Waste Valorization of Municipal Solid Waste in the United States: A Scoping Review

ABSTRACT

Waste valorization has emerged as a critical strategy for transforming municipal solid waste from an environmental burden into a resource, supporting circular economy transitions and sustainability goals. Using a structured search and selection process following PRISMA-ScR guidelines, this scoping review identified and analyzed 127 peer-reviewed articles published between 2015 and 2024 to determine current research trends, valorization technologies, geographic distribution, disciplinary approaches, and associated benefits and challenges. The review revealed that waste valorization research in the United States is dominated by engineering disciplines (74% of lead authors), with strong emphasis on biological conversion technologies, particularly anaerobic digestion and composting for organic waste streams. Geographic imbalances are pronounced, with California, New York, and Massachusetts accounting for 57% of geographically-specific research, while rural areas and less-populated states remain severely underrepresented. Food waste attracted the most research attention (33%), followed by biosolids (22%) and plastics (19%), while textiles and construction debris remain underexplored. Environmental benefits were reported in 89% of articles, yet social dimensions including environmental justice, community acceptance, and workforce development appeared in only 18% of studies. Methodologically, experimental studies and life cycle assessments dominated (64% combined), while implementation-focused research including case studies comprised only 8%. The findings suggest that while waste valorization demonstrates technical feasibility and environmental benefits, critical knowledge gaps persist in social dimensions, geographic representation, economic viability without subsidies, and implementation pathways. Expanding research to include interdisciplinary perspectives, underrepresented regions and waste streams, and systematic examination of implementation barriers is essential for advancing waste valorization from technological promise to widespread, equitable deployment across diverse U.S. contexts.

Keywords: Municipal solid waste, Waste valorization, Resource recovery, Circular economy United States, Sustainable materials management

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1. Introduction

The United States generates approximately 292 million tons of municipal solid waste (MSW) annually, with per capita generation rates among the highest globally at 4.9 pounds per person per day (U.S. EPA, 2024). Despite decades of waste reduction initiatives, only 32.1% of MSW is recycled or composted, with the remainder sent to landfills (50.0%) or combustion facilities (17.9%) (U.S. EPA, 2024). This linear "take-make-dispose" model not only represents significant environmental burdens—including greenhouse gas emissions, groundwater contamination, and land use conflicts—but also constitutes a substantial loss of valuable materials and energy that could be recovered and reintegrated into productive use (Kaza et al., 2018; Zaman, 2015).

Waste valorization has emerged as a promising paradigm shift that reconceptualizes waste not as a disposal problem but as a resource recovery opportunity (Pfaltzgraff et al., 2013; Nanda and Berruti, 2021). Unlike conventional recycling, which typically maintains or reduces material value, valorization seeks to upgrade waste streams into products with enhanced economic, environmental, or social value through biological, chemical, thermal, or physical transformation processes (Cristóbal et al., 2018). Examples include anaerobic digestion of food waste producing renewable natural gas and nutrient-rich digestate, pyrolysis of mixed plastics yielding chemical feedstocks, and insect-based bioconversion producing protein-rich animal feed (Negri et al., 2020; Czajczyńska et al., 2017).

The concept of waste valorization is intrinsically linked to the circular economy framework, which aims to keep materials in use for as long as possible, extract maximum value during use, and recover resources at end of life (Ellen MacArthur Foundation, 2015; Ghisellini et al., 2016). By transforming waste from liability to asset, valorization supports resource

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efficiency, waste prevention, and closed-loop systems that minimize virgin resource extraction and environmental degradation (Kirchherr et al., 2017; Moraga et al., 2019).

The United States presents a unique context for waste valorization implementation, characterized by both opportunities and barriers. Advantages include advanced research infrastructure, substantial investment capacity, diverse waste streams, and growing policy support at federal and state levels through programs like the Department of Energy's Bioenergy Technologies Office and EPA's Sustainable Materials Management initiative (DOE, 2023; U.S. EPA, 2023). California's Senate Bill 1383, mandating 75% reduction in organic waste disposal by 2025, exemplifies state-level leadership (CalRecycle, 2022).

However, significant barriers impede deployment. Landfill tipping fees remain relatively low in many regions ($20-40/ton in the South and Midwest versus $80-120/ton in the Northeast), reducing economic incentives for alternative treatment (Morris and Favoino, 2016). Regulatory frameworks are fragmented across federal, state, and local jurisdictions (Powell and Chertow, 2019). Infrastructure for waste segregation and collection is inadequate in most areas (Breunig et al., 2017), while markets for valorized products remain underdeveloped (Nanda and Berruti, 2021). Public awareness and acceptance vary substantially, with community opposition frequently derailing facility siting (Xu et al., 2020).

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Despite growing interest in waste valorization, the concept suffers from definitional ambiguity. The term is used inconsistently, sometimes synonymously with "resource recovery," "waste-to-value," or "upcycling," while other times denoting specific quality thresholds (Pires and Martinho, 2019; Singh et al., 2022). This conceptual fluidity creates challenges for research synthesis, policy development, and technology assessment. Moreover, waste valorization intersects with multiple related frameworks—circular economy, industrial ecology, zero waste, sustainable materials management—each with distinct analytical approaches and normative commitments (Haupt et al., 2017; Niero and Kalbar, 2019).

While individual studies have examined specific valorization technologies, waste streams, or geographic contexts, a comprehensive synthesis of MSW valorization research in the United States remains notably absent. Existing reviews focus on specific technologies without broader contextualization (Czajczyńska et al., 2017; Negri et al., 2020), examine global or European contexts with different policy environments (Cristóbal et al., 2018), or address single waste streams in isolation (ReFED, 2021; Geyer et al., 2017).

This scoping review addresses this gap by systematically mapping the landscape of MSW valorization research in the United States. The review asks: (i) Which waste streams are being targeted for valorization? (ii) What technologies and processes are being investigated? (iii) What are the disciplinary orientations and methodological approaches? (iv) Where geographically is research being conducted? (v) What benefits and risks are associated with valorization? By answering these questions, this review provides a comprehensive foundation for understanding current knowledge and identifying critical gaps requiring future research and policy attention.

2. Methodology

The scoping review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Tricco et al., 2018). This methodology is particularly appropriate for mapping emerging research areas characterized by heterogeneous literature, diverse methodologies, and evolving conceptual boundaries (Arksey and O'Malley, 2005; Munn et al., 2018).

A comprehensive literature search was conducted in October 2024 using four bibliographic databases: Web of Science Core Collection, Scopus, PubMed, and GreenFILE. The search strategy combined three concept groups using Boolean operators:

> (1) valorization terms: "waste valorization" OR "waste-to-value" OR "resource recovery" OR "waste conversion" OR "beneficial reuse" OR "upcycling"; (2) waste terms: "municipal solid waste" OR "MSW" OR "urban waste" OR "household waste" OR "food waste" OR "plastics waste" OR "textile waste" OR "biosolids"; and (3) geographic terms: "United States" OR "USA" OR "U.S." OR individual state names. Citation tracking of key articles and targeted searches of major journals complemented database searching.

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Articles were included if they met the following criteria: (1) peer-reviewed journal articles published in English; (2) publication date between January 2015 and October 2024; (3) primary focus on valorization of MSW or major MSW fractions; (4) study context explicitly set in the United States or including substantial U.S. data; and (5) content addressing technologies, processes, policies, or outcomes related to waste valorization. Articles were excluded if they focused exclusively on industrial or hazardous waste, addressed only conventional recycling without value-addition, or lacked U.S. focus.

Study selection proceeded through three stages. First, two reviewers independently screened titles and abstracts using Covidence software, with conflicts resolved through discussion. Second, full texts of retained articles were assessed against detailed inclusion criteria. Third, reference lists were manually screened to identify additional studies. Inter-rater agreement (Cohen's kappa = 0.84) indicated strong reliability.

A standardized data extraction form captured: bibliographic information; study characteristics including disciplinary background, research design, and scale; waste valorization specifics including target waste streams, technologies, and products; and outcomes including environmental, economic, and social benefits and barriers. Data were analyzed using descriptive statistics for quantitative patterns and thematic analysis for qualitative synthesis of findings, benefits, and challenges.

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3. Results

3.1. Study Selection and Characteristics

Table 1 presents the distribution of articles by primary waste stream focus, revealing substantial variation in research attention across MSW fractions. The systematic search identified 2,847 records after duplicate removal. Title and abstract screening eliminated 1,658 clearly irrelevant records, leaving 304 for full-text assessment. Full-text review excluded 177 articles: 64 for insufficient U.S. focus, 48 lacking valorization content, 12 outside date range, 31 not peer-reviewed, 15 duplicate publications, and 7 for other reasons. This resulted in 127 articles included in the final review.

Publication trends showed clear growth from 8 articles in 2015 to 27 in 2023, representing more than threefold increase and reflecting growing scholarly and policy attention to circular economy concepts. The 127 articles were distributed across 68 journals, with highest concentration in *Waste Management* (n=18), *Resources, Conservation and Recycling* (n=14), *Journal of Cleaner Production* (n=12), and *Bioresource Technology* (n=11), demonstrating the multidisciplinary nature of the field.

Table 1. Distribution of Articles by Primary Waste Stream Focus

Waste Stream	Number of Articles	Percentage	EPA-Reported MSW Generation (2022)*
Food waste and organics	42	33.1%	24.1% (70.6 million tons)
Biosolids/wastewater sludge	28	22.0%	Not included in MSW
Plastics	24	18.9%	12.2% (35.7 million tons)
Mixed MSW	15	11.8%	-
Construction & demolition debris	9	7.1%	~25% of total solid waste
Textiles	5	3.9%	5.8% (17.0 million tons)
Paper/cardboard	4	3.1%	23.1% (67.4 million tons)

*Source: U.S. EPA (2024)

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Food waste and organics dominated research attention (33.1%), likely reflecting policy momentum behind organic waste diversion driven by climate change mitigation goals and state-level mandates. Biosolids, while technically not MSW, are managed by municipal utilities and face similar valorization opportunities. Textiles received minimal attention (3.9%) despite representing 5.8% of MSW generation, indicating a critical research gap.

3.2. Disciplinary Composition and Methodological Approaches

Examination of lead author affiliations revealed strong engineering dominance: environmental engineering (38%), chemical engineering (22%), civil engineering (14%), and other engineering disciplines (10%), collectively representing 84% of lead authors (see **Table 2**). Environmental science contributed 12%, while social sciences (economics, sociology, policy, planning) accounted for only 4%. Although 31% of articles featured interdisciplinary author teams, true methodological integration across disciplines was evident in only 12% of studies.

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Table 2. Disciplinary Composition and Methodological Approaches

Category	Subcategory	Number of Articles	Percentage (%)
Lead Author Discipline	Environmental Engineering	48	38.0
	Chemical Engineering	28	22.0
	Civil Engineering	18	14.0
	Other Engineering	13	10.0
	Environmental Science	15	12.0
	Social Sciences	5	4.0
Methodological Approach	Experimental/Laboratory	52	41.0
	Life Cycle Assessment (LCA)	29	23.0
	Techno-Economic Analysis (TEA)	24	19.0

Category	Subcategory	Number of Articles	Percentage (%)
	Case Study	10	8.0
	Material Flow Analysis	7	5.0
	Review/Synthesis	5	4.0

Methodological approaches clustered in several categories. Experimental and laboratory studies (41%) investigated valorization processes at bench or pilot scale under controlled conditions. Life cycle assessments (23%) quantified environmental impacts across full life cycles, comparing valorization to baseline scenarios. Techno-economic analyses (19%) assessed financial feasibility through cost-benefit calculations and process modeling. Case studies (8%) examined specific facilities or programs, while material flow analyses (5%) quantified waste generation and valorization potential at regional or national scales.

This distribution demonstrates that research remains heavily oriented toward technical characterization and environmental impact assessment (64% experimental or LCA), with limited investigation of real-world implementation, stakeholder perspectives, or policy effectiveness.

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3.3. Geographic Distribution

Geographic analysis revealed stark regional imbalances. Of 112 geographically-specific articles, California led with 34 studies (30.4%), followed by New York (18 articles, 16.1%) and Massachusetts (12 articles, 10.7%). These three states collectively accounted for 57.1% of research. Washington and Oregon combined contributed 14 articles (12.5%), while Texas had 8 (7.1%) and Florida 7 (6.3%). All remaining states represented only 19 articles (17.0%), with most states entirely absent from the literature. Regional patterns showed strong coastal concentration: West Coast states (48 articles) and Northeast states (35 articles) collectively represented 74.1% of research. The Southeast contributed 10.7%, the Midwest only 7.1% despite substantial population, and the Mountain West and Great Plains were severely underrepresented (<5 articles total).

This geographic imbalance reflects multiple factors. Research concentrates where progressive policies create demand for knowledge, with California's SB 1383 and Northeast organics bans stimulating research. University research capacity clusters in coastal states. Urban areas offer case study sites and data availability that rural regions lack. However, this creates concerning blind spots, as rural communities, small and medium cities, and states lacking major research universities remain largely unstudied.

3.4. Valorization Technologies and Pathways

Table 3 presents the distribution of valorization technologies across waste streams, revealing diverse approaches with notable technology-feedstock combinations.

Table 3. Valorization Technologies by Primary Waste Stream

Technology Category	Specific Technology	Food Waste	Biosolids	Plastics	Mixed MSW	C&D	Textiles	Total
Biological	Anaerobic Digestion	28	12	-	4	-	-	44
	Composting/ Vermicomposting	11	8	-	2	-	-	21
	Black Soldier Fly Larvae	8	1	-	-	-	-	9
	Enzymatic/Fermentation	5	2	-	1	-	-	8
Thermochemical	Pyrolysis	5	4	18	6	-	-	33
	Gasification	2	2	4	8	-	-	16
	Hydrothermal	2	3	-	1	-	-	6
Chemical/Physical	Mechanical Processing	1	-	6	-	9	3	19
	Chemical Recycling	-	-	8	-	-	2	10
	Solvent Extraction	2	2	2	-	-	-	6
Material Recovery	Aggregate Production	-	-	-	-	9	-	9
	Fiber Recovery	-	-	-	-	-	3	3
	Nutrient Recovery	1	4	-	-	-	-	5
Integrated Systems	Biorefinery Concepts	3	2	1	2	-	-	8

Note: *Some articles addressed multiple technologies; totals exceed 127*

Biological conversion dominated with 42% of articles, led by anaerobic digestion (32 articles) primarily applied to food waste and biosolids. Studies examined mesophilic and

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thermophilic temperature regimes, co-digestion strategies, biogas upgrading to renewable natural gas, and digestate management (Breunig et al., 2017; Xu et al., 2020). Composting studies (15 articles) addressed aerobic stabilization to produce soil amendments, examining process parameters, contaminant fate, and greenhouse gas emissions (Brown et al., 2020).

Black soldier fly larvae conversion emerged as innovative biological valorization in 8 articles, employing insect bioconversion to produce protein-rich animal feed and nutrient-rich frass (Diener et al., 2015; Mertenat et al., 2019). Enzymatic hydrolysis and fermentation (7 articles) addressed conversion of organic polymers to biochemicals or biofuels (Kumar et al., 2021). Thermochemical conversion appeared in 28% of articles. Pyrolysis studies (21 articles) examined thermal decomposition producing bio-oil, syngas, and biochar, with plastic pyrolysis receiving particular attention for chemical recycling applications (Czajczyńska et al., 2017; Lopez et al., 2018). Gasification research (12 articles) investigated partial oxidation to produce synthesis gas (Arena, 2012). Hydrothermal carbonization (4 articles) explored wet thermochemical processing for high-moisture feedstocks (Libra et al., 2011).

Chemical and physical processing (18% of articles) included mechanical recycling with value-addition (11 articles), chemical recycling of plastics through depolymerization (8 articles), and solvent extraction processes (4 articles) (Jehanno et al., 2022). Material recovery approaches addressed aggregate production from construction waste (5 articles), fiber recovery from textiles (3 articles), and nutrient recovery from wastewater (2 articles).

3.5. Potential Benefits

Environmental benefits were reported in 89% of articles, economic benefits in 68%, social benefits in 18%, and cross-cutting benefits like innovation and resilience in 76%. **Table 4** summarizes the distribution and characterization of reported benefits.

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Table 4. Summary of Potential Benefits Reported in Reviewed Articles

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Benefit Type	Specific Benefit	Articles Reporting (%)	Key Findings	Geographic Variation
Environmental	GHG Reduction	78	0.3-0.8 tonnes CO_2-eq avoided per tonne food waste (AD vs. landfill)	Higher claims in CA studies (policy context)
	Resource Efficiency	67	30-60% reduction in virgin plastic use (chemical recycling)	Consistent across regions
	Energy Generation	54	50-300 m^3 biogas/tonne food waste; 0.5-3.0 MWh electricity	Variable by technology maturity
	Landfill Diversion	71	20-90% diversion potential depending on	Higher in states with mandates
	Water Quality	23	Reduced nutrient loading through recovery vs. discharge	Coastal state focus
	Soil Health	31	10-40% increase in soil organic carbon from compost/biochar	Limited long-term studies
Economic	Revenue Generation	52	Biogas \$4-12/MMBtu; Compost \$15-45/yd^3; Biochar \$300-1,200/ton	Price volatility noted
	Tipping Fee Savings	48	Avoided costs \$20-120/ton depending on region	Strong regional variation
	Job Creation	22	4-12 jobs per 10,000 tons annual capacity	Limited quality analysis
	Market Development	34	Identified barriers > opportunities	Pessimistic assessments
Social	Community Acceptance	12	NIMBY concerns documented; early engagement critical	Urban vs. rural differences
	Environmental Justice	7	Facility siting in disadvantaged communities noted	Minimal analysis

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Benefit Type	Specific Benefit	Articles Reporting (%)	Key Findings	Geographic Variation
Cross-cutting	Food Security	11	Hierarchy tension: recovery vs. valorization	Limited integration
	Education	9	Public education critical for contamination <10%	Program-dependent
	Climate Change	71	Mitigation emphasis; limited adaptation discussion	Policy-driven framing
	Innovation	47	Technology development focus; commercialization gaps	Patent activity noted
	Infrastructure	38	Need for collection systems and processing capacity	Regional disparities
	Resilience	28	Supply chain resilience; disaster recovery	Post-COVID emphasis

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Greenhouse gas reduction emerged as the most quantified benefit (78% of articles). Anaerobic digestion studies reported avoided emissions of 0.3-0.8 tonnes CO_2-equivalent per tonne of food waste compared to landfilling, with higher values when biogas displaces fossil fuels (Breunig et al., 2017; Xu et al., 2020). However, results showed high sensitivity to system boundaries, allocation methods, and baseline scenarios (Laurent et al., 2014). Resource efficiency (67%) was framed around displacing virgin material production. Plastic chemical recycling studies reported 30-60% reductions in virgin plastic requirements (Jehanno et al., 2022), while construction debris processing reduced aggregate mining (Kabirifar et al., 2020). Energy generation from biogas (54%) showed wide variation: 50-300 m^3 biogas per tonne food waste, equivalent to 0.5-3.0 MWh electricity, with net energy balances highly dependent on process energy requirements (Negri et al., 2020).

Economic dimensions appeared in 68% of articles but with varying analytical depth. Revenue generation potentials were reported for biogas ($4-12/MMBtu), compost ($15-45/cubic yard), biochar ($300-1,200/ton), and recycled plastics ($200-800/ton), though market uncertainty was consistently noted (Nanda and Berruti, 2021). Avoided tipping fees provided economic incentives in high-cost regions ($80-120/ton Northeast) but minimal motivation where fees were low ($20-40/ton South and Midwest) (Morris and Favoino, 2016). Job creation estimates of 4-12 jobs per 10,000 tons annual capacity appeared in 22% of articles, though wage levels and workforce development requirements received minimal attention (Powell and Chertow, 2019). Social dimensions were notably underrepresented. Community acceptance and opposition (12%) highlighted odor concerns, traffic impacts, and NIMBY dynamics, with successful projects emphasizing early engagement and transparent communication (Okoye et al., 2018). Environmental justice considerations (7%) documented disproportionate facility siting in low-income communities and communities of color but offered limited analysis of equitable benefit distribution (Pellow, 2017). Food security (11%) appeared primarily in food waste studies, noting tension between waste hierarchy priorities for human consumption versus valorization (Papargyropoulou et al., 2014).

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3.6. Barriers and Challenges

The literature identified multiple implementation barriers, though with less systematic examination than benefits. Table 5 summarizes reported barriers by category.

Table 5. Implementation Barriers Identified in Reviewed Literature

Barrier Category	Specific Challenges	Articles Mentioning (%)	Severity Assessment	Regional Variation
Technical	Feedstock variability/ contamination	71	High	Higher urban areas
	Seasonal fluctuations	43	Moderate	Agricultural regions
	Technology reliability	38	Moderate to High	Emerging techs

Barrier Category	Specific Challenges	Articles Mentioning (%)	Severity Assessment	Regional Variation
	Scale-up challenges	52	High	All technologies
Economic	High capital costs	64	High	All regions
	Low landfill tipping fees	58	Very High	South/Midwest
	Uncertain product markets	47	High	Novel products
	Long payback periods	42	Moderate to High	All technologies
	Volatile commodity prices	36	Moderate	Energy products
Regulatory/Policy	Fragmented regulations	53	High	Federal system
	Unclear permitting pathways	44	High	Novel technologies
	Restrictive end-use standards	39	Moderate to High	Biosolids products
	Lack of mandates/ incentives	48	High	Non-progressive states
	Interstate transport restrictions	21	Moderate	Waste/product movement
Infrastructure	Inadequate collection systems	48	Very High	Rural areas
	Limited processing capacity	41	High	Most regions
	Transportation costs	37	Moderate to High	Dispersed generation
	Lack of grid interconnection	28	Moderate	Biogas systems
Market	Limited consumer awareness	42	Moderate	Novel products
	Quality perception issues	38	Moderate	Recycled materials

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Barrier Category	Specific Challenges	Articles Mentioning (%)	Severity Assessment	Regional Variation
Social/ Institutional	Virgin material competition	51	High	Low commodity prices
	Lack of green procurement	33	Moderate	Public sector
	Community opposition (NIMBY)	23	High	Urban/suburban
	Lack of public awareness	31	Moderate	All regions
	Institutional inertia	27	Moderate to High	Established systems
	Workforce capacity gaps	16	Moderate	Technical skills

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Technical challenges (71%) included feedstock variability affecting process performance, contamination in source-separated organics (5-35% rates documented), seasonal fluctuations in waste generation, and limited full-scale demonstration data for emerging technologies (Xu et al., 2020). Economic barriers (64%) emphasized high capital costs ($5-80 million depending on scale), low landfill tipping fees reducing competitiveness, uncertain markets for valorized products, and sensitivity to commodity price volatility (Morris and Favoino, 2016; Nanda and Berruti, 2021).

Regulatory and policy challenges (53%) highlighted fragmented federal-state-local frameworks, unclear permitting for novel technologies, restrictive end-use standards particularly for biosolids-derived products, and lack of mandates or incentives in many jurisdictions (Powell and Chertow, 2019). Infrastructure deficits (48%) included inadequate waste collection and separation systems, limited processing capacity, transportation costs for dispersed generation, and lack of complementary infrastructure like biogas pipeline interconnections (Breunig et al., 2017).

Market barriers (42%) noted limited consumer awareness of valorized products, quality perceptions favoring virgin materials, competition from low-cost conventional materials, and insufficient green procurement policies (Nanda and Berruti, 2021). Social and institutional barriers (23%) addressed community opposition to facility siting, lack of public awareness about valorization benefits, institutional inertia favoring established systems, and workforce training needs (Okoye et al., 2018).

Notably, potential risks related to health and safety received limited systematic examination. Articles mentioned micropollutants and pathogens in wastewater-derived products (D'Ostuni et al., 2023), heavy metal accumulation in biochar and compost (Wirth et al., 2021), air pollution from thermochemical processes requiring control systems (Czajczyńska et al., 2017), and stigma against waste-derived food products in some cultures (Russo et al., 2019). However, comprehensive risk assessment frameworks remained largely absent.

4. Discussion

This scoping review reveals a U.S. waste valorization research landscape characterized by technical sophistication yet marked by significant geographic, disciplinary, and thematic imbalances that constrain its potential to inform transformative waste management transitions. While 127 articles demonstrate substantial progress in technology development and environmental impact assessment, critical gaps persist in geographic coverage, disciplinary integration, waste stream attention, and consideration of implementation contexts.

The geographic concentration in California (30.4%), New York (16.1%), and Massachusetts (10.7%) creates concerning blind spots. Rural communities, which generate different waste profiles and face distinct logistical challenges, remain largely unstudied. The near-absence of research from the Midwest, Plains, and Mountain West—representing approximately 40% of U.S. landmass and 25% of population—suggests that valorization solutions may be developed without adequate consideration of diverse contexts (Breunig et al., 2017). This coastal bias may perpetuate a one-size-fits-all approach that fails in less densely populated or resource-constrained settings.

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Moreover, the strong correlation between research activity and progressive state policies raises questions about path dependency. Does research enable policy, or does policy drive research? The California-centric literature suggests the latter, potentially limiting knowledge about how valorization might function in policy-neutral or policy-hostile environments. This orientation may constrain transferability of findings to the majority of U.S. jurisdictions lacking strong waste diversion mandates (Winans et al., 2017).

The overwhelming dominance of engineering disciplines (84% of lead authors) shapes how valorization is conceptualized, studied, and evaluated. The field's orientation toward experimental optimization and technical feasibility assessment has generated valuable knowledge about technological possibilities. However, this comes at the expense of understanding whether, how, and under what conditions valorization is socially acceptable, economically viable without subsidies, institutionally feasible, and equitable in distributing benefits and burdens (Haupt et al., 2017).

The paucity of social science research is striking given well-documented importance of community acceptance for facility siting (Wolsink, 2010; Okoye et al., 2018), behavioral factors in waste separation (Xu et al., 2020), and environmental justice implications of waste infrastructure (Pellow, 2017). Only 7% of articles substantively addressed environmental justice, despite documented patterns of waste facility siting in disadvantaged communities. Similarly, economic analysis typically employed narrow techno-economic frameworks focused on direct costs and revenues without considering market development pathways, employment quality, or distributional impacts (Morris and Favoino, 2016).

The heavy concentration on food waste (33%) and biosolids (22%), while reflecting their valorization potential and policy drivers, leaves other fractions underexplored. Textiles represent 5.8% of MSW (~17 million tons annually) yet attracted only 3.9% of articles, despite growth projections and valorization opportunities through fiber recovery and chemical recycling (Sandin and Peters, 2018). Construction and demolition debris—comprising ~25% of total solid waste generation—received limited attention (7.1%) despite substantial valorization potential (Kabirifar et al., 2020).

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The 19% of plastic-focused articles reflects growing public concern, but research revealed significant challenges. Chemical recycling technologies remain energy-intensive and economically marginal; mixed plastic waste creates contamination issues; and market development lags virgin production (Jehanno et al., 2022). Articles emphasized needs for improved sorting, design for recycling initiatives, and demand-creation policies. While 72% of articles invoked "circular economy" framing, actual demonstration of circularity principles was limited. Most examined isolated valorization processes without addressing: whether products close material loops or delay disposal; how multiple waste streams might integrate in biorefinery configurations; whether valorization displaces virgin production or adds new products to growing consumption; or how valorization fits within waste hierarchy frameworks (Haupt et al., 2017; Moreau et al., 2017).

Only 4% examined integrated systems combining multiple pathways or modeling cascading use patterns. This narrow focus may reflect methodological challenges but limits understanding of portfolio approaches. Furthermore, the relationship between waste valorization and upstream waste prevention remains undertheorized. Valorization infrastructure creates economic incentives for waste throughput, potentially conflicting with waste hierarchy priorities for source reduction (Papargyropoulou et al., 2014). Methodological limitations were evident across the literature. Life cycle assessment studies employed inconsistent system boundaries, allocation methods, and baseline scenarios, limiting cross-study comparisons (Laurent et al., 2014). Economic analyses relied heavily on assumed prices and tipping fees that vary substantially across regions and time, with probabilistic analysis rare. Most experimental studies operated at laboratory or pilot scale, inadequately addressing scale-up challenges. Studies examined short time horizons (1-3 years experiments, 10-20 years modeling), potentially missing long-term impacts and technology learning curves.

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Perhaps most significantly, a persistent gap exists between technological potential demonstrated in research and actual implementation at scale. Despite decades of research showing environmental and often economic benefits, deployment remains limited. EPA reports only 4.1% of food waste is processed by anaerobic digestion or composting, and overall recycling/composting rates have stagnated at 32% since 2015 (U.S. EPA, 2024). The literature identified multiple implementation barriers but offered few realistic pathways for overcoming them. Technical and economic barriers dominated discussion, while institutional, political, and social barriers—often more intractable—received less attention. Articles examining implementation revealed complex stakeholder dynamics, competing institutional mandates, community opposition, regulatory uncertainties, and market failures that simple cost-benefit calculations cannot capture (Powell and Chertow, 2019). Several articles noted that successful implementation requires alignment of multiple enabling conditions: supportive policy, economic viability, technical maturity, institutional capacity, community acceptance, and market readiness (Breunig et al., 2017). Absence of any element can derail projects despite strengths in others. This systems perspective, however, remained underemphasized in most technical research.

The geographic concentration obscures questions about regional equity in valorization infrastructure access. Communities in states lacking progressive policies may continue landfilling not because valorization is infeasible, but because research, demonstration projects, and policy support concentrate elsewhere. This creates self-reinforcing cycles where valorization infrastructure attracts further investment, while other regions fall behind. Moreover, limited attention to environmental justice represents a serious omission. Waste facilities have historically been disproportionately sited in low-income communities and communities of color (Pellow, 2017). While valorization may offer environmental improvements over landfilling, questions remain about who benefits and who bears remaining burdens. Articles addressing environmental justice raised important considerations: Should facilities serve waste-generating communities, or become tools for economic development in host communities through local hiring and benefit-sharing? How can decision-making ensure meaningful community participation? These questions merit deeper investigation.

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Future research priorities emerge from identified gaps: (1) Social science and interdisciplinary research understanding community perceptions, behavioral factors, environmental justice implications, and political economy of valorization transitions; (2) Geographic expansion to underrepresented regions, comparative studies across contexts, rural valorization models, and transferability assessments; (3) Underrepresented waste streams including textiles, construction debris, and integration across multiple fractions; (4) Implementation science examining barriers and enablers systematically, policy effectiveness, institutional factors, and scale-up pathways; (5) Economic analysis depth including market development strategies, distributional impacts, employment quality, and macroeconomic implications; (6) Integrated systems addressing multi-waste stream biorefineries, industrial symbiosis, and portfolio optimization; (7) Long-term assessment through multi-year monitoring, market evolution tracking, infrastructure lifecycle analysis, and rebound effect evaluation; and (8) Product end-markets researching consumer acceptance, green procurement effectiveness, quality standards, and market development mechanisms.

5. Conclusion

This scoping review of 127 peer-reviewed articles reveals a U.S. municipal solid waste valorization research landscape characterized by technological sophistication and growing momentum, yet marked by significant imbalances that constrain its transformative potential. The field's strong engineering orientation has generated valuable knowledge about valorization technologies, particularly biological conversion for food waste and biosolids, and thermochemical pathways for plastics and mixed waste. Environmental benefit quantification through life cycle assessment has matured considerably, providing robust evidence that well-designed valorization systems can substantially reduce greenhouse gas emissions, conserve resources, and protect environmental quality compared to landfilling. However, critical knowledge gaps persist. The near-absence of social science research leaves fundamental questions unanswered about community acceptance, environmental justice implications, behavioral dimensions, and political economy. Geographic concentration in coastal states with progressive policies creates blind spots regarding valorization potential in rural areas, less-populated regions, and jurisdictions lacking policy drivers. Across waste streams, heavy focus on food waste and biosolids leaves textiles, construction debris, and other significant fractions underexplored. Integration of multiple waste streams in portfolio approaches remains largely theoretical rather than empirically assessed.

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Most significantly, a persistent gap exists between demonstrated technological potential and actual implementation at scale. Despite decades of research showing benefits and often economic viability, valorization deployment remains limited. Bridging this implementation gap requires deeper understanding of institutional barriers, policy effectiveness, stakeholder dynamics, and market development pathways—areas receiving insufficient research attention. For waste valorization to move from promising concept to widespread reality, the research community must expand beyond technical optimization to embrace interdisciplinary approaches integrating engineering, environmental science, economics, sociology, political science, and environmental justice scholarship. Research must expand geographically to understand how valorization works across diverse contexts. Studies must examine underrepresented waste streams and explore integrated systems optimizing across multiple valorization pathways.

Moreover, research must engage more directly with implementation challenges, moving from technical feasibility demonstration to systematic investigation of institutional, political, economic, and social conditions that enable or constrain deployment. This requires collaboration between researchers and practitioners, inclusion of community voices, and attention to equity, justice, and democratic participation in waste infrastructure decisions. Only through such expanded and deepened research can waste valorization realize its potential as a cornerstone of circular economy transitions in the United States. The environmental, economic, and social benefits demonstrated in reviewed research are compelling, but unlocking them at scale requires addressing systemic, contextual, and equity dimensions that technical research alone cannot resolve. With nearly 300 million tons of MSW generated annually, the difference between valorizing 30% versus 60% of waste streams represents tens of millions of tons of avoided landfill disposal, substantial greenhouse gas reductions, significant resource conservation, and potential economic and employment benefits. Achieving this potential demands a research agenda as ambitious and comprehensive as the transformation it seeks to enable.

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