be influenced by memory, they provide valuable insight into how environmental change is experienced and understood by affected communities.

Results and Discussion

Navigating Water Insecurity.

The Donkor family demonstrated several strategies for adapting to persistent water insecurity. Rather than relying on a single source, household members combined purchased water, rainwater harvesting, selective use of local streams, and careful rationing to meet daily needs. Women adjusted cooking schedules, delayed household chores until clean water became available, and prioritized drinking water over other domestic uses during periods of scarcity.

These strategies illustrate resilience rather than stability. Although the family successfully adapted to changing environmental conditions, each adaptation required additional time, labor, financial resources, or personal sacrifice.

This chapter presents the findings from the qualitative case study of the Donkor family in Obuasi, Ghana, and integrates them with evidence from peer-reviewed literature, government publications, and reports from international organizations. The findings are organized into four major themes that emerged during the analysis:

1. Water insecurity and household adaptation.
2. Gendered caregiving and reproductive labor.
3. Livelihood dependence and environmental trade-offs.
4. Environmental governance and community trust.

These themes are interpreted through the complementary frameworks of Feminist Political Ecology (FPE) and Environmental Justice (EJ) to illustrate how environmental degradation intersects with gender, power, and household decision-making.

Water Insecurity and Household Adaptation.

The Donkor family consistently described access to safe water as one of the greatest challenges affecting their daily lives. Participants explained that rivers and streams previously relied upon for drinking, cooking, and washing had become visibly discolored because of illegal mining activities. As water quality declined, the family increasingly depended on purchased water, stored rainwater, and alternative sources that were often less reliable and more expensive.

One participant explained. "Years ago, we could fetch water from the stream without worrying about whether it was safe. Now, the water is brown after mining activities, and we have to think carefully before using it for drinking or cooking."

This finding illustrates that water contamination affects far more than environmental quality. It alters daily routines, household budgets, and perceptions of safety. Similar observations have been reported by Hilson and colleagues, who documented how illegal mining degrades water resources used by surrounding communities. Rather than replacing the family's experiences, these studies provide context demonstrating that the Donkor family's account reflects broader patterns documented across Ghana.

Discussion.

Viewed through an Environmental Justice lens, unequal access to safe drinking water represents an inequitable distribution of environmental risk. Although mining generates economic benefits for some actors, nearby households bear disproportionate environmental and health burdens. The family's experiences demonstrate that environmental degradation is lived through everyday decisions about where to obtain water, how to use it safely, and how to protect family members from potential exposure.

Gendered Caregiving and Reproductive Labor.

The interview revealed that women carried primary responsibility for obtaining water, preparing meals, maintaining household hygiene, and caring for children. As water sources became contaminated, these responsibilities required significantly more time and physical effort.

The family's experiences illustrate what Feminist Political Ecology scholars describe as reproductive labor, the unpaid work required to sustain households and communities. This includes collecting water, preparing food, caring for children, and protecting family health. Although this labor is essential, it often remains unrecognized within economic systems.

One participant described how obtaining water had become increasingly difficult:

"Sometimes I spend hours trying to find clean water before I can even begin cooking. By then the whole day is almost gone."

The consequences extended beyond physical labor. Time spent searching for water reduced opportunities for income-generating activities, education, and community participation.

Discussion.

Rather than affecting all residents equally, environmental degradation intensified existing gender inequalities. Feminist Political Ecology helps explain why women experienced greater impacts than other household members: social expectations placed responsibility for household water management and caregiving primarily on women. As environmental conditions worsened, unpaid domestic labor increased accordingly.

Livelihood Dependence and Environmental Trade-Offs.

One of the most significant themes that emerged from the interview was the tension between environmental protection and economic survival. While the Donkor family recognized that illegal mining (galamsey) had contributed to the contamination of local water sources and the degradation of farmland, they also acknowledged that mining had become one of the few viable sources of income available to many young people in their community. This tension illustrates the difficult reality faced by households in mining-affected communities, where environmental harm and economic necessity are deeply interconnected.

Participants described how the decline in agricultural productivity and access to clean water disrupted traditional livelihood strategies. Farming, which had long provided both food and income for the family, became increasingly difficult as soil quality declined and nearby streams became polluted. As a result, the household had to diversify its livelihood strategies to meet basic needs, including seeking employment outside of agriculture.

One of the study's most striking findings involved the irony that Kwame sought employment in illegal mining after his father's farming livelihood had been negatively affected by the environmental consequences of mining. This finding illustrates how environmental degradation and economic insecurity reinforce one another in a continuous cycle. Rather than representing a personal contradiction, Kwame's decision reflects the broader structural constraints faced by many young adults in mining communities where legal employment opportunities remain limited. His experience demonstrates that participation in galamsey is often driven less by personal choice than by economic necessity and the absence of sustainable alternatives.

The interview further revealed that the family's response to these challenges was characterized by resilience and adaptation rather than resignation. Household members adjusted spending priorities, relied on multiple income sources, and continually balanced immediate financial needs against concerns about long-term environmental and health consequences. Women, in particular, played a central role in managing these competing demands by stretching limited household resources, securing water from alternative sources, and maintaining daily caregiving responsibilities despite increasing environmental pressures.

Discussion.

This extends existing research by illustrating how environmental degradation and poverty interact at the household level. Previous studies have identified unemployment, rural poverty, and limited economic opportunities as major drivers of illegal mining in Ghana.

The Donkor family's experiences provide qualitative evidence of how these broader structural conditions influence everyday decisions within a single household. Rather than viewing illegal mining solely as an environmental issue or solely as an economic issue, the findings demonstrate that the two are inseparable.

From the perspective of Environmental Justice, Kwame's experience highlights the unequal distribution of environmental burdens and economic opportunities. Communities affected by mining often bear the health and environmental costs while having limited access to alternative forms of employment. Similarly, Feminist Political Ecology helps explain how environmental degradation reshapes household responsibilities. As traditional livelihoods became less reliable, women assumed greater responsibility for managing scarce household resources while continuing to provide care for children and other family members. Their resilience enabled the

family to cope with immediate challenges, but it also reflected systemic failures in environmental governance, rural development, and social protection.

Ultimately, this theme directly answers the study's research question. The Donkor family navigated the impacts of illegal mining through resilience, adaptation, and difficult compromises. They diversified livelihoods, rationed limited resources, and made challenging economic decisions to sustain the household.

However, these coping mechanisms came at significant personal, financial, and emotional costs. Their resilience should not be interpreted as evidence that existing systems are working; rather, it underscores the urgent need for stronger environmental governance, expanded livelihood opportunities, and policies that reduce the burden placed on families living in mining-affected communities.

Environmental Governance and Community Trust.

Participants expressed frustration regarding government responses to illegal mining. Although enforcement initiatives, including Operation Halt, had temporarily reduced mining activity in some areas, participants believed that illegal mining frequently resumed once enforcement teams departed.

One participant observed. "The government comes for a short time, but after they leave, the mining starts again. "Participants also described limited confidence that community concerns influenced environmental decision-making.

Discussion.

These findings align with previous research indicating that enforcement alone has not produced lasting reductions in illegal mining. Government reports and academic studies similarly conclude that long-term success requires stronger institutional coordination, community participation, and alternative livelihood opportunities.

From an Environmental Justice perspective, governance extends beyond law enforcement. It also includes meaningful public participation in environmental decision-making. Although women experience many of the daily consequences of water contamination, they often have limited opportunities to influence policies affecting water resources and mining regulation.

Integration of Findings.

Together, these themes illustrate that illegal mining affects households through interconnected environmental, social, economic, and political processes. Water contamination increased caregiving responsibilities, reduced economic opportunities, created health concerns, and weakened confidence in environmental governance.

The complementary theoretical frameworks strengthened interpretation of these findings. Feminist Political Ecology explained why environmental degradation disproportionately increased women's unpaid labor, while Environmental Justice illuminated how environmental risks and decision-making power were distributed unequally across the community.

Rather than viewing water contamination solely as an environmental issue, the findings demonstrate that it is simultaneously a public health, gender equity, governance, and sustainable development challenge.

Conclusion

This study examined how illegal mining-related water contamination affects household life in Obuasi, Ghana, through an in-depth qualitative case study of the Donkor family. Guided by the complementary frameworks of Feminist Political Ecology and Environmental Justice, the research explored how environmental degradation intersects with gender, caregiving responsibilities, livelihood strategies, and environmental governance.

The findings demonstrate that illegal mining extends far beyond environmental pollution. Water contamination reshaped the family's daily routines, increased the time required to obtain safe water, expanded women's unpaid caregiving and household responsibilities, and heightened concerns regarding the health of children and other family members. At the same time, the study revealed the difficult choices households face when illegal mining represents one of the few available sources of income despite its harmful environmental consequences.

Unlike many previous studies that focus primarily on environmental monitoring, water quality assessments, or national policy, this research contributes a household-level perspective that illustrates how environmental degradation is experienced in everyday life. By documenting the lived experiences of one family, the study demonstrates how environmental challenges are simultaneously social, economic, and public health challenges. This qualitative perspective complements existing quantitative research by providing a richer understanding of how communities adapt to environmental change while navigating competing demands for survival, caregiving, and income generation.

The study also highlights the value of integrating Feminist Political Ecology and Environmental Justice. Feminist Political Ecology explains how environmental degradation disproportionately

increases women's unpaid labor and caregiving responsibilities, while Environmental Justice demonstrates how environmental risks and access to decision-making are distributed unequally. Together, these frameworks provide a more comprehensive understanding of the interconnected challenges facing mining-affected communities.

Implications for Policy and Practice.

The findings suggest that reducing illegal mining requires more than environmental enforcement. Sustainable solutions should address the social and economic conditions that encourage participation in *galamsey* while strengthening environmental governance and improving access to safe drinking water.

Several practical implications emerge from this study.

Strengthen Environmental Governance.

Government agencies should continue enforcing environmental regulations while improving coordination among the Ministry of Lands and Natural Resources, the Environmental Protection Agency (EPA) Ghana, district assemblies, and local traditional authorities. Long-term monitoring and community participation are essential to sustaining improvements.

Improve Water Infrastructure.

[In Obuasi, the Ghana Water Company Limited \(GWCL\)](#) plays a vital role in ensuring access to safe and reliable household water while addressing the impacts of mining-related pollution. Specifically, GWCL is responsible for monitoring raw-water sources, treating contaminated water, testing water quality, and maintaining distribution infrastructure.

Furthermore, GWCL can collaborate with traditional leaders, community elders, women's groups, and local authorities to strengthen community participation in protecting water sources. Women can support

household water management and report changes in water quality, while community leaders can mobilize residents to protect rivers and prevent pollution.

Through these partnerships, continuous monitoring, public education, and improved treatment technologies, GWCL can reduce risks associated with mining pollution. Ultimately, integrating technical water management with community participation can promote sustainable water resources and improve safe household water access in Obuasi.

Promote Gender-Responsive Policies.

Because women bear primary responsibility for household water management, they should be meaningfully included in local environmental governance, water resource planning, and community decision-making. Policies that overlook women's experiences risk overlooking the individuals most affected by declining water quality.

Expand Alternative Livelihood Programs.

One of the study's most significant findings is that environmental protection and economic survival are deeply interconnected. The Donkor family's experience, particularly Kwame's decision to participate in illegal mining because of limited employment opportunities, illustrates that enforcement alone cannot eliminate galamsey.

Sustainable alternatives may include vocational and technical training, agricultural modernization, small-business development, legal small-scale mining opportunities, renewable energy and green economy employment, and wastewater and environmental restoration projects. These alternatives can reduce economic dependence on illegal mining while supporting community development.

Reflecting on this research, I was reminded of conversations with my uncle about rivers that once sustained farming, fishing, and daily household life. Hearing similar concerns from the

Donkor family reinforced that these environmental changes are not isolated experiences but part of a broader transformation affecting many communities across Ghana. This connection between my personal experiences and the interview findings strengthened my understanding of the human dimensions of environmental degradation.

Finding	Recommendation
Women spend more time collecting water	Expand community boreholes and piped water systems
Household spends income on sachet water	Subsidize safe drinking water in mining communities
Kwame left school for galamsey	Develop youth employment, vocational training, and agricultural livelihood programs
Weak enforcement (Operation Halt)	Strengthen enforcement while coupling it with community economic development
Women excluded from governance	Require women's representation on local water committees

Recommendations for Future Research

This study examined the experiences of a single household in Obuasi and provides an in-depth understanding of how one family navigates the environmental, social, and economic challenges associated with illegal mining-related water contamination. While this case study offers valuable insight into the lived realities of one household, future research should expand to include multiple families across different mining communities in Ghana to better understand how coping strategies vary across geographic, cultural, and socioeconomic contexts.

Future research should also explore how women and families develop resilience in the face of prolonged water insecurity. While this study documented strategies such as modifying household water use, adjusting livelihood decisions, and balancing caregiving responsibilities, additional research could examine which coping mechanisms are most sustainable and how community support networks influence household resilience over time.

Several additional areas warrant further investigation, including:

1. the long-term educational and developmental impacts of water insecurity on children living in mining-affected communities;
2. the effectiveness of Operation Halt and other government interventions in reducing illegal mining while supporting sustainable livelihoods;
3. women's participation and leadership in environmental governance and community decision-making;
4. the long-term public health effects of chronic exposure to mining-related water contamination, particularly among women and children; and

5. comparisons between communities that have successfully implemented alternative livelihood programs and those where illegal mining remains the primary source of employment.

Finally, future studies should continue integrating community voices with environmental monitoring and policy analysis. Combining scientific evidence with the lived experiences of affected households can provide a more comprehensive understanding of illegal mining and support the development of policies that are both environmentally sustainable and socially responsive.

Study Contribution

This study contributes to the growing body of research on illegal mining, water insecurity, and environmental justice by moving beyond environmental assessments to examine how environmental degradation is experienced within the daily life of a household. Rather than focusing solely on water quality measurements or policy discussions, this research centers the lived experiences of the Donkor family to demonstrate how illegal mining reshapes caregiving responsibilities, household decision-making, livelihood strategies, and perceptions of environmental change.

A key contribution of this research is its direct response to the research question: How do women in Obuasi navigate the impacts of illegal mining-related water contamination while balancing family health responsibilities and livelihood needs? The findings show that the family's response was characterized by resilience, adaptation, and difficult compromise. Women managed water scarcity by seeking alternative water sources, rationing household resources, and maintaining caregiving responsibilities despite increasing environmental pressures. At the same time, the

family's experience revealed the difficult trade-offs created by limited economic opportunities, including the decision of one family member to seek employment in the same mining activities that had contributed to the loss of the family's agricultural livelihood.

This study also demonstrates the value of combining Feminist Political Ecology and Environmental Justice as complementary analytical frameworks. Feminist Political Ecology explains how environmental degradation disproportionately increases women's unpaid caregiving and household labor, while Environmental Justice highlights how environmental risks, economic opportunities, and political power are distributed unequally within mining communities. Together, these perspectives provide a more holistic understanding of how environmental degradation affects families beyond its ecological consequences.

Finally, conducting this research deepened my own understanding of the complexity of illegal mining in Ghana. Before this study, I primarily viewed *galamsey* as an environmental and regulatory challenge. However, listening to the Donkor family's experiences revealed that it is equally a story of resilience, survival, and constrained choices. The interview reinforced that environmental restoration cannot be separated from poverty reduction, livelihood development, and community empowerment. By integrating academic literature, lived experience, and personal reflection, this study contributes a more human-centered perspective to ongoing discussions about sustainable development and environmental governance in Ghana.

Final Reflection

Conducting this research changed my understanding of illegal mining in several important ways. Before beginning the study, I primarily viewed galamsey as an environmental and regulatory problem. However, interviewing the Donkor family revealed that environmental degradation cannot be separated from household survival, caregiving, and economic opportunity.

The interview also challenged my assumptions about resilience. I expected participants to focus primarily on environmental destruction. Instead, they emphasized adaptation, perseverance, and their determination to continue providing for their families despite increasingly difficult circumstances. Their experiences demonstrated that resilience often involves difficult compromises rather than simple solutions.

Perhaps the most unexpected finding was the tension between environmental protection and economic survival. Learning that Kwame entered illegal mining after his father's farming livelihood had been affected by mining illustrated the complex reality facing many households. This finding reinforced that sustainable solutions must address environmental restoration and economic opportunity simultaneously.

Finally, this research strengthened my commitment to environmental justice. As a Ghanaian researcher, I recognize that these challenges are not abstract policy issues but lived realities affecting families across the country. Listening to participants' stories reminded me that behind every environmental statistic is the household adapting, sacrificing, and hoping for a better future.

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THE CLOUD IS NOT CLEAN

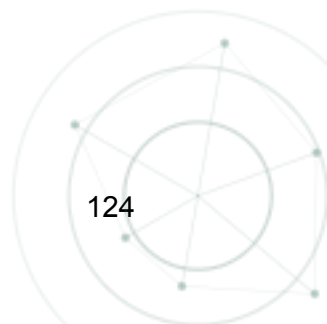
Building Sustainable AI Literacy at Work

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MESH Capstone Project

University of San Diego

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Introduction

AI is being adopted faster than many non-technical workplace users can understand it. Employees outside engineering, data science, and AI research are increasingly being asked, and sometimes required, to use powerful AI systems without first receiving enough education about how those systems work. We are asking individuals to design, build, and fly without so much as a single flight simulator session.

AI is no longer just about writing emails more efficiently or helping complete that spreadsheet. It is being developed into systems that are shaping how people think and make decisions, and even influencing policies. The voices heard in the development and deployment of these systems are few and far between. While many of us are being asked or even told that we must use AI or fall behind, we are not a part of the conversation of how it is being built, to what purpose, and who truly benefits from it. If AI is going to influence our future in such profound ways, we need more voices to be present in how it is built, questioned, and governed.

To most non-technical users, software and AI feel abstract and clean because digital interfaces hide the physical infrastructure required to deliver the service. That physical infrastructure, including data centers, electricity, cooling systems, cloud regions, chips, servers, and e-waste, remains mostly unknown to non-technical users. As [Monserrate \(2022\)](#) mentions, “That so many laypeople struggle to specify what the cloud is speaks to the dazzling success of Big Tech’s marketing, but also its careful obfuscation of the cloud’s material residues.” The invisibility of AI is the problem my capstone project is focused on. If people do not understand that AI has real costs, they cannot make informed choices about how or when to use it.

The use of AI has costs that are largely unknown to the people interacting with it. When an employee enters a prompt, the interface does not show the electricity used by the data center, the water required for cooling, or the eventual electronic waste associated with that infrastructure.

These impacts differ from those in software development generally. Writing or running conventional code does not automatically involve generative AI. My project focuses specifically on helping non-technical employees connect everyday AI use to the physical systems and resources that make it possible. Making those systems more visible is an important step toward helping employees ask better questions about when AI is useful, when it may be wasteful, and what responsible use could look like.

My core research question is: Can exposure to AI infrastructure, efficiency, and sustainability concepts inside a corporate AI enablement program change how non-technical employees understand and use AI? My project seeks to determine whether an AI literacy program can create shifts in behavior, awareness of efficiency, and understanding of costs and carbon among employees who are not engineers, data scientists, or sustainability specialists. This question matters because AI is being adopted across workplaces faster than most employees can realistically understand it. Many corporate employees are being encouraged, and many times forced, to use AI to work faster and automate more tasks. Although there is a push to adopt AI at breakneck speeds, employees are often not taught what AI systems require behind the scenes.

My capstone will be a baseline and early-learning study, not a full test of the entire program. The full AI Design Labs program runs for twelve weeks, but the capstone data I can realistically analyze will focus on the early portion of the program. The first several weeks are not separate from the program's sustainability focus. Participants are introduced to ideas about AI efficiency, infrastructure, carbon costs, usage habits, and GreenOps through weekly meetings, emails, Slack messages, and program communications. However, the early portion of the program is still primarily focused on confidence-building, problem selection, and initial experimentation.

Getting to where participants more fully connect everyday AI use to compute, infrastructure, and its environmental impact, develops over time. It isn't one single, "aha" moment where they'll suddenly connect all of the dots. Because of that, I cannot honestly claim that the early data proves whether sustainability education changed their behavior. What I can study at this stage is whether participants enter the program with limited AI infrastructure understanding, whether their confidence and hesitation begin to shift week over week, and whether early exposure to GreenOps language creates increased awareness of software's downstream impacts. This is consistent with pilot and feasibility research. Similar research often surfaces early patterns to help refine the longer-term intervention. [Teresi et al. \(2022\)](#) explain that "pilot studies test the feasibility of methods and procedures to be used in larger-scale studies" and that "most pilot studies should not be used to estimate effect sizes, provide power calculations for statistical tests, or perform exploratory analyses of efficacy." This supports my decision to treat my early capstone data as a baseline and evidence of the effect of early learning, rather than as a claim of the efficacy of the full program.

Although the literature I reviewed provides a strong foundation, it also reveals a gap. A gap that I can hopefully help to fill. There is a growing body of research on AI's environmental impact, Green AI, e-waste, data center energy use, and environmental justice. There is also some research on AI literacy and workplace behavior change. The gap that I hope to bridge exists between those two areas. My literature review is grouped into three main areas: AI for Sustainability, Sustainable AI, and AI Literacy and Education. The first section looks at how AI can support sustainability goals. The second section looks at the environmental costs of AI itself. The third section connects most directly to my capstone. It focuses on whether education and visibility can change how people understand and use AI.

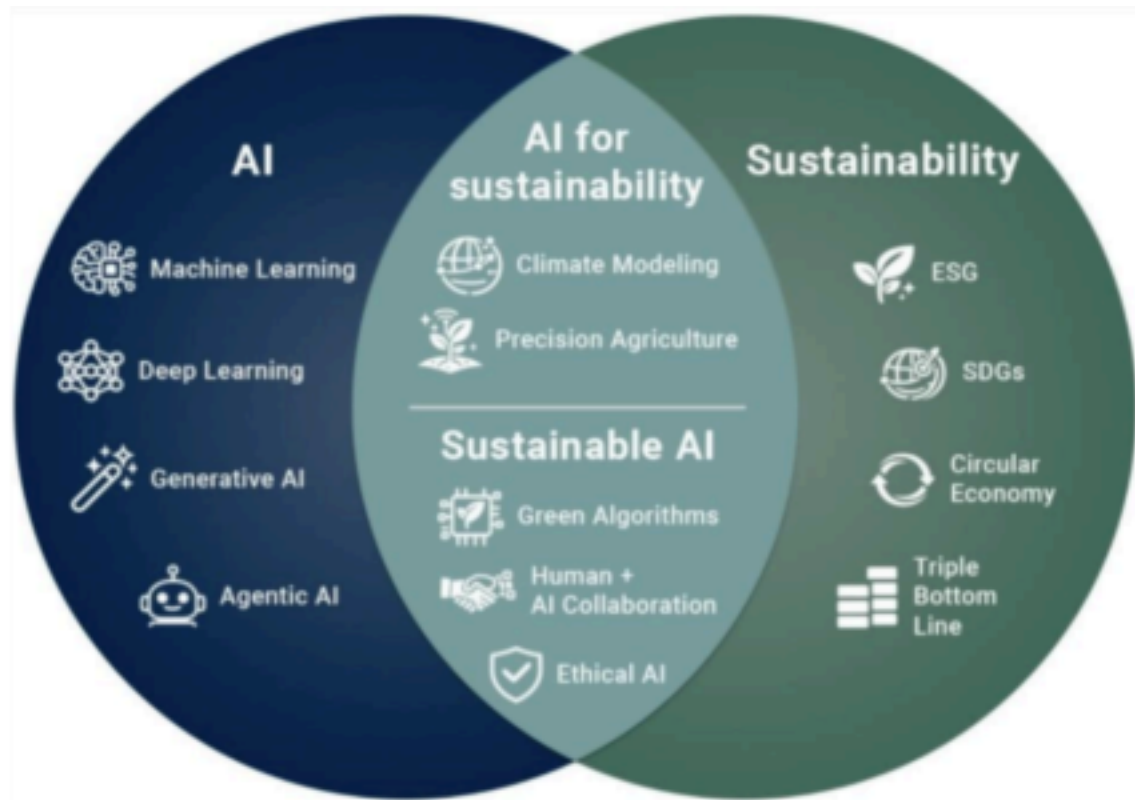


Figure 1. Relationship Between AI for Sustainability and Sustainable AI. AI for sustainability refers to the use of AI to support environmental or social sustainability goals, while Sustainable AI focuses on reducing the environmental, social, and ethical impacts of AI systems themselves. The overlap highlights how AI can simultaneously contribute to sustainability solutions while creating new sustainability challenges.

Purpose Statement

This project examines whether exposure to AI infrastructure, efficiency, and sustainability concepts inside a corporate AI enablement program can change how non-technical employees understand and use AI. It focuses on early changes in participants' awareness, confidence, uncertainty, and descriptions of efficient AI use. Because the data was collected during the early portion of a twelve-week pilot, the project identifies preliminary patterns rather than proving lasting behavior change or program efficacy.

Background

AI for Sustainability

A good place for us to start is the AI sustainability paradox. AI is both assisting sustainability efforts while simultaneously becoming one of the fastest-growing contributors to resource use, material extraction, waste, and energy demand, with global data-center electricity consumption increasing by about 12% per year since 2017, more than four times faster than total electricity consumption (International Energy Agency, 2025).

There are real benefits to using AI for sustainability. For example, AI-powered weather forecasting models can provide accurate, localized forecasts at much lower computational cost than traditional physics-based models, which may help farmers make better decisions about planting, fertilizer use, drought risk, and climate adaptation ([Jina & Winters, 2025](#)).

[Chouksey et al. \(2025\)](#) describe this as the “AI environmental sustainability paradox,” where AI can contribute to environmental improvements while also creating new environmental harm. This paradox matters because it keeps my project from becoming anti-AI or pro-AI. The challenge is finding the balance. The literature makes it clear that AI can help sustainability in meaningful and vast ways, ranging from climate forecasting to precision agriculture and even biodiversity monitoring. At the same time, [Chouksey et al. \(2025\)](#) argue that AI’s environmental impact is tied to “electricity, fresh water, limited supply of minerals, and depletion of electronic hardware.” It helps frame how the value of AI for sustainability cannot be judged only by its downstream benefits. AI may help organizations identify waste and optimize systems faster than humans could on their own. The irony is identifying waste while simultaneously creating it. AI can absolutely be a sustainability tool, but only if its own infrastructure, energy use, hardware lifecycle, and effects are managed responsibly.

The benefits of AI do not automatically erase its costs. For example, an AI system may help reduce agricultural water use or improve building efficiency, but its overall value also depends on the energy, water, hardware, and emissions required to develop and operate the model itself. The same system may produce a net benefit when used for a high-value task and unnecessary impacts when deployed repeatedly for low-value work. AI cannot be separated from the systems that shaped its design and use. Asking if AI is good or bad often fails to ask how AI is used, by whom, for what purpose, at what scale, and with what awareness.

AI requires vast amounts of energy to operate at scale. One way AI is paradoxically helping sustainability is through smart grid management. A smart grid uses technology, often AI, to match electricity supply with demand, respond to outages, and manage power from sources like wind and solar. [Ahmadi et al. \(2026\)](#) explain that AI can support real-time energy monitoring, optimization, demand response, fault detection, and the integration of renewable energy into power systems. Their review argues that AI-based smart grid tools can improve “stability, efficiency, and resilience,” especially as energy systems become more complex and renewable energy sources become more common ([Ahmadi et al., 2026](#)). This is important because it highlights that AI is not only a challenge to the environment but can also help make energy systems more adaptive, efficient, and reliable. At the same time, the review highlights implementation challenges, including computational complexity, scalability, explainability, and real-world deployment barriers. The value of AI as a tool for sustainability is hard to quantify, but it is a question we need to be asking. Sustainability needs to be built into the core of AI architectures, or else we risk creating a system that tries to solve its own problems as it creates more.

This connects directly to my project. Many corporate AI programs focus on productivity, speed, and innovation. Employees are being encouraged to use AI to save time, create content,

analyze information, and automate tasks. However, what we see when emails get more efficient is, well, more emails. Longer and more useless emails. In a comparative study of AI-generated business emails, [Jovic and Mnasri \(2024\)](#) found that LLM-generated emails often performed well in clarity, grammar, and politeness, but struggled with conciseness, structure, and word count control. While those faster emails or spreadsheets may seem free to the average user, it still depends on data centers, electricity, water, hardware, and model infrastructure.

Sustainable AI

Instead of asking how AI can solve environmental problems, Sustainable AI asks how AI can be developed and used in ways that benefit people and the planet while recognizing its potential for downstream harm. This includes electricity demand, water use, carbon emissions, hardware production, e-waste, model efficiency, and transparency. These impacts don't stay siloed in data centers. They show up as community land use, water stress, energy infrastructure, pollution exposure, and unequal distribution of environmental burdens. The IEA notes that data centers accounted for ~1.5% of global electricity consumption in 2024, or 415 TWh, and are projected to more than double to roughly 945 TWh by 2030; AI is identified as the most important driver of that growth alongside other digital services ([International Energy Agency \[IEA\], 2025](#)). Although this remains a relatively small share of global electricity consumption, data centers are concentrated in particular locations and require large amounts of continuous power. This in turn creates much greater pressure on some local electric grids, water systems, and surrounding communities (IEA, 2025; U.S. Department of Energy [DOE], 2024). [Walker and Goldsmith \(2026\)](#) explain that this growth is already reshaping local energy grids, water systems, and land use, with direct consequences for community well-being. They also note that many new facilities are being built in water-stressed areas and may rely on gas-fired generation or diesel

backup generators that contribute to climate and health risks.

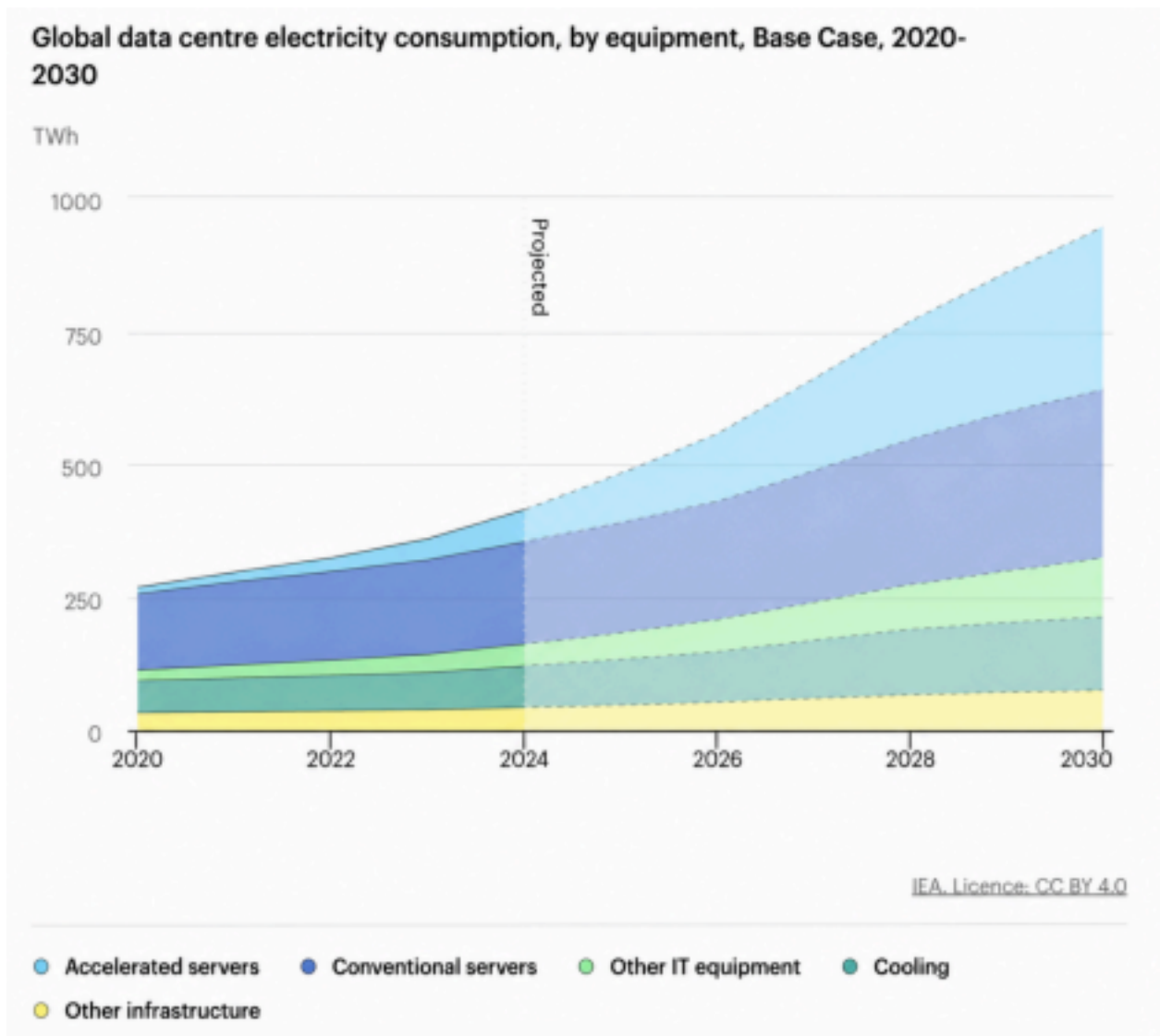


Figure 2. Projected Growth in Global Data Center Electricity Consumption, 2020–2030. Global data-center electricity consumption is projected to more than double between 2024 and 2030, with accelerated servers associated with AI representing an important source of growth. Adapted from the International Energy Agency (2025).

A major challenge in building sustainable AI systems and architecture is transparency. Model developers, cloud providers, and data center operators do not consistently disclose the information needed to evaluate the environmental impacts of AI systems. As Luccioni et al. (2025) explain, “there exists minimal and often no data quantifying these impacts,” and the information that is available often lacks the “accessibility, detail and scope” required for meaningful analysis. The IEA makes this problem clear, stating how “There is also a lack of transparency regarding the size and implementation of most user-facing commercial AI models, which makes it impossible to measure their compute requirements and ensuing energy demands” ([International Energy Agency \[IEA\], 2025](#)). This issue then grows beyond a technical one into a political and governance challenge. If the organizations building and deploying AI systems do not disclose enough information, then users, researchers, businesses, and policymakers are left working with estimates, proxies, and partial information. In my experience working for a large SaaS company, good-faith efforts to measure daily software usage became hand-wavy math because of this data-quality issue.

Sustainable AI is much more than writing better prompts or improving a data center’s PUE (Power Usage Effectiveness). It’s about making the full system visible: the energy, water, hardware, emissions, communities, governance gaps, and everyday user behaviors behind the tools people now use casually at scale. The literature makes clear that AI’s environmental impact is not only a technical issue. These issues extend beyond engineers, hyperscalers, or policymakers. It is a literacy issue. If employees are being asked to use AI more often, they also need a basic understanding of its costs. Not simply the financial cost of the license their employer pays, or their Pro subscriptions to their LLM of choice, but the real costs. This is where my project narrows in from the broader Sustainable AI/AI for sustainability conversation into AI literacy and education. The gap is not only that AI has hidden impacts, but also that most

non-technical users have very little education to help them see, question, or change those impacts in their own lives and work.



Figure 3. Barriers to Open and Sustainable AI. The figure organizes barriers to sustainable AI around three principles: reusability, reproducibility, and sustainability. It demonstrates that responsible AI depends not only on environmental reporting but also on accessible models, documentation, licensing, datasets, code, and reproducible research practices.

AI Literacy and Education

You don't need to know the horsepower of your car's engine to be a good driver.

However, you do need some basic driving skills. This is the gap in today's literature and work settings regarding AI. My capstone is not a technical audit of AI infrastructure; it is an applied education project that asks whether exposure to AI infrastructure, efficiency, and sustainability education can change how non-technical employees use AI and understand its costs and impacts. The AI literacy literature shows that many workers and professionals recognize AI's importance

yet lack confidence, hands-on experience, and a deeper understanding of its ethical and social implications. For example, a survey of 760 academic library employees found that participants recognized AI's potential benefits, but reported only modest understanding of AI concepts and gaps in discussing ethical implications ([Lo, 2024](#)). This is a close match to my project, as the participants in my AI Design Labs are not engineers, data scientists, or AI researchers. They are employees being asked to learn AI while still needing to do their day jobs.

This is important because corporate AI adoption often assumes a level of readiness that may not exist. Many organizations seem to be acting as if AI literacy will naturally appear through usage. Organizations should not assume that AI literacy will happen organically, and there lies a risk when implementing AI tools without appropriate training because it can lead to inefficient and unethical practices that together can contribute to a catastrophic failure. [Long and Magerko \(2020\)](#) define AI literacy as a set of competencies that allow people to critically evaluate AI technologies and use AI effectively in everyday life and work. That is an important distinction as it highlights that AI literacy is more than understanding prompt engineering. AI literacy means starting with human-centric approaches at the core of system architectures. The result is the ability to engage in critical evaluation, develop ethical and legal awareness, and use AI responsibly, so that individuals become “responsible and informed users and creators of generative AI” ([Annapureddy et al., 2025](#)).

Wait, What About Governance?

Through my preliminary research and program planning, I found that governance was a key factor in understanding the relationship between AI literacy and sustainability. This led me to question how employees and organizations were approaching AI use without clear structures for oversight, accountability, and risk management. In this context, AI governance refers to the

policies, roles, review processes, documentation, and accountability mechanisms that guide the selection, development, deployment, monitoring, and correction of AI systems. The NIST AI Risk Management Framework organizes this work around four functions: govern, map, measure, and manage. The framework emphasizes that responsible AI requires clearly assigned roles and accountability across an organization (National Institute of Standards and Technology, 2023).

While in the thick of my project work, I realized that my project was requiring me to learn something beyond what I knew about AI literacy and sustainability: Governance. The lack of which was staggering to say the least. Through learning on my own, asking questions, and networking, I started to notice how much AI activity was happening without a clear governance structure. While AI tools, workflows, and agents are being adopted rapidly, the oversight and review processes have not been able to keep up. My questioning and networking have led me into a de facto human-in-the-loop governance layer. I am not sure I have the requisite skill set for the role.

While I love to get bullet points for my resume like, “created and implemented a standardized AI Governance framework...” It’s concerning that it wasn’t already established and that it is such an immature practice internally. Governance is a very serious matter, especially when it impacts job seekers and employers. NIST describes governance as a “continual and intrinsic requirement” for effective AI risk management because it establishes the accountability structures, roles, policies, and oversight needed to manage risks throughout an AI system’s lifecycle. [\(NIST, 2023\)](#).

It is the structure that decides who is accountable, what gets reviewed, what risks are acceptable, and what happens when something goes wrong. As NIST states, “Without proper controls, AI systems can amplify, perpetuate, or exacerbate inequitable or undesirable outcomes for individuals and communities.” [\(NIST, 2023\)](#). The issue I am seeing is that, like with

sustainability, we are oftentimes trying to play catch-up. Instead of waiting for the drought to happen before we think about water, we need to build systems to embed Governance and sustainability from the start. Clear frameworks around the benefits to people and the planet should shape the entire lifecycle. Without that structure, it is unclear who owns risk, who approves use cases, who checks for bias, and who is ultimately responsible.

The risks are particularly significant in a workplace where AI systems may influence employment-related decisions. These systems can shape workflows, prioritize information, recommend actions, and affect how job seekers, employers, or employees are evaluated. The people building these systems bring their own assumptions, incentives, and priorities into the design process. The data itself is not neutral because humans decide how AI systems are designed, what information they use, and which outcomes are optimized. In employment settings, AI systems may be trained on resumes, employee records, performance data, or an organization's previous hiring decisions. If those records reflect earlier discrimination or unequal access to employment, the system may learn and reproduce those patterns. As Kim (2023) explains, "The employer doesn't have to explicitly state a discriminatory preference. The software might simply learn those preferences by observing its past hiring decisions." Removing protected characteristics is not necessarily enough to prevent this outcome because "an AI tool can exclude workers by relying on proxy variables."

It is through this project that I have realized that AI literacy must include governance literacy at its core. If an AI-assisted employment system consistently ranks candidates from one racial, ethnic, gender, disability, age, or socioeconomic group lower than otherwise comparable candidates, responsibility cannot be assigned to the system itself. Who is responsible? Is it the developer who created the model, the SaaS company that deployed it for matching candidates, or the recruiter who made the decision to say "no" to the candidate? Not knowing isn't a sufficient

answer, and we must have accountability for systems with such profound impacts. MIT Sloan describes mature AI ethics as a movement from talking about ethics to building policies, documentation, review processes, and action into everyday work ([Burnham, 2025](#)). That is why governance belongs in this project. Before people can change how they use AI, they need a framework with clear rules, clear ownership, and a better understanding of what they are actually using.

Visibility to Behavior Change

My research addresses gaps between AI literacy and sustainability by increasing awareness surrounding the invisible costs of AI use and tracking participant responses as they engage more deeply with AI. Although this project does not fully explore the relationship between visibility and behavior change, [Kollmuss and Agyeman \(2002\)](#) note that “in most cases, increases in knowledge and awareness did not lead to pro-environmental behavior.” Despite these limitations, increased visibility has the potential to foster an environment in which behavior can shift as new information is learned. There is a meaningful difference between being told that AI has environmental consequences and seeing a real-time measure of the water, electricity, or financial resources associated with its use.

The FinOps Foundation argues that ownership becomes meaningful only when the costs of cloud resources are made clear to the people using them, and that real-time cost visibility can encourage the “Prius effect,” in which “real-time awareness of consumption prompts immediate remedial action” ([FinOps Foundation, n.d.](#)). The point is not to teach every participant the full technical architecture behind AI and hope they change how they interact with tools. The point is to make the impact of otherwise invisible usage visible enough that people can adjust their behavior in the moment.

This is why AI literacy is critically important. The literature suggests that people do not automatically become responsible or efficient AI users simply because they have access to tools. Awareness alone may not change behavior. However, visibility, feedback loops, and practical, hands-on education can create conditions in which people make better choices in the moment. My project does not attempt to solve AI's environmental footprint. Instead, it asks: Can exposure to AI infrastructure, efficiency, and sustainability concepts inside a corporate AI enablement program change how non-technical employees understand and use AI? By bringing Sustainable AI, AI for Sustainability, and AI literacy together in a real workplace setting, this project tests whether making AI's true costs easier to see and understand changes how individuals use it, how confident they feel using it, and how much they understand its broad impacts. If my seltzer requires a facts label on the back of the can, so should my AI!

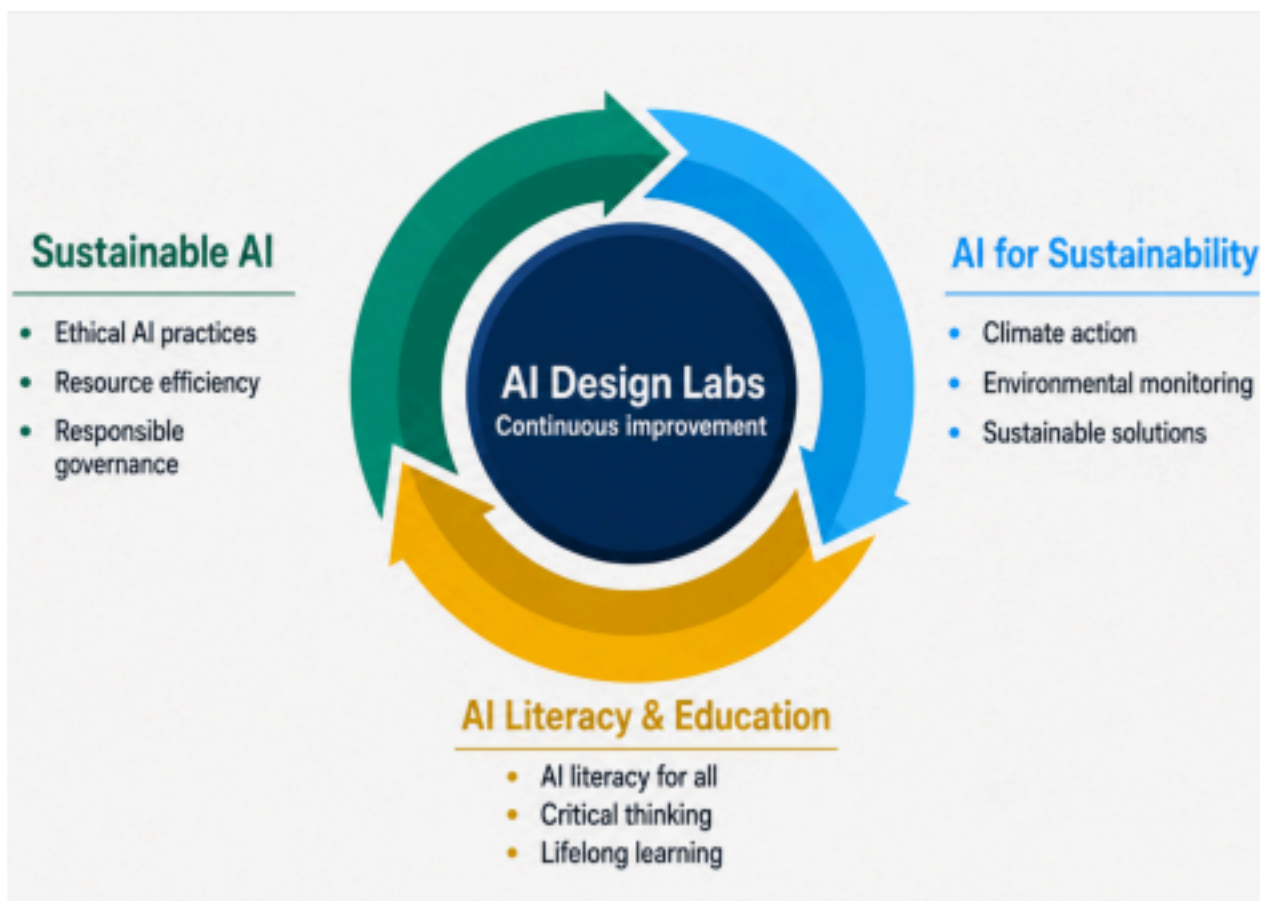


Figure 4. AI Design Labs Framework. Design Labs sits at the intersection of Sustainable AI, AI for Sustainability, and AI literacy and education. The framework connects governance, efficiency, and practical learning inside a workplace AI enablement program.

Positionality

My research question: Can exposure to AI infrastructure, efficiency, and sustainability concepts inside a corporate AI enablement program change how non-technical employees understand and use AI?

My mom loves to tell everyone how I would make my older sister watch *The Wizard of Oz* every single day, for about a year, when I was a kid. So you can imagine my horror when I considered the possibility that my thesis could be seen as a “straw man”. The straw man would be to say that companies think AI is a magic panacea or that employees do not care about the environment. I do not think either of those things tells the entire story or is fully true. The stronger argument against my project is this: maybe non-technical employees are not the right place to intervene. Maybe asking everyday workers to understand AI infrastructure, carbon, compute, and governance places too much responsibility on a small group of people who lack the power to make meaningful changes in the space.

The biggest decisions shaping AI’s environmental impact are not made by an employee writing a better prompt. The deep impacts are being made by model developers, cloud providers, executives, and policymakers. These groups are deciding which models to build, where data centers are located, how much electricity and water to use, what to disclose, and which risks they deem acceptable. [Cuéllar et al. \(2024\)](#) make this point, highlighting that “widely-used technologies in market economies (e.g., cars and semiconductor chips), commercial interest tends to be the predominant guiding factor.” If commercial interests are driving the AI train, it begs the question: Is my intervention, teaching individual employees about AI efficiency, too small to be meaningful? Should the work then only focus on governance, regulation, transparency, and

accountability?

So, as an individual with seemingly no influence, should I just throw in the towel? How do we become a part of the solution if we don't have a seat at the table? Reskilling literature argues that “employees must continuously update their skills to remain competitive” in AI-driven workplaces ([Lai et al., 2025](#)). This supports my Design Labs work towards AI literacy while shedding light on the immense pressure many employees are under. If workers are told to adopt AI quickly to stay relevant, then awareness of environmental impacts or carbon emissions may not be enough to slow overuse. My project won't solve AI's environmental footprint, it cannot force hyperscalers to disclose better data, and it isn't going to create full governance across the entire AI supply chain. In the first few weeks, Design Labs won't be able to definitively prove that education changed behavior. This project cannot provide a complete solution to these structural challenges, but it takes a step toward understanding how workplace AI literacy can help employees recognize them, ask better questions, and participate more meaningfully in governance.

Methods

AI Design Labs V2 is a 12-week workplace AI literacy and experimentation program for non-technical employees. Participants were recruited internally through a voluntary application process. To be included, participants needed to be current employees interested in developing their AI knowledge and testing AI within practical workplace use cases. Approximately 30 employees were enrolled across Sales, Customer Service, Training and Development, and Operations. Participants represented different roles, markets, and levels of prior AI experience. All participants volunteered to join the program, and participation had no bearing on their job performance. Of the 30 enrolled participants, 27 completed the baseline survey. By the

early-program survey, 23 participants responded. During the first four weeks, attendance varied as anticipated due to both planned and unplanned time off.

The program lasted 12 weeks and combined live sessions, Slack communication, Google Workspace, Jira, internal AI tools, surveys, project tracking, and participant reflections. The first weeks focused on building comfort, establishing shared AI language, selecting problems, and beginning experimentation. Later weeks focus more directly on applied projects, efficiency, and GreenOps concepts.

The project takes place over a 12-week program that includes a pre-program setup period before launch. The pre-program phase included building a Google Drive repository, creating application forms, setting up a Jira KanBan board, scheduling n8n workflows to automate Slack messages and reminders, building surveys, drafting communications, and preparing the GreenOps tracking tools. Because this program is fully voluntary, I needed to be flexible with my timeline. Participants may take PTO, they may find a new role, or decide they no longer find it valuable. Having dealt with this variability in my first attempt, I built in risk mitigations, such as a warm bench of participants who were not originally selected and can jump in.

Weeks 1 and 2 focused on comfort, kickoff, and problem selection. Weeks 3 through 5 focused on AI exploration, access to tools, and early experimentation. Week 5 included a short “efficiency moment” where the cohort began connecting AI use to compute, cost, and infrastructure. Weeks 6 through 9 are the main experimentation phase. Week 8 includes the mid-program survey. Weeks 10 and 11 focus on reflection, sharebacks, and showcase preparation. Week 12 is the final showcase, final survey, and outcome.

AI Design Labs V2 is a 12-week AI literacy and experimentation program. Participants learn basic AI concepts, explore tools, work in small teams, and then attempt to select or refine a real business problem. The program is not designed as a certification, product build, or technical

bootcamp. It is a structured sandbox experience meant to build awareness and help employees use AI more thoughtfully.

The project takes place inside my workplace. The project uses existing internal tools and workflows. The program itself runs through a combination of live sessions, Slack communication, Google Workspace, Jira, and internal AI tools. If AI is going to become part of everyday work, then everyday workers need some level of literacy about what AI is, how it functions, and what it costs.

My goal is to meet people where they are. My corporate AI Design Lab is a real-world AI literacy and education program for roughly 30 non-technical employees. It focuses on practical AI use, confidence-building, experimentation, and workflow improvement.

This project is for non-technical employees participating in an AI Design Labs V2, an AI literacy and experimentation program. The cohort includes about 30 employees from different roles, markets, and backgrounds. All participants are volunteers who are not engineers, data scientists, or AI researchers. They are regular corporate employees, like many workers right now, being asked to learn how to use AI in a practical way.

AI is being adopted across workplaces faster than most employees can keep up with. In many corporate settings, employees are encouraged to use AI tools to work faster, automate tasks, and improve productivity, but they are rarely taught the how or why. Furthermore, they are almost certainly not being told what those tools actually require behind the scenes. Monahan and Burlacu found that “nearly half (47%) of employees using AI say they have no idea how to achieve the productivity gains their employers expect.” ([Monahan, K., & Burlacu, G., 2024](#)).

This project is happening because AI adoption is outpacing AI literacy. Many employees are being told to use AI, but they are not always given enough information to understand the systems they are using. “The single biggest factor shaping how employees felt about AI...was

their level of AI literacy” ([SAP, 2025](#)). This leads to many issues. People may overuse tools because they feel pressured to use AI for everything, without understanding the downstream impacts of their technology use. They may use AI inefficiently because they do not understand how prompts, retries, model selection, and workflow design affect cost and computation.

At the same time, I do not think the answer is to turn an AI Design Lab training program into a sustainability training as well. Most people are already overwhelmed by AI and sustainability, separately. Asking them to care about carbon emissions before they understand the basics won't work.

Methods and Ethics

Preliminary research and program development have included project design, internal planning, literature review, program documentation, feedback loops, and the creation of data-collection tools. I designed the AI Design Labs program as a real workplace AI literacy initiative for volunteer participants across Sales, Customer Service, Training & Development, and Operations. As part of my program management, I created an RACI matrix, risk log, communication plan, Jira/Kanban workflow, participant tracker, lead tracker, baseline survey, and GreenOps measurement concepts. These have led to knowledge generated in several different forms. First, my project management skills have evolved and adapted. Trying to manage a project of this scale for volunteers while balancing school, kids, and my full-time day-to-day job has required many pivots and quick learning on the fly. Second, they have produced knowledge about what can and cannot realistically be measured in a program like this in the time frame of a capstone. Lastly, this process has helped me understand and frame my positionality. Managing my closeness to the program and the balancing act of bias has been a fun journey.

I used a mixed-methods approach. The quantitative side includes baseline, midpoint, and final surveys. My primary outcome is a change in participant awareness of AI cost, compute, and infrastructure. Secondary outcomes include confidence, hesitation, logged experiments, attempts required to produce a useful output, and self-reported changes in AI use. The qualitative side includes participant reflections, exit responses, group lead observations, and my own project notes. This is important because the project is not only about a number. It is about how participants begin to connect their learning of AI use to the larger system behind it. Ideally, participants begin asking better questions about when AI is useful, when it is wasteful, and what kind of work deserves AI support.

I am not only trying to measure a number. Some aspects of my project are quantitative, while others are qualitative. The program includes pre-, mid-, and post-program surveys measuring AI confidence, AI hesitation, awareness of AI costs and efficiency, and self-reported behavior. I also track prompt efficiency, token usage, and proxy carbon emissions. There are also exit survey responses and group lead observations that will become core data points. The numbers can show whether confidence, hesitation, or behavior changed, but the qualitative responses and observations can help explain why changes occurred or why they did not ([Guetterman et al., 2015](#)). It is important that I acknowledge who the participants are and that they may have their own biases. An individual contributor in a sales function looking to make a career shift may be overly agreeable when asked for feedback. An employee who was laid off from their last company by “AI” would bring their own set of biases. I won’t be able to eliminate all bias; that is unrealistic, and attempting to do so would be unhelpful. I do, however, need to be open and honest about where I can expect it to show up and account for it when I can.

During the program, I collect research data through an embedded GreenOps layer. In this project, GreenOps refers to the practice of making the resource and environmental consequences

of technology use more visible so that users can make more efficient decisions. This approach reflects the Green Software Foundation’s principle that “what you can’t measure, you can’t improve” and its emphasis on measuring software impacts to support meaningful reductions (Green Software Foundation, 2026). The preliminary research tracks AI confidence, AI hesitation, prompt efficiency, self-reported behavior, and understanding of cost or efficiency concepts, along with estimated emissions. Some of this will be quantitative, like pre-, mid-, and post-program survey scores. Some of it will be qualitative, like exit survey responses and lead observations.

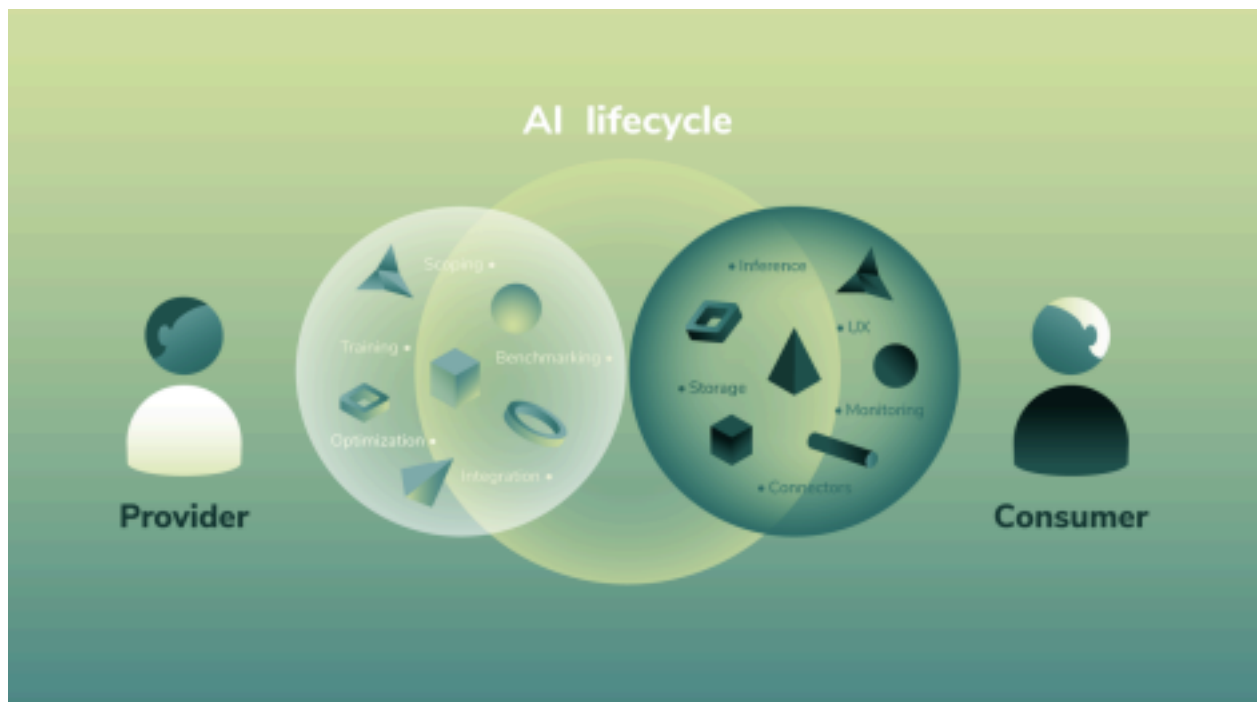


Figure 5. Provider and Consumer Boundaries Across the AI Lifecycle. The SCI for AI framework distinguishes between provider-side activities, including scoping, training, optimization, benchmarking, and integration, and consumer-side activities, including inference, user experience, storage, monitoring, and connectors. The framework demonstrates that AI’s environmental impacts extend beyond the visible user interaction and occur throughout the system lifecycle. Adapted from the Green Software Foundation (2026).

My method fits the research question because the project is about behavior and human

nature, not just metrics. A person might care about sustainability, but that does not necessarily mean their workflow changes; another person might become more efficient and use less energy without ever using the word sustainability or caring about being “green.” The interesting part of my project, one that is both exciting and challenging, is that it is not a “sustainability project.” The GreenOps layer is not presented as an environmental piece. The project’s focus is on education, efficiency, cost, and the intentional use of AI. My assumption is that this framing will be more effective for non-technical employees than asking them to care about carbon emissions from the beginning. This connects back to our coursework on community communication. Most people experience complex systems as “invisible and disjointed” and want clearer education about how those systems actually work ([Olson et al., 2019](#)). If participants do not understand what AI is and how it runs, asking them to care about its environmental impacts feels like expecting people to care about a problem they have never heard of.

I analyzed the early data through AI literacy, Sustainable AI, GreenOps, and workplace behavior change. One assumption I am making is that workplace behavior can be a valid form of knowledge. I am not only interested in whether participants can speak “AI” but also in whether they can define topics such as inference or carbon intensity. I am interested in whether what they learn meaningfully changes their understanding and approach to AI. Do they become more intentional? Do they use fewer unnecessary prompts? Are they better equipped to question AI policy decisions that impact their communities?

The project involves several supporting groups. I am serving as the project manager and researcher. I have two cohort leads who will support facilitation, small-group coaching, and weekly observations. Senior Leadership has remained informed with bi-weekly updates, while IT and Cloud Econ/Green Engineering have been consulted where needed for permissions, measurement, and sustainability-related guidance. The RACI structure is important because I am

not a neutral outsider. I designed the program, I am managing it, and I am also studying the results. That closeness creates bias risk, so role clarity, peer debriefing, and participant feedback loops are part of my research design.

My role and responsibility in this project need to be named directly. I am not an outside researcher. I designed the Design Labs program, I am managing the project, and I am also studying the results. That raises real concerns about conflict of interest. At the same time, I think it is important to be clear about the type of conflict of interest that exists in my work. This project is not tied to a promotion, sales quota, bonus, or direct financial gain for me. My day job is in sales. I do not work in AI research, sustainability consulting, or software engineering. I built Design Labs because I needed a real applied project for my capstone and because I believed non-technical employees need a better understanding of the AI they are interacting with at work. The program is also voluntary, and participants are not required to take part. It has no bearing on their job performance. While that does not completely remove the conflict of interest, it does drastically change the dynamic. The COI is not about financial benefit. The COI arises from the intellectual and professional closeness to the work. Since I created the program, I want the program to succeed, so I need to be careful not to view the results too favorably. Therefore, part of my project will include participatory research. [Vaughn and Jacquez \(2020\)](#) define participatory research as research that uses “systematic inquiry in direct collaboration with those affected by the issue being studied for the purpose of action or change.” This is an important point for my project. I am not studying AI enablement and any ensuing move towards GreenOps from the outside.

At the same time, being close to the work does not automatically make a project invalid. [Bero and Grundy \(2016\)](#) argue that researchers cannot be separated from their interests or their social position. I am not going to pretend that I am completely neutral. To best address this, I was

honest and clear about my role, separated facilitation from research as best I could, used MESH peer and mentor debriefings, and gave participants a chance to explain or clarify their responses. Sustainability and our path towards a better future will be messy. My project, like the cloud, isn't perfectly clean either. This is exactly why this project excites me! Working through the messiness is how we learn to apply what we have learned in MESH across disciplines.

I also clearly have many limitations. I do not have a control group for comparison. I cannot cleanly separate the effect of sustainability education from general AI practice. Participants are volunteers with demanding day jobs; their effort and attention in the program can fluctuate widely from one week to the next. The emissions piece is a difficult one to pin down. Even the most technically sound organizations struggle to precisely quantify AI workloads. As [De Vries-Gao \(2026\)](#) explains, estimates of AI's environmental impact are "complicated by the fact that data center operators do not publicly disclose the required inputs" and that most environmental reports do not clearly distinguish between AI and non-AI workloads. This means that token counts or cost data during the program can serve as rough proxies, but they cannot produce a precise carbon footprint.

Since my capstone project is taking place within my company, the voices that will be most present are corporate voices. This includes my own voice as the project manager, program leads, internal stakeholders, and participants who opted into the AI learning program. While these perspectives are useful, they are limited. The voices in my project already work in SaaS and have access to some advanced AI tools and organizational support. Missing from the project are the voices of workers who may be comparatively disadvantaged by AI use and adoption. The voices not being heard may work for businesses with fewer resources or that are slow to adopt new technologies. This matters because workplace AI is not neutral. [Doellgast \(2025\)](#) argues that corporate deployment of AI can reflect existing workplace power dynamics and often prioritizes

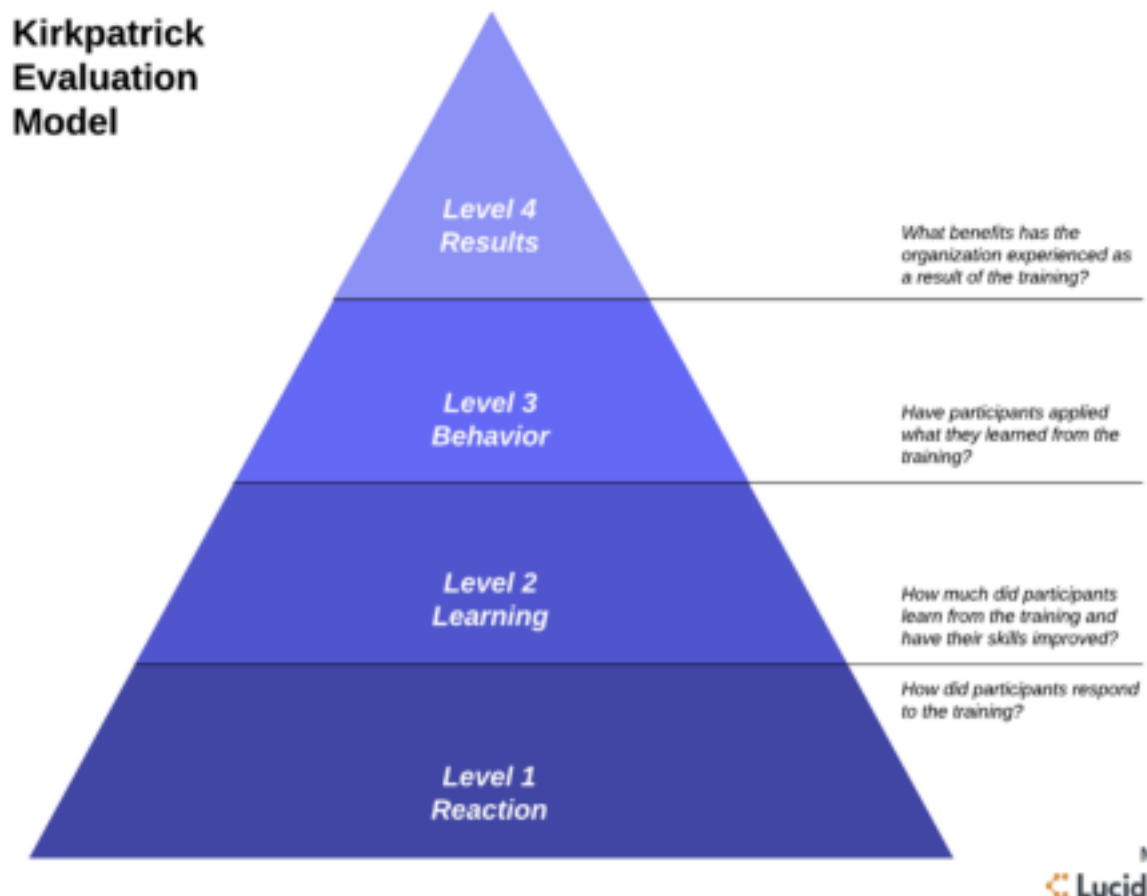
automation and short-term cost savings. Also missing are the individuals impacted across the AI supply chain, ranging from data center workers and local communities near energy infrastructure to environmental justice advocates.

Broadening my literature review to include sources that challenge the corporate AI adoption story will help me introduce more polyvocality. The way I frame my feedback and participation questions will also help. Instead of only asking whether AI helped people work faster or more efficiently, I can ask what work felt wasteful, uncomfortable, or ethically unclear, or what could be measured as such. [The World Resources Institute \(2026\)](#) notes that “a surge of new data centers is reshaping local energy grids, water systems and land use,” often happening with “limited public information about the long-term impacts.” This reinforces why my project should not only focus on corporate AI users but also consider the communities affected by the physical infrastructure that supports AI. My project won’t be able to answer everything. It can, however, help me start to ask better questions about how AI is being adopted in corporate settings, who has a voice, and who ends up paying.

While the results of this project were not load-bearing, they present a first look into how AI literacy can be approached in a workplace setting and lay the foundation for future research. Early results include survey responses, reflections, and early behavioral changes from participants. While those data points can help me begin to understand the program’s efficacy, they are limited. The results are from a few weeks ago; the cohort consists of volunteers who are being met where they are at the moment, and the feedback is based mostly on self-reported reflections and confidence. Measuring the carbon-equivalent output of experiments in the program is directional at best due to the multitude of difficulties in tracking AI use across workflows. Because of that, I cannot claim that the early results prove long-term behavior change. [Teresi et al. \(2022\)](#) support this kind of caution in pilot and feasibility research, where

early data is better used to understand feasibility, refine methods, and identify patterns than to prove full effectiveness.

The stronger result is the Design Labs framework itself. Design Labs was created as a structured workplace AI literacy model with a timeline, cohort roles, surveys, reflection points, weekly communication, project tracking, and a GreenOps layer built into the learning experience. This is an important distinction as [Salas et al. \(2012\)](#) explain that “training works” and that “the way training is designed, delivered, and implemented matters”. The goal was not to give non-technical employees access to AI and software tools. The structure of Design Labs was built to create a learning environment for employees coming from various backgrounds where they can practice, test real use cases, and ask better questions, allowing them to better connect everyday AI use to efficiency, cost, infrastructure, and sustainability.



***Figure 6. Kirkpatrick Evaluation Model.** The Kirkpatrick Model evaluates training across four levels: reaction, learning, behavior, and organizational results. Design Labs primarily measures Levels 1 and 2 at this stage.*

The program sits on four pillars: FinOps for AI, the Green Software Foundation's SCI specification, the NIST Risk Management Framework (RMF), and the Kirkpatrick Model of training evaluation. The Kirkpatrick model is important because the early Design Labs data can show whether participants found the program useful, whether their understanding of AI changed, and whether they began applying AI differently in real workflows. The data cannot yet prove long-term results. The FinOps layer provides a framework for discussing AI usage, costs, tokens, and business value. The Green Software Foundation's SCI for AI provides the project with a sustainability lens by connecting AI use to lifecycle measurement and carbon emissions. NIST AI RMF shows that responsible AI use requires organizations to govern, map, measure, and manage risk. Organizations cannot simply ask individual employees to make better choices on their own. Together, these four pillars make Design Labs more than the results of a one-off AI training program. They make it a reproducible workplace learning framework for non-technical employees that connects AI literacy to efficiency, sustainability, and governance.

Results

To understand the early results data from my project, I used the Kirkpatrick Model as the framework. The Kirkpatrick Model is a widely recognized framework for evaluating training effectiveness. It does so by measuring impact across four levels: participants' reactions to the training, what they learned, whether they applied that learning on the job, and the resulting organizational outcomes or return on investment ([Kirkpatrick Partners, n.d.](#)). This is a useful framework for this project because it is a pilot with an early-learning intervention. As [Teresi et al. \(2022\)](#) explain, pilot studies are better used to test feasibility, refine methods, and identify early

patterns than to make broad claims of efficacy.

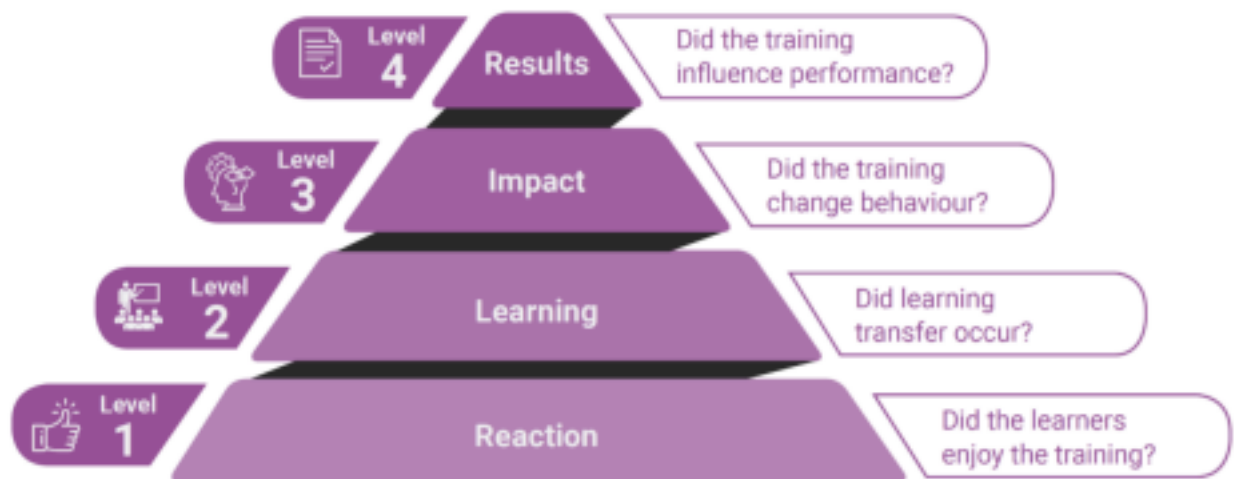


Figure 7. Applying the Kirkpatrick Model to Design Labs. The figure shows how training evaluation moves from whether participants enjoyed the program to whether learning changed behavior and produced measurable results. Because Design Labs is still in its early stages, the strongest evidence currently relates to participant reaction and learning.

Did learners enjoy the training? It is such a simple question that is often never considered. It is common to jump ahead and try to determine whether the training “worked” by interpreting its business value. If you think back to which classes you learned the most from, you would also most likely associate those courses with some level of enjoyment. [Mansfield \(2025\)](#) argues that enjoyment can have “a positive impact on multiple aspects of learning,” including deep-learning strategies, confidence, and long-term interest. Design Labs has been moderately useful and worth continuing, but not perfect. Participants rated the program’s usefulness at an average of 7.4 out of 10. This was slightly lower than I initially hoped, but it was consistent with a program that had spent its first four weeks establishing a shared foundation rather than delivering extensive hands-on experimentation. The written feedback also suggested that participants were not rejecting the program; they were asking for more applied practice, clearer structure, and additional opportunities to work directly with the tools. The qualitative responses help explain the number. Participants valued hearing how peers were applying AI in real workflows and seeing AI as something that could support more than basic writing tasks. One participant wrote

that “hearing how others apply AI to their individual workflows” helped expand their day-to-day output.

Several responses showed that participants still wanted more hands-on practice with specific tools, more troubleshooting, and clearer project structure. This is not unexpected at this early stage of the program. The feedback is valuable because it shows that the program is not simply being received as passive training. Participants are asking for more applied, workshop-style learning. This is exactly where the program is intended to move in weeks 5-10.

The first four weeks were designed to level set a group with varied AI experience, establish a common language, introduce shared expectations for experimentation, and begin layering in the GreenOps efficiency lens. For that reason, these early results should be interpreted with caution. The data shows promising engagement and useful direction, but it does not yet capture workshops, experiments, project work, and efficiency-focused activities that are scheduled for the coming weeks.

Through 4 weeks, was anything learned? Of the original 30 participants, 27 completed the baseline survey, and 23 completed the early survey, representing response rates of 90% and 76.6%. Average confidence remained exactly flat from baseline to early results, 6.6 out of 10. This could mean participants were developing a more realistic understanding of AI, but it could also mean that four weeks of the program did not increase confidence. The current data cannot distinguish between these interpretations. At first, I was disappointed. Then I remembered my own learning journey throughout MESH, and, as with my attempts at Arabic, Italian, and endurance running, the more you learn, the more you realize what you don't know. It is possible that confidence remaining flat does not mean participants failed to learn. As participants were introduced to AI infrastructure, costs, and responsible-use considerations, they may have become more aware of the subject's complexity and less likely to overestimate their own knowledge. At

the same time, the confidence question may have been too broad to capture more specific forms of learning, such as increased awareness of AI's resource demands. Because the current data cannot confirm either explanation, I will refine the later surveys to measure these areas more directly rather than treating my interpretation of the flat confidence result as fact. I will review and improve it in subsequent surveys rather than assuming my explanation for the flat result is correct. Awareness of AI infrastructure and financial costs increased from 6.4 to 8.0, while comfort with testing, adjusting, and improving prompts was high in the early results at 7.8 out of 10.

One result that stood out was that uncertainty and anxiety increased from 3.2 at baseline to 4.6 in the early results. On paper, that may look like a negative finding. In a corporate setting, especially one where senior leadership expects AI enablement to be tied to productivity, revenue, and change management, they would not want to see anxiety moving in the wrong direction. The increase may reflect uncertainty as participants recognize AI's complexity, but it may also indicate that the program introduced stress without yet providing enough tools to manage it. [Bohm et al. \(2024\)](#) explain that sustainability learning requires students to develop “metacognitive awareness and regulation of uncertainty.” As participants learn more about AI infrastructure, energy use, costs, and governance, they may feel less certain before ultimately becoming more capable.

Participant definitions of efficiency also became more specific. At baseline, efficiency was often described in general terms as saving time or working smarter. In the early results, participants began connecting efficiency to cost, energy, model choice, token usage, and avoiding waste. One participant described efficient AI use as “understanding the economy of AI usage in order to maximize output while minimizing cost and energy use.” Whether conscious or not, this suggests that sustainability and infrastructure concepts are beginning to enter participants’

working vocabulary. That said, using GreenOps terminology after four weeks of exposure does not necessarily demonstrate genuine understanding. A later activity will stress test whether participants can apply these concepts to new scenarios.

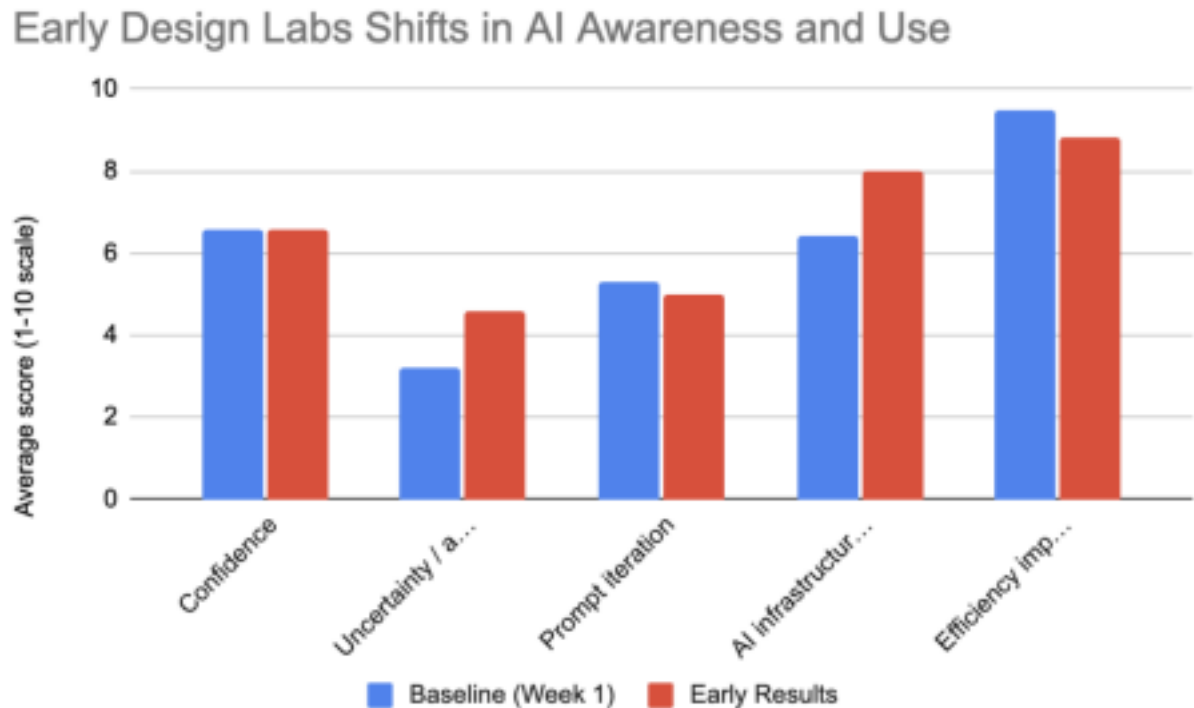


Figure 8. Early Design Labs Shifts in AI Awareness and Use. Early results show that confidence remained stable while awareness of AI infrastructure and financial costs increased. Uncertainty also increased, which may reflect participants developing a more realistic understanding of AI’s complexity.

As it is still only 4 weeks into the 12-week program, the early results do not prove that Design Labs has changed behavior or produced measurable organizational outcomes. Using the Kirkpatrick Model, these early results mostly show Levels 1 and 2: how participants are reacting, what they are starting to learn, and how awareness is changing. There are a few early signs of Level 3, especially when participants describe how they are learning to “streamline output without falling into AI rabbit holes via poor prompting, etc,” but it is too early to say those changes will last. Level 4 cannot yet be understood because real business impact takes more time and stronger evidence than I have at this point in the project.

What the data does show is that participants are engaged, they want more applied

practice, and they are beginning to describe AI efficiency in more specific and responsible ways. This aligns with recent AI literacy research, which argues that generative AI education should help people become “responsible and informed users” rather than simply faster users ([Annapureddy et al., 2024](#)). A successful AI enablement program should not focus solely on increasing adoption or “[tokenmaxxing](#)” (overusing unnecessary words, context, or prompts in AI tools in a way that wastes time, money, and energy). It should also help non-technical employees ask better questions, recognize tradeoffs, and make more intentionally informed decisions about when and how AI should be used.

Future Directions

My research question asks whether exposure to AI infrastructure, efficiency, and sustainability concepts inside a corporate AI enablement program could change how non-technical employees understand and use AI. The honest answer at this stage is: maybe. It is still too early to claim lasting change. Early results show that participants are engaged and that their awareness of AI infrastructure and financial costs increased. The strongest early evidence is a change in how participants describe AI efficiency. At baseline, participants generally described efficiency as saving time or working faster. In the early survey, they began using terms such as model choice, token usage, energy, cost, and waste. This shows a change in participants’ language and awareness, but it does not yet prove that they understand the concepts deeply or can apply them in practice. Because participants were introduced to this terminology during Design Labs, the change could reflect familiarity with the language rather than genuine learning. A later survey or activity will test whether participants can apply these ideas to a new situation that was not directly covered in the program. As [Teresi et al. \(2022\)](#) caution, “most pilot studies should not be used to estimate effect sizes...or perform exploratory analyses of efficacy.” This

supports treating early results as encouraging signs rather than as proof that the program was successful.

The lasting value of Design Labs lies in its framework. It demonstrates that AI literacy can be taught alongside efficiency, sustainability, and governance through practical workplace experimentation without expecting employees to become engineers or carbon accountants. The program was also designed to be reproducible and adaptable. Another organization could recruit a volunteer cohort, assign group leads, collect baseline data, conduct weekly learning sessions, ask participants to test AI against real workplace problems, and gather midpoint and final feedback. Consistent with design-based implementation research, future iterations should continue to use collaborative and iterative design to test whether the framework can be replicated and scaled without losing its purpose ([Penuel et al., 2011](#)).

The environmental, social, and political impacts of AI shouldn't fall on the shoulders of individual employees. The highest impact decisions still sit with hyperscale cloud providers, model developers, regulators, and policymakers. The NIST AI Risk Management Framework reinforces this point by stating that organizations should establish “appropriate accountability mechanisms, roles and responsibilities” ([National Institute of Standards and Technology, 2023](#)). Responsible AI, therefore, requires coordinated governance across people and organizations, rather than relying on individual employees to manage those impacts alone. While a program such as Design Labs cannot solve all of AI's challenges, it can help employees recognize them and make better decisions within their own work.

At the beginning of this capstone, I compared corporate AI adoption to asking people to design, build, and fly a plane without a single session in a flight simulator. Design Labs does not teach employees how to build the plane. It does, however, help them decide whether every trip really requires a flight. It gives them enough to question the destination, the cost, and whether

there is a better way to get there. Happy travels!

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The Limbo of Landfills

Kristen Werner

Abstract

This article investigates the ongoing conflict surrounding the pending closure of Seneca Meadows landfill in Seneca Falls, New York. It explores the ways that landfilling is perceived by nearby residents, and looks at the interconnected social, political and economic factors that influence waste management in rural New York. While landfilling is the most common form of garbage disposal in the U.S., this article will examine the associated impacts and argue that landfills should be a last resort for waste management. The article also discusses the role that money plays in maintaining landfilling practices that ultimately harm people and the environment. Experts agree that following Zero Waste techniques can drastically lessen the harm of landfills, but there are significant barriers to implementing them on a wide scale. These barriers are especially steep for rural areas like Seneca Falls, where the landfill's operations and tax payments provide the county government with most of its budget. This study highlights the structural and administrative challenges that prevent implementing Zero Waste techniques, while arguing that these methods are necessary to improve the impact of landfills on communities and the environment.

Introduction

During early autumn of 2024, the Sullivan County Department of Solid Waste received over 100 [emails](#) from residents concerned about the proposed construction of a waste incinerator in their small, rural New York town. The public comments mention worries about how the incinerator will release toxic and carcinogenic chemicals into the air, putting the public and environmental health in danger. In the summer of 2025, I became involved in this situation as a research intern, providing those opposed to the landfill with independent research about the pollutants released by incinerators and their detrimental health effects. This research was compiled into a fact sheet that was used in local legislation meetings during which comments on the incinerator were brought forward. While incinerators were once a popular method of waste management, their harms have become more well-known and no new incinerator site has been built in the

U.S. [since 1995](#). Why, then, was Sullivan County's local government considering constructing one of their own in 2024?

This rural town in the Catskills Mountains is currently facing a municipal waste crisis. Historically, the county sends its waste to the Seneca Meadows landfill, located in the picturesque town of Seneca Falls in the upstate Finger Lakes region. Seneca Meadows is New York's largest [landfill](#), accepting waste from all over the state, including a daily average of 1,500 tons from New York City. A New York Times article reported that, though the landfill has operated for decades, it has now reached capacity and its State permit expired in 2025. Sullivan County, faced with the closure of its sole waste repository, considered building a local landfill or incinerator as options in its Local Solid Waste Management [Plan](#). Having no final destination for waste is a big problem for Sullivan County, especially because of the annual influx of visitors who dramatically increase waste output. The Solid Waste Management Plan notes that during the summers, seasonal visitors and camp attendees can cause a population increase of 200,000-300,000 in a short time. 2021 data from the report shows a doubling of waste output during the summer months.

From the perspective of Sullivan County, it may seem like keeping Seneca Meadows open is a good thing. If it were to remain open, residents of Sullivan could continue sending their trash away without the need to build a local incinerator or new landfill. However, many people living in the adjacent town of Seneca Falls would disagree. Though [most trash](#) in the U.S. gets sent to landfills, evidence suggests that these facilities are a temporary solution to our [ever-growing](#) waste production problem. Over the past decade, dozens of [news stories](#) have been published detailing Seneca Falls residents' complaints of an inescapable foul smell from the landfill, as well as reported negative health effects from inhaling it, including headaches, nausea and throat irritation. The landfill is close to several schools, and parents have reported that their [children](#) have gotten sick at school from the polluted air and had to be taken home. Despite the fact that the landfill has reached capacity and is legally required to close, Seneca Meadows has applied for an [extension](#) to continue operating until 2040. They plan to extend the landfill's life by filling in a 47-acre valley within the site. The extension request, as well as several lawsuits filed against the landfill in response, are both currently [pending](#).



Seneca Meadows Landfill in 2023. Source: The New York Times

There are a variety of participants involved in this scenario with their own interests and motivations, from town residents, to waste management employees, to members of state and local governments. No one wants to be faced with a waste crisis. So then how did this situation become one? My paper will delve into the complicated web of social, political and economic factors that influence waste management in these areas of rural New York. In order to guide my research, I asked the following questions:

How do individuals in Sullivan County and Seneca Falls understand landfilling as a form of waste management?

What solutions could improve the local waste management landscape, and what challenges have kept them from being implemented?

Looking at the issue from this particular lens is important because waste management issues rarely form because there aren't better options; Rather, they represent a culmination of complex interactions between local laws and governments, residents of varying socioeconomic status, and external affiliated organizations. This research is important also because rural areas all over the country are facing similar issues as aging landfills reach capacity and close. The interconnected scenario involving Sullivan County and Seneca Falls is just one example among many that could benefit from a better understanding of how and why these issues develop.

Through my research, I wanted to better understand the full story of how this multifaceted problem developed. To do this, I chose sources from a variety of perspectives on the issue, from local residents' first-hand accounts to direct statements from Seneca Meadows landfill, as well as unaffiliated scientific and governmental organizations. Weaving together the various interests, motivations and actions of the entities involved in this scenario is crucial for understanding how this situation evolved.

Literature Review

To research this topic, I used mainly archival sources including news articles and technical reference data. News outlets local to upstate New York, including The Rochester Beacon and Finger Lakes 1, provided important information about the timeline and events of the ongoing landfill disputes in Seneca Falls. For scientific and technical data about landfill practices and environmental effects, I used academic research journals and resources from government organizations like the EPA. I also referenced the Seneca Meadows website to analyze how they presented their facility and its operations.

Waste & Environmental Justice

The residents of Seneca Falls are seeing their quality of life degraded by the Seneca Meadows landfill. Unfortunately, this is far from an unprecedented situation in the United States. In fact, the history of environmental justice is deeply enmeshed with issues regarding waste management. Robert Bullard, known as the father of Environmental Justice, performed seminal [research](#) involving landfills during the late 1970s in Houston, Texas. Britannica states that he did so to help his wife, attorney Linda McKeever Bullard, provide evidence for her class action lawsuit to stop the construction of a landfill in a Black Houston neighborhood; Although her 1979 lawsuit against Southwestern Waste Management, Inc. was litigated for 8 years, the landfill was ultimately approved for construction.

With the help of students in Bullard's college research methods class, he performed extensive mapping and demographic research of Houston and its suburbs. From this, Britannica reports, he discovered that five of Houston's six city-owned landfills were located in Black neighborhoods, despite Black people making up only a quarter of the population. His 1979 article from this research was the first to quantify [environmental racism](#): the disproportionate impact of pollution, industrial activity and environmental hazards on communities of color. Bullard would go on to extend his landfill research to other states, finding that [75% of waste sites](#) were located in Black neighborhoods in seven out of eight southern states. Later in his career, he would publish his findings in his book *Dumping in Dixie: Race, Class, and Environmental Quality*, which would become known as the "environmental justice bible", Britannica reports.

Bullard's early research coincided with four years of protests against a [toxic waste dump](#) in the predominantly Black community of Warren County, North Carolina. The University of North Carolina states that tons of toxic waste containing polychlorinated biphenyls (PCBs), chemical compounds known to cause cancer, were illegally dumped along 240 miles of North Carolina roadways. Then Mayor James B. Hunt Jr. announced a plan to collect this contaminated soil from the roadways and dispose of it in Warren County, UNC reports. They go on to state that, despite years of protests and legal action, the State still dumped over 7,000 truckloads of PCB-contaminated soil in Warren County. While unfortunately, the demands of these trailblazing protesters were not met, the impact of their fight remains significant today; UNC states that Warren County is now recognized as the birthplace of the environmental justice movement.



A police officer carries a protester to a police car in Afton, North Carolina on September 18, 1982. The protester was one of 39 people arrested while trying to block the path of trucks filled with PCB-laden soil.
Source: Steve Helber/Associated Press

Sullivan County and Seneca Falls are not predominantly Black [areas](#). However, it is important to note the significance that landfills and other waste disposal facilities held in catalyzing the environmental justice movement. Much of the literature on this subject suggests that waste management and environmental justice have been deeply intertwined throughout history, especially in the United States. Responsibly managing trash will only grow in significance as we produce more and more of it each year. Since 1980, the beginning of Bullard's career in environmental justice, municipal solid waste

generation has increased [93%](#). Fighting for sustainable, responsible and just waste management is arguably more important now than ever before. Researchers suggest that landfills and hazardous waste sites are more likely to be located in minority and low-income areas because they have less resources to fight back against their construction, making them easy targets of waste management corporations. I argue that, while Seneca Falls is not a minority community, the sparse and rural nature of the town as well as the local government's tenuous financial capabilities makes them an easy target for exploitation in the same way.

Sullivan County and the “NIMBY” Phenomenon

Faced with a potentially closing Seneca Meadows landfill, Sullivan County is left without a place to store their trash for final disposal. The Sullivan County Local Solid Waste Management [Plan](#) states that building a local landfill within Sullivan County would result in an immediate cost savings from reduced fuel and disposal costs from not having to travel long distances. However, the plan adds that challenges to building a nearby landfill include an investment of time and money. Finding a suitable location for a site and travel routes that do not congest local street traffic, as well as making sure to avoid water supply contamination, is a process that can take decades; Also, it estimates the cost to build the new landfill being between \$30 and \$40 million. For a small, rural county, this is an incredibly high cost. The Waste Management Plan also mentions that an additional challenge to building a local landfill is community apprehension to having this facility in “their backyard”. This refers to the “[NIMBY](#)”, or the “Not In My Backyard” phenomenon, a well-documented response to the prospect of something undesirable being built in one's direct vicinity. According to Britannica, these buildings are commonly large-scale corporate/industrial infrastructure or low-income housing projects. Britannica states that the “NIMBY” stance can be controversial because it implies that those who oppose construction of these projects want their burden placed on poor communities. Often, those opposing these projects for environmental reasons have a middle-class background. Having a strong stance against an undesirable facility constructed in one's middle-class neighborhood implies that they should be built elsewhere, potentially in poor neighborhoods, which already have more industrial activity to begin with.

The “NIMBY” phenomenon in the context of Sullivan County is complicated because a local landfill would only accept locally-produced trash. Unlike Seneca Meadows, which receives trash from all over the state (including New York City), Sullivan County's hypothetical smaller, local landfill would only contain Sullivan resident's trash. If the Sullivan County government anticipates a “NIMBY” community in opposition to the landfill's construction, we can ask ourselves: Are landfills ever a desirable solution for trash?

How Landfills Impact the Environment

The term “municipal solid waste landfill” ([MSWL](#)) describes an area of land that serves as a repository for non-hazardous household waste. MSW landfills are subject to state and federal regulations that require specific operating practices, including regularly compacting and covering of waste with soil, monitoring of groundwater quality, provision of funds for environmental protection, as well as long-term care once the landfill has closed, according to the EPA. Even with these existing regulations, the process of landfilling massive volumes of mixed household waste often leads to environmental contamination and pollution in a variety of ways.

MSW landfills are required to have a plastic or clay lining under waste to sequester [leachate](#): a liquid that collects in landfills as rainwater flows through trash, drawing out chemicals from it as it flows; However, these liners often [leak](#), causing the chemical-laden liquid to contaminate water sources. Leachate high in [ammonia](#) can negatively affect nearby water bodies by providing nitrates for algae that explode in population, creating “dead zones” without oxygen for aquatic life. [Plastics](#), which made up about ⅓ of all waste sent to landfills in 2018, are known to be made with over 10,000 chemicals that are classified as hazardous or having adverse impacts on human health. So even though hazardous materials are technically prohibited from MSW landfills, plastics serve as ample sources of chemicals that can contaminate groundwater and nearby land. The UN Environment Programme reports that these chemicals are highly mobile, accumulate in tissues, reduce fertility, damage the nervous system, cause cancer, and/or disrupt hormones. PFAS, or per-and-polyfluoroalkyl substances, are one of these chemical types found in plastic listed by the UN EP; We will discuss PFAS later on. Low [recycling rates](#) in the U.S. contribute to high volumes of plastic in landfills, which only worsens the contamination problem.

Beyond these problems, the most dire effect of landfills is how much [methane](#) gas they produce. The University of Colorado Boulder reports that methane is 84 times better at absorbing heat from the sun than carbon dioxide, meaning it is one of the most powerful greenhouse gases that contributes the most to climate change. Among other gases, landfills also release [hydrogen sulfide](#) or “sewer gas” which has a distinctly unpleasant rotten egg smell. Another damaging impact from landfills, per UC Boulder, is that creating them effectively destroys wildlife habitat; The average landfill size is 600 acres, and that translates to 1,800,000 acres of habitat that have been destroyed by currently active landfills alone.

The Treadmill of Production

Even when landfilling is done “correctly” according to environmental regulations, it still has negative effects on the environment and nearby communities. So then why do we continue to fill up landfills faster than ever before? One way we can

understand this conundrum is through the framework known as the Treadmill of Production. The [Treadmill of Production](#) is a sociological theory developed in the 1980s that helps explain why we as humans continue to harm the environment despite significant negative consequences. It is based on two processes that act together as a positive feedback loop, reinforcing each other: (1) The ongoing development and improvement of technology, and (2) a dominant preference for economic growth.

The development of new technologies with the goal of making money has been practiced on a wide scale since the industrial revolution. The Treadmill works like this: In order to manufacture the technology, resources are extracted and the environment becomes degraded in the process. Despite this environmental damage, the necessity for economic growth under capitalism leads to more resource extraction and more production of technology. The more sophisticated technology gets over time, the more extraction and production can occur at a lower cost and a faster rate. This cycle continues, faster and faster, as corporate entities fight to maintain profits. In order to do so, the least expensive modes of production are preferred, and damage to the environment is financially disregarded; That is, it is categorized as an externality. Often, modes of production that yield the most profits cause the most damage to the environment, so businesses are essentially incentivized to cause ecological harm. The competition between companies keeps this process going at an ever-increasing speed as they vie for the cheapest, most attractive technologies that will yield them the greatest revenue.

The Treadmill of Production explains very well our current predicament of unprecedented rates of waste production. Companies make products that are convenient and disposable in order to be the most attractive to consumers. Many of these items, like disposable diapers and Clorox wipes, are not recyclable and will take centuries to break down in a landfill. Plastic is the perfect material to feed the Treadmill of Production, as it is cheap, durable and versatile. Small, hard-to-recycle plastic pieces are found everywhere from packaging to cheap consumer goods. Even if a plastic product is recyclable, it's unlikely that it will get recycled in the U.S. due to a lack of universal and/or mandated recycling requirements. Instead of making durable goods that will last for consumers, companies want to make cheap, disposable goods so that we reliably continue coming back for more.

The Treadmill of Production leads us to what sociologists call [crescive troubles](#): A problem that gradually accumulates over time, going unacknowledged until it reaches a point of crisis. These issues go unnoticed or ignored due to their slow, creeping progression. In his article on this phenomenon, Thomas Beamish argues that our governments and human systems tend to avoid addressing these issues as they accumulate. The Seneca Meadows landfill and its associated issues are a perfect example of a crescive problem. In line with the Treadmill of Production, landfilling is so

widely practiced because it costs less to do so rather than building infrastructure that can remove and process recyclables and organics from the main garbage stream. Once a crecive problem grows into a crisis, however, the costs required to fix or improve the situation can be much higher than the cost to avoid the crisis in the first place.

Greenwashing

The issues associated with climate change and ecological destruction have become more well-known by the general public over the past few decades. As a result, people expect more from companies than ever before with regards to manufacturing responsibility and sustainability. In response, companies have employed a tactic known as [greenwashing](#): Falsely implying or claiming that their actions, goods and services are more sustainable than they actually are. One example of this is [Volkswagen's](#) "Clean Diesel" campaign, which advertised its diesel cars as sustainable, until the company was found to have rigged emissions tests; The cars emitted up to 40 times the legal pollution limit. Greenwashing tactics can also be much more subtle to quietly influence the way consumers think about a company. For example, plastic water bottles manufacturers will often have nature-themed labels, despite their integral role in worsening the plastic pollution crisis.

It costs little to nothing for a business to simply state that they are doing something sustainable, while maintaining business-as-usual behind closed doors. In addition, customers can be easily deceived if they do not have an in-depth knowledge of production processes and/or environmental science. A fundamental aspect of greenwashing is misrepresenting information, according to the Harvard Law School Forum on Corporate Governance. As the social and environmental ills of landfilling become more well-known, corporations associated with landfills heavily utilize greenwashing tactics in order to maintain their dominance over the waste management landscape.

Incineration - A False Solution to the Landfill Problem

In the context of greenwashing, a false solution is an activity or project that is advertised to mitigate or solve an ecological problem, when it in fact does not solve the problem and/or further contributes to ecological damage and climate change. Waste incineration is one such false solution that is commonly advertised as sustainable, especially when energy is captured from burning trash. Earlier, I mentioned that the local government in Sullivan County was considering constructing a waste incinerator to address the fact that Seneca Meadows landfill might close. They did so because a company called ReWorld was working to court locals and members of the government to build an incinerator there. Despite ReWorld's efforts, which included holding informational sessions to interact with locals, residents who knew the dangers of incinerators wrote in to express their vehement opposition to having one built in their

community.

The attractive myth about waste incineration is that you can completely get rid of your trash, and even capture energy in the process. The reality, however, is that the waste does not get destroyed, just consolidated into an incredibly toxic and highly mobile ash byproduct. A [study](#) found that despite filtration systems, this ash readily escapes incineration facilities and accumulates in the nearby land and water sources. The [pollutants](#) present in this ash include but are not limited to heavy metals like mercury, arsenic, and lead, as well as dioxins and furans. These compounds are listed as highly toxic pollutants by the [EPA](#). Communities who live near incinerators have [higher rates](#) of respiratory, cardiovascular, and urinary diseases, babies born prematurely and/or with birth defects, and several kinds of cancer.

On top of the toxic pollution, burning waste releases CO₂ and other planet-warming gases. While companies like ReWorld advertise incineration as creating energy from waste, the energy needed to power the high-temperature burning process makes the captured energy negligible. In fact, Energy Justice Network reports that if the materials burned were instead recycled or composted, 3-5 times more energy would be saved than it cost to burn; This is because it takes less energy to recycle products rather than extract raw materials. EJV goes on to state that incineration is the most expensive form of energy, partially because of how much it costs to construct and operate facilities. Finally, incineration is a false solution to waste problems because it incentivizes the production of more waste, not less, to continue feeding large machines. Although companies use terms like “waste-to-energy” and claim that incineration is a renewable energy technology, this is classic a greenwashing of touting a false solution for financial gain.

Gaps in Existing Literature

An important but underrepresented topic in current research involves attitudes and behaviors regarding waste disposal in the rural United States. Most articles on this specific topic were published before the year 2000, and more recent articles tend to focus on developing countries where waste management infrastructure is usually [weak](#). There is relatively little academic literature on the topic of rural waste management in the U.S., and I think much of this has to do with the nature of rural areas. Most small towns in the U.S. have low populations and few resources. It's less likely that a story from a small town will make national news than one in a bigger city, where much more people are affected by a given issue. In addition, there is evidence that large waste management corporations intentionally conceal the negative realities of their landfills in order to continue making large profits. I will discuss this point later in my paper. This study will fill gaps in literature by examining the unique problems facing rural towns in the United States regarding waste management, as well as how people who live in these towns perceive landfilling practices.

Methodology

Positionality

While I'm studying rural areas in New York state, I grew up in Tennessee and am currently located in California. As an outsider to this situation, I lack bias that a native to the area might have. In that way, my position as an outsider might serve as an asset. It is important to note that I have never lived near a landfill or any other type of trash disposal facility. However, I have been concerned about and fixated on waste since I was young. Even before I knew the scientific and political details of waste disposal, I had an anxious, gut feeling that the trash produced in my community was not being handled safely or sustainably. In high school, I started an Environmental Club and one of the first things we facilitated was a battery drop-off bin. I recently found out that this club still exists over 10 years later, and they participate in annual Earth Day cleanups of litter near campus. That is the best thing I could hope for: a legacy of collective action to mitigate the harms happening to our environment every day. In a similar way, I hope this research project will share knowledge that will help people make better-informed decisions regarding their own waste, as well as reject greenwashing and false solutions, in order to benefit their communities and the greater environment.

I find this topic compelling in terms of ethical impact because of how dire of a problem waste is around the world. In developed countries, we may have sophisticated waste management infrastructure that seemingly "takes care" of the high volumes of waste we produce. However, these high volumes of waste are simply carted to often marginalized areas either within or outside of the U.S. One of the reasons I feel deeply inspired and compelled by this topic is that the problems caused by excess trash production are hidden to many, but impossible to ignore for some.

Data Collection

To research this topic, I used mainly archival sources including news articles and technical reference data. For scientific and technical data about landfill practices and environmental effects, I used academic research journals and resources from government organizations like the EPA. To investigate corporate spending by waste management companies, I used the database OpenSecrets. News outlets, some national but most local to upstate New York, provided important information about the timeline, events and public reaction surrounding the ongoing landfill disputes in Seneca Falls. I decided to also group many of these articles as data for analysis to find out more about how people perceive landfiling as a form of waste management.

News Article Analysis

Over the past 10 years, many news articles have been published about the Seneca Meadows landfill reporting its status of operation, as well as the public's reactions to

and protests against it. I wanted to analyze how these articles reflect greater public perception of the landfill and its operations, and what this says about how people in this area perceive waste. I searched through articles published about the Seneca Meadows Landfill published between 2016 and 2026, selecting those that discussed the landfill operations itself and/or the public perception of the landfill. In order to eschew bias, I disregarded articles sourced from the landfill itself and from environmental activist groups that protest it. Out of 180 articles that mention Seneca Meadows, I selected 81 based on my source and subject parameters. I assigned each of these 81 articles a number from 0-1, with 0 representing fully negative coverage and 1 representing fully positive coverage. Neutral articles will land at 0.5.

Some articles are opinion pieces, and therefore constitute either a fully negative or fully positive take on the landfill. Most of the articles, however, are more objective and informational in their approach which I determined to be skewed more neutral. In these cases, I decide whether the piece is fully neutral, or leans more positive or negative, based on how much of the article's material constitutes positive or negative facts, respectively. For example, for a news article (non-opinion piece) that covers the landfill by reporting the quotes and perspective of its detractors, I rated it a 0.1; It contains solely negative information about the landfill, but does not explicitly endorse or legitimize the claims that it reports. Articles I've rated 0.2 contain mostly negative information, but do mention facts from the perspective of landfill representatives and/or proponents. The more information an article provides from the "landfill side" proportionate to the "anti-landfill side", I move towards a 0.5 score. A score of 0.5 applies to articles that dedicate proportionately equal coverage of the "pro" and "anti" side of whether or not to keep the landfill open. The same scoring logic applies towards articles that lean towards the 1 score.

Results

Scatter Plot of News Article Scores (0-1)

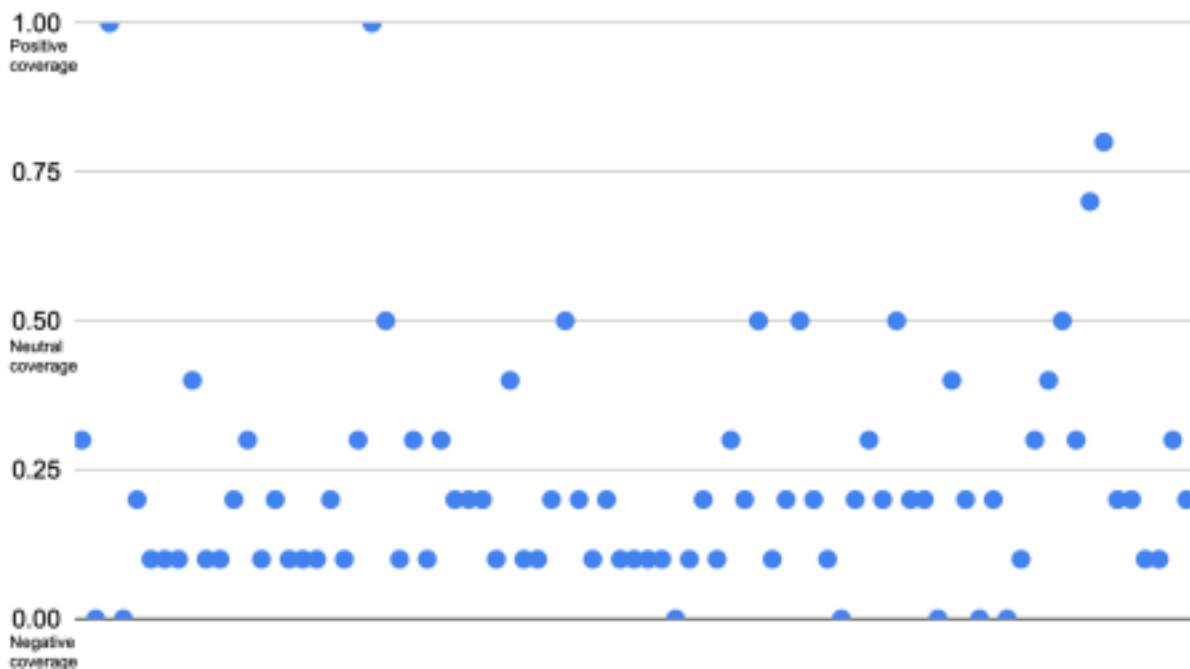


Figure 1. Scatter plot of news article scores about Seneca Meadows landfill from the past 10 years, rated from a scale of 0 (negative coverage) to 0.5 (neutral) to 1.0 (positive coverage).

Each of the data points on this graph represent one the score of one article. The articles came from a variety of sources, from local news sources to national outlets like ABC News and The New York Times. From this graph, it is evident that the majority of articles' scores fell below the .2 rating. This means that the majority of the articles about Seneca Meadows landfill provide mostly negative coverage about the landfill. The 7 articles that scored at the 0.0 mark were explicitly opinion pieces in opposition of the landfill remaining open. The 2 articles that received a 1.0 positive score were also opinion pieces; However, notably, both were written by the District Manager of Seneca Meadows Landfill: Kyle Black. In nearly every article that discussed the perspective of Seneca Meadows, Black's name was mentioned as the main representative of the landfill. This data reflects that no person has spoken out in a publication in total favor of expanding the landfill, except for the one person who is arguably the most invested in the landfill's operations and expansion. This meaningfully suggests that public perception of the landfill in this area is largely negative.

The only arguments towards positive aspects of the landfill involved the money it brings to the area. Without the taxes paid by the landfill and funds awarded to the town as part of its operation agreement, Seneca Falls would lose the majority of their local government budget each year to the tune of [millions](#) of dollars. The money comes from

Waste Connections, a multi-billion dollar Texas-based corporation, who spent [\\$200,000](#) in 2021 alone to fund campaigns for Seneca Falls Town Board members that would support the landfill; While this amount of money doesn't even dent WC's net worth, it completely buried the \$15,000 budget of the two Seneca Falls Town Board incumbent members and they subsequently lost the election.

The 6 articles that had a score of 0.5 (neutral) usually equally weighed the serious downsides of the landfill with the financial reality facing Seneca Meadows. These articles suggested the financial and political challenges that would come with closing the landfill, while maintaining the widespread complaints and concerns from nearby residents.

Regarding peoples' perception of waste, the scoring of these articles would suggest that the vast majority of people exposed to landfilled waste do not want to be around it. In other words, they have a negative view of waste when it is near them. I would argue that this data set suggests that living near a landfill negatively influences one's perception of waste. Given the content of the positively-scored articles, I would also argue that this data suggests that having access to money provided from waste management companies positively influences one's view on waste. In other words, you may not perceive trash through a negative lens if you can benefit monetarily from it. I think that this more positive perception is strengthened when the majority of your local government's budget comes from being around waste.

Discussion



An Earth Day protest against Seneca Meadows landfill by the environmental group Seneca Lake Guardian on April 22, 2023. Source: Gothamist

Ethical Implications

A point of ethical tension regarding this subject has to do with landfills and their mixed impact. While I argue that landfills are a band-aid solution to our rate of waste output, they can also serve as a financial backbone for many rural communities with little other economic activity. This [article](#) from Waste Dive discusses the potential impact on local taxes for Seneca Falls residents if the nearby Seneca Meadows landfill were to close. The landfill has reached capacity, is contractually obligated to close, and is facing ongoing protest from residents complaining about the smell and demanding it cease operations. However, the article states that if this were to happen residents would see their local taxes double. This has to do with the fact that Waste Connections, the corporation that owns the landfill, finances much of the local government's [budget](#).

It's an uncomfortable and contradictory reality that large corporations who build landfills in rural areas have virtually no investment in the community other than using their land. At the same time, they largely fund the local government. People in Seneca Falls are calling for the landfill to close due to their complaints of a terrible stench that reportedly causes headaches and nausea, as well as discourages tourism. If the appeals that the landfill has submitted go through and it remains open, this smell will continue to disrupt the everyday lives of nearby residents. However, if it closes, they will likely be forced to pay double in taxes. The fact that the cost of this issue is being placed on the most affected individuals with the least resources, in comparison to the company Waste Connections, is troubling. Making money off of trash seems to be much more prioritized over environmental and public health and safety. While money and jobs can easily be made through material recovery, recycling, and waste sorting, these methods require new infrastructure and force a change to the business as usual. I will delve more into this later on in the discussion.

Seneca Meadows' Role in Public Perception

The news article analysis suggests that positive press about Seneca Meadows landfill usually comes directly from the landfill itself. This is not the only method through which the landfill acts to protect its reputation. In addition to awarding the town millions of dollars in its operation agreement, Seneca Meadows' website reports a plethora of charitable [donations](#) to the adjacent towns of Seneca Falls and Waterloo, New York. The website boasts annual donations to the Seneca Falls Fire Department and boy scout troops, as well as Christmas bike giveaways and contributions to a local backpack feeding program for children. The website also states that for the past 18 years, the landfill has awarded hundreds of thousands in scholarship funds to graduating seniors; In 2023, they gave \$189,000 to students pursuing degrees in environmental careers. It's an ironic scenario that the same children who are reportedly being made ill at school from landfill odors may be awarded opportunities they would likely never get without the

landfill's presence. Indeed, they report annual revenue of \$75 million to the local government.

Despite well-documented claims of stress and illness from offensive landfill gasses, Seneca Meadows explicitly invalidates these on another page of their [website](#). An infographic on this page claims that hydrogen sulfide, the main odorous gas associated with landfills, has been measured as absent from the air 98% of the time since 2022. In stark contrast, 69% of nearby residents reported being able to smell the odor from their home, according to a survey of over 700 people reported by the [Rochester Beacon](#). 53% of survey respondents report being able to smell the landfill odors at their children's school, with dozens of families stating they've had to take their children out of school due to the noxious smell. The contrast between these claims from locals and the landfill's claim of a 98% smell free environment stands out to me as deeply incongruent. The Seneca Meadows' website makes no mention of the quantity or location of these hydrogen sulfide sensors, nor does it provide any external validation of this vague statistic.

What You Should Know
We believe it is important for everyone
to understand the actual facts about Seneca Meadows

Facts vs. Myths

Just the Facts, Please
You may have seen some of the myths about the Seneca Meadows landfill—typically repeated as if they are facts by a small group of vocal opponents.

Air Quality
NYSDEC has conducted multiple area community air screening programs. The reports concluded that the results "would not be considered a potential health threat or an immediate public health concern" and noted that "all results were similar to concentrations found in NYSDEC's ambient air monitoring network."

Misconceptions about Chemicals
Seneca Meadows follows all leachate disposal requirements. Locally, Seneca Meadows goes even further - leachate sent to a local wastewater treatment plant is first treated to remove PFAS, and the plant does not discharge to the Finger Lakes.

Landfills sequester most of the PFAS they receive. Landfills were identified by EPA as a preferred option to manage PFAS impacted waste streams.

PFAS

www.senecameadows.com

Infographics denying claims alleged against Seneca Meadows landfill. Source: Seneca Meadows Website.

Seneca Meadows' "mythbusting" (or rather, greenwashed) infographic also discusses PFAS in landfill leachate. PFAS, or per- and polyfluoroalkyl substances, are pervasive in consumer products like non-stick cookware lining, cosmetics, and fast-food packaging; The Journal of Hazardous Materials notes that they are found in high amounts in leachate for this reason. Their article notes that, over time, PFAS accumulate in tissues and can subsequently lead to organ damage, thyroid disease, fertility difficulties, hormone suppression, and cancer. The article, as well as [this one](#) from the Journal of Water Process Engineering, states that conventional wastewater treatments are ineffective at removing PFAS due to their extremely stable chemical bonds. These articles discuss PFAS as a problem emerging over the past few decades that is still in need of effective remediation solutions. Seneca Meadows' website, however, makes no mention of the common occurrence of leachate leaking through linings, simply stating that "Landfills sequester most of the PFAS they receive". It also states that leachate sent to a local wastewater treatment plant is treated to remove PFAS, despite the well-documented and aforementioned fact that conventional water treatments are ineffective at removing PFAS. Seneca Meadows' infographic insists that these "myths" are being "repeated as if they are facts by a small group of vocal opponents". Over a decade of local and national news articles would dispute this claim of a "small group" in opposition to the landfill's current operations.

Waste Connections, Inc.

Seneca Meadows landfill is owned and managed by Waste Connections, a Texas-based waste management corporation. They operate in 46 states and reported a net revenue of \$9.9 [billion](#) for 2025. Similar to the Seneca Meadow landfill website, the Waste Connections site boasts their commitment to sustainability while using vague language: they "aim to" collect landfill biogas, and note that separated organic waste "can be" beneficially converted to compost or energy. What they don't share on their page is the hundreds of thousands they have spent on government lobbying. Waste Dive [reports](#) that Waste Connections first reported lobbying spending last year. From the previous section, we learned that in 2025 the company financed a \$200,000 campaign budget for local Seneca Falls Town Board members who would vote to keep the landfill open. Waste Connections indeed began their lobbying efforts in 2025 with [\\$210,000](#) total spent. The database reported an increase in spending for the company in 2026 of \$310,000 spent on lobbying. Waste Dive's report also states that federal lobbying spending for waste management companies doubled what the sector spent in 2019.

Why has spending increased so much? Waste Dive reports that an increased federal interest in liability, reliable regulations, and compliance in the waste sector has

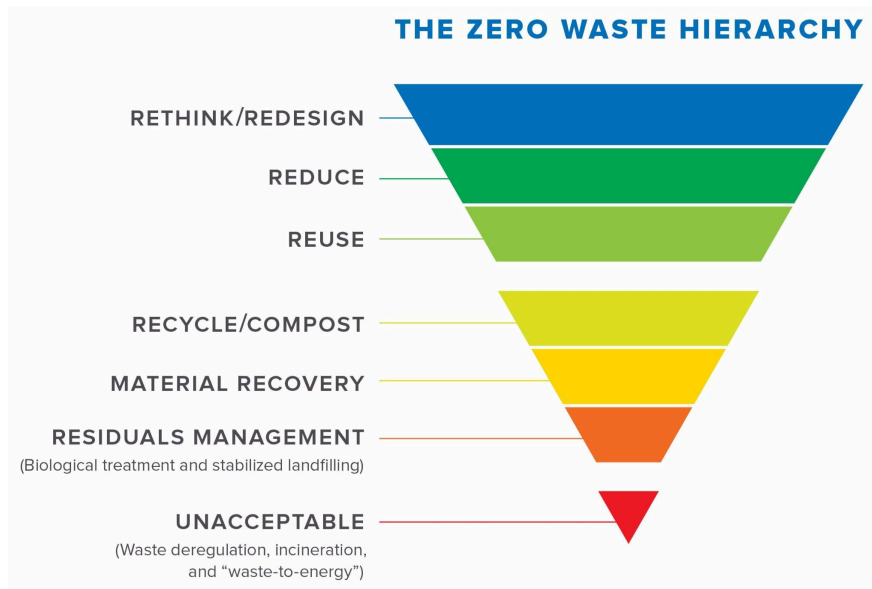
catalyzed the jump in spending. They go on to state that top policy priorities include recycling, waste disposal site remediation, and PFAS. In addition, as top waste management companies have consolidated and moved from being local to national corporations, there's more interest in how the Federal government can affect their profits. Finally, Waste Dive reports that representatives of the waste industry have begun to interact more closely with Capital Hill in order to "change narratives" about the work they do. I would argue that, as environmental regulations around waste management grow in strength and scope, companies are spending this lobbying money to court federal officials so that they support bills and laws that uphold traditionally established business operations.

Solutions to Current Waste Problems

Zero Waste Techniques

Separating organic materials from the total waste stream is one of the best ways to reduce the volume of trash sent to landfill. Not only does this reduce the amount of space the landfill takes up, it also reduces greenhouse gas emissions by removing the main source of landfill's [methane](#) production. The EPA reports that in 2022, landfills constituted 14% of all methane produced in the United States; Of those landfill emissions, 58% of them are derived from wasted food in landfills. Composting is effectively organics recycling, because food scraps that are normally wasted can be made into new materials like soil and fertilizer.

Another way to significantly reduce waste sent to landfill is to increase recycling, specifically of plastics. As of 2018, 12% of all municipal solid waste produced was [plastic](#). However, the EPA reports that just 9% of these plastics were recycled; The plastics recycling rate has improved from a mere 2% in 1990, but has not surpassed 9%. Increasing plastics recycling has massive potential for reducing waste sent to landfill and making landfills less harmful facilities to operate.



Zero Waste Hierarchy diagram. Source: Energy Justice Network.

These last two paragraphs discuss aspects of the [Zero Waste Hierarchy](#), a guide for reducing waste as much as possible. Zero Waste does not mean that there is zero waste produced; Rather, this is the ultimate goal. This goal is pursued through following the hierarchy, which is organized in an upside-down pyramid listing methods from most to least desirable. Rethink/redesign, reduce, reuse, recycle/compost, material recovery, residuals management, and finally, unacceptable: incineration and waste-to-energy. Rethink/redesign refers to the need to design our consumer products for either durability and reuse, or for easy, safe and biodegradable decomposition, depending on the item's use. After recycling and composting, material recovery refers to taking usable materials from waste streams before eventual landfilling. Residuals management refers to the proper treatment and stabilization of landfills after everything that can possibly be reused or recycled is removed.

Following the Zero Waste Hierarchy would mean making sure that all recyclable, compostable, and reusable items are removed from waste streams before they get sent to landfill. As is apparent from the nation's aging landfills and low recycling rates, this is far from what happens in the U.S. today. These processes require financial, infrastructural, administrative and behavioral changes that can be difficult to achieve on a large scale. However, as landfills continue to age and fill up this country, following the Zero Waste Hierarchy will become more and more important for everyone's wellbeing.

Barriers to Zero Waste

Throughout this study, we have discussed barriers to implementing Zero Waste practices like recycling and composting. In the U.S., these include the absence of mandatory and standardized recycling requirements, as well as a lack of cultural focus

on early education on sustainability and recycling. European countries have much higher rates of recycling, in part due to the [European Commission](#)'s programs that facilitate sustainability education early in schools. European countries also tend to sort their recyclables into categories, rather than mixing them all in one bin. While this requires more effort and knowledge on the consumer's behalf, it also increases recycling rates by preventing contamination of recyclable materials through mixing. In this way, a lack of early education on recycling and sustainability in the U.S. affects consumers' behavior and makes them less likely to recycle; At the same time, the prevalence of zero-sort recycling renders people less discerning about what they dispose of as recycling. This leads to non-recyclable items making their way into the recycling stream, which can cause issues and damage to machinery.

Another obstacle preventing Zero Waste practices is the previously discussed Treadmill of Production. Corporations will continue to fight for profits by offering consumers convenient, disposable products. These products will continue to proliferate in our waste stream until government regulation is enacted to control their production. Despite the ongoing damage of our current waste systems, regulation is becoming more stringent. Several states have passed laws involving the environmental policy approach known as extended producer responsibility (EPR). The purpose of [EPR laws](#) is to hold businesses accountable for the social and environmental impacts of their products. These laws shift the responsibility of proper waste management from consumers to producers by requiring them to engineer their products to minimize impact, as well as investing in recycling to make it easier and more accessible. While the damage that landfills have caused can't be undone, we can move towards a future where our products do less harm and useful materials do not get wasted.

Summary

This study challenges dominant narratives about the effectiveness of our current waste management systems. Despite the millions spent by waste management companies on lobbying, mounting evidence suggests that our current methods of trash disposal are not sustainable in the long-term. As our waste stream continues to increase, these issues will only worsen in the coming years without proactive intervention. In this report, data regarding the news coverage of Seneca Meadows landfill was analyzed and plotted to suggest a mostly negative attitude towards the landfill remaining open. The negative opinions about the landfill's activity, as well as the "NIMBY" phenomenon, suggest that people see landfills as undesirable to live around (especially when the waste comes from elsewhere). This article argues that waste management corporations leverage financial power over small towns through lobbying and funding political campaigns in order to exploit their land at the expense of local residents' wellbeing. Finally, this study posits that following the Zero Waste Hierarchy as the best way

forward, while acknowledging the challenges facing its widespread implementation in the waste management industry and everyday life.

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Challenges Facing the Aerospace Industry in the Transition to Renewable Energy

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ABSTRACT

This study focuses on the aerospace industry in San Diego county, and the challenges that they face when it comes to the transition from fossil fuels to renewable energy sources. The aerospace industry is one of the largest in San Diego county, with manufacturing facilities located throughout the area. The aerospace manufacturing facilities are where the products are generated, utilize large amounts of fossil fuels to power the facility and operations. When it comes to these facilities, it begs the question of why they continue to use fossil fuels instead of transitioning to renewable energy, and what challenges are resulting in this lack of change.

As noted by the city of San Diego, there are policies in place that allow for the transition to take place, but place a large emphasis on public facilities instead of private ones, like the aerospace industry. Additionally, there is a viewpoint, as noted by blogs from people of different backgrounds, of greenwashing when it comes to renewable energy, which provides an opinion as a potential challenge for the lack of transition. Finally, there are also sustainability reports from different aerospace industry companies, where one focuses more on renewable energy and the other places a smaller emphasis on it.

These challenges all pose an aspect of human interaction and what is valued as important within each company and the county as a whole, one where a transition to cleaner energy is highly valued compared to one where there might be a larger emphasis placed on lowering water consumption. Overall, it all boils down to a couple main challenges. Through research and analysis of opinions, facts, and ideas, it can be seen that some of the larger challenges faced by the aerospace industry in San Diego, emerge from opinions surrounding renewable energy, city policies, where the responsibility for the transition falls, and opinions of companies surrounding the importance of renewable energy.

INTRODUCTION

When someone thinks about the Aerospace Industry, what is the first thing that comes to mind? Oftentimes, it revolves around airplanes, specifically the use of commercial airplanes. Commercial airplanes are the most common product, the one that is most well known, in the Aerospace Industry, based on their continual presence in the lives of those are continually able to travel commercially utilizing planes. Whether someone lives near an airport, hears or sees airplanes passing overhead, lives near a manufacturing facility, or more, they are consistently present in the lives of people and the environment. San Diego County is one of the major hotspots for the aerospace industry in the United States and is home to many production facilities for companies ranging from 50 people to 50,000. The aerospace industry is never going to disappear, but the question remains: Will it continue to solely rely on the use of fossil fuels to power its product generation and usage?

Although commercial airplanes may be the most common product created, they do not cover the entirety of the products generated by the aerospace industry as a whole. The Aerospace Industry generates a large number of different products tied to aviation and space exploration. Starting with the bigger items, there are rocket engines, the physical bodies of the rockets, communication boxes for telemetry and radio frequency communication, antennas, and more.

Additionally, there are smaller products as well, like transponders, LED lighting, and more. However, one thing that is consistent with all products and the process required to generate them is the use of fossil fuels. Fossil fuel use is not only required for product usage, like fueling a plane to fly from one destination to the next, but it is also required to power the manufacturing facilities. Fossil fuels are needed to power entire facilities and manufacturing floors as they require energy to ensure machines are running for creation, testing, and more. Through this, there is a continual need for fossil fuel use to generate not only proper product action, but also to generate these products in the first place. According to the [EESI \(Environmental and Energy Study Institute\)](#), “when fossil fuels are burned, they emit greenhouse gases like carbon dioxide that trap heat in the earth’s atmosphere and contribute to climate change. In 2019, fossil fuels accounted for 74 percent of U.S. greenhouse gas emissions.” Excessive burning of fossil fuels is severely detrimental to the environment, highlighting the importance of transitioning over to different sources for energy and electricity.

An alternative that has been provided to work against the excessive fossil fuel use is renewable energy. Renewable energy sources are not finite, and they do not have the same impact on greenhouse gas emissions and air pollutants. Renewable energy sources range from wind and solar power to biofuel and other naturally derived fuel alternatives. There are incentives and policies that have been instituted by San Diego County to make it more affordable and desirable for facilities to install renewable energy, but not as well as one may think. Not only are there these actions implemented by San Diego County, allowing there to be an improved financial aspect for a transition to renewable energy sources, but there are also the positive environmental impacts that can be created through the transition. So why are more companies not making the transition?

Building from all the information above, the real question to focus on surrounds: What are the challenges facing the implementation of renewable energy sources in San Diego aerospace production facilities, and how has this resulted in minimal transitions over to different energy sources?

In order to provide more information on this question posed, the presence of different forms of research will take place. There will be a collection of data from previously generated pieces that provide information on fossil fuel use in the industry and other specifics, providing insight into the continual use of the fuel in the past, and currently, to show the reliance the industry places on it. Additionally, there will be firsthand experience regarding the declining use of fossil fuels from my own personal experience at my company and the changes that have been made in order to move forward with the use of renewable energy sources, showing that the change is possible, and can be completed to transition away from fossil fuel use. This will allow for others to discern that production facilities can make the change to renewable energy, and move further away from dependence on fossil fuels.

Next, there will be the presence of other perspectives brought into play from people of different backgrounds, to provide different opinions and information on what they think about renewable energy and how it may have the ability to have a positive or overall negative impact.

Specifically, there will be the inclusion of opposing viewpoints, like those who view the widespread use of renewable energy as a form of “greenwashing” to further develop a more holistic view of how renewable energy is seen. The opinion pieces will provide further insight into what is not only a common issue among the use of renewable energy, but how greenwashing can result in a lack of transitions. It continually highlights the phrase of “the lesser evil,” as in all reality there is no truly green energy source, one way or the other, there will be pollution or some sort of impact on the environment. However, the greenwashing perspectives of others allow people to see the flaws, but still discern that change can be made.

LITERATURE REVIEW - GAPS IDENTIFIED!

1. Introducing the Topic...

Fossil fuels are finite resources that, today and in the past, have been one of the major ways to produce energy and provide electricity. Fossil fuels are still highly apparent in today's society throughout many different sectors. They are used in residential homes, commercial buildings, by cars, used by airplanes, and more. Fossil fuels oftentimes can be seen as the main source of energy within the industry, but what consequences come along with the constant burning of fossil fuels to generate energy? According to [Hannah Ritchie et al.](#), one of the main issues that arises from the burning of fossil fuels is that when they are burned to produce any sort of materials or forms of energy, greenhouse gases are emitted; one of the main greenhouse gases being CO₂. CO₂ is a greenhouse gas that continually adds to climate change, which can result in extreme temperature changes while also increasing global average temperatures, which can result in heightened natural disasters, air pollution, extremely warm temperatures, and more. These impacts can uproot people from their homes, communities, and more, resulting in a direct impact on human life and the way in which people are able to function about their everyday lives. Fossil fuel burning is not the only cause of these emissions, but it is the main contributor. Additionally, when it comes to the areas in which the majority of these emissions stem from, which industries are the main culprits with the largest amounts of CO₂ and other greenhouse gas emissions? Building off of the previous mention of airplanes, airplanes and other products are generated as part of the aerospace system, which is one of the industries that utilizes immense amounts of fossil fuels not only to power their products, but to provide electricity and generate power to manufacturing floors to ensure all product parts are properly created. According to [Muhammad Umar et al.](#), the aerospace sector contributes nearly 25% of all global CO₂ emissions, which equates to one-fourth of all global CO₂ emissions. This includes both production/manufacturing as well as product use, like airplane and rocket use. As noted by [the diagram generated by Energy.gov](#), which covers the use of fossil fuels within Aerospace product and parts manufacturing in 2018, indicating that the primary energy use by these processes/facilities resulted in using 124 TBtu (Trillion British Thermal Units) of energy, which generated 6 MMT CO₂e (Million Metric Tons Carbon Dioxide Equivalent). During this investigation in 2018, it was noted that 87% of the fuel type used at the manufacturing facilities was natural gas, which is a fossil fuel. See the image below to discern the fuel usage and how it has led to the large amount of CO₂ emissions.

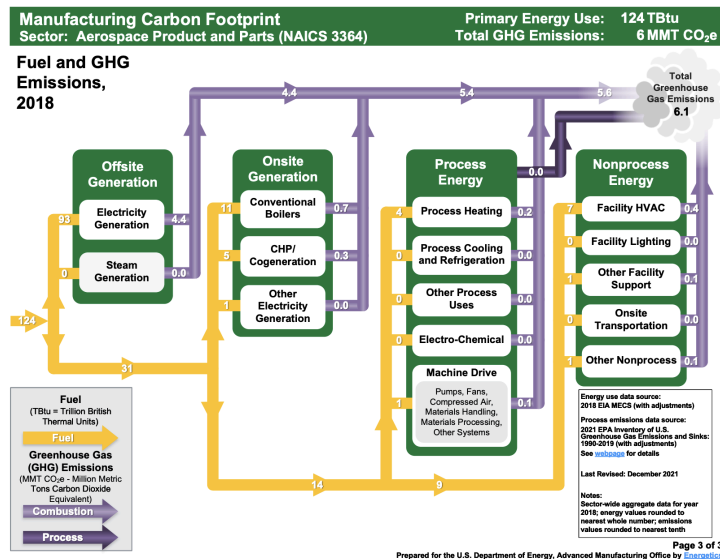


Chart generated by [Energetics](#).

So, when it comes to fossil fuels, is there any way to combat the consistent burning of the material within the facilities that house production/manufacturing floors?

The short answer is yes, through a transition to renewable energy. However, these methods can be quite complex for installation, depending on the source. There are many different sources of renewable energy, some of them being: solar power, wind power, biofuel, and more. Solar power and wind power are often the most common for large-scale buildings, like a manufacturing facility. To provide some background on renewable energy sources and their installation, solar power will be explored in further detail. According to [Isabelle Kagan](#), solar carports and other versions of renewable energy are beginning to take flight. Yet, there are some cons to the installation of these methods in general. Some of the cons that surround the installation of solar panels and carports stem from the costly and more complex installation of the materials, the long permitting processes and zoning requirements enacted by the city, and finally, the regular maintenance of cleaning and fixing that is necessary to ensure that the installed panels remain functional.

One of the large areas taking advantage of renewable energy sources is Southern California, specifically Los Angeles County, Orange County, and San Diego County. In California, there is a big push toward moving to renewable energy to continually move away from the use of fossil fuels. According to [CCST \(California Council on Science and Technology\)](#), “over the past two decades, the state has developed and implemented a multipronged strategy that has achieved substantial progress toward reducing California’s greenhouse gas emissions, utilizing both sectoral policies and a Cap-and-Trade Program that operates across multiple sectors. Through executive orders by the state’s Governors and extensive action by the Legislature, California has set bold and legally binding goals to achieve deep reductions in greenhouse gas emissions by 2030 and carbon neutrality by 2045.” It has also been noted by the [CCST](#) that in order to reach the desired decrease in emissions in California,

there is going to need to be a replacement of fossil fuels and DCP with a combination of renewable energy resources like solar, wind, geothermal, biomethane, and hydroelectric power to consistently lower greenhouse gas emissions that continually add to climate change as well as air pollution. So, why are there not more aerospace industry manufacturing facilities in San Diego, which is part of Southern California, working to transition over to renewable energy sources and push away from the use of fossil fuels? As noted previously, a lot of the issues that arise with the installation of renewable energy sources come from a lack of profit and lost time within corporate agendas. There are very long permitting processes to obtain permission to erect the structures to house renewable energy sources, like a solar carport. Additionally, there are high costs that come with the installation of these, including the need for contractors, electricians, and permits, even when the incentives from the city or state come into play. Finally, one of the major points that can result in a refusal to install stems from the inconvenience and slowdown of work that it can cause companies. As noted by [Sophie L. Hallsedt et al.](#), in the present time, some Aerospace companies recognize sustainability issues as a business opportunity rather than undesirable pressing situations. From my own experience at my own company, L3Harris Technologies, located in San Diego, California, the installation of the actual structure has occupied over a year and a half. Closing down different parts of the parking lot of the building for periods of 4 months at a time. Additionally, when the carport needs to be connected to the electrical system of the building, there has to be an entire shutdown of electricity, meaning the entire building was left without power for over 16 days. In other terms, this signifies that the production processes were further delayed as nothing could be done without power, so profits were lowered while costs continued to rise.

II. Review of previous studies and changes made...

As noted in previous studies from other explorations in the aerospace industry, there have been changes made in the use of fossil fuels, but the focus has not been on transitioning production facilities and manufacturing floors toward renewable energy sources to directly shift away from fossil fuel usage. As noted by [Eleonore Pierrat et al.](#) in 2017, the estimated carbon footprint of the industry is 18 MtCO₂/yr, which is driven by airframe manufacturers, with material production and aircraft manufacturing emitting 8.1 MtCO₂e. Yet, even with all these emissions and energy usage for the production processes of the aerospace industry, which stem from fossil fuel usage, only 1% of the energy requirement was reported to stem from renewable energy sources. However, in this research, the main focus was not placed on the implementation of renewable energy; instead, it was placed on waste and the recyclability of metals and other materials to lower the need to obtain new material consistently. The focus was placed highly on the material demand required for production, and took a cradle-to-grave approach when it came to determining the ways in which emissions and fossil fuel usage could be lowered within the industry under the scope of materials that make the products.

A similar route was taken by [Khaled Bawaneh et al.](#), except the focus was placed on manufacturing facilities in the Midwest. Although this does not fall within the Southern California region, there are ideas and routes taken to move away from fossil fuel use that have

also not been seen throughout the region as well. This research placed the main emphasis on energy intensity, which relies on fossil fuels to generate the electricity required for energy usage; and the piece noted that “the aerospace industries spend a [disproportionate] amount on electricity and fuel when comparisons are made to other industries,” and within the United States in 2018, energy-related carbon dioxide emissions account for 84% of the total emissions in the United States with the industrial sector consuming nearly 33% of the annual energy usage. However, a gap was noted in this piece as they provided the data in order to discern the energy intensity of the aerospace production facilities, but did not provide any insight on how to lower the energy usage, and in turn, the fossil fuel requirements to power the facility and their greenhouse gas emissions. The piece focuses on creating and displaying the data at hand so it can be used by others for Life Cycle Sustainability Assessments (LCSA). This is a highly common method seen in literature surrounding the energy use and fossil fuel use of manufacturing facilities in the Aerospace industry; however, it also shows that the provided options to lower fossil fuel emissions through renewable energy are often not at the top of the list of choices, even though they provide the ability to continually lower emissions. To provide more clarification on the link between electricity use and fossil fuel use and emission generation, the statement from [Muhammad Umar et al.](#) provides more clarity: “Machining mainly uses electricity and doesn't emit direct GHGs [greenhouse gases]. Emissions come from electricity production.” So, when it comes to the electricity use of a site, the generation process for the needed electricity utilizes fossil fuels, which then burn and generate more emissions. Umar and his team research the use of the LCSA, again, to link the aerospace industry to possible renewable energy sources. Their research found that in the United States, only 23% of energy was generated from renewables, compared to 60% from fossil fuels. Yet, through this research and determination, this study took a different route in focusing on how to reduce fossil fuel use and emissions. The changes emphasized the importance of streamlining manufacturing processes, incorporating artificial intelligence models to obtain more sustainable practices and changes, and focusing on supply chain and material procurement. A common theme in the literature focuses on the supply chain within the manufacturing processes of the aerospace industry to lower emissions and transition away from fossil fuels. This is seen in the two studies noted previously, as well as in the one by [Sophie I. Hallstedt](#), which focuses on the SAVE method paired with LCA (Life Cycle Assessment) to analyze sustainability issues in the industry. The assessment focuses on lowering emissions by changing design processes and recirculating materials within manufacturing processes.

These three studies continually highlight ways in which the transition away from fossil fuels to lower emissions can be completed within the Aerospace Industry. There is a large spotlight placed on supply chain changes, design changes, and, in general, just providing guidelines and data to conduct assessments within certain facilities to determine what can be done in order to transition away from fossil fuels and become more sustainable. Yet, a consistent gap noticed stems from the implementation of renewable energy sources to eradicate the use of fossil fuels entirely, and in turn, lowering emissions as well. Renewable energy sources are noted

in many studies, particularly their limited presence in energy generation and use. In order for the Aerospace Industry, specifically the production facilities, to truly make the transition away from fossil fuels in San Diego, renewable energy sources need to lead the conversation. This gap in information and data provides a pathway for my project to be highly important in showing the role that renewable energy sources have in the transition away from fossil fuel use. Additionally, the impact of the fossil fuel use within production facilities on communities that reside within the areas surrounding them has not been noted heavily in studies and literature surrounding this topic of sustainability within the Aerospace industry. Many of the studies focus heavily on the technical aspects of fossil fuel use and generation and how to lower it, but they continually leave out the impact that the high use of fossil fuels has on people and the environment. There is also minimal information provided on the positive changes in air quality and greenhouse gas emission rates felt by the communities when facilities have made these changes.

Through my project and exploring the potential challenges for renewable energy implementation in the aerospace industry, a path of importance can be shown based on the possibilities it provides to further the transition away from fossil fuel use in the industry, as well as to show a way in which facilities in the San Diego area can implement renewable energy sources to work closer to the transition away from fossil fuel use as a whole. Through this process, there will also be the ability to determine the reasoning behind why certain facilities and companies do not implement renewable energy sources at the facilities, and the option to work with their hesitations to provide reasons to further the swap of energy sources, as well as the ability to exhibit responses to their reasoning and resolve certain aspects of their concerns. For example, in San Diego, one reason for the minimal implementation stems from the lack of progress made in policies. [RE-2.1-SA-3](#) focuses on increasing renewable energy generation at non-residential developments through new policies or incentive programs. This action highlights that, although there are currently no incentives or policies directly implemented in San Diego, they will be implemented in the future based on San Diego's renewable energy policy, and this action is a key step.

METHODOLOGY/PROCESS

The methods used within this case study cover different aspects of the research question, not only the technical data side of things, when it comes to the inclusion of data from aerospace company sustainability reports, but also opinions from others and how policies are also generating a form of challenges for the transition to renewable energy for the facilities.

To begin, a bit of context is to be provided surrounding the aerospace industry and the current use of fossil fuels present within it. The aerospace industry is one that uses an immense amount of fossil fuels not only for daily production but also for product use. Additionally, a dive into the current incentives that San Diego provides when it comes to the transition to renewable energy is also included. This information is placed here as it allows for it to be seen that there are incentives that exist and that not all companies are taking advantage of ways that they can install renewable energy sources, while still retaining a positive profit margin, which oftentimes is one of the most important focuses for businesses. There is a highlight placed on aerospace industries

in particular, and how they choose to focus on other routes for reducing fossil fuel usage, like energy-efficient equipment and more, versus actually making the transition to renewable energy. This is covered further in the policy and implementation section of the project, highlighting the direct correlation between the actions of companies and the “guidelines” versus “requirements” put into place by the cities and counties in which they are located. This section specifically allows for the idea of responsibility to come into play - specifically, who does the responsibility fall on when it comes to working towards the transition to renewable energy, and how this can pose a challenge for the industry in itself, depending on the situation. Opinions and power can intermingle when it comes to the implementation of these different energy sources, and if those in power do not feel the responsibility to make the change, there will be no change. The difference between “responsibility” and “obligation” can be noted here as there is an obligation from the city to make a change to align with regulations and policies, but the responsibility falls upon those who have the power to make a more distinct, positive change.

Overall, there is context provided as well as a dive into other aspects of the industry that surround specific reasons why there are challenges faced by the industry to transition to renewable energy to power production facilities, as well as the current impact of the aerospace industry as a whole when it comes to the use of fossil fuels and the environment.

Moving further into the piece, one of the methods used stems from quantitative data obtained from my own company, L3Harris Technologies' sustainability report, which is then compared to the sustainability report published by Northrop Grumman. It allows for a number of changes to be seen when it comes to the aerospace industry's fossil fuel use for production and manufacturing facilities. Additionally, some aspects of my first-hand account, with the installation of renewable energy sources to power my company's San Diego production facility, will also be included to provide more information surrounding what challenges arise through the permitting and installation process. This serves as a combination of quantitative and qualitative data based on the metrics provided by the sustainability reports, as well as the first-hand experiences that will be described surrounding the implementation of the solar carport (renewable energy source). It will also provide a direct view into how certain companies value renewable energy, specifically if it is a main focus of their sustainability policies and changes, or if it is really placed on the back burner, showing internal challenges faced by those in companies who may be pushing for the use of renewable energy sources.

Finally, one of the larger sections of this project, that covers one of the largest challenges for the aerospace industry to implement renewable energy there will also be the inclusion of the term “greenwashing” and other sources included on this to cover all the bases regarding how, although this is a positive change, it is not an end-all, be-all solution based on the views and possibilities that arise with the shift to renewable energy. In order to have a holistic view on the challenges faced by the aerospace industry and the transition to renewable energy, there needs to be the placement of opposing opinions surrounding the use and implementation of renewable energy. This section includes excerpts and thoughts/opinions from blog posts created by those who are not directly affiliated with the industry. It allows one to see the differing opinions of

people surrounding renewable energy as a whole, introducing another challenge faced by the industry in its entirety. Specifically, the one surrounding the voice of public opinion as well as the way that human opinions and ideas are able to sway changes and decisions; if renewable energy is shown as a negative, why would there be a desire to implement it? Especially, if it will hinder production at some point.

Overall, all of these aspects blended together provide insight into the main challenges faced by the aerospace industry. It allows for different perspectives and viewpoints to be discerned for an overall understanding of challenges, providing different views and opinions to ensure that the challenges really take different aspects into consideration - not just the technological or policy challenges, but also the human-oriented ones, like opinions and different viewpoints.

RESULTS AND DISCUSSION

Aerospace and Fossil Fuels - Digging in Deep!

To begin, there have been advances within renewable energy in the aerospace industry, but not in the area in which one would expect. Production facilities, which are the focus of this project, are often left out of the equation. The majority of the changes desired and completed within the industry surround the actual products, specifically the planes that are generated and the rockets. For example, the piece [Renewable energies and sustainability in the aerospace industry](#) some of the changes that have progressed in the past stem from the development of lighter airplanes; this has to do with more aerodynamic designs as well as the use of metals that have a lighter atomic weight, which continually results in an overall lighter airplane. Another route that has been taken in the past is the introduction of hybrid and electric aircraft, which continually allow for less fuel consumption, which in turn results in a lower use of fossil fuels as well as less greenhouse gas emissions. This can also be seen with renewable energy sources, for example, there is currently a study occurring to see if there is a possibility for planes to be powered by solar energy, a renewable energy source, this brings an aspect of renewable energy into the fold, but solely when it comes to product use, like an airplane flight, versus the actual generation and manufacturing of the product which continually uses fossil fuels as well.

Although there is a large focus on the sustainable changes in the industry surrounding, there have been some changes at specific locations in San Diego when it comes to placing a focus on the manufacturing facilities, but not when it comes to renewable energy. For example, one aerospace company, [GKN Aerospace](#), in 2026 completed a sustainability assessment of the Industrial Training and Assessment Center (ITAC) for its production floor. Through this, it was allowed for the company to see the areas that utilized large amounts of energy that are not necessary. This is something that is common within the industry when it comes to the production facilities, going through this form of assessment. As noted above as well, it is necessary to determine which practices within the facility can be changed or altered to utilize less energy. Although these are always a good sustainable practice, it does not diminish the requirement for fossil fuels required to power the facility in any large capacity. Oftentimes, the assessment brings up turning off computer monitors or equipment when they are not in use. This is a good practice

and will reduce the amount of energy required to power the facility, but on the off chance the electronics cannot be turned off, there is no direct solution determined by these assessments to lower fossil fuel usage at the production facilities. General Atomics is another large aerospace company that is located in San Diego County, and as of June 2026, they have opted to continually expand their operations in San Diego. There has been mention of the grants that the company has received in order to obtain the ability to complete this expansion. According to the [Area Development News Network](#), “to support the project, General Atomics was awarded a \$20 million California Competes Tax Credit [in 2026]. Administered by GO-Biz, the program is designed to encourage business investment, job creation, and economic growth throughout California.” Although this announcement does not directly pertain to the continual fossil fuel usage of the company in San Diego, it brings up the notion of grants and credits allowing for the expansion of their facilities. This mention solely brings up another point of the ability for companies to also utilize these sorts of grants and tax credits to their advantage when it comes to renewable energy installation. San Diego County continually presents options for industrial facilities to complete these installations through grants and funding, as the entire state of California is hoping to make the transition to carbon neutrality. It then also begs the question, with the expansion of this large-scale company in the county, how much will their emissions increase? How much more fossil fuel will be required to provide electricity and energy to the production facilities where their work is completed? With an expansion of new infrastructure there is the ability for the facility to transition to renewable energy with more ease than those with older buildings and electrical connections. This would continually allow for a further movement away from fossil fuel usage, while also allowing for the company to take advantage of the resources California has provided for newer infrastructure installments. So if there is no change to this cleaner source of energy, what is the reasoning behind the lack of change?

As noted in the literature review section, there are minimal pieces that really dive into the carbon footprint that is generated directly from the production facilities of the aerospace industry, but the aviation and space industry contribute about 2.4% of global CO₂ emissions, and with the continued work being generated, and according to [Charles Antony Raj](#), the “environmental footprint represents a 29% increase over the 2013 emission levels, highlighting the rapidly growing climate impact of this sector.” The aerospace industry is directly responsible for large amounts of emissions, but this total increase covers all aspects of the industry, including product generation, use, and more. As mentioned previously, the majority of the carbon emission tracking emerges from the use of planes and rockets, which continually use large amounts of fossil fuels, but this also includes the use of fossil fuels at their production facilities, which are required in order to generate the products and all components.

Renewable energy is consistently becoming a larger part of our society and continues to become more apparent, yet, minimal production facilities in the San Diego area are using it as a way to lower their emissions and to transition to cleaner energy sources. Blogs and opinions of those who are within the industry and those who are not in the industry to discern their thought process behind why this is not a constant option taken on by the larger companies within the

industry. As many articles and researchers tend to focus solely on the larger products like planes, and less on the more mundane tasks like the buildings and processes behind generating these products, these are also the opinions and thoughts which provide insight into the thoughts of those who are interested and impacted by these facilities

Facility Studies - are companies focused on a transition to renewable energy?

One of the methods focused on a case study of L3Harris in San Diego. This facility is located in Kearny Mesa and is one of the aerospace manufacturing facilities that has made the transition to renewable energy in San Diego. However, one thing to keep in mind while reviewing this sustainability report is that although the facilities are making changes to allow for more sustainable workplaces, it is a company, so there is also an emphasis placed on cost-saving initiatives. A large number of the changes that are proposed and generated often have to tick both of the boxes in order to be considered. So, there are sustainable changes at play within this company, but it is important to remember the importance that money and finances play when it comes to the implementation of any sort of project.

Although a large amount of the information surrounding facility properties and use of materials is proprietary, the company provides an annual sustainability report that is sent out to the public that details the statistics of use for emissions, waste, and more. Although this report directly provides data from the company as a whole, these numbers paired with my experience at my facility and the changes that have been made for renewable energy provide insight into the changes that have been made and the positives that will arise in the present time and in the future surrounding the change to renewable energy.

Diving into the [L3Harris corporate sustainability report](#), there are multiple different metrics that the company chooses to cover, like waste reduction, greenhouse gas reduction, water use reduction, and, more importantly, a transition to 40% of all energy used by the company stemming from a form of renewable energy. The time frame of this sustainability report stems from the 2020 years up until 2030, providing ample time and capital to allow for sites to approach this goal.

Additionally, the site aforementioned earlier in this section is one of the sites that has transitioned over to 95% renewable energy to provide power to the location. According to the [L3Harris sustainability report](#), “in September 2024, our San Diego, California, site broke ground on new solar carports, which will fulfill approximately 95% of the site’s electricity demand with on-site solar energy. Construction took place throughout 2025, and we are in the final stages of fully connecting the solar carports to the building and to the local grid.” Currently, the company's goal of 40% has been surpassed 5 years early; they are not at the statistic of 42%. That signifies the desire to continue moving forward with renewable energy even though the main goal has already been surpassed. To provide a more overarching view on the use of renewable energy throughout the company, below is a table that indicates the metrics from 2021 to 2025 for renewable energy use and installation.

		2021	2022	2023	2024	2025
Metric	Units	Data	Data	Data	Data	Data
Other Direct Line Energy (Scope 2)	Terajoules	101	95	95	92	70
% Renewable Energy	Terajoules	3%	24%	22%	23%	30%
% Renewable Energy (Electricity only)	Terajoules	4%	35%	32%	33%	42%
Energy Intensity Ratio	Terajoules/\$ Total Revenue			1.80E-07	1.70E-07	1.5E-07

Renewable energy percent throughout [L3Harris facilities](#) - electricity and other sources

The continual increase in renewable energy usage can be seen, showing that different projects within the aerospace system have been generated. This data covers the company in its entirety, so it is important to note that this is not just for the San Diego facility, but they are one of the main contributors to the statistic that has allowed it to move forward toward more renewable energy sources.

On a different note, another aerospace manufacturing facility in the same realm of business is Northrop Grumman, and they have also provided a 2025 sustainability report. In the [sustainability report](#), there is also a renewable energy goal, which is to reach 50% renewable energy by 2030. Similar to L3Harris, this sustainability report covers the entire company and not the site that is specific to San Diego; however, from my own personal experience, it can be seen that the physical facility has no presence of renewable energy as the power source that has been installed on the facility property. As noted in the report, “in 2025, [Northrop Grumman] sourced 13% of our electricity consumption from renewables,” which is comparatively lower to the 42% noted by L3Harris. See the image below for the data provided by Northrop’s sustainability report.

TOPIC	2023	2024	2025	GRI	SASB
ENERGY					
Energy consumption (GJ)	10,928,080	10,688,470	11,076,100	302-1	RT-AE-130a.1
Renewable energy consumption (GJ)	922,540	678,100	779,540		
Percentage of energy that is renewable	8%	6%	7%	302-1	RT-AE-130a.1

Renewable energy percent throughout Northrup Grumman’s facilities from the [sustainability report](#)

In Northrop’s sustainability report, there is minimal mention of renewable energy. It takes up one small side section of one slide on a 30-page report. When comparing the two sustainability reports, it can be seen that one company favors the presence of renewable energy over the other, even though they are involved in the same industry and their locations are in the same area. It really brings up the question of the obstacles the industry is facing in installing renewable energy sources, to make it a focus, and why more locations are not focusing on making it a top priority.

To provide a bit of insight on possible obstacles or reasons given by companies to not install renewable energy infrastructure, like a solar carport, I am going to dive into the installation of the solar carport and what that consists of; the generation and construction of these projects are often quite long-term projects. The initial conversations for these sorts of projects began prior to the ground-breaking, starting construction, due to the immense planning required by the city for permitting as well as the facility to make adjustments to normal operations to ensure that all areas function and are accessible to employees. It can create some issues with everyday tasks like parking for employees, as for a solar carport, large sections of the parking lot for a facility are closed to install the solar panels, as well as the structures to hold them. Additionally, as mentioned earlier, the permitting process for construction through the city of San Diego can take months for approval, which can continually delay a project based on the date that is provided by the city to allow for construction to begin. Finally, and admittedly, what I believe is the largest reason behind why manufacturing facilities are not making this switch is the need for a total shutdown of the facility, no electricity from their local provider, for a certain amount of time as a shutdown is required to connect the solar panels. This shutdown requires an entire shutdown of all building power in order to connect the electrical system over to the panels. The size of the facility and the amount of electricity needed will also impact the infrastructure installation and the amount of time required for the shutdown. When this shutdown happens, all manufacturing can cease to progress due to lack of power; meaning that the manufacturing stalls for whatever period of time is required. This can result in a loss of manufacturing time, and it has the potential to result in a loss in profit based on the lack of materials and products being generated. Although this does not highlight all of the possible obstacles, it provides insight into the mindset of businesses that are present within our society and the high reliance on profit over the desire to transition to a cleaner form of energy, almost as putting profit over the environment and people, when profit is placed at a higher importance than transitioning to a clean energy source. This can be seen not as an “obstacle” but just a possible reasoning behind the lack of transitions to renewable energy at these facilities, highlighting the priorities of the businesses.

All of the permitting and construction processes, which are briefly mentioned above, bring up more potential obstacles when it comes to the different installation processes of renewable energy sources. These prove to be closer to obstacles based on the planning, permitting, and infrastructure that needs to be erected in order to allow for the energy sources to be completed and generated.

Greenwashing in the Industry

In order to incorporate different viewpoints surrounding renewable energy and its installation, a deep dive has been completed for blogs and other opinion platforms that include the opinions of people in and outside of the aerospace industry. The blogs mainly cover the perspectives people have on renewable energy and whether it can really be considered a solution to fossil fuel usage. Although these blogs are not directly correlated to aerospace production facilities, this piece surrounds the implementation and use of renewable energy, or the lack thereof, surrounding the use and implementation, and these blogs provide more viewpoints on

possible reasons for the lack of implementation. The greenwashing point of views provided below provide more insight into a possible challenge faced by the industry when it comes to the implementation of renewable energy, the challenge in this case being the opinions of those who are involved with the process, not finding it as a solution to their consumption of fossil fuels. I do want to make note that the majority of choices by enterprises stem from financial decisions and constraints; however, this viewpoint, when paired with that idea, does provide a possible challenge faced by the industry when going through a possible renewable energy source implementation.

One of the opinions that can be found surrounding renewable energy is that it really does not provide a new source of “green power.” According to [Lindwall](#), greenwashing can be defined as “the act of making false or misleading statements about the environmental benefits of a product or practice. It can be a way for companies to continue or expand their polluting as well as related harmful behaviors, all while gaming the system or profiting off well-intentioned, sustainably minded consumers.” An example of this could be the ways in which companies are providing “energy efficient” actions to their employees, like shutting off monitors, turning of lights when not in use, and such, instead of really tackling the main issues surrounding their negative environmental impact - like excessive fossil fuel usage to power the facility as a whole. Although these energy efficient choices are important to make change, they really should not be the center of focus for companies when larger scale changes can be made to make a greater impact, for example, a company that may utilize fossil fuels to power all of the fleet vehicles encouraging personnel to turn off monitors to lower their carbon footprint, while completely avoiding switching over to electric vehicles to remove their excessive fossil fuel usage shows a lens of greenwashing when it comes to certain actions companies take.

Moving forward with this topic, according to [Michael Gillenwater](#), who has written a blog surrounding how green power really appears to be another form of green washing, there is also a more contractual reason why green power, like renewable energy, appears to contribute to the overall viewpoint of greenwashing. His idea stems from the contractual agreements that companies are able to make in order to purchase green energy to power their facilities, when in reality, there are oftentimes where facilities cannot choose whether the electricity they receive comes from the grid that is powered by a renewable energy source or fossil fuels - this is specific to facilities do not have their own infrastructure generated, for example, a carport installed at a facility provides the electricity to that facility, but those who do not have their own infrastructure fall under this contractual side of things. He notes how “we need to consider the implications of endorsing contractual approaches for attributional environmental accounting more broadly. Can anyone contractually buy ‘environmental attributes’ for anything and adjust their environmental accounts accordingly?” This provides a unique perspective on why renewable energy, when used for industrial facilities, can be seen as greenwashing. It also brings the idea of how renewable energy can be used by companies to sort of place a spotlight of sort on it to deter viewers/eyes from the other impacts they have. For example, if a company were to install solar panels for energy, but continued to use fossil fuels to power their products and cars used throughout the

facility, there is a change they can highlight, but still other large factors that contribute to the negative environmental impacts. Compared to other opinions that have been generated, this one focuses on the process of facilities and companies “purchasing” green power, like renewable energy, from power plants, but Gillenwater confirms through his search and piece that at that time, it could not be chosen which power grid a facility was connected to, referencing whether one was powered by green energy or fossil fuels. [Gillenwater](#) does include that this is not something completed out of malice, instead it does show the good intention surrounding the desire to use green power, but it is a “fundamentally flawed foundation - that buying a virtual attribute can substitute for physically consuming a specific good or service.”

Another blog that takes a different approach, focusing more on the materials and the impacts of continually using renewable energy, was created by [Alasdair Green](#), who is a member of the AAB energy team, confirming that he has insight and knowledge surrounding the use of renewable energy. Alasdair opens his piece with the two sentences, “With significant renewable energy-driven growth in the electrification of our homes, vehicles, and infrastructure, this means there will be a very large increase in demand for base metals, such as copper, in the manufacture of wiring and components. Other essential metals such as lithium and cobalt used in batteries are in extremely high demand and bring with them their own environmental and ethical supply problems.” His blog post continues to highlight the issues that stem from renewable energy and how it also has negative environmental impacts based on the consistent need for materials. These earth metals require mining and large extraction processes to obtain them, which continually utilizes resources and can cause detrimental changes to the environment in which these processes are enacted. Additionally, [Green](#) brings up the point of electric cars and how it is quite important to continually reduce the amount of emissions generated by them: “emissions are still produced, however, at the power station that generates the electricity [to power and charge them].” He brings up the common stance surrounding the fact that even though the electricity used to power certain items or facilities is green, there is still the need to process that energy and supply it in a way that generates emissions, so in a way, it seems almost like a cancel-out process for emissions and not a complete removal of them. While any action is better than none, this brings up another aspect that was mentioned previously about positive aspects being in the spotlight, the EVs, but the other impacts, the energy processing, to be somewhat overlooked since they are not the mainly market part. This also brings up the point regarding the lesser-evil which is mentioned at different times throughout this piece, as well as being further explained in this section, when it comes to the comparison of renewable energy sources and fossil fuels. This information provides some insight into the view on renewable energy that someone involved in the energy industry has.. Simplified, it really leads to the main point: do the changes really result in any sort of benefit or change from using fossil fuels if emissions are generated regardless? In all reality, this boils down to the idea of a “lesser evil.” Which one really will result in less impact and allow for there to be a greener source for something that is never going away, like electricity. As noted, the renewable energy sources are this lesser evil as they may have an impact in the creation, but

throughout their use, there is the ability for there to be less emissions and negative impacts compared to the consistent burning of fossil fuels.

Additionally, the [Quora user “James Michael Cavanagh.”](#) who is a musician and author and is not directly involved in energy proceedings or the aerospace industry, brings up another point on opinions people have about the renewable energy implementation in the aerospace industry. He began his post with the notion, “to me, the whole Green direction, while being well-intended, has become a trendy talking point. It has become so politicized that it has created controversy.” This brings up the idea surrounding renewable energy being a trendy topic. Are the changes really happening to improve the environmental impact of companies, or mainly because it is a hot topic in the media and makes them look more desirable? He continues by noting the weaknesses of wind and solar power, specifically that there is insufficient involvement and manpower from the government and other industries to keep the “farms” and power generation adequate for use. Yet, while noting the weaknesses, he does include the acknowledgment that a transition will eventually be necessary, but not for an environmental reason, but on the fact that the fuel resource is finite and eventually it will run out. This provides another viewpoint that does not directly surround the environmental impact being the need for change, but provides a different stance on the use of finite resources being entirely depleted. This provides more insight into the possible minds of those heavily involved in corporate America, being that the change will be needed as the source may run out, versus making the change to preserve the environment and lessen the impacts.

All of these viewpoints provide further insight into a potential challenge the industry faces in installing renewable energy sources, specifically surrounding the ongoing beliefs people have when it comes to renewable energy and if the installation will actually make a positive change. Through a greenwashing lens, one can see the potential negative thoughts people have about renewable energy as a whole. The blogs above provide three different opinions from people with different backgrounds, and it is likely that many others share similar opinions. When it comes to implementing changes within a facility, there is consistent input from others. So, if someone who is highly important in making the decision to transition to renewable energy holds this opinion, could it derail efforts to move away from fossil fuels as the main energy source? In my opinion, the short answer is yes. The views provided in the blogs provide valid reasons as to how renewable energy can be seen as greenwashing, and if someone is to have that opinion, this could be one of the challenges faced by the aerospace industry when it comes to implementing renewable energy to power their production facilities and move away from fossil fuel use. However, with this topic, using differing viewpoints on renewable energy as a whole, it can be seen that there is no “one right solution” when trying to eliminate the use of fossil fuels; so, it really boils down to which is the lesser evil, as mentioned previously, and which source will allow for there to be a lesser impact. When comparing fossil fuels to renewable energy, renewable energy is the lesser of the two evils based on the overall impacts and the abilities it poses for the future. Overall, greenwashing is most definitely prevalent in the realm of renewable energy, creating a possible challenge for the aerospace industry to overcome for implementation,

and yet, the inclusion of these differing opinions allows for one to have an alternate viewpoint on renewable energy and see why it really boils down to why it may be the best option compared to the current process surrounding the use of fossil fuels.

Greenwashing 2.0 - Object Analysis: Are Solar Panels Truly Sustainable?

A deep dive into object analysis continues to bring the greenwashing viewpoint surrounding renewable energy, based on all of the implications surrounding one of the most important items to actually generate solar energy. The chosen item to focus on is a solar panel that can be installed to generate electricity from sunlight.

The story of these items shows development and progress in the transition away from fossil fuels. It provides hope for a renewable energy source, but also can further the agenda of pollution and impact lower-income communities based on where the materials need to be sourced and how they need to be sourced, allowing for one to see based on the negative impacts that occur during production, how portions of this type of energy can be seen in a “greenwashing” light. Metal, which is a main component of the solar panels, must be mined in order to get them in the quantities needed to generate large amounts of the panels. However, this is a very niche object if you begin to look at all the small interior parts that create the makeup of the panel itself. Yet, the small interior parts are really what allow one to understand all the processes and impacts that these panels really have - the makeup of the panel is like the details of the story. Where it comes from, where it is, how it works, why it is important, the impacts it has, etc.



Graphic generated and used by the [U.S. Department of Energy](#) to explain solar panels and solar energy

Solar panels are installed in this world to generate renewable energy. They were designed to make electricity more accessible to those who may not have direct access to the electrical grid and to move away from fossil fuel use. According to [Re-Volv.org](#), solar panels became highly important in the Western hemisphere as “the rise of solar power is closely tied to rising awareness of the dangers of climate change and the need for low-cost, zero carbon sources of electricity. Following the signing of the Kyoto Protocol in 1997, a growing number of countries instituted policies to promote the use of solar in the 2000s, led by Japan, Germany, China, and even the United States, which put in place solar tax credits in 2005 despite not being a party to the Kyoto Protocol.” However, this is how the solar panel is situated in the Western hemisphere;

what about the other hemisphere? Solar power is utterly expensive and labor-intensive to obtain, based on the requirements for obtaining the metals through mining as well as the requirement to create the panel in itself. So, although it can be seen throughout Europe and the United States, it may be less prevalent in the countries that need it more than others. Additionally, the mining required to obtain the metals to make the panels generates large amounts of waste through excessive water use, the tools required to mine, and excessive labor (often obtained illegally). Communities surrounding these mining areas can face high water costs, lack of water, polluted water, high electricity costs, illegal use of land, and ecosystem destruction. This often happens in the countries in which the metal is obtained, which often are not the countries that use the solar panels, but instead the ones that would benefit more from their installation if there is not a direct line to the electrical grid. This poses the question: are the benefits of using solar panels higher than the requirements and negative impacts of obtaining the materials to create them? Why are some areas and communities able to obtain and use these panels, while others are not?

The excerpt above leads to the question of who has power over this object, which directly links to those who generate them and who control the cost of use and installation, oftentimes, large corporations that abuse their power to generate profits. The perception of this object, though, has multiple lenses. It can be perceived as a solution, but also a burden based on the amount of resources and how the resulting treatment of people is.

This object is highly meaningful to my project as it can lend more to the opposing viewpoint of greenwashing when it comes to the implementation of renewable energy. Based on the history of the object/material, the negative environmental impact associated with obtaining these metals to create the solar panels is evident. Mining, resource waste, impacts on communities, and more are further illustrated in this deep dive. It allows for alternate opinions and perspectives to be found surrounding the use, development, and implementation of renewable energy as an alternative to fossil fuels. It highlights the environmental and communal impacts of obtaining the materials required to complete these panels and eventually utilize them.

San Diego County Policies- A focus placed on Public Facilities

Another possible challenge that is posed surrounding the implementation of the renewable energy sources for the aerospace industry production facilities stems from the policies within San Diego county.

San Diego county does in fact make efforts in order to continually completed the transition away from fossil fuel usage, as noted by the [City of San Diego](#), since 2024, their goal is to have zero emissions generated from the municipal buildings by 2035 and also to remove natural gas from 50% of the municipal buildings by 2030 and have it entirely removed by 2035. They recently launched a framework that allows for the buildings within the city to discern how to decarbonize their buildings and to eliminate the use of non-emergency fossil fuels in their entirety; through this, their strategies incorporate the implementation of renewable or zero-carbon energy to power municipal building operations. This piece does show the commitment that the city of San Diego has when it comes to the transition away from fossil fuel usage, specifically natural gas, in the realm of municipal buildings. However, it does continue to

beg the question if renewable energy is so highly engrained in their processes, why are more sites not making the transition if the goal is 100% by the end of 2035? This brings in the challenge, as the majority of companies likely view this as a “long time away” when in reality, the installation of renewable energy, if it will be centralized on the site, can take multiple years to install based on the size and desired power capacity. At my own facility, which recently has installed a solar carport to provide electricity through renewable energy, it has taken over a year and a half to get all the infrastructure installed as set up all the electrical component, and it still has not been directly connected to the facility yet. So, mindset of companies here can be seen as a potential challenge if people do not continue to realize that these changes cannot be made on a whim, they require time, planning, and patience based on permitting processes, installation, and agreements with electrical companies to correctly hook up the facility to the power.

Additionally, San Diego county places an emphasis on public municipal properties when it comes to transitioning away from fossil fuels. As noted by [The City of San Diego](#) under their “Public Utilities” section, using solar power as an example for this, photovoltaic solar power systems are connected to several public facilities like the Alvarado Water Treatment Plant, the Bayview Reservoir and Water Pump Stations, the Metropolitan Operations Center III, the Metropolitan Operations Center IV Carport, and the Otay Water Treatment Plant. Another piece that highlights similar actions is the “Sustainable Building Policy” generated by the [City of San Diego](#). This policy has a section under standards that highlights “City-owned and occupied new construction and major renovation projects of buildings containing more than 1,000 square feet of conditioned space shall include or made ready for onsite renewable energy generation as required by San Diego Council Policy 900-03, Zero Emissions Municipal Buildings and Operations Policy.” These are all facilities that generate now, or in the future based on the policy, a form of renewable energy in order to complete their operations, however, it is noted that all of these are public facilities or new facilities. What about the old facilities and/or the private ones? A large number of them are water treatment plants, which are used by vast amounts of areas in San Diego county. Yet, this brings up another possible challenge, specifically derived from this information, if San Diego county is focusing on their public facilities, where is the focus with the private facilities, like aerospace industry production facilities. This begs the question if the city will provide a direct incentive to private locations to directly transfer over to renewable energy, or if it will have to also stem from the accord of the private companies in themselves. An incentive for older infrastructure private facilities would allow for transfers to be more prevalent, allowing for people to feel as if they have the ability to make the change as it is noted by the governing body in which their facility is located. This provides another possible challenge when it comes to why more facilities might not be transitioning, if it is not directly incentivized or required by the county, why would the companies have any interest in transferring over? This highlights the importance of responsibility when it comes to the installation and use of renewable energy, if it falls on the state/county, or if it falls on the company itself. This situation highlights that the responsibility falls upon the companies themselves, they have to make the change and create the route for installation and use. The

policies provide a baseline of what needs to be done within the county to remain in compliance, but in order to take it a step further and create change within the company and the culture of it, those in power within the company have to take the first step. Thus, posing yet another challenge, another challenge of opinions and human interaction. If companies do not view the transition as profitable, due to delay of work, cost of installation, cost of energy, etc., it is likely that it will not occur. This then creates the challenge, if no one on the board is bought into the installation of the renewable energy or using it from a different source, there will be no transition, resulting in a continual use of fossil fuels. Continuing to pump GHG into the atmosphere, degrading air quality, raising global temperatures, and more.

On a different note, a large amount of the requirements enacted by the City of San Diego focus on becoming “energy efficient.” This terminology can have multiple different meanings if speaking to different people who have different opinions. [Minkyu Song](#) noted how the standards enacted by the California Energy Commission (CEC) focuses on the installation of energy efficient heat pumps and other equipment, improved ventilation standards, and more. From this piece it can be noted that the San Diego implementations do not directly revolve around the implementation and use of renewable energy. Their terminology when it comes to energy efficiency is replacing old equipment that uses more power to save electricity. Newer equipment often is more energy efficient, requiring less intensity of power from the energy grid, which in turn does provide some reprieve for the grid and lower the requirement of energy needed. While this is a good alternative, it does not entirely resolve the issue of fossil fuels, but just lowers the amount required when facilities are in use at any point. This provides another challenge stemming around why the transition is not happening at more aerospace facilities, and it once again falls along the lines of responsibility. It proves that if companies are able to transfer and change their equipment, they fall within this “energy efficient” segment, meaning that to them, they do not directly need to make the change to renewable energy since they are already within the guidelines, especially if it is an older facility and not a newer one, which is noted in the [City of San Diego Council Policy CP 900-14](#). So, it is another responsibility and opinion challenge, and it all boils back down to showing that in these cases it falls heavier on the companies to truly make the transition, and without any incentive or forced requirement, are they really making the change to renewable energy as quick as they should?

SUMMARY

Overall, the deep dive into the challenges faced by the aerospace industry when it comes to the implementation of renewable energy appears to stem not only from the technical side of installation and community/county policies, but also the opinions people in the industry have regarding the importance of renewable energy sources. There are always technical and implementation challenges that come with renewable energy, but the opinions and beliefs of other surrounding the true “greenness,” for lack of a better term, of people really pose the largest challenge. This stems from a connection between opinions and beliefs with the importance of decisionmaking and power within the industry. The opinions of those in power are the strongest

when it comes to making a decision, so if those with the power have no interest in going toward the transition, there often will be no change.

Oftentimes, influence, power, and choices are also intertwined with capital gain, if there is minimal room for savings, or profit, there is a notion that the change will not occur. Although this is not the desirable case, it is the situation surrounding the implementation of renewable energy based on the delays it can pose with installation as well as the cost of installation when it comes to permitting and more.

CONCLUSION

Going back to the beginning, so really what is the reason behind why these companies do not make the change to renewable energy? There are a cluster of factors behind this notion, starting with the opinions of those in power, when it comes to the importance of renewable energy. Which also leads to the opinions of those not in power, if no one is going to lobby for the change, if no capital gain or savings have been noted, will there be any reason for the consideration to even happen in the first place? There are technical challenges that come with the installation of renewable energy, but all in all, the largest challenge faced appears to be the opinions/beliefs of those in power, paired with their notion of “their responsibility” to not only the companies and investors, but also the environment as a whole.

So, after a thorough review and deep dive into the industry and diving into all the challenges at hand, it can be noted that one of the larger challenges stems from the question - who bears the responsibility to make these changes? As noted in the piece, the responsibility really does fall upon the industry and companies within it, so if there are people not willing to make the change, will it ever really get made at all? From all the information provided, it can be seen that the next steps required to overcome these challenges heavily rely on moving implementation processes forward, while also providing more information and teaching the people within the companies the true benefits of renewable energy. There needs to be knowledge provided to permit growth and understanding about how the transition will assist not only themselves in the long run, but also the environment as well. Through these changes, there would be the ability to reduce the impacts of these challenges faced to ensure they can be overcome, while also furthering the notion that fossil fuels must be phased out of the industry based on the destruction and devastation they can, and have already, caused.

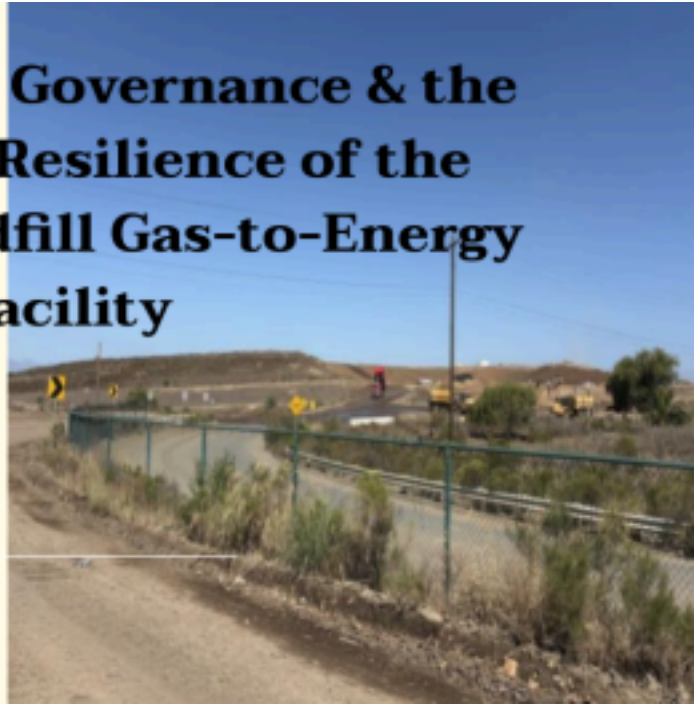
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Collaborative Governance & the Long-Term Resilience of the Miramar Landfill Gas-to-Energy Facility



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Collaborative Governance and the Long-Term Resilience of the Miramar Landfill Gas-to-Energy Facility

Abstract

Critical infrastructure is frequently evaluated according to its technical performance; however, comparatively less attention has been given to the governance arrangements that enable infrastructure systems to endure over time. The Miramar Landfill Gas-to-Energy (LFGTE) Facility in San Diego, California, represents a longstanding collaboration among municipal government, the U.S. military, and private industry. While previous studies have largely examined landfill gas-to-energy facilities through engineering, environmental, and regulatory perspectives, this study investigates the institutional conditions that have sustained Miramar's operation for more than two decades.

Using a qualitative single-case study design, this research integrates peer-reviewed literature, publicly available government documents, technical reports, and a semi-structured stakeholder interview to examine the governance framework supporting the Miramar LFGTE Facility. Findings indicate that the facility's longevity is not adequately explained by technological innovation or California's supportive renewable energy policies alone. Rather, Miramar's continued success is better understood through collaborative governance characterized by long-term land-use planning, complementary stakeholder incentives, adaptive institutional relationships, and sustained public-military-private partnerships.

The study further suggests that while landfill gas-to-energy technology is technically replicable, long-term project success depends upon governance capacity rather than engineering alone. By reframing the Miramar LFGTE Facility as a case study in collaborative governance, this research contributes to broader discussions of resilient infrastructure and institutional resilience while offering practical insights for policymakers, infrastructure planners, and communities seeking to develop durable, adaptive, and collaborative public infrastructure systems.

Keywords: *landfill gas-to-energy; collaborative governance; resilient infrastructure; institutional resilience; public-private partnerships*

1. Introduction

Invisible Infrastructure and the Importance of Waste Systems

Communities depend upon infrastructure systems that quietly sustain public health, economic activity, environmental quality, and resilience. Yet many of these systems remain largely invisible until they fail or are disrupted by extraordinary events. As climate change increases the frequency and severity of natural disasters, the resilience of these systems has become an increasingly important determinant of community preparedness, recovery, and long-term sustainability.

San Diego is no exception. Often recognized for its coastline, climate, and quality of life, the region depends upon complex infrastructure systems, including water treatment facilities, electrical transmission networks, transportation corridors, military installations, and waste management systems, that quietly supports the health, safety, and economic vitality of the region. Although these systems are essential, they rarely receive public attention.

Waste management represents one of the clearest examples of this invisible infrastructure. It is essential to modern society, but as mentioned, often overlooked until extraordinary events expose its importance. Most residents rarely consider where their waste goes after collection or how municipal waste systems contribute to broader environmental and community objectives. Yet in a growing urban region with a significant military presence, thriving tourism industry, and expanding population, waste generation is an unavoidable consequence of our comfortable lifestyles. Even as municipalities pursue ambitious zero-waste initiatives and recycling programs, certain waste streams, including those generated by disasters, cannot simply be eliminated.

Annual wildfire events throughout California are testaments to this reality. Following the 2025 Los Angeles County wildfires, the [U.S. Army Corps of Engineers](#) estimated that approximately 4.25 to 4.5 million tons of disaster debris required removal, including structural ash, burned vehicles, metals, concrete, contaminated soil, chemical and other hazardous materials. Federal cleanup operations alone removed more than 2.5 million tons of debris within months of the disaster. To place this volume in perspective, Los Angeles County typically generates approximately 10 million tons of municipal waste annually, meaning a single wildfire event produced nearly half of the county's annual waste stream almost instantaneously.



Figure 1: U.S. Army Corps of Engineers - Los Angeles County Wildfire Debris Removal Mission

The consequences of these events extend well beyond emergency response. Disaster debris affects landfill capacity, hazardous waste management, transportation systems, watershed health, drinking water quality, and long-term community recovery. As climate-driven disasters become more frequent and severe, resilient waste infrastructure has become an increasingly important component of climate adaptation rather than merely a municipal service. Despite California's extensive wildfire mitigation strategies and robust municipal waste management programs, disaster debris often exists between these planning frameworks rather than within them, recognizing the need to view waste infrastructure as part of broader resilience planning.

Landfills are frequently viewed as environmental liabilities because they occupy valuable land and generate methane, a [greenhouse gas with significantly greater global warming potential than carbon dioxide](#). However, advances in landfill gas collection have enabled many facilities to evolve beyond passive waste disposal sites. Modern [landfill gas-to-energy](#) (LFGTE) systems capture methane produced through waste decomposition and convert it into renewable energy, reducing greenhouse gas emissions while creating an additional public value.

One notable example is the Miramar Landfill and Greenery in San Diego, California. Beyond serving as the city's primary municipal landfill, Miramar captures landfill gas and converts it into renewable energy that supports both municipal and military operations. The facility supplies energy supporting Marine Corps Air Station (MCAS) Miramar and the adjacent North City Water Reclamation Plant while also contributing to regional energy resilience through renewable power generation.

First and foremost, Miramar appears to represent a straightforward engineering success. Methane is captured, electricity is generated, and greenhouse gas emissions are reduced. Existing technical literature largely evaluates projects such as Miramar using performance metrics including methane capture rates, energy production, emissions reductions, and economic feasibility.

However, technical performance alone does not explain why Miramar has remained operational for more than two decades.

Unlike many infrastructure projects, Miramar exists within a complex network of institutional relationships involving the City of San Diego, MCAS Miramar, Opal Fuels, regulatory agencies, and numerous public stakeholders. These relationships have required sustained collaboration across organizations with distinct missions, responsibilities, and priorities. While the engineering supporting landfill gas recovery is well understood, comparatively less scholarly attention has been given to the governance arrangements that enable these infrastructure systems to endure over long operational periods.



Figure 2: Key Institutional partners in the Miramar Landfill Gas-to-Energy Facility

This distinction shifts the central focus of the project. Rather than asking whether landfill gas-to-energy technology works, this research examines the institutional conditions that have allowed one particular system to endure.

Accordingly, this study asks:

What governance and partnership arrangements have enabled the Miramar Landfill Gas-to-Energy Facility to operate for more than two decades, and can those conditions be meaningfully replicated in other municipalities?

This question extends beyond San Diego. Municipal governments throughout the United States face increasing pressure to improve infrastructure resilience while addressing climate change, renewable energy goals, aging public assets, and growing waste generation. Understanding the governance arrangements that sustain long-term infrastructure may provide valuable insights for policymakers seeking resilient and durable public infrastructure solutions.

This paper argues that the Miramar Gas-to-Energy Facility longevity is better explained through collaborative governance than engineering alone. While landfill gas technology provides the technical foundation, decades of institutional collaboration among municipal government, the military, and the private sector have enabled the facility to continue creating value for multiple stakeholders. Understanding these governance conditions offers lessons that extend well beyond landfill gas-to-energy projects and contributes to broader discussions of infrastructure resilience and public-sector collaboration. While previous studies largely evaluate landfill gas-to-energy facilities through engineering and environmental performance metrics, this study reframes Miramar as a case of collaborative governance, recognizing that institutional resilience may be as important as technical performance in explaining long-term infrastructure success.

2. Methodology

2.1 Research Purpose

The purpose of this research is to examine the governance and partnership arrangements that have supported the Miramar Landfill Gas-to-Energy Facility for more than two decades. While existing literature thoroughly documents the engineering, environmental performance, and regulatory aspects of landfill gas recovery, comparatively less attention has been given to the institutional relationships that sustain these projects over time. By examining Miramar as a governance case study, this research strives to better understand how collaborative partnerships contribute to resilient public infrastructure.

2.2 Research Question

As previously stated, the central research question guiding this study is:
What governance and partnership arrangements have enabled the Miramar Landfill

Gas-to-Energy Facility to operate for more than two decades, and can those conditions be meaningfully replicated in other municipalities?

Supporting questions include:

- How do different stakeholders define project success?
 - What institutional relationships have contributed to project longevity?
 - What governance mechanisms support long-term collaboration? •
- Which characteristics appear transferable to other municipalities?

2.3 Research Design

This study employs a qualitative single-case study approach. [Case study methodology](#) is particularly appropriate when investigating contemporary phenomena within their real-world context, especially when the boundaries between phenomena and its surrounding environment are not clearly defined. Because this research strives to understand how governance relationships have evolved across multiple organizations over time, a qualitative case study provides the depth necessary to examine institutional complexity that would be difficult to capture through quantitative methods alone.

Rather than comparing multiple landfill gas projects, the research intentionally focuses on a single case to allow for a detailed examination of the historical, institutional, and organizational conditions that have contributed to Miramar's long-term operations. Although Miramar possesses characteristics that may not be universally replicable, studying the interactions among municipal government, the military, and private industry provides an opportunity to better understand collaborative governance within critical infrastructure systems.

This research also draws upon approaches commonly used in infrastructure [governance](#) and [public administration](#) studies, where qualitative case studies have been widely employed to examine collaborative governance, public-private partnerships, and institutional resilience.

Also, this study will focus primarily on three institutional actors: City of San Diego, Opal Fuels (Fortistar), and MCAS Miramar.

These organizations represent municipal government, private industry, and federal military interests, respectively. Together, they form the core relationships that appear to have shaped the project's development and continued operation. Additional stakeholders may be referenced when relevant, but the primary analysis will focus on interactions among these three entities.

2.4 Data Collection

Data is collected from three primary sources. First, a review of peer-reviewed literature established the theoretical foundation for landfill gas-to-energy systems, collaborative governance, public-private partnerships, institutional resilience, and resilient infrastructure.

Second, publicly available documents, including City of San Diego publications, regulatory permits, technical reports, policy documents, and organizational materials, provided historical context, governance information, and operational details regarding the Miramar Landfill Gas-to-Energy Facility.

Finally, primary data were collected through a semi-structured interview with an MCAS Miramar Public Works Officer. The interview provided institutional perspectives regarding the historical evolution of the partnership, stakeholder roles, governance arrangements, operational priorities, and perceptions of long-term project success. Interview findings were used to complement and contextualize information obtained through documentary sources rather than serve as the sole basis for analysis.

2.5 Data Analysis

Data were analyzed using qualitative thematic analysis. Interview notes, government documents, technical reports, and relevant literature were reviewed through multiple rounds of close reading to identify recurring concepts related to governance, stakeholder relationships, institutional resilience, long-term collaboration, land-use planning, and infrastructure management. Initial observations were manually organized into thematic categories, which were then compared across data sources to identify areas of commonalities and distinctions.

Themes were developed through an iterative process of document review, note comparison, and ongoing reflection. This inductive approach allowed governance patterns to emerge from the collected evidence while remaining informed by established concepts in [collaborative governance and public administration](#) literature.

To strengthen credibility, findings were validated across peer-reviewed literature, government documents, organizational publications, and interview data. Comparing [multiple independent sources](#) reduced reliance on any single perspective and increased confidence in the consistency of the resulting themes.

2.6 Theoretical Framework

Analysis was informed by theories of collaborative governance, public-private

partnerships, institutional resilience, and boundary-spanning organizations. These frameworks provided analytical perspectives for examining how organizations with differing institutional missions sustained collaboration over an extended period while adapting to changing environmental, regulatory, and operational conditions.

Rather than evaluating engineering performance alone, the study considers governance as the primary mechanism through which infrastructure resilience is created and maintained. This perspective recognizes that durable infrastructure depends not only on technological innovation but also on institutional arrangements capable of sustaining collaboration across organizational boundaries.

2.7 Scope and Limitations

This research focuses exclusively on the Miramar Landfill Gas-to-Energy Facility and therefore does not seek to produce universally applicable conclusions. Instead, the findings provide analytical insights into how collaborative governance may contribute to the long-term resilience of complex public infrastructure.

Several limitations should be acknowledged. First, the study relies upon a single case and one primary stakeholder interview, limiting the range of institutional perspectives represented. Second, certain contractual agreements, financial records, and operational decisions remain proprietary or otherwise unavailable to the public. Finally, because governance relationships evolve over time, the findings reflect conditions documented during the period of this research rather than every stage of the project's historical development.

3. Literature Review

To better understand Miramar's longevity, the literature review proceeds in three stages. First, it establishes the historical development of the Miramar Landfill and the evolution of its landfill gas-to-energy facility. Second, it examines California's regulatory and policy environment as an enabling context for landfill methane utilization. Finally, it reviews scholarship concerning collaborative governance, public-private partnerships, and institutional resilience that provides the theoretical framework for analyzing Miramar's long-term success.

3.1 Historical Context of Miramar

Understanding the long-term operation of the Miramar Landfill Gas-to-Energy Facility requires first examining the historical circumstances that shaped its development.

Although the facility is frequently recognized for its renewable energy production and methane recovery, its origins lie in a series of land-use, governance, and infrastructure decisions made decades before landfill gas was considered a viable energy resource. These early decisions established the institutional relationships that continue to support the project today.

By the late 1950s, [San Diego](#) experienced rapid population growth, suburban expansion, and economic development driven largely by the region's expanding military presence and defense industry. Between 1930 and 1950, the city's population more than doubled as military personnel, defense workers, and their families relocated to the region, creating increased demand for housing, transportation, water, wastewater treatment, and municipal solid waste services. Simultaneously, continued military expansion heightened the importance of protecting installations from incompatible surrounding development, encouraging long-term land-use planning that preserved operational flexibility while accommodating regional growth.

The Miramar Landfill was established in 1959 after the [City of San Diego](#) entered into a long-term lease agreement with the U.S. Navy to develop a municipal landfill on federally owned property. Rather than representing a simple real estate transaction, the agreement reflected a mutually beneficial land-use strategy. The City secured a long-term solution for municipal waste disposal, while the Navy preserved a compatible buffer around the air station that protected military operations from residential encroachment and conflicting land uses.

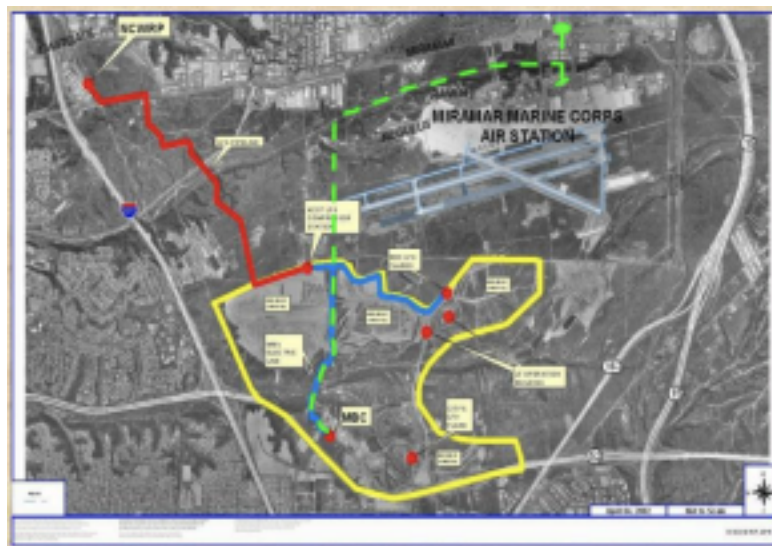


Figure 3: Fortistar - Miramar Landfill Map

This planning decision continues to influence the facility today. Unlike many municipal landfills that experience increasing development pressure as surrounding communities expand, the Miramar Landfill remains bordered primarily by military property, industrial uses, and open space. According to an interview conducted for this study with an MCAS Miramar Public Works Officer, maintaining this buffer has remained an important objective because it preserves operational flexibility, supports mission readiness, and minimizes conflicts between military activities and surrounding land uses. More than six decades later, the original land-use strategy continues to provide benefits for both the City and the military.

As San Diego continued to grow, the Miramar Landfill evolved beyond a conventional disposal site into a comprehensive municipal waste management facility. In addition to accepting municipal solid waste, the site meticulously expanded to include recycling operations, green waste processing, household hazardous waste collection, composting, and educational programs designed to support the City's [Zero Waste Plan](#). These changes encompass broader strides in waste management policy that increasingly focused on resource recovery and environmental stewardship.

The next major development occurred as advances in landfill gas collection technology created opportunities to beneficially utilize methane generated during the natural decomposition of organic waste. Historically regarded as an environmental liability because of its contribution to greenhouse gas emissions, landfill methane increasingly came to be viewed as a renewable energy resource. Capturing and converting landfill gas into electricity enabled municipalities to reduce emissions while simultaneously producing renewable energy and improving the [environmental performance](#) of landfill operations.



Photo 1: Landfill Gas Well (taken by A.Causey)

At Miramar, this technological advancement also expanded the project's

governance framework. While the City of San Diego retained responsibility for landfill operations under its long-term lease with the federal government, the landfill gas recovery system was developed through collaboration with the private sector. [Fortistar](#), now operating as Opal Fuels, invested in and operates the landfill gas-to-energy facility, providing the technical expertise and operational capabilities necessary to capture, process, and market landfill gas as a renewable energy resource. As a result, what began as a municipal landfill operating on military property gradually evolved into a long-term public-military-private partnership supporting waste management, renewable energy production, greenhouse gas mitigation, and energy resilience.

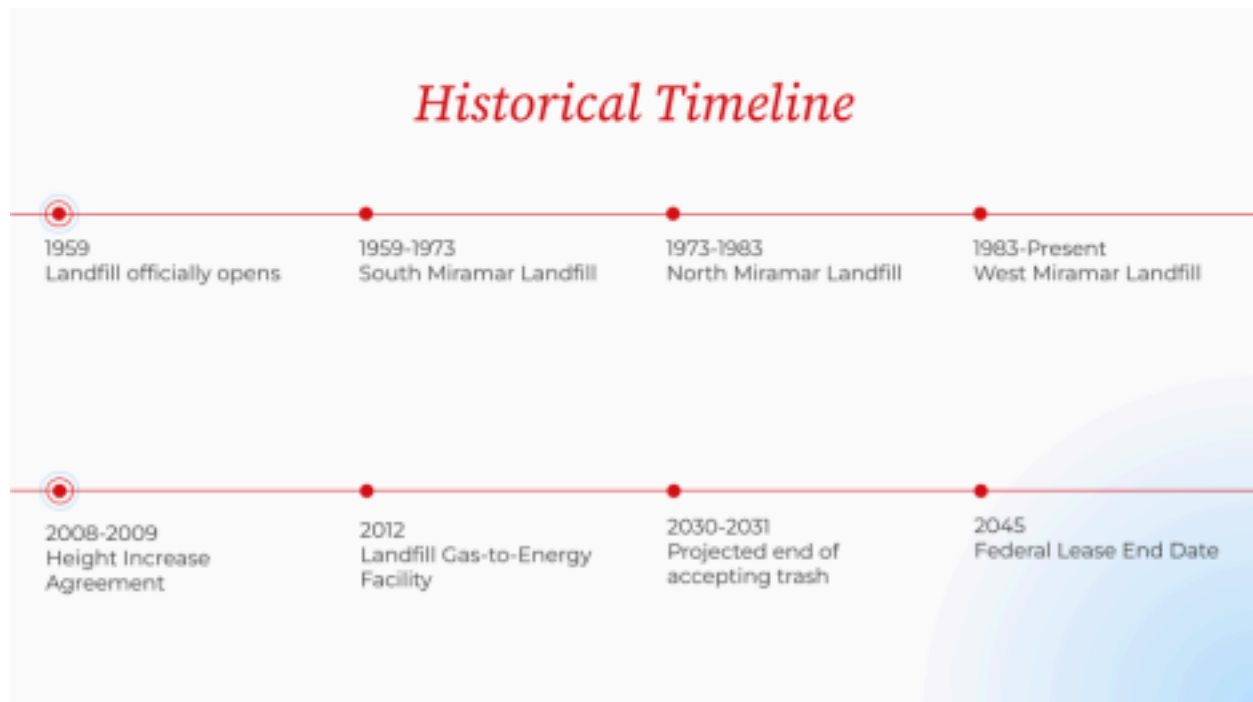


Figure 4: Historical Timeline of Miramar Landfill

Historical documents and stakeholder perspectives further suggest that the partnership has endured because each participating organization continues to derive distinct yet complementary benefits. According to the MCAS Miramar Public Works Officer, the military benefits from preserving a compatible land-use buffer while also strengthening installation energy resilience through renewable energy generation and battery storage capabilities. The City benefits from long-term waste management capacity, regulatory compliance, renewable energy production, and environmental stewardship, while Opal Fuels benefits from contractual stability and long-term energy production. Rather than pursuing identical objectives, each organization has maintained incentives that reinforce continued collaboration.

Another important historical consideration is the anticipated future of the facility. Although the current lease between the [City of San Diego](#) and the federal government

is expected to remain in effect until approximately 2045, the landfill itself is projected to stop accepting waste before the lease expires. Closure of the landfill, however, will not signify the end of the energy project. Landfill gas continues to be generated for decades after waste placement ends as buried organic material continues to decompose anaerobically. Therefore, methane recovery and renewable energy production are expected to continue well into the post-closure period, extending the operational life of the facility while continuing to support [environmental](#) and energy objectives.

Viewed chronologically, the Miramar Landfill's governance framework did not emerge strictly from advances in landfill gas technology. Rather, it evolved through decades of strategic land-use planning, institutional collaboration, and adaptive infrastructure management. The original lease agreement established a durable partnership between the federal government and the City of San Diego; subsequent technological innovation created opportunities for private-sector participation; and continued collaboration transformed a municipal landfill into a resilient public infrastructure asset. Understanding this historical evolution provides the foundation for examining the broader policy environment that enabled landfill gas-to-energy development throughout California.

3.2 California as an Enabling Environment

The historical context of the Miramar Landfill explains how long-term land-use planning and institutional collaboration established the foundation for a successful landfill gas-to-energy facility. However, history alone does not explain why landfill gas recovery became a viable infrastructure strategy. Equally important was the broader policy and regulatory environment in which the project developed. California's emergence as a national leader in environmental regulation, climate policy, and renewable energy created conditions that encouraged municipalities and private industry to view landfill methane not as a waste byproduct, but as a valuable renewable energy resource.

California's leadership in landfill gas utilization was shaped by several converging factors. Rapid population growth throughout the second half of the twentieth century increased municipal solid waste generation while simultaneously intensifying pressure on limited landfill capacity. At the same time, the state experienced worsening air quality, recurring drought, increasing climate-related risks, and growing public concern regarding [environmental degradation](#). These conditions prompted California to pursue increasingly comprehensive environmental policies that focused on emissions reductions, resource conservation, and sustainable infrastructure development.

Rather than addressing these issues as isolated environmental challenges,

California increasingly recognized the interconnected nature of waste management, air quality, climate change, and energy policy. This systems-oriented approach encouraged integrated policy solutions that simultaneously reduced greenhouse gas emissions, promoted renewable energy development, and advanced long-term environmental resilience.

Unlike many states that historically approached landfills primarily as waste disposal facilities, California gradually adopted policies encouraging resource recovery and environmental stewardship. This transition reflected a broader evolution in waste management philosophy, recognizing that municipal solid waste contains recoverable materials and energy resources capable of supporting environmental and economic objectives. [Landfill gas recovery](#) emerged as one component of this larger strategy by reducing methane emissions while simultaneously generating renewable electricity and renewable natural gas.

California's climate leadership became particularly evident following the passage of the California Global Warming Solutions Act of 2006 ([Assembly Bill 32](#)), which established the nation's first comprehensive statewide program to reduce greenhouse gas emissions. Implemented by the [California Air Resources Board](#) (CARB), AB 32 required California to return greenhouse gas emissions to 1990 levels while encouraging technological innovation and investment in low-carbon infrastructure. Because methane possesses a significantly greater global warming potential than carbon dioxide over a 100-year timeframe, reducing landfill methane emissions became an important component of the [state's climate strategy](#).

Building upon AB 32, [CARB](#) adopted increasingly strict landfill methane regulations requiring municipal solid waste landfills to install, operate, and maintain landfill gas collection and control systems while minimizing fugitive methane emissions. Rather than treating methane simply as a regulatory compliance issue, California's policies encouraged beneficial utilization of landfill gas through renewable energy production whenever feasible. These regulations created greater regulatory certainty while reinforcing the long-term economic viability of landfill gas recovery projects.

California also strengthened market demand for renewable energy through its [Renewable Portfolio Standard](#) (RPS). Originally established through Senate Bill 1078 and subsequently expanded by Senate Bill 100, the RPS requires electric utilities to procure increasing percentages of electricity from eligible renewable energy resources. Although landfill gas represents only one component of California's [renewable energy portfolio](#), the RPS contributed to stable market conditions that encouraged investment in landfill gas-to-energy facilities while supporting broader state objectives related to greenhouse gas reduction, energy diversification, and grid resilience.

In addition to statewide legislation, California's regulatory environment benefited from coordination among multiple governmental agencies. The California Air Resources Board, California Energy Commission, California Public Utilities Commission, CalRecycle, regional air quality management districts, and local permitting authorities collectively established a governance framework supporting landfill gas recovery through environmental regulation, renewable energy incentives, permitting oversight, and technical guidance. At the federal level, the U.S. Environmental Protection Agency's [Landfill Methane Outreach Program](#) further promoted landfill gas utilization by providing technical assistance, documenting successful projects, and encouraging partnerships among municipalities and private industry.

Collectively, these policies positioned California as a national leader in landfill gas utilization. The state consistently ranks among those with the greatest number of operational [landfill gas energy projects](#), reflecting decades of regulatory consistency, technological investment, and public commitment to renewable energy development. Miramar therefore developed within a policy environment that actively encouraged methane capture, renewable energy production, and long-term investment in sustainable infrastructure.

However, California's regulatory framework alone still does not fully explain Miramar's continued success. Numerous landfill gas-to-energy facilities operate under the same state regulations and policy incentives, yet their operational longevity and institutional performance vary considerably. California created favorable conditions by establishing regulatory certainty, environmental standards, and economic incentives for landfill gas utilization, but these policies cannot independently explain why the Miramar partnership has remained successful for more than two decades.

California's regulatory and policy framework should therefore be understood as a necessary enabling condition rather than a sufficient explanation for the Miramar Landfill Gas-to-Energy Facility's long-term success. While state policies established the technical, regulatory, and economic environment that made landfill gas recovery both feasible and attractive, they do not fully explain why Miramar has remained operational for more than two decades. Addressing that question requires moving beyond policy and technology to examine the governance structures, institutional relationships, and collaborative partnerships that have sustained the project over time. The following section reviews the literature on collaborative governance, public-private partnerships, and institutional resilience to establish the theoretical foundation for analyzing Miramar's enduring success.

3.3 Governance in Public Infrastructure

While California's regulatory environment established favorable conditions for landfill gas-to-energy development, policy alone cannot explain why certain infrastructure projects remain successful over multiple decades while others struggle to sustain long-term operations. Addressing this question requires moving beyond engineering performance and environmental policy to examine the governance arrangements that enable organizations with differing missions, authorities, and incentives to work collaboratively toward shared public outcomes. Accordingly, this section reviews literature on collaborative governance, public-private partnerships, institutional resilience, boundary-spanning organizations, and stakeholder alignment to establish the theoretical framework guiding this study.

Modern public infrastructure is increasingly characterized by institutional complexity. Critical infrastructure systems rarely operate under the authority of a single organization. Instead, they depend upon sustained collaboration among [public agencies](#), private industry, regulatory bodies, utilities, nonprofit organizations, and community stakeholders. These cross-sector relationships reflect the growing recognition that contemporary infrastructure challenges frequently exceed the financial resources, technical expertise, legal authority, or operational capacity of any single institution.

Collaborative governance has therefore emerged as an increasingly important framework for understanding how organizations jointly address complex public challenges. [Collaborative governance](#) is defined as formal, consensus-oriented decision-making processes in which public agencies directly engage non-state stakeholders to develop and implement public policy or manage public resources. Expanding upon this work, [collaborative governance](#) is also described as a dynamic system built upon principled engagement, shared motivation, and the capacity for joint action. Rather than relying exclusively on hierarchical authority or contractual obligations, collaborative governance emphasizes trust, communication, mutual accountability, and long-term relationship building as mechanisms for sustaining cooperation among organizations with different institutional missions.

Within infrastructure development, collaborative governance frequently operates through [public-private partnerships](#) (PPPs). These partnerships combine public oversight with private-sector investment, technical expertise, and operational management to deliver infrastructure and public services that neither sector could efficiently provide independently. Successful PPPs depend upon far more than contractual agreements alone. Long-term performance is strengthened when participating organizations establish clearly defined responsibilities, equitable risk allocation, effective communication, and governance arrangements capable of adapting

to changing regulatory, financial, Durable infrastructure partnerships are often characterized less by static organizational structures than by their ability to evolve while preserving shared institutional commitments. This emphasis on adaptation aligns closely with the concept of institutional resilience. Although resilience is often discussed in engineering terms, focusing on the ability of physical infrastructure to withstand disruption, scholars increasingly recognize that [infrastructure resilience](#) also depends upon the organizations responsible for planning, operating, financing, and governing these systems. Institutional resilience refers to the capacity of governance systems to sustain collaboration, adapt to changing environmental and political conditions, and continue delivering public value despite evolving circumstances. From this perspective, resilient infrastructure is not solely a product of robust engineering but also of institutions capable of maintaining stable partnerships while responding to new challenges over time.

As discussed throughout the MESH program, supporting these collaborative arrangements are boundary-spanning organizations and individuals. [Boundary spanners](#) play an essential role in addressing complex public problems by connecting institutions with differing authorities, expertise, cultures, and priorities. Rather than functioning within a single organization, boundary spanners help translate information, build trust, coordinate decision-making, and identify opportunities for collaboration across sectors. Within sustainability and infrastructure governance, these functions become particularly important because technical, environmental, regulatory, and political considerations frequently intersect.

Amongst each of these governance concepts is the principle of stakeholder alignment. Long-term infrastructure projects are more likely to endure when participating organizations derive complementary value from continued collaboration. Importantly, alignment does not require stakeholders to pursue identical objectives. Municipal governments may prioritize public service delivery, environmental stewardship, and regulatory compliance; private firms may focus on operational efficiency, innovation, and financial sustainability; military organizations may emphasize mission readiness and infrastructure resilience; while regulatory agencies concentrate on environmental protection and public accountability. [Governance frameworks](#) that acknowledge these differing priorities while creating mutually beneficial outcomes are generally more durable than those requiring complete consensus regarding organizational missions.

Collectively, this body of literature explains that collaborative governance plays an increasingly important role in the long-term performance of complex infrastructure systems. Research concerning collaborative governance, public-private partnerships, institutional resilience, and stakeholder collaboration provides valuable theoretical frameworks for understanding how organizations coordinate around shared infrastructure despite differing responsibilities and priorities. Likewise, technical literature thoroughly documents the engineering principles, environmental benefits,

and regulatory frameworks supporting landfill gas-to-energy systems. However, these bodies of scholarship have largely developed independently.

Relatively less research explicitly examines how collaborative governance, institutional resilience, stakeholder alignment, and long-term public-private partnerships interact to sustain landfill gas-to-energy facilities over multiple decades. Existing studies frequently emphasize either technological performance or governance theory without integrating the two into a comprehensive explanation of infrastructure longevity. This gap is particularly evident for projects involving municipal governments, military installations, and private-sector operators, where governance complexity extends beyond traditional public infrastructure management.

The Miramar Landfill Gas-to-Energy Facility provides an opportunity to examine this intersection. Rather than evaluating whether landfill gas technology functions effectively or whether collaborative governance is theoretically beneficial, this study investigates how governance arrangements, institutional relationships, and stakeholder incentives collectively supported the long-term evolution of a critical public infrastructure asset. By integrating historical context, policy analysis, and governance theory with empirical evidence from public documents and stakeholder interviews, this research strives to contribute to a more comprehensive understanding of how collaborative governance enables infrastructure resilience over extended operational lifespans.

4. Results & Discussion

4.1 Governance Framework & Replicability

The literature review established that landfill gas-to-energy systems are technically well understood and that California provides a favorable regulatory environment for renewable energy development. However, document analysis and stakeholder interviews suggest that these factors alone do not adequately explain the Miramar Landfill Gas-to-Energy Facility's longevity. Rather, the project's continued success appears to result from a governance framework that has progressively aligned the interests of municipal government, the military, and the private sector while adapting to changing operational, environmental, and regulatory conditions.



Figure 5: Governance Framework

Unlike many infrastructure projects that serve a single institutional objective, the Miramar facility creates distinct yet complementary forms of value for each principal stakeholder. The City of San Diego fulfills its statutory responsibility for municipal solid waste management while simultaneously reducing greenhouse gas emissions, contributing renewable energy to the region's energy mix, and operating the landfill as a financially self-supporting enterprise. Since its establishment, [Miramar](#) has functioned as an enterprise fund rather than relying on tax revenues, generating revenue through disposal fees that exceed operational costs while supporting numerous municipal services, including landfill maintenance, illegal dumping cleanup, public education, recycling programs, and environmental restoration.

[The Center of Policy Initiatives](#) further describes Miramar as a public asset whose value extends beyond waste disposal. In addition to serving as the region's only publicly owned landfill, the facility supports composting, recycling, household hazardous waste collection, renewable energy generation, and environmental stewardship while extending landfill capacity through innovative engineering and operational practices.

The military derives a different, but equally important, set of benefits from the partnership. During an interview conducted for this study, an MCAS Miramar Public Works Officer explained that the original lease agreement accomplished more than providing land for municipal waste disposal. Establishing the landfill as a compatible land use adjacent to the installation preserved a long-term development

buffer that protects operational flexibility and minimizes conflicts between military operations and surrounding development.

“Desire to lease land to increase training capabilities..”

- MCAS Miramar Public Works Officer

The interview further revealed that the landfill gas-to-energy facility contributes to military readiness not simply by generating electricity, but by supporting installation battery storage and strengthening overall energy resilience. Although previous public communications have emphasized electricity production, the interview highlighted that resilient energy infrastructure and operational continuity represent equally significant benefits from the military’s perspective.

Opal Fuels, portfolio company of Fortistar, represents the third component of the governance framework. Through a long-term contractual partnership with the City of San Diego, the company provides the technical expertise, capital investment, and operational management necessary to recover landfill gas and convert methane into renewable energy. Unlike many infrastructure projects with relatively short operational horizons, landfill gas recovery continues long after waste placement ends because methane generation persists for decades during anaerobic decomposition. Although the landfill itself is projected to close before expiration of the current federal lease, renewable energy production is expected to continue well into the post-closure period, reinforcing the long-term value of the partnership for all participating organizations.

Collectively, the Miramar governance framework has endured because each stakeholder derives distinct, but mutually reinforcing, benefits from continued collaboration. Unlike governance arrangements requiring organizations to pursue identical institutional objectives, Miramar exemplifies that long-term partnerships can remain resilient when participating organizations achieve complementary outcomes through shared infrastructure. The City advances environmental stewardship and public service delivery; MCAS Miramar strengthens mission readiness and energy resilience; and Opal Fuels maintains a stable, long-term renewable energy operation. This alignment of institutional incentives appears to be a defining characteristic of the project’s durability and closely reflects principles identified within the [collaborative governance](#) literature.

These findings also provide insight into the broader question of replicability. When asked whether the Miramar governance model could be replicated elsewhere, the MCAS Miramar Public Works Officer did not characterize the project as unique. Instead, he identified several enabling conditions that contributed to its success, including the military’s willingness to lease land while preserving mission readiness, the landfill’s location within a major metropolitan region capable of supporting a highly skilled technical workforce, an adaptive regulatory environment, and sustained

community support for continued landfill operations.

The interview suggested that successful replication depends less on reproducing the physical infrastructure than on recreating the institutional conditions that support it. These findings closely align with the [governance](#) literature reviewed in Section Three. While landfill gas recovery technology is readily transferable, governance systems are inherently shaped by local institutional relationships, stakeholder incentives, regulatory capacity, and community context.

Accordingly, Miramar should be understood less as a model of engineering innovation than as a model of collaborative governance. The technology supporting landfill gas recovery is mature and widely available. What distinguishes Miramar is the durability of the institutional relationships that have sustained the project through changing regulations, evolving environmental priorities, and decades of organizational collaboration.

4.2 Policy Implications

Resilient public infrastructure depends upon more than sound engineering and favorable regulatory conditions. While California's policy environment created the technical and economic conditions necessary for landfill gas recovery, the project's sustained success has ultimately depended on governance arrangements capable of adapting to changing operational, environmental, and institutional conditions over more than six decades. The partnership among the City of San Diego, MCAS Miramar, and Opal Fuels are examples of how infrastructure can continue creating public value when participating organizations maintain complementary objectives while remaining sufficiently flexible to respond to evolving circumstances.

One of the most significant findings of this research is that Miramar's governance framework should not be viewed as a static organizational arrangement but rather as an adaptive partnership. Successful partnerships are sustained through continuous adaptation rather than fixed [organizational structures](#). Throughout the facility's history, the participating organizations have responded to changing environmental regulations, technological advancements, landfill capacity limitations, evolving military energy priorities, and community expectations while preserving the foundational institutional relationships that support the project. This capacity for adaptation appears to be as important as the original governance structure itself. Rather than attempting to preserve a single operational model indefinitely, the partners have continuously adjusted their responsibilities and priorities while maintaining a shared commitment to long-term project success.

At the same time, this research suggests that Miramar represents a convergence of favorable institutional and geographic conditions that may not be easily reproduced elsewhere. Not every municipality has access to federally owned land capable of supporting long-term landfill operations. Likewise, relatively few military installations are located adjacent to major metropolitan areas with access to highly skilled technical workforces, comprehensive utility infrastructure, established regulatory institutions, and private-sector partners capable of operating robust renewable energy facilities. These characteristics should not be viewed as prerequisites for successful landfill gas-to-energy projects, but they do suggest that infrastructure governance is inherently shaped by local context.

Policymakers should be cautious about attempting to replicate Miramar by reproducing its physical infrastructure alone. Instead, greater attention should be directed toward replicating the governance principles that have supported its longevity. This study suggests several lessons for future infrastructure projects.

First, long-term infrastructure should be planned through collaborative governance rather than organizational independence. Complex infrastructure systems increasingly require cooperation among public agencies, private industry, regulators, utilities, and community stakeholders. Establishing governance structures that promote communication, clearly define responsibilities, and encourage shared decision-making may prove more valuable than relying solely on contractual obligations.

Second, infrastructure partnerships should be designed around complementary institutional incentives rather than identical organizational objectives. The City of San Diego, MCAS Miramar, and Opal Fuels each evaluate the project according to different measures of success. The City prioritizes effective waste management, regulatory compliance, environmental stewardship, and fiscal responsibility. MCAS Miramar emphasizes mission readiness, energy resilience, and preservation of compatible land uses. Opal Fuels focuses on reliable operations, renewable energy production, and long-term contractual stability. The partnership has endured not because these organizations pursue the same mission, but because the governance framework allows each stakeholder to achieve distinct yet mutually reinforcing outcomes.

Third, policymakers should recognize the importance of long-term land-use planning when developing resilient infrastructure. Decisions made decades before the landfill gas-to-energy facility was constructed, including the establishment of the landfill on leased military property and preservation of a compatible land-use buffer, created opportunities that later enabled renewable energy production and strengthened the region. Infrastructure resilience often begins with strategic planning long before technological solutions are implemented.

Finally, public infrastructure should be evaluated using governance-based measures of success in addition to traditional engineering and environmental performance metrics. While methane capture rates, renewable energy generation, greenhouse gas reductions, and regulatory compliance remain important indicators, they provide only a partial understanding of long-term project performance. Institutional resilience, stakeholder collaboration, governance continuity, and the ability to adapt to changing conditions may ultimately be equally important determinants of infrastructure durability.

Although this study focused on a single case, future comparative research could examine whether similar governance principles emerge in landfill gas-to-energy facilities operating under different ownership structures, regulatory environments, or military and civilian partnerships. Such comparison would strengthen understanding of which governance characteristics are broadly transferable and which remain specific to Miramar's institutional context. Additional research examining financial agreements, contract structures, and stakeholder decision-making processes could further strengthen understanding of how collaborative governance contributes to resilient infrastructure over extended operational lifespans.

Resilient infrastructure is not created solely through engineering innovation. Rather, resilience emerges through institutions capable of sustaining collaboration, adapting to change, and maintaining shared public value across decades of evolving environmental, political, and organizational conditions.

5. Conclusion

This study sought to answer the following research question: **What governance and partnership arrangements have enabled the Miramar Landfill Gas-to-Energy Facility to operate for more than two decades, and can those conditions be meaningfully replicated in other municipalities?**

Miramar's continued success cannot be explained by engineering or public policy alone. While advances in landfill gas recovery technology and California's supportive regulatory environment created favorable conditions for renewable energy development, they do not adequately account for the facility's exceptional longevity. Instead, the evidence indicates that Miramar has endured because of a durable governance framework built upon long-term institutional collaboration among the City of San Diego, MCAS Miramar, and Opal Fuels.

Historical analysis reveals that the foundations of this partnership were established decades before renewable energy production became a central objective. The original lease agreement between the federal government and the City of San Diego

created a compatible land-use strategy that simultaneously supported municipal waste management and military operational readiness. Over time, advances in landfill gas recovery technology transformed the landfill into a renewable energy asset, while evolving partnerships expanded its value to include greenhouse gas mitigation, municipal infrastructure support, and military energy resilience. Rather than replacing earlier institutional arrangements, these developments strengthened and expanded them.

The literature review further revealed that landfill gas-to-energy technology, California's renewable energy policies, and collaborative governance have each been studied extensively within their respective fields. However, relatively less research integrates these perspectives to explain how governance arrangements sustain landfill gas-to-energy facilities over multiple decades. This case study contributes to that gap by confirming that technical systems and governance structures should not be evaluated independently. Instead, long-term infrastructure performance emerges from the interaction of engineering, institutional relationships, regulatory environments, and stakeholder incentives.

Perhaps the most significant contribution of this research is the shift in perspective regarding infrastructure success. Conventional evaluations of landfill gas-to-energy projects focus on methane capture, electricity generation, greenhouse gas reductions, and economic performance. While these indicators remain important, they provide only a partial explanation of long-term success. Miramar establishes that institutional resilience, the capacity of organizations to sustain collaboration, adapt to changing conditions, and continue producing shared public value, may be equally important to infrastructure performance as the engineering systems themselves. This provides broader understanding of infrastructure resilience in which technological capability and institutional capacity are viewed as complementary rather than independent determinants of long-term success.

Although Miramar possesses characteristics that may not be universally replicable, the governance principles forming its success offer valuable lessons for policymakers and infrastructure planners. Collaborative governance, complementary stakeholder incentives, adaptive institutional arrangements, and long-term strategic planning represent transferable concepts that may strengthen other complex public infrastructure projects, even where local circumstances differ.

More broadly, this research suggests that resilient infrastructure should be understood not simply as a technical achievement but as an institutional one. Communities often devote considerable attention to designing resilient physical systems while investing comparatively less effort in designing resilient governance systems capable of sustaining those assets over generations. The Miramar Landfill Gas-to-Energy Facility proves that engineering makes resilient infrastructure possible,

but enduring governance is what allows that infrastructure to continue serving communities through decades of changing environmental, economic, and political conditions. As communities confront increasingly complex infrastructure challenges, investing in resilient governance may ultimately prove as important as investing in resilient technology.

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**Building Community Trust: Investigating the use of an Afrofuturisti-based school
Garden on Volunteer Habits**

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**Capstone Project
August 9, 2026**

Building Community Trust: Investigating the use of an Afrofuturisti-based school Garden on Volunteer Habits

Chapter 1: Introduction

Section 1.1: Introduction of Project

Communities are increasingly disconnected from their respective school systems and the stakeholders within them. Since 2020, remote and telework opportunities have disengaged families from neighborhoods by allowing them free rein to move across state lines ([Frost, R., 2025](#)). Conversely, homeowners who locked in low financing opportunities sit comfortably and anchor the culture of their respective neighborhoods. Along with community mobility, time, financial obligation, and childcare add to unpredictable community-school system relationships. Trust between community stakeholders and school districts is built through activities designed to promote community participation, excitement, engagement, and retention. Researchers have long studied the effects of positive community participation on the well-being and success of students, but school systems and community mobility trends are unpredictable in a post-COVID society. Research performed by [Ilham et al.](#) in 2024 found that telework heavily influenced mobility patterns, shifts from public transportation to car dependency, walking, and cycling, and an increase in online shopping over brick-and-mortar stores. Residents seeking more greenspace were prompted to move to larger lots as the reduced commuting times allowed.

Mobility across community boundaries is driven by economic fluctuations, with low-income households, renters, and young families carrying a large portion of mobility numbers ([The Urban Institute, 2009](#)). There are various factors that explain mobility trends, “but mobility can also be a symptom of instability and insecurity, with many low-income households making short-distance moves because of problems with landlords, creditors, or housing conditions” ([Coulton, C. et al., 2009](#)). Efforts aimed at improving neighborhood relations must account for the “slow pace” of families that stay within the community, while acknowledging the part the transient members play in the character of the community. Neighborhood perception, cleanliness, and crime influence decisions to move out of or into neighborhoods ([Jones, A. & Dantzler, P., 2021](#)).

Researchers have long studied the effects of positive community participation on the well-being and success of students, but school systems and community mobility trends can change the character of neighborhoods. Research performed by [Ilham et al.](#) in 2024 found that telework heavily influenced mobility patterns, shifts from public transportation to car dependency, walking, and cycling, and an increase in online shopping over brick-and-mortar stores. Residents seeking more greenspace were prompted to move to larger lots as the reduced commuting times allowed. Can trust between community stakeholders and school districts be built through student-led activities designed to promote community participation, excitement, engagement, and retention?

However, in 2023, [Harvard’s Joint Center For Housing Studies](#) found that mobility trends were semi-permanent – between 2020-2022 the trends hold true – but continued their pre-pandemic

decline. The contradictory information regarding post-COVID mobility may tell the truth and is, as human nature often is, a cornucopia of circumstances, or we may have to wait for more research paradigms to emerge to tell the full story. What we do know as observable realities are the transformations in the school system since the last generation, the issues with homeownership and renting factors (out of scope), time utilization and maintenance (driven by cost of living expenses), and socialization indicators.

Section 1.1: Purpose of the Project

This study builds on research (performed pre-COVID) that sought to understand the factors that produce favorable community-to-school district engagement and volunteer retention. This study will specifically investigate if a school garden grounded in Afrofuturism can build community trust, stewardship, and partnership with the school district (students, teachers, parents, and administration stakeholders). The study builds on investigations into the theoretical and applicable success of school gardens, and adds a cultural layer to introduce a multicultural education component outside of what is employed inside of the classroom. This study's goal is not to find broad solutions, but to perform a feasibility assessment.

While the students will remain the designers of the full program, the feasibility study will take the opportunity to approach the school garden from an Afrofuturistic framework, as well as analyze data through constructivism and interpretivism epistemological theories. The basis of the research question is an investigation of human nature, habits, and influences. Constructivism and interpretivism are paradigms that hold that human existence is constructed through personal beliefs, experiences, and knowledge, and that the interpretation and acknowledgment of differing realities reveal that each contains distinct knowledge, all of which must be considered to create an accurate picture of reality.

Section 1.2: Afrofuturism as a Paradigm

Afrofuturism builds on culture, heritage, present goals, and future aspirations. Sustainability concepts, cultural competency, and soft skills are hallmarks of many school gardens, and Afrofuturistic attributes encourage delving deeper into indigenous and ancestral traditions. This shift in framework seeks to understand how a different lens and perspective can affect engagement. Afrofuturism imagines the future through innovative applications of the past. Speculative science fiction and art are the mothers of Afrofuturism, and this project seeks to translate their themes into an applicable gardening-lesson process.

Introducing sustainability ideas, methods, and activities in early development can help plant seeds that grow into sustainable habits and lifestyles. Since school gardens that employ outdoor education modules aren't novel, the study approaches the program through an Afrofuturistic lens, adding depth and nuance to the progressing body of literature.

The goal of the proposed garden is to encourage students to invest in sustainable, healthy stewardship of their food, leading to sustainable practices as they grow older.

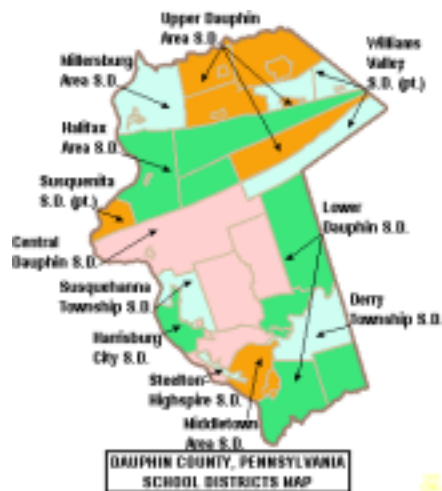
Approaching gardening through an Afrofuturistic lens will encourage the younger generation to practice agricultural stewardship through stories of their cultural identity. Afrofuturistic ideals will be used as an example of one such identity. This framework will enable all children to be in community with each other and with the Earth. By encouraging a cultural approach to food consumption, we can foster ownership and responsibility for preserving their past, present, and future. This mission is reflected through survey questions and interviews, and explored through community conversations

Section 1.3: School Gardens As Living Laboratories

School gardens have long since proven to be excellent additions to curriculum and student life during school hours, activities, and properties. Most school gardens are used to enhance academic instruction, improve nutrition and relationships with fresh produce, and improve life skills ([Graham, H. et al., 2005](#)). Gardens are also used to build and sustain environmental consciousness and stewardship within student, teacher, and administration participants. Longstanding research shows schools with garden activations can enhance behaviors, provide space for students to decompress, learn ecological principles, and foster a sense of responsibility for their school community ([Kelemen, E., Czett, K., & Szentendrey, R., 2025](#)).

Anecdotal evidence and empirical research have produced an extensive body of literature that explores the benefits of school gardens. The United States Department of Agriculture supplies school districts with instructions to build “living laboratories” (USDA, n.d.), and the US Botanical Garden provides guidebooks and supplemental teaching materials. Research has shown that students benefit from outdoor learning opportunities witnessed through improved time management, critical thinking, patience, physical appearance, behavior, nutrition, math, science, physics, and environmental course scores. Improved student-to-school relations have also been captured through case study research.

Section 1.4: Study Area



Study Area Map

This study seeks to understand how a school garden can provide shared opportunities for both community members with and without children to foster stewardship with the school district. Swatara Township Middle School is located in Swatara Township, Harrisburg, Pennsylvania. The student body is ranked #6 in middle school diversity within the city ([US News, n.d.](#)) The school is 21% white, 31% black or African-American, 23% Hispanic or Latino, 14% Asian or Asian Pacific Islander, 11% mixed race, 0.3% American Indian or Alaska Native, and 0.2% Native Hawaiian or other Pacific Islander ([US News, n.d.](#)). The student-teacher ratio is 13 to 1, with math and reading proficiency sitting at 41% and 53%, respectively. It is considered a large suburb with 100% of the families designated as economically disadvantaged.

Section 1.5: Assumptions and Limitations

Section 1.5.1: Assumptions

Schools within the Central Dauphin school district require a thorough volunteer application and background check for all community members who enter the school grounds or participate in school-sanctioned activities, events, and outings. Considering this potential barrier to community participation, the study assumes all school-sanctioned programs will include at least one school system stakeholder. The attitudes of the school system stakeholders that act as oversight are not considered within this study.

Section 1.5.2: Limitations

By deploying electronic surveys, the study is limited by the comfort levels with technology of the community members. Elder neighbors may not understand how to access the survey information via the QR codes on the posted fliers.

Chapter 2: Cultural Plurality in Multicultural Education

Michigan State University Professor Julian Chambliss studied Afrofuturism and incorporated his digital scholarship into MSU's Department of English, Libraries, and Museum. In an interview, Chambliss describes Afrofuturism as an ideology that "[a]t [its] core...Afrofuturism is an emphasis on trying to create a system that's more equitable with a core goal of collective care for everyone," ([Bigsbyha, 2025](#)). He goes on to say, "[a] lot of times Afrofuturism is really asking us to think about how the system we know can be made safe for everyone," a sentiment that underscores the art and theatrical expression of Afrofuturism within media and performing arts. But Afrofuturism can leap beyond artistic expression and impregnate other fields and disciplines. Afrofuturism provides an additional framework that questions how knowledge is qualified, and the inequities that compound because of the hegemony of knowledge practices. The speculative nature of Afrofuturism asks how to bring equality to structural systems and policy practices.

The theme of questioning through speculation is voiced throughout Afrofuturist literature. Race and capitalism ([Toussaint, 2024](#)), past, present, and future limitations ([NHMAAC, n.d.](#)), and technology ([Blacks In Tech, 2019](#)) are some areas where Afrofuturism thrives. Research using Google Scholar, the University of Texas library system, and the University of San Diego library system highlighted voids and areas of opportunity within the available resources. [Esenou and Okoye](#) (2024) make a case for the use of Afrofuturism paradigms outside of arts and entertainment. Research around inequalities within school districts has often positioned marginalized stories as data points without storylines. The aforementioned authors cite relevant research that suggests the stories of marginalized communities can provide innovation within school-based programs. Durose, Perry, and Richardson (2021) write that co-production acknowledges and values "the contribution and stake that those who are not professional or academic researchers have in the research process." Design within an Afrofuturistic framework "provides a space to combine knowledge production, applied creativity and the public to address racial inequalities," ([Eseonu, T. & Okoye, F., 2024](#)).

In his interview, Chambliss reiterates the importance of understanding the past to speculate the future. This emphasis on ancestral knowledge can be applied to indigenous communities, migrant families, and immigrant neighborhoods. The use of Afrofuturistic principles encourages cultural plurality over programs that only highlight diversity, equity, inclusion, and accommodation. In their 2019 article, [Schachner et al.](#) studied the diversity climate within school systems in Germany and found that students "experienced a greater sense of belonging at school, had better grades and were more satisfied with their lives" when involved in equitable instruction. This sense of belonging was felt by students of both minority and majority cultural identities. Raising the cultural awareness of teachers and administrators can close the achievement gaps created by discrimination and "color-blind" policies.

School systems are comprised of various climates, but "the cultural diversity climate is one

specific facet of school or classroom climate, which encompasses how issues of cultural diversity are approached or dealt with at school“ ([Schachner, K. et al., 2019](#)). Structural diversity and diversity climate are additional constructs that affect student life and deserve their own investigations. Structural diversity programs seek to enhance diversity, equity, inclusion, and accommodation through inter-mixed seating assignments, equal treatment, and the formulation of common goals. These policies govern physical space and relationship building through equal treatment, leading to the idea of a “color-blind” classroom ([Schachner, K. et al., 2019](#)). Approaches that seek to “overcome” differences can inadvertently quell the expression of a minority identity and its knowledge practices.

Acculturation, diversity, and cultural pluralism were studied when German schools were faced with an influx of immigrant students. [Schachner et al.](#) (2016) used the [Roeser et al.](#) (2011) definition of school climate, “the experience of norms, goals, values, interpersonal relationships, teaching and learning practices, and organizational structures in everyday school life”, to establish the location and positionality of their study. Fostering diversity, equity, and inclusion includes limiting discrimination in intergroup settings and reducing the harm that accompanies diversity. Cultural pluralism refers to the concept that diverse cultural groups coexist while maintaining their unique identities, without the expectation of assimilation into a dominant culture ([McFeeters & Bennett, 2019](#)). Cultural pluralism is used in multicultural education schemes that employ four factors: 1) instruction of students from different backgrounds, 2) the study of other cultures, 3) critical thinking development, and 4) a focus on human relations ([McFeeters & Bennett, 2019](#)).

[Voight et al.](#) (2015) researched school system climate by empowering school culture through historical contexts and discussions. The authors determined that historical perspectives are “necessary to provide a context for understanding the contemporary developments and discourse in multicultural education” (Voight et al., 2015). Structuring programs that reflect multicultural issues and concerns is “associated with better psychological outcomes and better well-being. In a classroom climate reflecting cultural pluralism, cultural diversity is welcomed and appreciated as a resource” (Schachner et al., 2019). The work of early African-American scholars provided the foundation for multicultural education paradigms - as DuBois (1935), Woodson (1919/1968), Bond (1939), and Wesley (1935), with the early architects building upon the foundation of African-American educators and philosophers (Voight et al., 2015).

Multicultural education integrates diverse cultural perspectives, histories, and values into the curriculum and promotes educational equity, inclusivity, and critical thinking by ensuring all students feel connected to themselves, peers, and the school system. The proposed school garden program approaches the design through a cultural framework, continuing the elevation of culturally responsive teachings.

Chapter 3: Literature Review

While immigration is an important standard in researching community mobility, this study will treat all mobility as a matter of movement from place to place, regardless of immigration status. Students of immigrant families require community resources that fall beyond the scope of this study. Immigration status is important when reporting on resources, economic opportunities, and career opportunities, but the proposed school gardening program intuitively takes those families and neighborhoods into account by making space for all students to feel part of the program's vision. The framework of the program is based in Afrofuturism because this lens allows all students to call on their personal and familial history for guidance and encouragement. The program, at its core, is powered by ancestral knowledge.

The progressing literature review was completed by investigating the factors that drive community mobility, the ways that parents interact with the school system, school garden activations from across socio-economical and geographical locations, and how Afrofuturism intersects with the writings of environmental justice professor Dr Robert Bullard. While investigating the intersection of stakeholders, the majority of community mobility research focused on potential outside resources provided by government policies and community nonprofits geared towards improving the economic conditions of families, employment mobility, transportation, after-school activities, and tutoring opportunities. Due to a reliance on individual actors and factors of such movement ([Jones & Dantzler, 2020](#)), there is a gap in research around community mobility.

Jones & Dantzler (2020) used the Anne E. Casey Foundation's [Making Connections](#) survey dataset to synthesize relationships between neighborhood perception and the likelihood of movement to or from the neighborhood. The Making Connections study surveyed 10 US cities and collected mobility data and, through various geographically tailored programs, aimed to improve the conditions of low-income neighborhoods. Jones and Dantzler used the same data to investigate how perception plays a part in whether people stay or left the neighborhoods. The authors noticed "city and metropolitan areas are influenced at multiple levels – residential relocation, urban decline/renewal and the formation of new neighborhoods, to name a few" and "[p]erceptions are directly tied to attachment – positive perceptions lead to a deeper level of attachment" in the neighborhoods (Jones & Dantzler, 2020). When asking "How can a student-led school garden influence the perception of a community?", it can be hypothesized that to present a positive perception, a school gardening program must align with the positive vision collectively held by the families in the neighborhoods that make up the community. This positive vision can be captured from relationships and conversations between the stakeholders.

These conversations will help flesh out the "four important domains of neighborhood perceptions" captured by Jones & Dantzler: *neighborhood satisfaction*, *neighborhood safety*, *neighborhood decline* and *neighbor's agency* (Jones & Dantzler, 2020). Including *perception* as a metric that measures community engagement of a student-led school garden will require

thoughtfulness in how survey questions are phrased for the families that have the opportunity to leave the community. If phrased correctly, the questionnaires should be able to answer: *What anchors a community?* By highlighting the visibility of the garden, the perception of the school, and in extension the neighborhood, will aid in a positive first impression. Current residents can enjoy the beautification of their community, and potential newcomers will sense the pride from the families.

[The Urban Institute](#), in collaboration with the Making Connections study, found family's connections to economic opportunity, positive social networks, and effective services and supports" often led to the likelihood of families remaining in the neighborhood (Coulton, C., Theodos, B., Turner, M., 2009). Mobility rates are higher for low-income families and can be linked to "instability and insecurity, with many low-income households making short-distance moves because of problems with landlords, creditors, or housing conditions" (Coulton, C., Theodos, B., Turner, M., 2009). The initiative also concluded that "dynamics of residential mobility and neighborhood change pose critical challenges for community-change initiatives," providing evidence that creative interventions may help to create a sense of attachment. Programs built around student health and well-being can help provide context and stories that can present a welcoming neighborhood perception. Instead of trying to quantify and qualify neighborhood characteristics, which can always be in flux, it is beneficial to focus on a stable constant within communities. Building strong community-school district relationships can foster feelings of ownership, protection for the students, and stewardship of neighbor-neighbor, neighborhood-neighborhood, and community-school relationships. Long-term residents as well as newcomers can build and sustain the character of their community by rallying around a central, unbiased cause. Because, as stated by Jones & Dantzler (2020), "demographic and environmental changes in the neighborhood can dampen neighborhood attachment because they may alter residents' closeness to other residents, expectations of other residents, and safety concerns", any community programming must include opportunities to nurture these connections.

The [CDC](#) provides resources for schools and parents to improve school-parent engagement and volunteer opportunities; however, the [Anne Casey Foundation](#) makes a strong case why parent involvement is different from parental engagement. The Foundation draws this distinction through the implementation mechanisms of the activities. Involved parents make appearances at activities already determined by the school, while an engaged parent becomes part of the school's decision-making process. (Anne Casey Foundation, 2023). The tentative framework of this study's proposed program is reliant on parents' active participation, shifting them from being passive attendees to active contributors. School programs that encourage parental involvement, such as after-school art programs, tutoring, counseling, or scholastic activities, have been shown to increase parental engagement. However, the community at large are not usually invited to these programs. A school garden increases the visibility of the parent-school relationship and, in turn, invites the community into that relationship.

16) Environmental Justice calls for the education of present and future generations, which emphasizes social and environmental issues, based on our experience and an appreciation of our diverse cultural perspectives.

The goal of sustainability education within the program is to spark inquiry through early childhood exposure. The planting of cultural produce and subsequent recipe sharing will act as a vehicle for cultural exchange and understanding.

Different frameworks and reference points that can aid in creating community-centered projects. Approaching this study from an Afrofuturistic lens helps situate the program such that familial and ancestral knowledge is an active driver of success. Finding literature that explores the use of afrofuturism outside of the Arts has proven difficult. There are enormous opportunities for this framework to be adopted outside of its main point of study.

The Afrofuturistic lens “as a research method encourages the imagination” and can “progressively plac[e] value on the knowledge produced by these [marginalized] communities, opening up creative and innovative methods of accessing such knowledge,” (Eseonu, T. & Okoye, F., 2024). Research around inequalities within school districts have often positioned marginalized stories as data points without storylines. [Caruthers \(2024\)](#) understands Afrofuturism as a framework that “empowers individuals from marginalized communities to envision a future where they are not only represented but also celebrated for their unique contributions.” Afrofuturism, while created out of the African-American experience, is a framework that can be used to empower community members, students, and the school district to shape the space that they share.

By using the framework of Afrofuturism, we can instill creativity and innovation within the students. However, this creativity is paired with patience and resilience. Nurturing produce within the garden is mirrored by the nurturing of relationships between all stakeholders. By letting the students tailor the programming, we can role-play scenarios that may come about throughout their education and into early adulthood. Capitalism requires extreme labor in extreme timeframes. Afrofuturism slows down that time frame and expands the space in which creativity can grow and be nurtured. It isn't about a race to a technological future, it is about envisioning a future through the pace and grace of the past. Gardening can slow down an ever-increasing consumption-based world.

Chapter 5: Means and Methodology

The study uses a mixed-methods research approach that uses qualitative research articles and quantitative data aggregate from survey data, interviews, and community conversations. Four surveys are serving four stakeholders: Community Members, Parents, School System, and Students. Stakeholders play active and intertwined roles that support a healthy, sustainable, and functioning school garden program. The survey introduction states the project's mission and

rationale and defines each stakeholder. Intersections are inevitable, so overlapping the questions ensures that surveys are completed for the full set of active participatory roles a respondent holds.

Because all stakeholders are community members, the basis for each survey is the [Community Member](#) survey questions. Questions in this section gauge respondents' sentiments about their community, including its character, emotional ties, and likelihood of relocating. They are designed to provoke responses that illustrate the general closeness of community members to one another and their locality. Questions capture demographic data, mobility histories, and neighborhood character expectations, and are used to understand community motivations. As mentioned above, questions regarding race were intentionally omitted from the demographic questions.

[Parental surveys](#) include the Community Member questions with an added section focused on parents' relationship with the school system. This section collects data on parents' feelings and their interactions within school buildings and administration. Parents strongly influence the school climate through their presence and participation, and the study will show if their participation is conditional.

[School System surveys](#) include sections from the Community and Parent surveys to allow for the intersection of respondents' various positions. These questions examine how members of the school system feel about the relationship between school building activities and residents. Correlations, if any, between school system position and community sentiments are a tertiary finding, but will be available through the dataset. Sentiments parsed from this survey provide context to the available avenues for community participation.

[Student surveys](#) are focused mostly on students' willingness to participate in the garden. The program's framework is designed to be driven by student voices, expectations, and stories. The survey collects responses to adapt the activities to students' areas of interest. Their responses will be analyzed to determine if the framework is worth pursuing.

Interviews supplement the study by expanding the story told by the survey responses. This mixed-methods approach combines surveys and interviews to build a community relationships profile that tracks willingness to participate in a culturally influenced school garden program. The survey sets baseline interactions to help assess the influence of the program's cultural aspect. Interviews examine whether volunteers would forgo participation, even when the garden's stated goal is to build community trust. The goal is intentionally stated to provide succinct reasoning for the study's design and to contribute to the literature in the field.

An infographic of the program framework is used to hold secondary conversations after the first round of survey responses. The infographic explains how Afrofuturistic principles will be applied alongside basic gardening activities. Participants are asked for their knee-jerk reaction,

from *Not Interested* to *Very Interested*, and those feelings are investigated. At the end of the conversations, the participants are asked to re-evaluate their positions. A change in these responses will indicate that educating community members will benefit local programming.



Figure 1: Afrofuturistic gardening infographic.

Section 5.1: Race Within The Study’s Survey Parameters

Race plays an integral part in society and plays a role in how respondents answer survey questions ([AbrAjano et al., 2018](#)). The study subsequently decided not to include “race or ethnicity” as a demographic survey question because it was deemed counterintuitive to the study’s purpose. Studies show respondents may be compelled to answer unauthentically when asked their race, nationality, or ethnicity (Abrajano et al., 2018). Huddy & Feldman (2009) found that overt prejudices can sway public programs and policies if they seem to benefit Black communities. Although Afrofuturism is an African-American creation, the study’s focus was on the principles of the genre, and asking about race was deemed immaterial to understanding the community’s reflections as a unit. Using the 2008 presidential election as a model, Huddy & Feldman found that when asked if race was a factor in the Democratic primaries, about 17% did not vote for Barack Obama because of race. Their study was written in a way that respondents felt safe enough to respond honestly without fear of being categorized as racist ([Huddy & Feldman, 2018](#)).

Chapter 6: Data and Results

Section 6.1: Survey Results

The surveys were disseminated electronically through Google Forms, and links were provided via email, text, and community bulletin boards. The study area was one neighborhood with 54 single-family homes. The Parent Survey includes all of the questions from the Community Member survey, plus questions that capture information on household students. The School System surveys include the questions from the Parent Survey, plus school system-specific questions. The Student questionnaire investigates students' feelings around their school community.

Section 6.1.1: Community Member Surveys

Of the 54 single-family homes, 11 Community Member surveys were completed, a 20.3% respondent rate illustrating community members without children. The age of respondents range from 17-65, with the majority, 36.4%, falling between 25 and 36. Of these respondents, nine answered the optional question: "*Are you childfree by choice?*", with 77.8% responding "Yes".

The next section of the questionnaire captured mobility data. On mobility trends, 72.7% noted that they moved once, 18.2% moved twice, and 9.1% have moved three times. Of those who relocated, all respondents claimed the move was their choice, highlighting the need for a better life or for a significant other. When asked about neighborhood desirables, 72.7% say they do not scout neighborhoods for children, while 27.3% say they do. Diversity, cleanliness, crime, and noise levels are traits respondents look for in a new neighborhood. Crime, unfriendly neighbors, lack of diversity, and disruptive behavior influence the respondents to move out of a neighborhood.

The next set of questions cover volunteer attitudes and relationships with school systems. When asked about attitudes toward volunteering, 54.5% said they are not interested in volunteering with school systems. The reasons for the disinterest vary, but time and work commitments, administration and teachers, and disinterest in being around children were the main factors that influence this decision. Of those that would want to volunteer, mentorship, enjoyment, and community connections were the influences. Community member respondents say they interact with the school system through providing financial support (18.2%), attend sporting events (45.5%), musical production attendance (36.4%), fair attendance (18.2%), nonprofit work and church (9.1% each), and 18.2% stated not at all.

At the beginning of the survey, respondents are asked if they would participate in a school garden built on Afrofuturistic principles, 44% said "No", 22% responded with "Yes", and 33.3% responded with "Maybe". The Afrofuturism Gardening principles infographic was included at the end of the survey, and 83.3% of respondents agreed with them. The last question of the questionnaire re-examined the willingness of respondents to participate in the garden, and 33.3% responded with "Yes", and 66.7% of respondents replied with "Maybe".

Section 6.1.2: Parent Survey

Respondents of the Parent Survey captured 22.2% of the study neighborhood. The demographic data of the participants range from 25 to 65, with 58.3% falling in the 37-50 age range. The children ranged in age from preschool to high school, where most of the respondents' children attending middle school, shown in Figure.

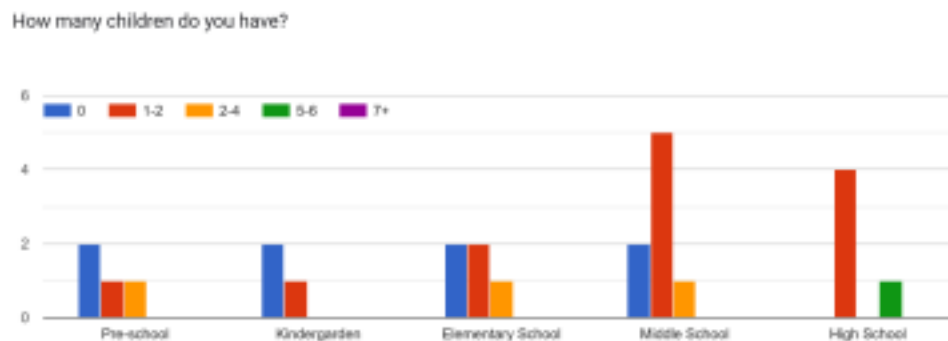


Figure 2: Table of children of Parent respondents.

The parents were asked their motivations for community mobility, and the trends were affordability, safety, location, and school quality. Sports, walkability, and greenspace were secondary concerns. The respondents noted that socioeconomic trends of renters versus homeowners, culture of neighborhoods, and a sense of togetherness can change with community mobility fluctuations. Affordability and school stakeholders (33.3% and 50%, respectively) influence whether respondents moved away from their neighborhoods (Figure 6.2).

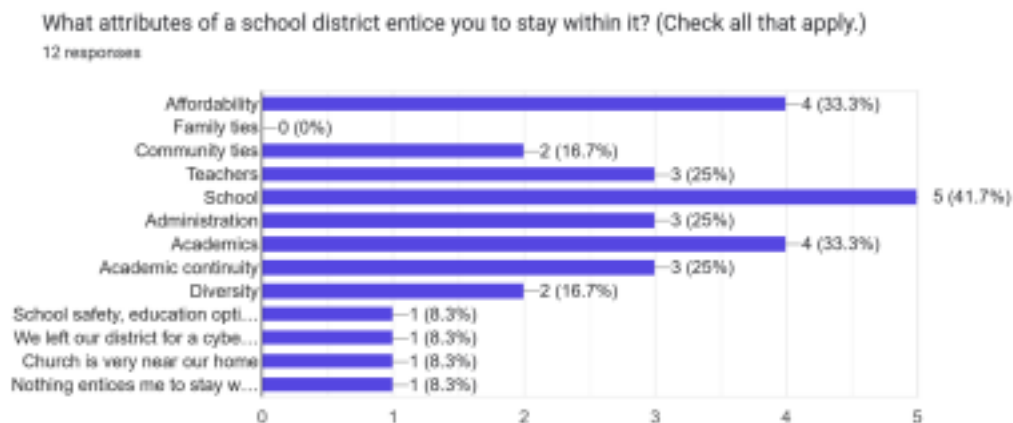


Figure 3: Table showing factors that influence parents to stay within the school district. Continuing to the Community Member section of the survey, 100% of respondents noted they moved willingly at least once in the last five months (at the time of the survey, August 2026). One-third of respondents say they scouted their new neighborhood for children,

mirroring the responses from the Community Member-only respondents.

Parents were asked about their volunteer activities, and 58.3% said they would volunteer. Of the respondents, 50% said they volunteer occasionally, 8.3% replied that they “Sometimes” volunteer, and 16.7% responded that they never volunteer. The factors that influence these trends are time (83.3%) and childcare (33.3%).

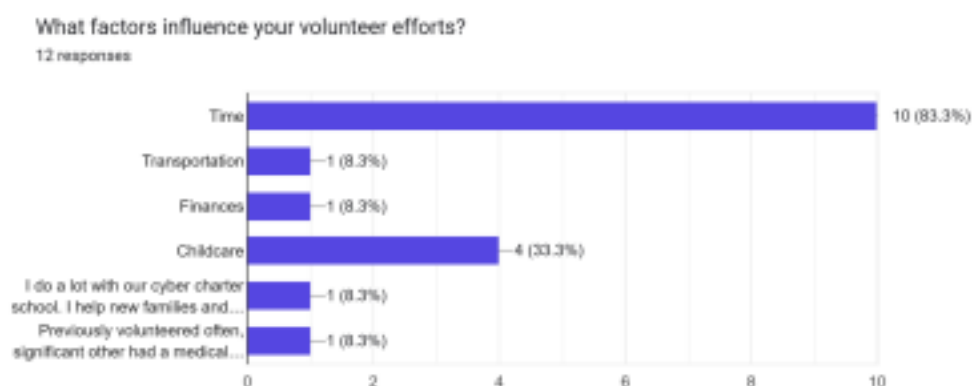


Figure 4: Factors that influence parent volunteer habits.

Parents are deterred from interacting with the school system because of the bureaucracy of the school, attitudes of other volunteers, and a lack of communication from administration and staff. Influential factors for volunteering include mentorship (33.3%), enjoyment (58.3), and community connections (58.3%).

Following the script set by the Community Member survey, parents were asked if they would participate in a garden built on Afrofuturistic principles, and 30% replied “Yes”, 16.7% said “No”, and 33.3% said “Maybe”. After reviewing the infographic, 62.5% said “Maybe”, while 37.5% responded “Yes”. Most of the comments were supportive of the framework, with one respondent noting logistics and funding would be crucial components that could act as barriers to its development.



Figure 5: Parents’ responses to whether they would support an Afrofuturistic-based

school garden.

Section 6.1.3: School System Survey

The School System survey includes all stakeholders who work within the school system. Three teachers, one aide, and one school psychologist completed the School System survey. The ages range 25-65, with 60% falling between 37 and 50.

The School System questions include volunteer opportunities offered by the school district, volunteer habits, and community-school system relationship observations.

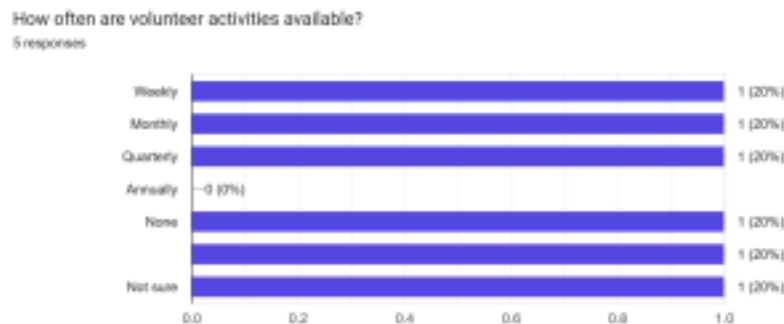


Figure 6: School volunteer opportunities

There is an even split between the 5 respondents on how often volunteer opportunities are available for the study area school. Most of these opportunities, 60%, are tied to specific sports or activities. Three respondents state tutoring and PTO Days are available opportunities, but two respondents noted they were not sure of any extra activities. Volunteer retention was linked to student behavior and time constraints for both teachers and parents. When asked if volunteers uphold their obligations and/or commitments, 60% of respondents marked “Sometimes”, and 40% replied “Yes”. The respondents observed community-school relations are “poor”, with one commenting that location within the school district determines how communities interact with the district.

The Community Member section mimics the trends from the Parent and Community Member surveys, with 75% of respondents responding “Maybe” when asked if they were interested in volunteering for a school garden program. Volunteer habit data shows that 50% of respondents volunteer “Often”, and 50% volunteer “Never”. Time is a major barrier to volunteering with the school district. As a Community Member, the respondents point to student behavior as a reason they do not volunteer. When they do volunteer, 20% say it is for mentorship, 60% responded it is for enjoyment, and 40% noted community connections as their reason. When it comes to community mobility, respondents say safety and affordability are factors that dictate where they live within the district. Discourse and disruptions from neighbors are reasons they would consider moving away from their neighborhood.

Respondents found the proposal encouraging, and 100% of the respondents responded they would “Maybe” participate. They aligned with the Afrofuturistic principles, with one respondent adding “indomitable spirit” to the list.

Section 6.1.4: Student Survey

The student surveys were completed by high school students, age 14-16. They all responded they have a lot of friends at school, but when asked about friendships in their neighborhood, 66% of them responded that they did not have friends, and 33% noted they lived away from their friends. They were asked about their personal journeys in school, and 33% said they felt they were doing their best, and 33% believed they were not. They pointed to more interesting lessons and more time for note-taking as examples that could help them improve.

The respondents were evenly split when questioned whether they would participate in a school garden, with 33% saying “Yes”, “No”, and “Maybe”, respectively. They believe they can improve on sports, academics, and extracurricular activities. All participants, however, do believe a garden can help them with responsibility, consistency, and food access.

When asked about the Afrofuturistic principles, all respondents agreed with them, and would add “Growth” as a principle.

Section 6.2 - Stakeholder Interviews.

Interviews were conducted with participants within the Central Dauphin school system. The participants completed the School System survey before the interview. This ensured that the participants were familiar with the material within the study’s framework. The interviewees were provided a consent form before continuing with the interview.

The first interview was conducted with the school district’s head psychologist, denoted as IVA, while the second interviewee was a middle school Physical Education teacher (IVB). With more than 15 years of experience, IVA answered the questions with insights into the district's history, attitudes, and delinquencies, and IVB provided an in-school perspective. Located in Central Pennsylvania, Central Dauphin consists of 19 schools and has 12,500 enrolled students. Overcrowding and population surges necessitated the creation of another high school to serve the district's east side. This change inadvertently created a “good school” and “bad school” delineation within the community (IVB teaches within the Central Dauphin East side of the district.) Understanding the district's historical context enabled IVA to provide succinct answers to the interview questions.

The interview commenced after the participants acknowledged they had completed the initial survey. The interview began from that frame of understanding. The conversation initiated with questions about volunteer activity within the school district, then narrowed the focus to the immediate school within the study's scope. When asked about volunteer opportunities, IVA said that some parents donate time at school, act as chaperones for field trips, and mentioned a group that reads with students after school. IVB echoed that sentiment and added that they feel more opportunities are needed, noting that the main source of outreach is Facebook campaigns seeking help. When asked about the reliability of volunteers, IVA reflected that most volunteers

are reliable and noted that time constraints contribute to retention. IVB's answer centered on the definition of reliability and what constitutes "mostly there more times than not". Organized activities, such as the reading group mentioned by IVA, have a high reliability rate, but chaperones often wait until the day of the event to decide not to attend. Participation is available during IVB's school hours, with a note that "we could always use more, like 20 more humans just in the hallways," but understands that the volunteer application can be arduous.

Relationships are fundamental to building trust between the school district and IVA, and the district noted the building-specific limitations that govern school-community interactions. The district has a buy-in initiative, and principal expectations and ambitions control the success of those initiatives. Family Engagement Specialists organize outreach that strives for the goal to strengthen the "continuity between home and school, but parents need buy-in, so that's the relationship piece that's missing." Speaking from the intersection of education and physical health, IVB discussed various sports-based volunteer opportunities and the track open to the public. This participant reiterated the need for more opportunities and suggested movie nights, and both participants suggested community dinner nights.

When asked how to improve these relationships, IVA said to meet parents where they are. Chronic absenteeism is a district-wide problem, and addressing its root causes can improve students' relationships with school and, by extension, their parents' relationships with the district. By providing resources and understanding the unique circumstances, parents won't feel "blamed" for their child's attendance records. The participant does not want to apply labels to individuals when the problem is systemic. Time came up as an issue for IVB, and they reiterated the opportunities among parents, teachers, students, and administrators that are driven by community dinners.

With an understanding of volunteer habits, focus switched to the school garden. Both participants responded enthusiastically with a yes when asked whether students would participate in a student garden. IVA said, "anything that is non-structured learning, meaning a non-traditional setting than sitting at a desk staring at a board and looking at the teacher", and IVB added, "the kids love gardens; you got to have the right person to make it interesting, and kids still love to play in dirt." IVA suggested high school students could mentor the younger ones within the parameters of the garden, "like Big Brother, Big Sister".

Each participant had fully reviewed the principles of Afrofuturism and their thoughts on the proposed framework. Both participants were in alignment with the principles, but IVA would add "indomitable spirit" to capture the soul of "resilience". IVB was satisfied with the principles. Both participants felt the program framework would be well received by the district's students. They both, however, stated that time is also a factor in their ability to participate in a school garden.

Chapter 7: Discussion

The purpose of the study was to understand community sentiments about their neighbors, the students, and the school system as a whole, and gauge whether enacting a school garden built off of Afrofuturistic principles would help facilitate community building and community-school partnerships. It's important to understand the motivations of community members in order to create programs that foster a sense of togetherness and ownership of both the neighborhood and the school community. A support system built on trust and multiculturalism will help communities grow with a shared identity while encouraging good behavior and academic success for the students.

The data from the surveys show there is a gap in consistent and exciting volunteer opportunities provided by the school system. This gap can be filled with activities that take into account the time constraints of all stakeholders. Creating a standing volunteer opportunity, such as a school garden, would alleviate the strict "one-time only" volunteer opportunities that surround musical productions or sporting events. A program that has an open invitation to volunteer may help with retention and reliability.

The interviews were reviewed, and the intersections and roles of participants are more important than I realized. Answers from those within the school system will vary depending on their hierarchical relationship with students, building locations, and the socioeconomic status of families. Time constraints are the leading indicators for volunteer retention. I expected more pushback on the term "Afrofuturism", but educating participants helps to improve their understanding and acceptance.

The use of multicultural education within volunteer opportunities is a gap in the research investigating community-school partnerships. This study can add nuance to the discussion surrounding community togetherness, mobility, and student behavior habits inside and outside of the classroom. This study chose an Afrofuturistic lens, but including indigenous, practices from other cultures would flesh out the conversation surrounding cultural plurality. The research does not stop at this study's chosen lens, and can be repeated through the ancestral knowledge of any and all cultural practices.

Section 7.1.2: Polyvocality within the data

The ascribed stakeholders represent the lived experiences of those who will ensure the success or failure of community-school partnerships. This study includes representatives from each stakeholder group, and those perspectives have added nuance to the issues between community members, students, parents, and the school system. Understanding the current state of those relationships is foundational to supporting mediation. The current state of affairs has made time the deciding factor in mending these relationships, so understanding schedules, transportation distances, and leisure hobbies will help create opportunities that most align with schedules and interests.

Section 7.2: Future Research

Future research can repeat this study, and adding the “Race” demographic questionnaire may provide more insight to the motivations and comfortability of the respondents. This study chose not to include it because the neighborhood, as a whole, was considered a stakeholder, but adding those questions could help understand if concerns can be drawn across the racial lines of the respondents.

ANNOTATED BIBLIOGRAPHY				
Book	Citation (APA	Summary of work	Evaluation of	Relevance of the

	format)		the work	work to your case study
Anne E Casey Foundation Parental Involvement vs. Parental Engagement. https://www.aecf.org/blog/parental-involvement-vs-parental-engagement	Anne E Casey Foundation. (2023). Parental Involvement vs. Parental Engagement. https://www.aecf.org/blog/parental-involvement-vs-parental-engagement?gad_source=1&gad_campaignid=23557514628&gbraid=0AAAAAD3xzvHe6dM5EcGn6v7Bo-IZlmaek&gclid=CjwKCAjwuO_QBhAWEiwAikVhU1rAXTKxuGKetxGOdy9DKLfgV49BXhX-OoMfBgeuIGZh5ZtmqtfYWxoCDh4QAvD_BwE	The article defines parental involvement, parental engagement., and provides examples for both	This work is concise in its contextualization of the different ways in which parents interact with school systems.	The work helped provide a foundation for the type of parental interactions that would ensure a successful school garden.
Banks, J. A. Chapter 1: Multicultural Education: Historical Development, Dimensions, and Practice. Review of Research in Education, 19(1), 3-49.	Banks, J. A. (1993). Chapter 1: Multicultural Education: Historical Development, Dimensions, and Practice. Review of Research in Education, 19(1), 3-49.	This article introduced multicultural education, how it affects students, how it manifests through teacher attitudes, and how to employ multicultural educational frameworks.	The article provides an in-depth look at the ways multicultural education can be incorporated within lessons and school activities. The work is concise in its definitions, but opens up ways of deploying multicultural activities. The work does not limit its valuations of equity to just mixing students together.	The work helped build the framework of the survey questions and proposed garden program.

Biggsbyha. J.A. Ask the Expert: MSU Professor Julian Chambliss on “What is Afrofuturism?” - College of Arts & Letters. College of Arts & Letters.	Biggsbyha. (2025). Ask the Expert: MSU Professor Julian Chambliss on “What is Afrofuturism?” - College of Arts & Letters. College of Arts & Letters. https://cal.msu.edu/news/ask-the-expert-msu-professor-julian-chambliss-on-what-is-afrofuturism/	This article is a transcript of a conversation with Julian Chambliss, a professor of Afrofuturism. The article helps explain Afrofuturism principles and how it can be applied outside of the arts.	This conversation provides a framework for Afrofuturism. It	The quotes by Chambliss helped create the framework for the proposed garden.
Blacks In Tech. Afrofuturism: A framework for empowerment and liberation	Blacks In Tech. (2019). Afrofuturism: A framework for empowerment and liberation - Blacks In Technology. Blacks In Technology - The #1 place for Blacks In Technology. https://www.blacksintechology.net/afrofuturism-a-framework-for-empowerment-and-liberation/	This article explains how Afrofuturism can be used as a vehicle to liberation.	It is a brief synopsis how how to apply Afrofuturism within tech and the arts, such that they help speculate futures and instill hope.	This article helped link Afrofuturism to liberation and social justice.
Buchen, I. H. The Impact of Cultural Diversity on Faculty and Students. Equity	Buchen, I. H. (1991). The Impact of Cultural Diversity on Faculty and Students. Equity & Excellence in Education, 25(2–4), 228–232. https://doi.org/10.1080/1066568910250232	The article looks at the school cultural system, and how the different stakeholder visions align or refract from the collective vision held by the school system. It explains and identifies areas of opportunity to incorporate diverse lessons.	The work helped explain the value cultural lessons have on stakeholders. It also provided possible pitfalls of such lessons. Overall, it provided a nuanced look at diversity efforts within schools.	The article helped tailor survey questions, and build-out the framework for the program.
Burt, Kate Gardner, et al. “Development of the GREEN (Garden Resources, Education, and Environment Nexus) Tool: An	Burt, Kate Gardner, et al. (2017). “Development of the GREEN (Garden Resources, Education, and Environment Nexus) Tool: An	The article looked at various garden programs, stakeholder analysis, and the success rate of volunteer outreach. The article creates a tool to help organizers create	The work is comprehensive, and the tool is intelligently designed. The tool provides a framework that	The article helped structure the volunteer habit portion of the survey, as well as helping build the framework of the garden.

Evidence-Based Model for School Garden Integration.” Journal of the Academy of Nutrition and Dietetics	Evidence-Based Model for School Garden Integration.” Journal of the Academy of Nutrition and Dietetics [United States], vol. 117, no. 10, October 2017, pp. 1517-1527.e4, https://doi.org/10.1016/j.jand.2017.02.008 .	sustainable school garden programs.	starts with community outreach, and follows the program to harvest.	
Bullard, R. (2011) Book Review: Sacrifice Zones: The Front Lines of Toxic Chemical Exposure in the United States. Environmental Health Perspectives. Vol. 119, Number 6, June 2011.	Bullard, R. (2011) Book Review: Sacrifice Zones: The Front Lines of Toxic Chemical Exposure in the United States. Environmental Health Perspectives. Vol. 119, Number 6, June 2011.	A book review of Steve Lerner's book, Sacrifice Zones. Lerner traveled to 12 different communities impacted by unjust zoning laws to hear the stories of the population living there	Bullard explains the methodology behind Lerner's visits to the different communities. Bullard's thoughts on Lerner's work help to frame the argument for these sacrificed zones	This book review helps to parse out the main ideas of Sacrifice Zones and those ideas substantiate the issues and prejudices within zoning laws.
Byrd, C. The Associations of Intergroup Interactions and School Racial Socialization with Academic Motivation. The Journal of Educational Research	Byrd, C. M. (2015). The Associations of Intergroup Interactions and School Racial Socialization with Academic Motivation. The Journal of Educational Research, 108(1), 10–21. https://doi.org/10.1080/00220671.2013.831803	The article uses survey data to investigate the feelings associated with race of school-aged children. The results show students have a sense of belonging with culture-rich school climates, and do not subscribe to the notion of being colorblind.	The authors of the article found a hole in the literature surrounding racial attitudes in school by leaning into the various dimensions of a student's life. The study looked holistically at a child, and allowed them to tell their full stories.	This article provided valuable insights on how successful cultural plurality can be in the classroom.
Caruthers, S. Afrofuturism as Liberation and Design with Ingrid LaFleur. Getting Smart	Caruthers, S. (2024). Afrofuturism as Liberation and Design with Ingrid LaFleur. Getting Smart. https://www.gettingsmart.com	This article provides details on how to explore Afrofuturism with children. It also speaks on how Afrofuturism is used to help communities	The article shows the many ways that Afrofuturism can be used to make life better. The	Ideas from this article are used within the garden framework, as it is linked to environmental

	rt.com/2024/08/22/afrofuturism-as-liberation-and-design-with-ingrid-lefleur/	dream bigger.	interview with ingrid LeFleur helps contextualize the principles so that they may reach a larger audience. This work helps build on the other literature selections.	justice.
CDC Parental Engagement in Schools	CDC. (n.d.). Parent Engagement in Schools. https://www.cdc.gov/healthy-youth-parent-resources/parent-engagement/index.html	Tips and tricks for parents to get involved within schools.	The webpage helps schools and parents find ways around factors that restrict parental involvement with school activities. It is a basic list, can provide a starting point.	The suggestions helped create the parental survey.
Channing Division of Network Medicine. https://www.brighamandwomens.org/research/departments/channing-division-of-network-medicine/environmental-risk-factors-for-chronic-disease	Channing Division of Network Medicine. https://www.brighamandwomens.org/research/departments/channing-division-of-network-medicine/environmental-risk-factors-for-chronic-disease	Research depository for epigenetics	great foundational knowledge	Useful information on research and conclusions about epigenetics
Coulton, C. J., Theodos, B., & Turner, M. A. Family mobility and neighborhood change. Urban Institute.	Coulton, C. J., Theodos, B., & Turner, M. A. (2026, April 14). Family mobility and neighborhood change. Urban Institute. https://www.urban.org/research/publication/family-mobility-and-neighborhood-change	The authors used an existing study's data to investigate the factors that influence community mobility. It provided context on neighborhood perceptions, school-community relations, and time availability.	The data and results from this study helped build the picture of how mobility impacts volunteer habits. It is a succinct and thorough study.	The study helped create the community mobility survey questions.

Danilova, N. Stress Response and Immunity: Links and Trade Offs	Danilova, N. (2020). Stress response and immunity : links and trade offs / Nadia Danilova. Bentham Books.	Nadia Danilova investigates the effects of stress from the microbial level. Her research shows how living species, bacteria, and plant life respond to prolonged stress, the processes that occur within the cells, and the results of those changes.	Danilova takes a purely scientific approach to understanding the changes that occur when organisms are placed under stress. Her findings are based on observed data.	Danilova's research shows a direct correlation between the trauma that cells endure and their ability to operate at their optimum levels. Her work proves the negative impact that stressors have on the functionality of a living organism.
Dimouli, I., Koumparou, D., & Golfinopoulos, S. K. From School Gardens to Community Oases: Fostering Environmental and Social Resilience in Urban Spaces	Dimouli, I., Koumparou, D., & Golfinopoulos, S. K. (2024). From School Gardens to Community Oases: Fostering Environmental and Social Resilience in Urban Spaces. Geographies, 4(4), 687-712. https://doi.org/10.3390/geographies4040038	The study followed a school garden initiative in Greece to monitor its progress and impact. It looks at the inclusion of the greenspace into the larger community fabric.	The study is part of the literature exploring how school gardens can improve the community outside of the school. This study looked at the urban setting and the improvements that greenspace can bring. It helps further the conversations surrounding urban gardening.	The work helped support the application of a school garden as a vehicle for multicultural education
Eseonu, T., & Okoye, F. Making a Case for Afrofuturism as a Critical Qualitative Inquiry Method for Liberation. Public Integrity	Eseonu, T., & Okoye, F. (2024). Making a Case for Afrofuturism as a Critical Qualitative Inquiry Method for Liberation. Public Integrity, 26(6), 674–685. https://doi.org/10.1080/10999922.2023.2251277	This article synthesized the principles of Afrofuturism and how they could be used in academia as a paradigm for research.	The article provides a framework that allows Afrofuturistic principles to be used in academia.	The article helped create the Afrofuturism framework and principles.
Frost, R. Five Ways Residential Mobility Has Changed in the Pandemic Era. Harvard University	Frost, R. (2023). Five Ways Residential Mobility Has Changed in the Pandemic Era. Harvard University	The article researched the different ways community mobility changed during Covid, but went further to	The article expanded the research on Covid mobility trends, and	The article helped provide a nuanced picture of how Covid may have changed the

Joint Center for Housing Studies	Joint Center for Housing Studies. https://www.jchs.harvard.edu/blog/five-ways-residential-mobility-has-changed-pandemic-era	research post-Covid numbers and concluded that mobility trends had leveled out to pre-Covid numbers.	provides a picture where remote work no longer played a role in mobility.	landscape of community mobility. This helped craft the mobility survey questions.
Frug, J. (1996). The Geography of Community.	Frug, J. (1996). The Geography of Community. Stanford Law Review, 48(5), 1047–1108. https://doi.org/10.2307/1229380	The author writes about how communities were formed by legislation	This work makes the argument that zoning is the root cause for the divisiveness of communities	The examples of forced urban segregation will help support the idea of more holistic city planning
Harvard Law State Preemption of Local Zoning Laws as Intersectional Climate Policy. (2020)	State Preemption of Local Zoning Laws as Intersectional Climate Policy. (2020). Harvard Law Review, Vol. 135, Issue 6, Chapter 3. https://harvardlawreview.org/print/vol-135/state-preemption-of-local-zoning-laws-as-intersectional-climate-policy/	The authors of this essay detail how zoning laws were used against low income and minority communities	This is a very well executed and thought out paper that synthesizes the issues with zoning and their inherent racist application	This publication will be used to support that US zoning laws started as inherently racist programs
Holbert, N., Dando, M., & Correa, I. (2020) Afrofuturism as critical constructionist design: building futures from the past and present, Learning	Holbert, N., Dando, M., & Correa, I. (2020) Afrofuturism as critical constructionist design: building futures from the past and present, Learning, Media and Technology, 45:4, 328-344, DOI: 10.1080/17439884.2020.1754237. https://doi.org/10.1080/17439884.2020.1754237	The researchers invited 5 teenage Black students to visualize their future using Afrofuturistic principles and art direction	The outcome of the work sessions produced futures that incorporated themes of sustainability, renewability, ancestor honoring and community building	This exercise illustrated the different ways that changing your perspective can open your mind to unexplored possibilities
Huddy, L. & Feldman, S. On Assessing the Political Effects of Racial Prejudice. Annual Review Political Science	Huddy, L. & Feldman, S. (2009). On Assessing the Political Effects of Racial Prejudice. Annual Review Political Science. 12:423-447. https://doi.org/10.1146/	This article reviewed the intersection of race in political surveys. The article data showed respondents were more likely to respond more authentically when not required to reveal their	The article was focused on political leanings, which were segregated on racial and political lines. It gave insight to	With the focus of Afrofuturism, the survey questions needed to be race-neutral. This helped illicit honest feelings surrounding the proposed

	annurev.polisci.11.062906.070752	race.	how race-based survey questions can sway honest answers.	framework.
Tracy Huynh, Chris Magwood, Victor Olgyay, Laurie Kerr, and Wes Sullens, Driving Action on Embodied. Carbon in Buildings, RMI and U.S. Green Building Council (USGBC), 2023, https://rmi.org/insight/driving-action-on-embodied-carbon-in-buildings/ and https://www.usgbc.org/resources/driving-action-embodied-carbon-building		The USGBC released their 2023 directive that put a renewed effort into decarbonizing buildings	The authors of the new LEED directive to push the built world towards decarbonization	These directives will help
Ilham, Mostafa Ayman, et al. "To Move or Not to Move: A Review of Residential Relocation Trends after COVID-19."	Ilham, Mostafa Ayman, et al. "To Move or Not to Move: A Review of Residential Relocation Trends after COVID-19." Cities, vol. 151, no. 105078, August 2024, https://doi.org/10.1016/j.cities.2024.105078 .	The article investigates mobility trends linked to work-from-home/remote job access during COVID. It looked at trends such as shopping changes, city walkability, and the desire to be near greenspace as factors that influence mobility trends.	The work provided a solid picture of low income areas, but there is an opportunity to expand on the research by re-positioning the conversation outside of these neighborhoods.	The essay was an invaluable resource to understanding how COVID impacted neighborhood cultures.
Imarisha, W., & brown, A. M. (Eds.). (2015). Octavia's brood: Science Fiction Stories From Social Justice Movements.	Imarisha, W., & brown, A. M. (Eds.). (2015). Octavia's brood: Science Fiction Stories From Social Justice Movements. AK Press. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/sandiego/detail.action?docID=1996052	This anthology of speculative fiction uses afrofuturism to tell stories about the future	The stories in this anthology use afrofuturism to write their stories and create new worlds outside of the confines of capitalism	The authors of this anthology show us that our imaginations hold the key to sustainability

Johnson, D.G. Rethinking the Social Responsibilities of Engineers as a Form of Accountability	Johnson, D.G. (2017). Rethinking the Social Responsibilities of Engineers as a Form of Accountability. In: Michelfelder, D., Newberry, B., Zhu, Q. (eds) Philosophy and Engineering. Philosophy of Engineering and Technology, vol 26. Springer, Cham. https://doi.org/10.1007/978-3-319-45193-0_7	This essay defines engineer's responsibilities and investigates what it would entitle to hold engineers accountable for their projects	This work thoroughly explores wht engineers have a responsibility to the betterment of society with their designs	This essay helps create a more focused directive to how enineers can practice their social responsibility
Jones, A., & Dantzler, P. Neighbourhood perceptions and residential mobility. Urban Studies	Jones, A., & Dantzler, P. (2021). Neighbourhood perceptions and residential mobility. Urban Studies, 58(9), 1792-1810.	The article studied the factors that influence mobility within communities. Neighborhood perception include cleanliness, crime, and safety. It also looked at how neighborhood togetherness is affected by mobility.	The article provided valuable insight to what makes neighborhoods appealing to new and old residents. It specifically looked at low-income neighborhoods, and the reasons for matriulation into and out of the areas. It provided a story for the data.	The trends uncovered helped create the community mobility survey questions.
Kelemen, E., Czett, K., & Szeentendrey, R. School Gardens as Commons: Fostering Relational Values for Biodiversity Through Participatory Environmental Education. International Journal of the Commons	Kelemen, E., Czett, K., & Szeentendrey, R. (2025). School Gardens as Commons: Fostering Relational Values for Biodiversity Through Participatory Environmental Education. International Journal of the Commons, 19(1), 431–443. https://www.jstor.org/stable/48857229	The article looked at school gardens as a commons of shhared resources. Along with food, they look at the intangible resources - time, patience, etc- that are shared and traded as common goods.	The article showed how shool gardens can help shield students agaiinst environmental and social shocks. It approaches the garden as a tool as well as a resource.	The article was used to support the idea of advancing the use of school gardens beyond tools for academic success.

Lane, H. M., Morello-Frosch, R., Marshall, J.D., Apte, J.S Historical Redlining Is Associated with Present-Day Air Pollution Disparities in U.S. Cities.	Lane, H. M., Morello-Frosch, R., Marshall, J.D., Apte, J.S. (2022). Historical Redlining Is Associated with Present-Day Air Pollution Disparities in U.S. Cities. Environmental Science & Technology Letters 2022 9 (4), 345-350. DOI: 10.1021/acs.estlett.1c01012	The researchers investigated the air pollution of 202 US cities, using census data and the federal Home Owners Loan Corporation mortgage sheets. They found that the disparities in air pollution readings are directly correlated with the redlined districts. While the practice of redlining has been phased out, its impacts are still felt by residents, generations after the fact.	The researchers completed an intense and thorough examination of the housing data, the census data, and the pollution levels. The protocol that they followed was duplicated to obtain their dataset.	The results of this study supports my hypothesis that racist policies from the past have real life consequences in the present. Their findings, in conjunction with the work of Danilova, show how environmental deficiencies can show up in the DNA of the residents.
Lin, S. S., & Kelsey, J. L. Use of race and ethnicity in epidemiologic research: Concepts, methodological issues, and suggestions for research. Epidemiologic Review	Lin, S. S., & Kelsey, J. L. (2000). Use of race and ethnicity in epidemiologic research: Concepts, methodological issues, and suggestions for research. Epidemiologic Reviews, 22(2), 187-202. doi: https://doi.org/10.1093/oxfordjournals.epir.ev.a018032	This article explains how race is used within research frameworks and paradigms. It provided context to the impacts of asking about race in data collection.	The article was well investigated and provided data on how asking about race influences survey responses.	The factors discovered in the article helped support not including race in the surveys.
Mitchell, B., Franco, J. (2018). HOLC “Redlining” Maps: The Persistent Structure Of Segregation And Economic Inequality	Mitchell, B., Franco, J. (2018). HOLC “Redlining” Maps: The Persistent Structure Of Segregation And Economic Inequality. National Community Reinvestment Coalition. https://ncrc.org/holc/	Dr Mitchell aligns the current maps with the HOLC maps of the 1950's to highlight the areas that were deemed "hazardous" are underserved	Mitchell, et al go into great detail over the harm that the practices of the HOLC	This publication will support the argument that zoning and prejudice allowed toxins to be dumped in underserved communities
National museum of african american history and culture Afrofuturism	National museum of african american history and culture. Afrofuturism. https://nmaahc.si.edu/explore/stories/afrofutur	The webpage is a cursory introduction of Afrofuturism and its uses in the arts	The museum's info was pointed and told the history of Afrofuturism.	The information on the website helped situate the conversation around Afrofuturism.

	ism-explained			
Nichols, S.P. Professional responsibility: The role of the engineer in society	Nichols, S.P. Professional responsibility: The role of the engineer in society. SCI ENG ETHICS 3, 327–337 (1997). https://doi.org/10.1007/s11948-997-0039-x	The author of this paper highlights the importance of ethical engineering	This work thoroughly explores what engineers have a responsibility to ensure their designs do not harm society	An indebted assessment of the social contract that all engineers make
Perrino, J. (2020). “Redlining” And Health Indicators: Decisions Made 80 Years Ago Have Health Consequences Today	Perrino, J. (2020). “Redlining” And Health Indicators: Decisions Made 80 Years Ago Have Health Consequences Today. National Community Reinvestment Coalition. https://ncrc.org/redlining-and-health-indicators-decisions-made-80-years-ago-have-health-consequences-today/	The author draws a connection between the zones the HOLC deemed hazardous, and the environmental impact of the health of those populations	Perrino's brief introduction and reflection on how the HOLC maps led to redlining is broken down into language that is easily digested.	This is a great example of the link between legislated prejudice and health
Ratner, S. (1984). Horace M. Kallen and Cultural Pluralism	Ratner, S. (1984). Horace M. Kallen and Cultural Pluralism. Modern Judaism, 4(2), 185–200. http://www.jstor.org/stable/1396461	The author writes about what culture is, how it is created, who participates in a culture and the traits that exist within a culture	The deep dive into culture in this paper	This paper will be used to help define culture as a living, evolving system of relationships
Ressler RW. What Village? Opportunities and Supports for Parental Involvement Outside of the Family Context. Child Youth Serv Rev. 2020 Jan;108:10.1016/j.childyouth.2019.104575. doi: 10.1016/j.childyouth.2019.104575. Epub 2019 Dec 4. PMID: 32132763; PMCID: PMC7055705.	Ressler RW. What Village? Opportunities and Supports for Parental Involvement Outside of the Family Context. Child Youth Serv Rev. 2020 Jan;108:10.1016/j.childyouth.2019.104575. doi: 10.1016/j.childyouth.2019.104575. Epub 2019 Dec 4. PMID: 32132763; PMCID: PMC7055705.	The article investigated the factors that influence parental participation within school districts. It looks at the different demographics, careers, educational levels, transportation, and childcare factors to understand when and why parents get involved in school programs.	The work is thoughtful and takes an unbiased look at the weight on parents, while incorporating socioeconomic situations and context.	This work helped craft the parent survey questions and fill in assumptions.

Richardson, T.A. At the Garden Gate: Community Building Through Food: Revisiting the Critique of "Food, Folk and Fun" in Multicultural Education. Urban Rev	Richardson, T.A. At the Garden Gate: Community Building Through Food: Revisiting the Critique of "Food, Folk and Fun" in Multicultural Education. Urban Rev 43, 107–123 (2011). https://doi.org/10.1007/s11256-009-0146-x	The article looked at school gardens and school food initiatives and their connection to student self worth and cultures. The study concluded school food programs can incorporate multicultural education while providing food for the community.	The article is comprehensive in its investigation of successful and failed student garden programs. It provides alternate avenues for culture to be showcased within school fairs in a way that doesn't "other" nondominate cultures.	The article provided important context to the ways schools use food programs.
Salas R. N. (2021). Environmental Racism and Climate Change - Missed Diagnoses	Salas R. N. (2021). Environmental Racism and Climate Change - Missed Diagnoses. The New England journal of medicine, 385(11), 967–969. https://doi.org/10.1056/NEJMp2109160	Dr Salas uses her work in the emergency room to highlight the importance of examining environmental factors when forming medical diagnosis	Salas gives an excellent and detailed explanation of why it is important to have a few life review of all patients	This is an example of why understanding environment with respect to health diagnosis is vital to providing adequate care
Schachner, M., Peter Noack, Fons J R Van de Vijver, Katharina Eckstein The Associations of Intergroup Interactions and School Racial Socialization with Academic Motivation. The Journal of Educational Research	Maja K Schachner, Peter Noack, Fons J R Van de Vijver, Katharina Eckstein, The Associations of Intergroup Interactions and School Racial Socialization with Academic Motivation. The Journal of Educational Research, Issue 4, July/August 2016, Pages 1175–1191, https://doi.org/10.1111/cdev.12536	This study looked at diversity programs versus the cultural plurality framework. It shows how diversity, equity, and inclusion schemes can enforce "colorblind" classrooms, but plurality creates belonging and self esteem.	The study helped distinguish between harmful, surface level actions and intentional feelings of togetherness.	The study helped provide support for the proposed garden by establishing the difference between diversity and acceptance.

Schachner, Maja K., et al. "How All Students Can Belong and Achieve: Effects of the Cultural Diversity Climate Amongst Students of Immigrant and Nonimmigrant Background in Germany." <i>Journal of Educational Psychology</i>	Schachner, Maja K., et al. "How All Students Can Belong and Achieve: Effects of the Cultural Diversity Climate Amongst Students of Immigrant and Nonimmigrant Background in Germany." <i>Journal of Educational Psychology</i> [Washington], vol. 111, no. 4, May 2019, pp. 703–16, https://doi.org/10.1037/edu0000303 .	This article expands on multicultural education and how it affects students and teachers. It looks at immigrant and non-immigrant families within a community in Germany.	The study helped show how multicultural education can create a sense of belonging for all students and backgrounds.	The article is an excellent resource in crafting multicultural volunteer opportunities.
Schmitt, A., Malchow, B., Hasan, A., & Fallkai, P. The impact of environmental factors in severe psychiatric disorders	Schmitt, A., Malchow, B., Hasan, A., & Fallkai, P. (2014). The impact of environmental factors in severe psychiatric disorders. <i>Frontiers in Neuroscience</i> , 8, 75891. https://doi.org/10.3389/fnins.2014.00019	The authors of this paper researched the environmental triggers and causes of schizophrenia	This is excellent investigative research on the effects of stress and the environment on genes and DNA. The researchers used their supporting study to reach a logical and sound conclusion.	This paper includes research on how and what specific mutations take place in order to cause certain diseases
Taylor, D. Toxic communities : Environmental racism, industrial pollution, and residential mobility.	Taylor, D. E. (2014). <i>Toxic communities : environmental racism, industrial pollution, and residential mobility</i> / Dorceta E. Taylor. (1st ed.). New York: University Press. https://doi.org/10.18574/9781479805150	Dorceta Taylor takes a deep dive into environmental racism to try to parse out the actions that environmental justice advocates can undertake. Taylor looks at different types of environmental harm, drawing a stark distinction between the types of toxins and their long term effects on the community. She also researches why it is hard for these residents to relocate out of the toxic	Taylor's look at various forms of environmental racism, from neo-colonialism to redlining communities into harm. The multifaceted approach she employs allows for a full view of the issues and their root causes.	Taylor's work is extremely relevant to my case study, as she plainly lays out the direct route from racism to adverse health conditions. She also concludes that the different historical uses of the land and industrialization methods need to be taken into consideration when designing any remediation through

		areas.		environmnetal justice work.
Toussaint, E. C. The power of Afrofuturism to imagine new worlds. Current Affairs Inc	Toussaint, E. C. (2025). The power of Afrofuturism to imagine new worlds. Current Affairs Inc. https://www.currentaffairs.org/news/afrofuturism	The essay explores how Afrofuturism shows up in everyday activities.	The work was intriguing by shoing the adaptability and polymathic properties of Afrofuturism	The article helps to adapt Afrofuturism through different media and realms.
US News Swatara Twsp Demographics	US News. (n.d.). Swatara Township Demographics. https://www.usnews.com/education/k12/pennsylvania/swatara-middle-school-268937	Demographics of the study area.	The webpage is a straightfoward repository for data.	The numbers helped solidify the study area.
Voight, A, T. Hanson, M. O'Malley, L. Adekanye The Racial School Climate Gap: Within-School Disparities in Students' Experiences of Safety, Support, and Connectedness. American Journal of Community Psychology,	Voight, A., Hanson, T., O'Malley, M. and Adekanye, L. (2015), The Racial School Climate Gap: Within-School Disparities in Students' Experiences of Safety, Support, and Connectedness. American Journal of Community Psychology, 56: 252-267. https://doi.org/10.1007/s10464-015-9751-x	The article researches the different types of school climates, and add historical context to the relationships of the stakeholders. The auhors lean on early works by African--American scholars to support the case for plurality.	This work builds a successful arguement for the use of multicultural education. It names the limitations and adversities, creating an honest picture,	This work is important to the design of the multicuultural edcuation aspect of the proposed garden program.
Wachira, J. (2020). Wangari Maathai's Environmental Afrofuturist Imaginary in Wanuri Kahiu's Pumzi	Wachira, J. (2020). Wangari Maathai's Environmental Afrofuturist Imaginary in Wanuri Kahiu's Pumzi. Critical Studies in Media Communication, 37(4), 324-336. https://doi-org.sandiego.idm.oclc.org/10.1080/15295036.2020.1820543	This essay studied the use of afrofuturism in Wanuri Kahui's short story dipicting a world without water	This essay provided deep insight into the various ways that Pumzi personified the importance of water for the world. The afrofuturistic storytelling helps to illustrate the connection from	The author highlights the importance of ancestors and water. This work will help support veiwing sustainability from a different lens

			the past to the future that water can represent	
Zipperer, W.C., & Northrop, R. (2020). Urban Development and Environmental Degradation-Oxford Research Encyclopedia of Environmental Science.	Zipperer, W.C., & Northrop, R. (2020). Urban Development and Environmental Degradation-Oxford Research Encyclopedia of Environmental Science.	The authors of this paper investigate urban sprawl and urban stream	This is a thorough paper that makes the connections bewtween urbanization and the degradaton of the environment and populace	The authors provide information that will be used to explain why a new approach to urban planning is necessary

**Addressing the Core of the Trash Epidemic: The Efforts in Cleaning Up the East Fork San
Gabriel River**

Final Capstone Project

Celina Rong

ESH-540

Abstract

With a growing population and the rapid generation of trash, the average person generates about [4.9 pounds of trash a day](#). However, with this figure, the amount of trash that the United States generates per year is more than [258 million tons](#), which, in turn, gets transported to already overflowing landfills. In 2018, studies demonstrated that 2,000 active landfills in the United States were nearing full capacity, which has the United States discussing [constructing more landfills](#).

The East Fork of the San Gabriel River has experienced a continuous issue where trash has overtaken many areas of this water body. Regional and federal agencies alike have spent a strenuous amount of time learning and adapting to how to navigate this ongoing problem and what the root of the trash epidemic is. As time continues, environmental agencies at both the federal and local level are experiencing funding cuts, a lack of grants, diminishing roles, and higher workloads. This study utilizes in-depth discussions and investigations into the underlying issues for a rampant problem that all natural resources experience with a high visitor population. The purpose of this case study is to illustrate how the shortage of staff, funding, and resources in our government directly correlates to the insurmountable amount of trash that ends up in our rivers and engineering collapses that affect our communities, wildlife, and governmental agencies. The results note that it is pivotal to redirect governmental efforts to prioritize our environment and ecosystem to strengthen our community relationships with our precious natural resources.

Introduction

I currently work in the Santa Ana Regional Water Board in the Basin Plan and Regional Planning unit, where I send out 401 Certifications and Waste Discharge Requirement Orders. Previously, I was a Scientific Aide in the Los Angeles Regional Water Board, where constant controversial projects are happening all at once, and as I started my first semester in the MESH program, I happened upon the subject of the East Fork San Gabriel River and its ongoing waste predicament. Though I initially wanted to focus more on the technical and scientific issues that plague this specific stretch of the San Gabriel River, the deeper I searched, the answer was in front of me. As simple as it could be to point blame at the population and their relationship with perceived obsolescence, our federal government and our capitalistic tendencies remain the core problem at hand.

Getting in touch with nature in any capacity is vital for humans to have a better understanding of what needs protecting. There are not many accessible areas in Southern California where people can find a flowing river to recreate in. Many people do not have the means to get to these areas easily. However, being able to utilize our natural resources and water bodies to enjoy comes with a certain responsibility.

The East Fork San Gabriel River has been a thriving tourist destination in Southern California for ages. People from all walks of life visit this gorgeous body of water to escape the harsh sun of a Southern California summer. The [East Fork](#) provides a third of the water

supply in Los Angeles County and is one of the most highly visited sites for in-water activities. Nearly “[8000](#) people visit these four informal picnic areas, a total of 39 acres, each day during the summer,” which results in “over 400 32-gallon bags of trash each day”. With the rising population, each year, the number of visitors increases, and in turn, the amount of trash found in the East Fork soars. Even with the East Fork Trash TMDL that was implemented in 2000, the trash problem continues to grow. People have taken advantage of their ability to put something out of sight, out of mind. In many cases, families and groups will go into the East Fork with coolers, snacks, and toys to further relax in the river. However, once their day is over, the trek back up the informal access points with their load of trash just seems more than is worth the energy, which leads them to dump their leftover waste next to the river.

Accordingly, this study asks:

How are the United States Forest Service and the Los Angeles Water Resources Control Board currently responding to the trash epidemic in the East Fork of the San Gabriel River?

Local and federal governmental agencies have worked tirelessly to keep this waste situation at bay but to no avail. The merciless funding cuts that we have seen in the political space have sliced up these departments that protect our water resources, leaving fewer staff to pick up the growing workload of their dwindling workforce. My focus for this project was to discuss these issues with local government entities such as the State Water Resources Control Board, along with federal government entities like the United States Forest Service and the Environmental Protection Agency. To get more context, I reached out to neighboring local volunteer communities that work closely with this stretch of the San Gabriel River in hopes of fleshing out the bigger picture and how it is affecting our local communities. I conducted interviews with state employees from the Los Angeles Regional Water Resources Control Board, the State Water Resources Control Board, and federal staff from the Environmental Protection Agency.

Volunteers, citizens, and organizations have been recruited to aid in trash pick-up to no avail. The degrading infrastructure and continuing waste issue have become a safety concern in more ways than one. This environmental and safety hazard has gone on to affect the neighboring communities, recreational use, and public health.

Literature Review

The guiding question that led to my pursuit of the existing literature was ‘how is the water from the East Fork going to be affected for domestic and industrial use?’ Overall, the waters are utilized for drinking water and water-contact recreation, which indicates that they are monitored for nitrate, heavy metals, and bacteria levels. Furthermore, ‘how has the idea of perceived obsolescence in society impacted this watershed?’ A substantial issue that natural resources and commonly recreated parts of our ecosystem suffer from is the mentality that perfectly functional items can be discarded and left at the bottom of this system. The San

Gabriel Watershed has a rich history along with its residents that have dealt with the hardships of being at the center of one of the most visited water systems in the state of California. In delving into the pressing issue of how the waste problem came to be, the historical context of the watershed and its many uses need to be addressed. Furthermore, this literature review will discuss the natural degradation and natural disasters that plague this area. Finally, it reviews the human impact and mentality that has accelerated its need for updated infrastructure.

I. History of the San Gabriel River

The San Gabriel River watershed, the largest watershed in the San Gabriel Mountains, encompasses [690.7 miles](#). The San Gabriel River watershed in its entirety has resulted in heavy wetland losses due to [development](#). Some of the major [tributaries](#) to the San Gabriel River are Walnut Creek, San Jose Creek, Coyote Creek, and a number of storm drains. With this new age, most perennial and intermittent ponds and marshes no longer exist. The [Gabrieleno Indians](#) were able to make use of the land and relied on the water source to maintain their lifestyle. They utilized their extensive knowledge of the vegetation, land, and natural resources to construct huts and canoes. For centuries, the San Gabriel River has been the lifeblood of the people of the land. A [2004](#) thesis notes that since being urbanized, people urged that the river be utilized for recreation and wildlife instead of just for flood control and urban runoff.

II. Neighboring Communities in the San Gabriel Valley

The application of socio-economic background is pertinent to grasp the social inequities of the San Gabriel Valley. From the start of World War II, the area of the San Gabriel Valley, known as the SGV, has been the rising home of Asian Americans, Mexicans, and other minorities as they began to shift out of the Los Angeles area, notably [East Los Angeles](#) and Chinatown. In the *LA Times*, Bianca Mabute Louie recounts that by the 1970s, Monterey Park, a subset of the SGV, was predominantly “white people holding a majority at 50.5%, Latinos at 34%, Asian Americans at 15.3%, and Black Americans hovering at 0.2%,” which made this area the first ethnoburb in the country. The term [ethnoburb](#) was coined in 1997 and first published in 1998, demonstrating a suburban residential area with a notable immigrant population.

The community of [San Gabriel](#) has had a lack of funding for housing and a lower income than the rest of Los Angeles County. Generally, people renting out older homes and apartments in San Gabriel would have to run air conditioning units in the sweltering heat of the summer or go without air conditioning altogether.

Many families that include a high number of minorities would seek elsewhere to escape the high temperatures. The East Fork San Gabriel River has been an oasis for decades for people within the community and tourists to enjoy the nature Los Angeles County has to offer. Studies from the East Fork San Gabriel Project demonstrate that 93% of the visitors along the river itself are Latino, many in family groups escaping the heat and enjoying the shady river setting. The lack of cleanup and control over the waste being discharged into the river is affecting

minorities and everyone who visits. Especially in an ethnoburb such as San Gabriel, there has been difficulty in obtaining the funds and manpower to maintain this beautiful water body. However, due to a lack of accessibility, when there is a true emergency, people cannot escape what was supposed to be a beautiful summer getaway because of the failing infrastructure.

There are numerous other locations across Southern California that compare to the case of the East Fork of the San Gabriel River. A similar problem can also be found at Arroyo Seco, located in the Angeles National Forest. Arroyo Seco is heavily impacted by trash, bacteria, metals, and chemicals due to the heavy [urbanization](#) in this area. Like the San Gabriel River, Arroyo Seco has various dams, culverts, and diversions that support the Lincoln Avenue Water Company to [provide water](#) for Altadena and the City of Pasadena. Though Arroyo Seco is smack in the middle of Los Angeles County, the volume of visitors averages more than [500](#) per day on busier weekends. But similarly, Arroyo Seco water quality suffers from day use and garbage left by visitors. River access also proves difficult, as access is not easy and the trek can be complex. Oftentimes, people end up leaving more behind than anticipated, which leads to unnecessary amounts of waste in and around the river. However, Arroyo Seco implemented eight educational and community-building programs on-site and in the communities in the [Gorge](#). Strengthening the collaboration within the community through these collaborative efforts has shown immense value for this resource and opens new avenues for such an important recreational area. The parks have recommended increasing training opportunities for agency staff, along with stakeholders, volunteers, and the general public. With that said, guidance on improved signage paired with intentional changes to infrastructure was emphasized to give education and better opportunities for passersby to gain a better understanding of our natural resources and the care it takes to upkeep them.

III. Erosion and Natural Disasters

Erosion is a common occurrence within the San Gabriel River area and has a few contributing factors. Recent wildfire activity has occurred in areas where the slopes are steep, which shifts the vegetation cover on the slopes and accelerates the erosion. During the storm seasons, the San Gabriel Mountain soil gets saturated, leading mud, trees, and rocks to shift quickly down the steep slopes and meander through the canyons. The rain carries silt, sand, and gravel from the high elevations and deposits it in the stream channels, which will make its way to the Pacific Ocean.

In July 2024, the [Fork Fire](#) erupted during the day, which was initially predicted to only be five to ten acres but resulted in 300 acres of land being ripped through by the flames. Families were enjoying a shady, cool escape from the sweltering heat of the Los Angeles sun, and in turn, needed to make a swift escape in light of the spreading fire. [Flores](#) illustrates how he and his family found themselves being evacuated from their favorite recreational spot during a wildfire.

However, the next day, the [Bridge Fire](#) broke out, decimating 51,000 acres. Both the Fork Fire and Bridge Fire demonstrate the precarity of the East Fork San Gabriel River. A frequent [visitor](#) recounts that “my nightmare scenario has always been that the canyon is

completely packed, no one can get in or out, and we have a fire break out on a slope right above the river,r” which notes a specific problem. East Fork San Gabriel River was not built with recreational infrastructure in mind, and the infrastructure that was built back in the [1950s](#) is greatly deteriorating. There are not a lot of places to dispose of trash near the river; therefore, waste is seen whichever way you turn. People have noted that even though there are ‘No Littering’ signs, the [roadsides](#) were heaped with all manner of garbage: rotting food, barbecue grills, bottles, ice chests, soiled diapers, and float toys. There are no limitations, no rangers on site, and no rules that are left to be broken. People must tromp through trash to get down to the river and stomp back up to get back to where they parked. This is a noticeable hazard that could have very well hindered people from evacuating during the Bridge Fire and Fork Fire. Thankfully, everyone had made it out alive, which is surprising due to the lack of accessibility in East Fork San Gabriel River.

IV. Perceived Obscure

Obsolescence is the devaluing of material objects, and this simple idea has warped the [human-object relationship](#) as our capitalistic society has altered our thought process on how long products are actually supposed to last. It has become less common for people to repair material objects and more common for people to buy a whole new version of the same product. This problem is incredibly prevalent because companies subconsciously feed the newest version of products as the must-have new fad. To repair objects like technology, it can cost more than it is worth to repair, which gives into the idea that people would rather have a brand new piece of technology for just a bit more in cost. In previous years, everyone was much more frugal and cautious of spending and waste. However, a budding [consumer culture](#) created many opportunities to get rid of many outdated technologies and old fashions, but it “coexisted with long traditions of reuse and careful economy.” To form a society that pinched and scraped for resources in times of scarcity, objects were made with care and were built to last. Durable products are becoming more and more scarce these days as companies began to notice that they would make more money creating an [accelerated turnover](#) of commodities to sustain capitalistic impulses through everlasting consumption. Consumer habit is an inherent pollutant to society and the environment as it creates more waste in spaces that impacted communities reside in. Capitalism has created a cycle that is dependent on the fast tracking of consumption.

Due to this idea, waste generation has skyrocketed throughout the most recent decade. The United States was the largest generator of waste and by 2000, the United States was producing [192 million tonnes up from 131 million tonnes](#) in 1980. Plastic production scaled to 322 million tonnes internationally by the year 2015. With these findings, the generation of trash was a planted seed to sow consumer discontent. Packard’s [1960 research](#) traced planned obsolescence in the American automobile industry back to the 1920s. As the market was insanely saturated, the only pathway to maintain and increase revenue was to persuade automobile owners to switch cars not out of necessity but because of the societal pressure that they were outdated. The deliberate cultivation of social anxiety and shame is perpetuated by

the societal fear that our possessions are subpar. The constant social pressure to keep up appearances by having the latest technology, makeup, cars, etc, supports this notion that this unconscious tension was manufactured.

V. Environmental Pollution

The significant levels of litter deposition not only affect humans and public health, it will also affect the flora, fauna, and water quality of the East Fork of the San Gabriel River and neighboring areas. The [Forest Service](#) identified the East Fork as a location of high ecological significance, providing key refugia for imperiled native fish, including the threatened Santa Ana sucker and the sensitive Santa Ana speckled dace and arroyo chub.

Different portions of the East Fork [sustain](#) a coastal trout, endangered mountain yellow-legged frog, and various other sensitive wildlife species. The entirety of this area is overflowing with biodiversity. Unfortunately, the beauty of this ecosystem is overshadowed by the onslaught of trash that contaminates the waters that the wildlife utilize as shelter. As human trash and waste enter the system, USFS observations and the DPW note that a majority of the trash that enters the river terrace areas is made up of: “[paper products](#) (i.e. napkins, plates, boxes; containers for 12-packs) toys, plastic products (i.e. cups, grocery bags, beverage containers, six-pack rings, utensils, chip bags, candy wrappers), glass products (i.e. beverage containers, often broken) and Styrofoam products (i.e. cups, plates, broken ice chests)”. Even more alarmingly, a major hazardous element is disposable diapers. Many of the families that visit the East Fork typically have children. These [diapers](#) present a large threat to water quality and public health from pathogens if left in the water. Other items that have been thrown away, such as charcoal, are toxic or biologically detrimental pollutants that may pollute the waterbody.

If scientists and engineers were able to address the ongoing trash crisis, the effects would be felt throughout the ecosystem. The bacteria that would be prevented from entering the waterways would make the waters less hazardous and cleaner for all the living things that would utilize the river.

Methodology and Research Questions

The literature review set the tone that the East Fork of the San Gabriel River was already going to be in need of restructuring. However, the analytical data alone is not sufficient in showing why this specific stretch is in such disrepair. A site visit was scheduled to take place in order to get a closer look at the problems firsthand. Furthermore, staff from federal, state, and volunteer agencies were contacted to be interviewed to gain more perspectives on how the issue was exacerbated. The original extent of my research was to look more closely at the regulatory side of the East Fork of the San Gabriel River, which includes the Trash TMDL. I had originally planned to utilize the trash monitoring and reports that should have been submitted regarding the Trash TMDL and associated grants for the East Fork.

On July 18, 2026, at 7 am, I went down to the East Fork of the San Gabriel River to see

what the conditions were truly like. The first thing I noticed driving down East Fork Road was just how many cars were already parked and lined up to the end of the road. The main parking lot at the end was already blocked off because it was at capacity. By 7 am, there were easily 200 cars lining the stretch of the road next to the East Fork. As I made my way down one of the informal access points, I noticed that there were roughly 11 different portions of East Fork Road where there were more than five cars lining the road. Most of these sections had more than 15 cars lined up. Approximately, there were 200 cars already parked. I had stopped near the end of the road to hike down to the East Fork River, and there were more than 20 families getting together with tents up, children swimming in the river, and grilling up food. It was wonderful to see people getting together and enjoying our natural resources. As I spent 10-20 minutes taking pictures of the East Fork and the visitors that were already there, more families were hiking down by the minute as I watched people carefully make their way down to the river with full hands. I only visited the portion of the river that people had settled to spend their day instead of hiking the trails, as all the trash seemed to be spilling out of the receptacles up on the road. Even at the beginning of the day, there were already numerous overflowing trash receptacles that animals had gotten into. Trash was seen littered on the sides of the road, but it was unclear if it was dumped there or had blown over from the massive dumpsters. Either way, the trash was making its way down the slopes and closer to the East Fork even at 7 am. If that is how full the trash already was at the beginning of the day, I could only imagine the state they would be in at the end. A concern that popped up was whether the dumpsters were being cleared every day during the weekend or if it was once a week.



Image 1: Visitors in the East Fork
Recreating



Image 2: Visitors swimming in the East
Fork



Image 3: Visitors using pool floaties in the East Fork



Image 4: Spilled trash from waste
receptacle



5: Litter amongst the slopes



Image 6: Overflowing waste receptacle

On the hike back up to my car, I did notice there were a few dilapidated stairs that were in desperate need of repair. This demonstrates that there were a few structures and access points that were available over the years but were long overdue for an uplift. More people would rather hike down the slopes than use the stairs that feel like they could give way due to the eroded nature. Heading back down the mountain, I counted roughly 50 more cars heading up, which doesn't include all the ones that had already made it up the mountain while I was investigating. Perhaps I should not have been surprised by the sheer amount of people that dedicated their

early morning to making the trek down to the East Fork, but it's beyond my scope of just how many people were visiting the system that one day alone. Even so, the numbers provided in the Trash TMDL seem to become more and more outdated as I got a better scope of the gathered population that visited this area. To flesh out my findings and observations, I talked to staff from different governmental agencies that have had a heavy hand in managing the San Gabriel River and different watersheds in Los Angeles County, I noticed that many of the pitfalls come from the steep increase in population, the lack of funding, and staff within governmental agencies to keep these kinds of projects afloat.

The following questions were utilized to form my research methodology:

- What social, political, and economic attributes have led to the degradation of the East Fork of the San Gabriel River?
- Given the economic and political problems associated with the funding to renovate facilities in the East Fork, what other obstacles keep the East Fork from being a zero waste system?
- Are there any solutions that can be developed to hold visitors accountable for littering in the river?
- Is more outreach a viable strategy to make the community more aware of the trash problem that has plagued the East Fork?

Interview Questions

1. Please introduce yourself and describe your relationship to the East Fork of the San Gabriel River.
2. If you'd like to share, please detail the environmental and social issues that have impacted the watershed over time.
3. What are some issues that you have noticed that have prevented the East Fork from constructing the needed renovation of its infrastructure?
4. Can you provide some approaches that could rein in the trash issue at the East Fork?
5. With your understanding of water quality, do you have any recommendations for managing outdated infrastructure and waste?

Findings From Interview with Deseret Weeks

In beginning the hunt for interviews, Deseret was the first person to answer my persistent emails. Deseret Weeks is an Environmental Scientist who works in the TMDL Unit at the Los Angeles Regional Water Resources Control Board and has worked closely with the Trash TMDL and its implementation of it. The interview was done through Teams on June 28, 2026. She notes during the interview that problems that have arisen during the drafting of the

renovation of the East Fork of the San Gabriel River are the Trump Administration's gutting of the United States Forest Service, which has resulted in high turnover rates, fewer staff, and more work for the remaining staff. The political fluctuations that have greatly affected federal programs such as the United States Forest Service, in turn, affect our local natural resources and the maintenance of our water sources. Ms. Weeks spoke on how another major issue that this area has seen is the rise in population, which has contributed to the influx of visitors, making the East Fork more difficult to manage as people from all over San Bernardino County, Los Angeles County, and Orange County make their way to the closest available resource to recreate in. She emphasizes multiple times that the trash problem is caused by recreation, especially in the summertime. An important topic Ms. Weeks mentioned is the idea of perceived obsolescence and how people who visit the area bring in makeshift toilets, which are essentially plastic buckets, to use the facilities in and leave them at the bottom of the river. She explains her relationship to nature and how she spent her childhood in natural waters and had never seen these kinds of issues and laziness until now. Though she has an understanding of the urge for humans to be in nature and connect with our environment, she expressed disdain for how people bring in the capitalistic mindset that once things are "thrown away," then it is out of sight, out of mind. The myriad types of plastics that get bunched up into plastic or foam coolers that then get left at the East Fork is a constant issue that was noticed. The mindset in American society that it is appropriate to leave waste anywhere is a selfish and convenient way for people to set and forget. In a regulatory sense, the human thought process is not mentioned because of the formal nature of the documents. However, Ms. Weeks brings to light that a lot of litter problems are because of the underlying issues of our human habits. Single-use plastics are littered across the slopes and waters.

She mentions that the East Fork of the San Gabriel River was recently awarded a [319\(h\) Grant](#), which gives federal funding to states and other entities to lower nonpoint source pollution and enhance water quality under the Clean Water Act. She stressed that the inflation directly caused by the Trump Administration tariffs had a major impact on the project because they proposed a budget of 3 million dollars for the renovations proposed, but the cost of labor and materials has skyrocketed since the tariffs were imposed. As a result, the money associated with the 319(h) Grant does not match the actual costs of the project. The project now has to be rebid for the third time because of this major roadblock. Ms. Weeks mentioned that the project was going to limit informal access points to combat erosion and tighten up on safety and security by adding in boulders and an access gate to direct the flow of visitors to specific access points. She also emphasized that due to the lack of funding across the board, it limits the amount of collaboration between federal and state agencies to address these pertinent issues that have plagued this area for ages.

Findings From Interview with Christopher Marquis

I have been in communication with Chris since I began working in the Los Angeles Water Resources Control Board in 2022. He provided extensive background on the process of the Trash TMDL and was instrumental in the culmination of my project. I conducted my

interview with Chris Marquis, a Senior Environmental Scientist, on July 3, 2026, via Teams. He previously worked in the TMDL and non-point source section at the Los Angeles Water Resources Control Board, where he played a pivotal role in creating the Trash TMDL for the East Fork of the San Gabriel River. Overutilization and lack of infrastructure have accelerated the degradation of this area in the East Fork. Many overlooked communities utilize this space and premium natural resources to recreate. With its proximity being so close to the Los Angeles Metropolitan area and the San Gabriel Valley, this natural space is a comfort to many underserved Hispanic and Asian communities that reside in the area. With the lack of infrastructure, there have been numerous landslides, debris, and fecal matter issues that have resulted. Mr. Marquis shared similar sentiments as Ms. Weeks that a portion of the holdup was due to the inflation of materials and construction costs. He noted that many of the upgrades that would have been the best option for the project had to be downgraded, such as the toilets being put in the facilities.

Mr Marquis mentions the various internal and budget problems that impacted the East Fork. The Trump Administration's attempt to gut these programs has made implementation of these projects more challenging. With the understaffed and underfunded United States Forest Service working with their limited resources, the East Fork and projects similar have suffered immensely. Furthermore, the funding constraints caused by tariffs, inflation, and greed have made matters difficult in fitting all the necessary renovations into the original allotted grant funding given. Mr. Marquis notes that the grant was for a 3.5 million dollar budget and a scope of work that he oversaw. Overall, the prices of the materials went up, and the options shifted. Originally, the plan was to install Sweet Smelling Toilets that would have been incredibly beneficial under these circumstances; however, they had to downgrade to a more economically friendly option that would degrade faster and would result in the toilets needing to be replaced sooner. Corners had to be cut in order to fit the constraints of the budget.

Even so, Mr. Marquis informed me of a new Waste Discharge Requirement for trash in the East Fork, which is a larger-scale implementation that is permanent. This gives the state a bit more leverage in regulation, where they do not need to be reimplemented every five years for a conditional waiver for this continued project. Mr. Marquis emphasizes that a positive change that could work in favor of the East Fork would be a higher participation amount with the conditional waiver. Though it was mandated, it was voluntary. Entire municipalities were opting out of reporting their findings. With the Waste Discharge Requirement, there are stronger regulatory teeth in place. This will yield a better outcome for environmental protection and trash in the Los Angeles region. Part of the proposal was to implement a bus system that would take visitors from a rest stop in Azusa during weekends and holidays, which would help with access to the East Fork. Furthermore, the United States Forest Service was going to do more community outreach and education media for the East Fork and for the San Gabriel Monument. However, they were decommissioned because of the erosion into the water body, but the bus proposal would have been a step in the right direction in making the East Fork safer and more accessible for the public. To make this area more sustainable for people to recreate at the East Fork, the infrastructure is in desperate need of an uplift. Though many of the issues that occur in this area

are because of population and recreation, it is one of the only spaces where people can visit a flowing river and reconnect with nature that is difficult to find in Los Angeles County. To block off people from visiting in any capacity would serve as a detriment to the community that is desperate to reestablish their relationship with the environment.

Findings from Interview with Avra Heller

From my interview and communication with Chris Marquis, he sent me Avra's contact information and urged me to reach out. They had worked closely during the early stages of the 319 grant for the San Gabriel Mountains. I conducted my interview with Avra Heller, Environmental Protection Agency Region 9 Clean Water Act 319 Grant Manager, on July 10, 2026. She is the regional lead for the grants, and the 319 grant for San Gabriel was elevated to the federal level at the Environmental Protection Agency from the state board and regional players, and she was informed that this was a priority project for the United States Forest Service. She indicated that it was moved further up the chain to White House-level staff. This grant was going to be utilized to expand the territory for the San Gabriel Mountains, which was heightened with the press interest about the trash impacts. A major part of the increased interest at the federal level was because of the elevated interest to the public, along with the Trash TMDL, which makes it a non-point source pollutant, which makes it viable for Clean Water Act and restoration funding. Ms. Heller notes that normally trash is within the municipal storm system's impacts, but because of the Trash TMDL, it falls outside of their jurisdiction. She had been working closely with the Forest Service, State Water Resources Control Board, and Mountain and Rivers Conservancy for roughly 2 years but has been in contact since the Biden Administration. Ms. Heller, similarly to Mr. Marquis and Ms. Weeks, noted the setback with the increase in cost for construction and materials that affected the funding push. The continuous barrage of natural disasters that also affected the timeline of the project includes multiple fires, floods, and active problems in close proximity to the project site. She has high hopes that the project will start this calendar year or by the next at the latest. The grant funding is entirely from the Environmental Protection Agency Clean Water Act.

Avra also emphasizes that this is a critical resource for people in East Los Angeles, as there are many communities that lack access to wilderness areas. She mentions that there are multi-generational families that have routine get-togethers at this resource and have for many, many years. Like Deseret, she shares concern that the trash problem increased because there's a lack of culture in taking out the waste with them. There are not enough receptacles for trash and not enough toilets in the facilities. A common issue that is brought up is the buckets of human waste found at the site that people are using as makeshift toilets. This anecdote is a well-circulated one that emphasizes the need for renovation and upgrades to the facilities.

Findings From Interview with Steve Evans

After learning more about the inner workings of state and federal staff, I had reached out to Friends of the River, an advocate group created by river guides in the 1970s to work on water

policy issues and legislation for the rivers and dams of California. From the cold emails, Steve Evans reached out to me, eager to share his experiences. I conducted the interview on July 31, 2026 with Steve Evans who grew up in Covina and would visit the East Fork before it became popular. He has done extensive work wilderness and wild scenic river protection for federal public lands throughout the state. Furthermore, he has worked with Friends of the River since 1988. He was a staunch advocate for scenic rivers to be studied and played a hand in convincing public agencies to study and identify eligible scenic rivers including the San Gabriel River. Evans currently works part-time with CALWild, a state agency that conducts work in mostly federal lands, in creating draft legislation and has collaborated with numerous politicians for wild and scenic designation for water resources.

In discussing the United States Forest Service, Evans expressed his disdain in their lack of motivation to designate the Forks of the San Gabriel River as scenic study rivers. In 2005, the US Forest Service did not move forward with checking suitability for the San Gabriel River. They had found it suitable but never completed the suitability study which made it difficult for designation. In 2026, Evans worked to gain the designation and complete the work that US Forest Service fell short of. Like the previous staff I had interviewed, Evans was involved in developing the project to upgrade the facilities for the East Fork that was ultimately shelved.

Evans makes a distinction that the difference between federal and state is that a majority of the state wild and scenic rivers are on federal lands. However, the state has no control over land use in these parcels. Federal agencies manage the funding and maintenance of these areas. Federal agencies are responsible for creating management plans for these federal rivers to ensure that the long term protection of these values are overseen.

Having worked in government throughout various administrations, Evans emphasizes that he has never seen an administration like the Trump Administration blatantly go after land management agencies in slashing funding and gutting the agencies. As a result, these agencies are left as shells of their former glory to pick up the work of their fallen staff members and lose knowledge and experience from staff with decades of expertise. With the cuts, Evans and his coworkers are still grappling with the damage that has been done to the land use agencies. The lack of staff is evident in the quality of the lands managed and Evans notes that the San Gabriel National Monument is a poster child of land mismanagement with the lack of staff and will by the agency at the helm. Evans highlights that the East Fork of the San Gabriel is an urban park experience that needs more management. But the US Forest Service manages the system as if it's a remote national forest that does not get visitors. Even so, the East Fork has historically had millions of visitors for years. Though there is a collected understanding that the public should be able to recreate in these systems, there simply isn't room for the amount of visitors at the site. Unfortunately, though there are limits to use, it makes practical sense as this national monument has such close proximity to large urban areas. Evans made a fantastic point in comparing the situation to a theater. Once a theater reaches capacity, you do not allow people to loiter in the aisles and sit on the steps when there is a capacity limit. It becomes a safety hazard and impedes access.

Clean Up and Renovation

In interviewing staff from different agencies, there has been added concerns about contamination of the region's largest watershed, citizens, volunteers, state, and federal agencies have gotten more involved in transforming the run-down conditions of the East Fork San Gabriel River. In recent years, citizens and homelessness advocates have brought attention to the homeless encampments that reside along the San Gabriel River. As the numbers for homelessness have increased by [24% in San Gabriel](#), 127% in Azusa, and 366% in Irwindale, there is no doubt that many people have flocked to the East Fork to find shelter. [Mel Tillekeratne](#), founder and executive director of The Shower of Hope, stated that "you can't tell 300 people, 'Pack up your (stuff) and leave, and you don't get to come back. You have to provide an alternate place to camp or stay for however long it takes" which begs the question, what will happen to the people living near the river when a natural disaster occurs. This issue will quickly escalate from not only a public health problem but a safety problem.

The worsening conditions of the East Fork not only affect tourists but also the disadvantaged communities that rely on this river for everyday use. The East Fork Project has pledged to update these conditions of the 2.5-mile stretch to renovate the area for tourists to visit. The bustling recreational areas were not built to accommodate the [4.5 million](#) people who visited in 2021. The East Fork Project, utilizing \$10,000,000 to \$15,000,000, is working with Watershed Conservation Authority (WCA) and the US Forest Service to enact this mission. Furthermore, this stretch of the San Gabriel Mountains has suffered from long-term neglect as there is a lack of resources for environmental protection and cleanup. Even so, the team had created a sustainable, conceptual [model](#) that includes "visitor parking and transit stops that will be concentrated near six well-designed river access points that channel visitors to multi-lingual interpretive signs, restrooms, trash receptacles, and river overlooks," which was the beginning of managing the crowds. Another complication is the sheer volume of trash. Would the trash receptacles that are being proposed be enough? With the growing number of tourists each year, the amount of waste continuously swells.

Numerous organizations have signed on to find solutions to the waste complication in the East Fork San Gabriel River. The Los Angeles Regional Water Quality Control Board adopted the Trash TMDL, amended in May of 2000, to tackle trash deposition and litter. The Forest Service implements daily sweeps, which consist of the collection and removal. "approximately [200 32-gallon bags](#) of uncontained trash from the area each weekend day," the work has proved to lack the staff required to completely eradicate the problem. The [Trash TMDL](#) goal is for zero waste in the river; however, most of the trash is found "in the river terrace area, and not in the river itself". As the East Fork did not anticipate the sheer amount of visitors it would get, there is a lack of trash receptacles, signage, parking areas, available staff, and designated picnic grounds. All these factors, including the blatant littering, contribute to the litter issue. Furthermore, the litter puts the following [existing beneficial uses](#) of the East Fork of the San Gabriel River at risk: water contact recreation, non-water contact recreation, warm freshwater habitat, cold freshwater habitat, wildlife habitat, spawning habitat, and wetland habitat.

Results and Discussion

In discovering how the United States Forest Service and the Los Angeles Water Resources Control Board are currently responding to the trash epidemic in the East Fork of the San Gabriel River, I've observed that staff from both the federal and state sides have addressed the bad habits people bring when they leave their waste at the bottom of the system. There has been a bit of discourse in terms of monitoring standards from the Water Boards that the TMDL does urge for stronger monitoring data, but it is mostly voluntary. From my findings in the literature review and interview with Mr. Marquis, there needs to be stronger regulations and policies that hold agencies accountable when they are out of compliance.

If scientists and engineers can conduct surveys and studies on how the East Fork of the San Gabriel River could mitigate the trash issue, there may be a few viable solutions. The main goal should be keeping trash and waste out of the East Fork. Firstly, there needs to be funding, on a political level, and added regulations and fines for littering in this area. Public outreach and advertising the true detriment that littering and trash deposition in the river could have may make the community more conscious of what happens to their trash. The Forest Service needs to gain more volunteers and staff to patrol these areas and prevent contamination before it enters the water; they could mitigate the amount of pollution that would affect the water quality. The main problem lies in the political nature of our country, which seeps into our society and their poor habits. The East Fork provides Los Angeles County with one-fourth of its water supply; the water must be protected. In conducting these interviews with staff from both the State Water Resources Control Board, the Regional Water Resources Control Board, and the Environmental Protection Agency, it shines a light that this project is a high priority in many aspects. However, a lot of the pitfalls come from the political side of our current administration and where they think our funding should go. Many uncontrollable factors impact the East Fork of the San Gabriel River in ways that could not have been predicted decades ago. Even so, there is also a mentality that people carry with them that they are not responsible for the trash they bring down to the river. Though the East Fork is going to get a much-needed uplift, my talks with regional and federal staff indicate that there will be more community outreach, educational programs, and events that could further educate our communities and get them more involved in why this unique and pertinent system needs protection.

The recent implementation of a Waste Discharge Requirement in this area will give the state more grounds for regulations and policies that will require more monitoring and testing to be conducted. There is a chunk of information that is missing regarding the actual amount of trash being dumped currently. A positive change that could give us accurate data would be to have more eyes on the project and involve community volunteers more. With firsthand experience, Citrus College volunteers could provide feedback and reports at the end of their course that would aid the state and federal agencies in what changes they would like to see.

From my findings with Steve Evans, an incredibly useful solution would be implementing a reservation system for the East Fork of the San Gabriel River and putting up a security gate. If people have reserved their spots, they will be able to recreate. There would be a waitlist system that notifies interested parties when spots are available but it would also save

the public time on knowing when the East Fork is going to be at capacity for a specific date. The East Fork needs to be treated in the same way as Yosemite is and needs the same type of treatment. Overlooking the capacity issue continues to create more problems down the line and reinforces bad behaviour. If the operations were treated properly, the East Fork would be operating as a high capacity and high value visitor spot instead of a rural, middle of nowhere, hidden, unknown area.

Another solution could be patrolling the waters more often. However, these ideas could come at a cost. Mr. Evans provided knowledge that the United States Forest Service could work more closely with the state agencies and allow them to aid them in their workload. As the federal government continues to crumble, I've seen first hand the nonresponsive side of the United States Forest Service. It certainly is long overdue for support and better communication between the local agencies and the United States Forest Service. As engineers and scientists, sometimes we don't take note of the implications of what certain solutions could entail. These solutions could disrupt the ecosystem while attempting to clean up the trash. Fish may migrate somewhere else because of the disturbance and added activity in the water. This would alter the food chain, which could have positive or negative effects on the ecosystem. As we think of solutions, we need to be incredibly cautious with the approach and look from all angles at how this would not only affect the human population, but also the ecosystem and wildlife that reside here.

Understandably, the complexities of the government and our societal habits have resulted in the East Fork of the San Gabriel River suffering. The underfunded and understaffed programs that oversee this river need to be prioritized, which will greatly benefit the people of the community and the thriving ecosystem. Restoring the East Fork challenges society to examine the infrastructure of natural locations, the results of waste, and the safety hazards that occur because of the lack of attention and care. In setting up regulations, such as the East Fork Trash TMDL, it provides stricter guidelines on achieving the goal of zero waste in the East Fork of the San Gabriel River. Though an even stronger solution would be educating the public and garnering social media attention that urges people to clean up after themselves. In the modern era, accountability carries a tremendous amount of weight.

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**From Compliance to Community Care:
Understanding Food Recovery in San Diego County**

University of San Diego

MESH Program Capstone Project

Mackenzie Anderson

Introduction

Through my work experience at a San Diego food recovery nonprofit, I've noticed a gap between food recovery policy and how it's actually implemented in grocery stores. Throughout San Diego, food recovery systems seem to vary from grocery store to grocery store, with many staff members managing the programs lacking education on waste protocols. Grocery store workers may see bruised or damaged produce as just unsellable inventory that must be removed from the sales floor. At the same time, volunteers who regularly sort through this unsellable food are in awe of the sheer amount of excess and the qualification for "unsellable". Food waste, therefore, is not just a material or logistical issue; it's also shaped by the people who make the system function.

This project explores the question: How do grocery store workers and food recovery volunteers differently understand food waste and their roles within food recovery systems in San Diego County? This question matters because grocery store staff and volunteers are both directly involved with implementing food recovery protocols. However, these groups come from different institutional positions, and their motivations or backgrounds on the issue may differ. Much of the onus has been placed on families who may waste meal leftovers, rather than on enforcing corporate responsibility. Even within food recovery systems, a grocery store's hauling and packaging disposal are put off-site at a local food pantry that already experiences strained resources. The goal of this project is not just to offer a critique of food waste systems but to see what more effective and equitable alternatives look like.

My positionality strongly shapes this project. As someone working within a food recovery nonprofit, I approach this topic from both a research and participant perspective. I have relationships with grocery partners, firsthand knowledge of recovery systems, experience

navigating government compliance, and a strong belief in the importance of community-based food access. I recognize that this professional background may bias me towards seeing something as more or less effective. I am also personally invested in the success of food recovery and driven by the belief that access to nutritious food should be a human right. I want to separate observation from interpretation, including assumptions about who cares more about this issue than others. The epistemological assumptions informing this project are rooted in the belief that knowledge comes from data and lived experience. This project is informed by interpretivism and pragmatism. Interpretivism helps frame food waste as something people understand through their lived experience; the idea that what food is deemed “edible” is [socially constructed](#) amongst volunteers. While pragmatism recognizes that practical knowledge from the people doing the food recovery work can help improve food recovery systems.

Ultimately, gaining the perspectives of both of these frontline groups, it can inform more effective food recovery partnerships. It can also identify gaps in training or communication and examine whether institutional roles shape responsibility. Above all, this should challenge the idea that food waste is inevitable. By centering the grocery store workers and volunteers who make daily decisions about surplus food, this research asks us to see food recovery not simply as a regulatory program, but as a network of community care and human relationships.

Literature Review

Food Waste and Food Recovery

Presently, the [San Diego Hunger Coalition](#) estimated that nearly 1 in 4 San Diegans were food insecure. That’s about 25% of people in the county who don’t know where their next meal is coming from. This statistic suggests that a significant part of our community not only lacks access to food but likely also lacks access to fresh, nutritious food. Food insecurity can greatly

impact an individual's health; adequate access to nutrition is crucial for cognitive development and maintenance as a person ages. A [2024 study](#) focused on food insecurity among seniors and its contribution to increased cognitive decline, a population that is increasingly vulnerable to food insecurity in San Diego. Funding cuts at the federal level, especially to food assistance programs like CalFresh, threaten to increase food insecurity for many who rely on these programs to feed their families.

At the same time, the [USDA](#) has found that up to 40% of all food produced in the United States goes to waste, with about one-quarter of that food lost at grocery stores. For many grocery stores, edible food becomes “unsellable” based on retailer appearance standards, demand, or packaging damage. [Recent studies](#) have pointed to the EPA’s goal of cutting food waste in the United States in half by 2030, citing the environmental implications of increased methane production when food ends up in landfills. In San Diego, food recovery has increasingly become a solution to this issue, as it not only supports the environmental goals but also the social issue of food insecurity. Food recovery is the process of redirecting excess food back into the community rather than into waste streams. In San Diego, [ProduceGood](#) is a local nonprofit organization that rescues edible food from backyards, grocery stores, farmers markets, and farms and delivers it the same day to local food programs. Given the steady rates of food insecurity in San Diego, ostensibly, there’s no reason edible food should be going to waste. Retailers also budget annually for “shrink” and hauling costs, building food waste into their budgets. In 2016, [California Senate Bill 1383](#) was enacted to address this ongoing food waste stream, with the goal of diverting 20% of edible food to feed people. This bill came with a fee structure that wasn’t enforced until 2025, fining grocery stores annually if they failed to meet state goals. The [EPA Wasted Food Scale](#) is often referenced to understand priorities for diverting food waste: feeding people should be the

first priority, followed by feeding animals and composting. A key provision of SB 1383 is that grocery stores are required to compost all inedible food waste, rather than dump it in the landfill. While composting education among grocery store staff may be lacking, many composting facilities can now sort and separate contaminants such as food packaging. While composting provides a slightly better solution, there are still emissions implications, as anaerobic digestion still produces methane gas. While landfills still remain the largest source of emissions in the waste sector, these emissions have [continued to decline steadily since 2022](#).

While SB 1383 has made progress in San Diego County, there have been significant differences in food recovery programs from grocer to grocer. Most existing studies on food waste and food recovery focus primarily on environmental impacts, waste metrics, and compliance. Less attention has been paid to how grocery store workers and volunteers view their responsibilities within food recovery networks. While policies and infrastructure are important, they ultimately rely on the people responsible for implementing them day to day. Understanding how grocery store staff and volunteers perceive food waste and their role in our food system may provide insights into the gaps and successes of food waste legislation like SB 1383.

Beyond the Landfill

Every piece of food that's grown, harvested, and transported contains acres of land, gallons of water, miles of transportation emissions, and hours of labor. Each time edible food is discarded instead of eaten, the energy and resources used to get that food into your community are also wasted. A [2010 study](#) highlighted that food is not only a source of energy but also requires immense amounts of energy, especially fossil fuels, for its production, transportation, and preparation. The United States and other parts of the world continue to adopt new agricultural technologies, resulting in reduced food loss at the production level. The trade-off

with much of this new tech and automation is that it requires an immense amount of fossil fuels, further contributing to climate change. Porter pointed out that if [food production needs to rise by 70%](#) to meet the population in 2050, efficiency improvements will also need to increase across the supply chain. Giving the potential for emissions to increase at a staggering rate. It will be imperative to implement proper food waste protocols and effective legislation to prevent an increase in food waste, especially at grocery stores. Food production accounts for nearly one-tenth of the energy consumed annually in the United States, presenting a significant opportunity to reduce energy loss and mitigate food waste. Education and training for grocery store staff could play a huge role in this, acknowledging that the human decision-making process is at the center of what becomes food waste to begin with.

SB 1383 and the Limits of Compliance

ProduceGood's [grocery gleaning program](#) was born of the implementation of SB 1383, which prompted many grocery stores to seek out food recovery organizations. [SB 1383 requires](#) commercial food waste generators, such as grocery stores, to partner with food recovery organizations to donate as much surplus edible food that they would otherwise dispose of. The legislation requires these food waste generators to establish written agreements with recovery organizations and to demonstrate compliance by providing annual reports detailing the types and amounts of food recovered, and the frequency of recovery. In San Diego County, one enforcement and compliance mechanism is [The Solana Center](#). Their organization provides technical support and conducts inspections of food waste generators. These inspections are reported to municipalities and state agencies and also serve as a connector for some non-compliant grocery stores, with the Solana Center having resources for local food recovery partners.

When SB 1383 was introduced nearly ten years ago, it seemed like an opportunity to decentralize our food recovery system. Today, the food recovery landscape looks much different. From my experience over the past five years working at ProduceGood, we are seeing food waste streams being increasingly monopolized by larger regional food banks. These food banks, like Feeding America, are typically already written into large corporate waste mechanisms. While convenient, this leads to more box-checking to achieve food recovery compliance, rather than creating more equitable food recovery systems. These larger regional food banks not only secure a significant amount of local funding, but we've seen an increase in donation dumping at local feeding partners. A gap in SB 1383 is that the burden of these food waste streams created by these large corporations, including compost, boxes, and plastic packaging, is being placed on feeding organizations that pick up food from these grocery stores. Rather than having the grocery stores absorb the waste and hauler costs. Many of the people who bear this burden directly, both at the grocery store and among volunteers recovering food, are left to shoulder it. Another issue with donation dumping is that many grocery store staff lack adequate training in composting.

[Sarah Caggiano of the Lewis and Clark Law School](#) points out that although San Diego municipalities provided green bins, there was little to no outreach or education on proper composting. While many studies assume that stronger policies and reporting will improve food recovery outcomes, it's clear that policies just provide a framework. People play a huge part in how these systems function in practice, although many volunteers and grocery store staff typically view their role in our food system as menial. This raises questions about education and responsibility from the various people involved in our food recovery system.



Compost bin at Jimbo's Carmel Valley food recovery event.

Education, Training, and Organizational Culture of Food Recovery

The rise of food recovery has led many grocery stores to implement internal policies around waste management and recovery. Costco is one of the largest grocers in the United States. Its annual [Sustainability Report](#) states that its only food recovery partner is Feeding America and notes that nearly 50% of all food donated was fresh produce. Their report offers a very broad look at the food recovery underway, and although it touts large recovery numbers, it's hard to contextualize how much of their waste is actually being recovered. A San Diego grocer, Jimbo's, shares that it partners with [seven organizations](#) to recover its excess food. Providing a contrasting model that diversifies its food donations. Costco also mentions that they have staff training on

proper recycling, but there were no specific callouts for compost or sorting education. It's debatable whether these reports and sustainability metrics are really making an impact. Food recovery in general is a step in the right direction, but as [ReFED notes](#), waste is built into supermarket retail strategy. It could be assumed that, rather than having grocery stores engage in source reduction, recovery metrics have now become another economic incentive rather than an issue to solve.

A [2018 report](#) found that many of the top grocery stores received failing grades in food waste accountability, recycling, and prevention. This suggests that while corporations can report impact at a high level, there seems to be a gap in the day-to-day operations. A recent [worker-centric study](#) interviewed frontline grocery store employees about food waste reduction protocols and their understanding at work. Some of the responses that stood out were that employees received mixed messages: they are supposed to sell only the highest-quality products, but they also need to donate the freshest, most appealing food. This literature suggests that grocery store staff are bearing the burden of food recovery without adequate resources and capacity. It also suggests that state policies, such as SB 1383, may have limited impact because they operate only within conflicting economic structures. This struggle could also be compounded in a grocery store that has limited staffing and no dedicated sustainability role for this process.

Volunteers and Community-Based Food Recovery

Volunteers also play a vital role in the food recovery process. At ProduceGood, grocery gleaning volunteers sort through excess at grocery stores, ensuring feeding partner organizations receive only the freshest produce. All the rotten food items are sorted out and left with the retailer for disposal. These volunteers spend countless hours sorting through bags of grapes,

cherry tomatoes, and lettuce bundles. According to the [Independent Sector](#), the value of a volunteer hour in California in 2025 was \$41.75. At ProduceGood specifically, nearly 1,400 active volunteers annually keep the food recovery programs running. That's a nearly \$60,000 value for their time and labor annually, making food recovery volunteers an essential part of the process of working towards healthier, more sustainable futures. There is limited information on the commonalities between food recovery volunteers and grocery store staff. Some studies have found that long-term food recovery volunteers are typically older adults, more often women. [The literature also suggests](#) that long-term volunteering is more common when there is a sense of connection, both among volunteers and at food waste generator sites. This project will uncover the motivations behind volunteer involvement in food recovery.



ProduceGood volunteer, Susan H., at a Seaside Market food recovery event.

Perceptions of Food Waste and Contributions to the Literature

In recent years, more pressure has been placed on policymakers and companies to reduce their edible food waste. Increased tracking and waste reporting are crucial, as you can't fix something that you haven't measured. Our unregulated best-by dates on food also [influence consumer purchases](#) based on perceived freshness. For many grocery store employees, navigating food recovery alongside corporate profit gains creates tension, leading to little progress or box-checking. This can prevent food recovery from being viewed as environmental and community care. Studies have shown that people also perceive the [responsibility for food waste](#) as falling on individuals. This raises the question of whether individuals adopt different food waste mitigation strategies after regularly volunteering at food recovery events. Could food recovery be reframed as a social initiative that brings people closer to their waste and their community?

Community food redistribution programs are much more than just sustainability initiatives; they can create healthier, more resilient communities. This is something that volunteers and grocery store staff may not even be aware of their impact. While food waste literature and policy assume a shared responsibility for waste, different stakeholders may have fundamentally different understandings of it. Educational gaps in grocery stores and food recovery programs reflect top-down policies that aim to achieve a broader goal without empowering the community in the process. This project contributes to future literature on volunteer labor, community-based food systems, and corporate influence on food waste research. Instead of treating food waste as a downstream issue, which is already primarily handled by communities, how can responsibility be shifted back to corporations? A shift towards focusing on human perceptions rather than just policy outcomes.

Methodology

Research Question and Focus

At the center of this research project is the tension I see day to day: grocery stores have edible food they can no longer sell, and food recovery organizations, volunteers, and feeding agencies work daily to redirect that food to the community. Yet the success of these systems relies heavily on people's understanding of waste management, food recovery, regulatory compliance, and community care. I'm not just looking at whether food recovery "works", but rather how the people closest to the system understand their role in it. To better understand whether grocery store workers see food waste as a compliance issue, a store operations issue, an environmental issue, or a community health issue. I also want to understand how volunteers, who are also at the front of food recovery, view their experience in the food recovery system. Do they see themselves as primarily reducing waste, feeding their neighbors, supporting climate action, or something else entirely? Comparing these perspectives matters because our food recovery systems rely on both groups, though they may be driven by different motivations.

Food waste is often discussed in terms of numbers: pounds recovered, tons diverted, emissions avoided, and servings provided. These numbers matter, but behind each number are grocery store staff making decisions about what is no longer sellable, receiving managers following safety protocols, nonprofit staff scheduling pick-ups, and volunteers being flexible with the varied amount of food to sort through. If San Diego County wants to build a more effective and justice-centered food recovery system, we have to understand the humans behind the policy implementation. Policy alone cannot change a system if the people who implement it lack training, resources, and a sense of connection to the work's larger purpose.

Participant Observation at ProduceGood

One of the primary methods of this research is participant observation. Having worked at [ProduceGood](#) for over five years now, particularly managing the grocery gleaning program, has given me firsthand experience alongside volunteers and grocery store workers. These observations took place at ProduceGood grocery gleaning events, where volunteers sort through grocery-store produce donations. These events took place across three different grocery store locations in San Diego and can provide observations of interactions among grocery store staff, ProduceGood (nonprofit) staff, and volunteers. During these events, I observed:

- How volunteers describe the food they're sorting
- What kinds of produce are considered edible and non-edible
- How grocery store staff communicate with ProduceGood
- How much training and direction volunteers receive
- How responsibility is assigned or assumed during food recovery
- Any other notable moments of frustration, surprise, or connection

As a staff member of ProduceGood, my positionality is not that of an outside observer. Many of our volunteers and grocery store staff already have a preexisting relationship with me. One [characteristic of participant observation](#) is the long-term nature of the relationship between “researcher” and “observer”; my relationships with volunteers over the last few years supported this method. My role at ProduceGood also gave me unique access to a range of stakeholders in our food recovery system. It also gave me practical knowledge of how these systems work and of some of the day-to-day struggles that may not be apparent to someone completely outside the system. However, this also creates a potential bias as my perspective from a grassroots organization makes me personally invested, not only in food recovery but also in creating a more

equitable food system. This bias often shows up in critiques of capitalist models, including grocery stores.

Anonymous Surveys

While participant observation provides a firsthand view of food recovery events and the interplay between volunteers and grocery store staff, surveys allow for a wider scope of feedback. The food recovery volunteers who participated in this data collection are active volunteers (within the last 12 months) at ProduceGood. These volunteers specifically regularly volunteer at ProduceGood’s “Grocery Gleaning” program, sorting and recovering produce at grocery stores. The grocery store staff survey was sent to Costco Carlsbad, Seaside Market in Cardiff, Lazy Acres in Encinitas, and Jimbo’s at three locations (Carlsbad, Escondido, and Carmel Valley).

Data Source	Number Included	Description
Grocery Store Worker surveys	11 responses	Staff involved in the produce department, receiving, sustainability, or waste handling.
Food Recovery Volunteer Surveys	28 responses	ProduceGood active volunteers that are part of the Grocery Gleaning program.
Participant Observations	3 events	Grocery gleaning events in North County San Diego.

Whose Knowledge is Shaping the Story

Much of the current literature and research comes from academic researchers and feeds into policy documents. Food recovery nonprofits are also widely represented, often from a more logistical perspective. The limitations of these perspectives are that they are largely shaped by the entities that study, manage, or coordinate food recovery. This project incorporates the voices

of grocery store workers and food recovery volunteers to gather practical knowledge that may not be considered by policymakers and in sustainability reporting. Both of these groups shape how the food recovery system actually functions. While I address food insecurity as a driver for food recovery, it may not directly include the voices of people receiving recovered food. This matters because food-insecure populations are often invoked to justify food recovery, but they are not always included in the design of food recovery programs. Other voices that are still largely missing include indigenous food sovereignty leaders, farmworkers, and corporate decision-makers.

Results

Survey Findings

Finding Area	Grocery Store Workers	Food Recovery Volunteers
Main view of food waste	Operational, compliance, and company sustainability goals	Community care, hunger relief, and environmental impact
Main barriers	Food safety concerns, limited space, storage, and transportation	Lack of public awareness and inconsistent food donations
Relationship to SB 1383	Aware of the policy, not connected to the implementation and impact	Mixed policy awareness, more grounded in community impact
Sense of responsibility	Corporations are mostly responsible for reducing food waste	Individuals are mostly responsible for reducing food waste

The responses from grocery store staff were split between Costco Carlsbad and Jimbo's staff. Grocery store workers reported greater knowledge of the front end of food waste, including the rules and legislation governing what gets donated. Volunteers reported more barriers and a more varied idea of who is responsible for reducing food waste. Both groups reported that they felt they were essential in supporting nutrition access in our community. Direct contact with food waste and food recovery also led volunteers to better understand the issue. Grocery store workers

reported logistical concerns as a major barrier and gap in implementing SB 1383. Similarly, the majority of volunteers reported that grocery stores are not doing enough to reduce food waste, with many reporting “Lack of knowledge of food recovery resources, not slotting man hours to implement food recovery.”

Participant Observation Findings

These observations provided more context for *why* the survey responses looked as they did. Food recovery functions differently across different store settings. At Jimbo’s Carlsbad, the grocery staff was more present. Setting up tables in the morning for volunteers, continuously brought produce out throughout the shift, and checked in with our volunteers. Many of the regular food recovery volunteers were on a first-name basis with the Jimbo’s Carlsbad staff. This closeness made the volunteer shift feel more like part of the grocery store staff’s daily operations, fostering a stronger sense of shared responsibility. In comparison, Costco Carlsbad had more logistical barriers, including rotating staff, more formal rules for entering the receiving area, and volunteers stationed farther from the store during their shifts. These observations support the survey findings from grocery store workers that logistics is a main barrier to SB 1383 implementation.

My observations also showed that food recovery volunteers bear much of the final decision-making for food donations. While grocery store staff set aside the initial donations, the volunteers sort, discard, and assess which food items are still edible and stable enough to donate. The volunteer survey findings showed that a significant reason for volunteering is to support people experiencing food insecurity. Direct contact with food waste and the community that may be receiving the food could support the idea that volunteers feel more responsible for ensuring edible food is not wasted. Many volunteers, whether it was their first shift or their 20th,

continued to be surprised by the edible food that would have otherwise gone to waste, with one volunteer stating, “Wow, this [bag of apples] would be great for a week of kids' lunches.”



ProduceGood volunteer, Susan K., at a Jimbo’s food recovery event.

Comparative Themes

From all of this data, several themes emerged. Food recovery is much more than just an environmental policy or compliance number. Community health and nutrition access is a major motivator for volunteers involved in the food recovery system. Knowledge of SB 1383 varied across both groups, suggesting that policy alone isn’t effective without understanding. This lack of understanding can limit the long-term impact on statewide environmental goals. Another key theme is that the implementation burden falls on people and nonprofits. Many of the identified gaps in SB 1383 implementation are not further supported by the policy alone, including transportation, awareness-raising, availability of food recovery organizations, and volunteer

capacity. And finally, the majority of respondents viewed their role in the food recovery system as essential, but perceived responsibility for reducing food waste was divided among individuals, corporations, and government agencies, with individuals being the most frequently selected group.

Discussion

My findings show that food recovery in San Diego is not just a matter of policy compliance or a sustainability goal. By asking how grocery store workers and food recovery volunteers understand their roles differently, I uncovered a human system shaped by hidden labor, institutional power, and the larger capitalist grocery system that continues to produce waste. SB 1383 has provided a framework for food recovery, but my findings suggest that implementation still relies heavily on grocery store staff, volunteers, and nonprofit organizations, who may not receive sufficient support or decision-making authority.

The food recovery framework established by SB 1383 was a huge milestone for California, but its implementation falls short and is inconsistent across San Diego County. While grocery store workers reported having a good amount of knowledge about the legislation and their stores' food recovery goals, logistical barriers consistently came up across different grocery stores. In contrast, food recovery volunteers had a mixed understanding of the policy but a much more nuanced idea of the barriers, with awareness and inconsistent donations from grocery stores. This suggests that SB 1383, while well-intentioned and ambitious in its goals, could be more effective if it were less top-down. Additional resources, education, and capacity for food waste generators and food recovery organizations could result in more edible food being recovered in the long run.

By observing food recovery shifts across grocery stores, it's clear that store culture affects their food recovery relationships. Jimbo's, whose sustainability goals are baked into their mission statement, showed a stronger staff commitment. This included having relationships with ProduceGood volunteers and more support during the food recovery shift. This closer relationship made the shift feel more like part of the grocery store operations and fostered a greater sense of shared responsibility. In comparison, while Costco Carlsbad staff reported the same understanding of their store's food recovery procedures, the food recovery shifts themselves felt more separate from the grocery store operations. This varied experience reveals a greater power dynamic in which grocery stores largely shape how food recovery happens. They decide when food is considered unsellable, where volunteers are allowed to recover food, how much staff time is given to supporting this process, and whether food recovery is integrated into the store culture. Although volunteers and nonprofits largely manage grocery stores' food waste, they are forced to adapt to varying grocery store conditions. This institutional power shapes the food recovery relationship, rather than a shared set of values. While grocery stores generate the waste and surplus, nonprofits and volunteers are responsible for getting the edible surplus to feeding organizations. Further, food-insecure communities are even further down the chain of power. Raising a justice concern: while these communities are typically used to justify the need for food recovery, they are rarely included in decisions about how food recovery programs operate.

From a broader environmental justice lens, food waste represents a greater issue of wasted resources: water, land, energy, transportation, and labor. Food recovery not only prevents these precious resources from being wasted, but it also provides an opportunity to feed our community at a time when food insecurity continues to rise. Current federal policy affecting food

assistance programs like CalFresh has [changed eligibility standards](#), putting families at risk of losing essential funds to afford meals. Some of the changes include loss of benefits to refugees, asylees, and victims of human trafficking. Food recovery organizations, like ProduceGood, provide over 1 million servings of fresh, nutritious produce to these vulnerable communities. By recovering food for donation to a local mutual aid organization, we can support families who may have lost their CalFresh benefits while also keeping edible food out of the waste and compost streams. San Diego food recovery systems also clearly illustrate a distributive-justice imbalance among grocery stores and nonprofit volunteers. Grocery stores benefit from compliance, reduced waste-hauler costs, and the ability to boast sustainability reporting to consumers. Their institutional power also limits the actual negative impacts of noncompliance. Many large grocery stores face a measly \$100 annual fee for noncompliance, a drop in the bucket for a grocery store's billion-dollar annual budget. Nonprofit organizations and their volunteers carry much of the hidden burdens, like sorting, transportation, management of packaging waste, supply fees from large food banks, unpaid labor, and decision-making. A more holistic policy would place greater waste-management accountability where food waste starts, rather than downstream.

The treadmill of production can also connect my findings to a broader critique of our capitalist system of abundance. The [treadmill of production](#) is the theory that capitalist systems are built around constant growth, competition, and consumption. This leaves businesses, workers, governments, and consumers stuck in a cycle of production, selling, and waste, even when it harms the environment. Grocery stores operate within a profit-driven system that rewards abundance: full shelves, perfect produce, constant availability, and convenience. As we see in food recovery events, food is considered “unsellable” not always because it's inedible, but

because it no longer meets the market standards. This means that the value of an apple or tomato is determined by its ability to generate profit, not by its resources or its ability to nourish people. While food recovery and legislation like SB 1383 respond to the waste created by this system, they don't challenge or change the system itself. Pounds of food are recovered each year and put back into the community, allowing grocery stores to share their sustainability reports, but their model continues to depend on the very waste they report as environmental impact. With large food banks creating fee systems that require smaller food pantries to pay to access grocery-store surplus, it's clear that food waste and food recovery have increasingly become another commodified waste stream. Food recovery exposes one of the contradictions of capitalism: that edible food can lose market value while still containing immeasurable social and nutritional value.

Building a More Just Food Recovery System

Improved Training and Communication

A key recommendation for a pathway forward is improved training and communication on food recovery and food waste reduction strategies. Grocery stores need clearer training on donation procedures, composting, and what counts as edible versus inedible. Training should reach all staff handling surplus food, not just managers. This could ease some of the tension that arises from volunteers having inconsistent donations and staff being unsure about food safety standards. Grocery stores could share a one-page food recovery SOP or post visual guidelines for food donations in receiving and warehouse areas. Grocers could also include SB 1383 education in their onboarding process for new staff. Volunteers also need adequate training, as they are the final decision-makers on what gets donated and what gets discarded. Stronger communication

also needs to be forged between nonprofits, grocery stores, and feeding partners. These could be quarterly check-ins or surveys to gauge satisfaction with scheduling, the quality of food donations, and logistical issues.



ProduceGood volunteer driver and Jimbo's Carlsbad staff.

Building Shared Responsibility Into Store Culture

My observations and surveys showed that store culture can impact how a food recovery program operates. At Jimbo's Carlsbad, for example, the staff had a stronger presence and relationship with the weekly volunteers. This made the shifts feel more integrated and better aligned with Jimbo's more environmentally focused mission. Jimbo's also lists the local

organizations it partners with on its website. Similarly, volunteers who regularly volunteer at Jimbo's reported that they seemed to have a higher sense of accountability as food waste generators. In contrast, Costco was much more separate from volunteers, with limited relationship-building between volunteers and the grocery store staff. This also directly correlated to Costco volunteer survey responses, indicating that they could do more to reduce their food waste and make their food recovery programs run smoothly. Future food recovery partnerships should move beyond written agreements and focus on relationship-building, because stronger food recovery networks tend to emerge where volunteers and grocery store staff recognize each other as part of the same process.

Strengthen SB 1383 Implementation

For food recovery policy to create meaningful change, it needs to move beyond just compliance. Implementation should include key supplemental elements like education, funding, and accountability. For food recovery to create a more equitable food system, it should resist monopolization by larger food banks. Encouraging food waste generators to work with smaller, mutual aid networks. Further, the fee for noncompliance needs to be impactful enough for larger corporations to actually make a change, not simply be a drop in their annual budget. The policy should also address downstream burdens like packaging, donation dumping, and transportation costs. All of which are largely absorbed and managed by local feeding programs that are already limited in staff and capacity. We should move away from the perspective that social service organizations are a catchall for unintended costs of waste. A more holistic version of SB 1383 would not only require grocery stores to have a food recovery agreement but also assess whether the agreement is equitable and supported by adequate staff and resources.

Conclusion

This project illuminates the challenges and perspectives of food recovery volunteers and grocery store workers. There are some key limitations that future research should address, including perspectives from people receiving recovered food, feedback from feeding agency staff, and interviews with municipal SB 1383 staff. Centering the voices of those receiving recovered food matters because they are used as justification for the issue, but are often left out of decision-making. It may also be beneficial to track more quantitative food recovery outcomes alongside store volunteer and staff training. This could further support my proposed ideas or challenge whether they actually result in a greater impact. At the same time, source reduction should be included among food waste reduction tactics.

Ultimately, this project challenges the idea that food waste is inevitable. A bruised apple, or a punctured package of cherry tomatoes, although considered devoid of profit, still contains nutrition and social value. Food recovery shows that this value can be restored while actively building community. While volunteers and grocery store staff may see their roles differently, they are both key pieces of the puzzle. To create a more equitable food system in the future, building relationships and community is crucial. Both of these groups need more support through increased responsibility upstream. This would build a food system where edible food is never treated as waste in the first place.

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