Urban Food Systems Symposium

Michigan Focused Biomass Waste Circular Economy Case Studies

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This project developed two case studies to demonstrate a biomass waste circular economy with a focus on food and agriculture waste in Michigan. Each case study was chosen as a representation of the potential pathways for urban food and agriculture waste to be recycled throughout the system. The first case study examines food waste taken from the University of Michigan's two major athletic and event complexes, Michigan Stadium and Crisler Center, to use as input for an anaerobic digester for the campus to produce biogas and liquid digestate. To make the purchase of an anaerobic digester beneficial to the university, a minimum of four years of use will be required when selling the liquid digestate and utilizing the energy output. The second case study examines soybean and cherry pit waste from Michigan farms to act as input for Sustainable Aviation Fuel (SAF) for the Detroit Wayne County Airport (DTW). Each agriculture waste source was chosen based on the production quantity throughout the state. Michigan is the number one producing state of tart cherries and a major producer of soybeans. This method of using agricultural waste does not become beneficial for the immediate future due to the price of SAF technology; however, the combination of cherry pit and soybean waste and production can produce 93 days of fuel for DTW, which will significantly reduce the carbon footprint of the airport. The goal of this project was to address the growing waste crisis and establish solutions that are beneficial to both communities and the environment. Our work emphasizes the need for systemic changes in how waste is approached and highlights the positive potential outcomes achievable through the effective utilization of biomass waste as a resource.

Keywords

Agricultural Waste, Anaerobic Digestion, Athletic Facilities, Food Waste, Sustainable Aviation Fuel

Disciplines

Environmental Studies | Food Studies | Sustainability

Presenter Information

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*These authors contributed equally to this work.

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This project developed two case studies to demonstrate a biomass waste circular economy with a focus on food and agriculture waste in Michigan. Each case study was chosen as a representation of the potential pathways for urban food and agriculture waste to be recycled throughout the system. The first case study examines food waste taken from the University of Michigan's two major athletic and event complexes, Michigan Stadium and Crisler Center, to use as input for an anaerobic digester for the campus to produce biogas and liquid digestate. To make the purchase of an anaerobic digester beneficial to the university, a minimum of four years of use will be required when selling the liquid digestate and utilizing the energy output. The second case study examines soybean and cherry pit waste from Michigan farms to act as input for Sustainable Aviation Fuel (SAF) for the Detroit Wayne County Airport (DTW). Each agriculture waste source was chosen based on the production quantity throughout the state. Michigan is the number one producing state of tart cherries and a major producer of soybeans. This method of using agricultural waste does not become beneficial for the immediate future due to the price of SAF technology; however, the combination of cherry pit and soybean waste and production can produce 93 days of fuel for DTW, which will significantly reduce the carbon footprint of the airport. The goal of this project was to address the growing waste crisis and establish solutions that are beneficial to both communities and the environment. Our work emphasizes the need for systemic changes in how waste is approached and highlights the positive potential outcomes achievable through the effective utilization of biomass waste as a resource.

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INTRODUCTION

Waste is a major challenge facing much of the world, both in emerging and industrialized economies. To combat this continually growing challenge, the U.S. Environmental Protection Agency (EPA) created a waste management hierarchy for communities and industries as a guideline to ensure successful and proper management, with source reduction and reuse as the top strategy (U.S. Environmental Protection Agency, 2017). Individual companies and industries are tasked with reducing their waste (which occurs at varying stages of the product's lifecycle) for both economic and environmental benefits.

The rate of municipal solid waste (MSW) generation has been increasing in the United States since 1960, with per capita waste generation steadily increasing alongside. In 2018, the U.S. EPA reported total MSW generation was 292.4 million tons, which is equivalent to 4.9 pounds of waste per person per day (U.S. Environmental Protection Agency, 2017). As of 2018, food waste was the largest component category to end of life in landfills at 24.14% (with yard trimmings, wood, and paper included, biomass waste accounts for about 50%) (U.S. Environmental Protection Agency, 2017). As demonstrated, with the increasing rate of total waste generated in the U.S. and food comprising the largest percentage of waste in landfills, there is potential to change the way the nation approaches waste and, in turn, significantly decrease the amount ending in landfills. This would equate to approximately 58 million tons of diverted waste for alternative use.

The U.S. Energy Information Administration (EIA) defines biomass as renewable, organic material that comes from plants or animals (U.S. Energy Information Administration, 2023). Biomass waste primarily derives from municipal waste and wet waste—wet waste includes, but is not limited to, crop waste, forest residues, purpose-grown grasses, industrial waste, urban wood waste, and food waste (U.S. Office of Energy Efficiency & Renewable Energy, n.d.). Biomass involves many different industries and includes numerous products in the current U.S. market. With its broad uses, biomass waste has incredible potential in the development of a circular economy in the United States, a practice that the U.S. has not commercialized but has been a way of life for indigenous people for centuries (Craigen, 2021). Biomass waste can be used to develop by-products such as organic fertilizer or a fuel alternative to traditional fossil fuels (U.S. National Renewable Energy Laboratory, n.d.). The U.S. EPA defines circular economy as the reduction of materials used in manufacturing, redesigning of products and services to require fewer materials at all phases, and recapturing waste to use in place of virgin, extracted materials and resources (U.S. Environmental Protection Agency, 2021). The development of a biomass circular economy will have multifunctional benefits that include reduction of MSW entering landfills, reduction of greenhouse gas emissions, reduction of consumption of virgin materials, and reduction of reliance on fossil fuels. In turn, it can boost the national economy by keeping by-products and biomass fuels within the United States or by exporting to countries reliant on imports of fuels (U.S. National Renewable Energy Laboratory, n.d.).

This project developed two case studies as representative examples of biomass waste circular economies focusing on food and agriculture waste, respectively. Each case study was based in Michigan due to our client's location and the information the research team had access to. The research team was located at the University of Michigan and had the benefit of collaborating with the Michigan Office of Campus Sustainability to obtain data on food waste from one Michigan football regular season game. The goal of these case studies was to address the potential pathways to reduce food and agriculture waste at the University of Michigan and throughout the state of Michigan and to identify the economic and environmental benefits of diversion pathways.

METHODS

Case Studies Methodology

The case studies utilized quantitative and qualitative information collected in two separate industries, with the aspiration of influencing different stakeholders about the opportunities of partaking in a biomass waste market. The two case study topics were decided based on areas of interest from our client and growing biomass industries.

The first case study examined the potential impact Michigan Athletics could have on the reduction of carbon emissions and the cost-benefit of composting year-round at the two largest athletic facilities using a campus-purchased anaerobic digester. Using a collaboration with the Michigan Office of Campus Sustainability, we obtained data on waste produced from the Purdue vs. Michigan football game on 11/04/2023. The data was separated into both cubic yards and tons for categories including landfill, compost, recycling, and food donations. Using these numbers and assuming the 2023 football season was a typical schedule of home and away games (7 home games), we calculated the amount of compost waste that would be produced in a single season of only Michigan football. Comparing the amount of compost waste in tons produced in a single season and the current anaerobic digester fact sheet on Chomp's website (Chomp Energy, n.d.), we concluded that Michigan football would not produce enough compost waste to run Chomp's Mini AD for a single season. With this information, we looked beyond Michigan football and considered additional waste input from Michigan's Crisler Center (home to university basketball, wrestling, gymnastics, and occasionally volleyball) in combination with the stadium. The organic waste produced from Michigan Stadium in a single academic year was calculated using the single-game statistics as an average and scaled up to account for roughly seven home games a season. Calculating the organic waste produced in a single academic year at Crisler Center required a bit more calculations and assumed the same average organic waste per person would be produced at Crisler Center as was in Michigan Stadium. This per-person average was applied to an estimate of the attendance for all Crisler Center athletic events over the total 55 events held throughout one academic year. These two calculations were totaled to determine the potential organic waste produced from both Michigan Stadium and Crisler Center and the associated Anaerobic Digester scale that would be both environmentally and financially beneficial for the university to invest in. A detailed breakdown of the calculations and further description can be found in Supplemental Materials.

The second case study examined a pilot program for potential sustainable aviation fuel production by using locally sourced feedstocks such as cherries and soybeans for the Detroit Wayne County Airport (DTW) and considered both economic and environmental impacts. Detroit Wayne County Airport represents a bold step towards decarbonizing the aviation industry while supporting local agriculture and economic development. The techno-economic analysis, which compared the economics of a new, local production facility with various feedstocks, served as the basis for estimating the ranges for the minimum selling price (MSP) of SAF. The economic analysis followed the method outlined by the port authority of New York and New Jersey, with evaluation and comparison conducted by NREL for a new, local production facility using multiple feedstocks (Moriarty *et al.*, 2021).

RESULTS

Michigan Athletics

The following case study evaluates the potential university and community benefits of diverting athletic event food waste from landfills via anaerobic digestion (AD). The EPA defines anaerobic digestion as the process through which bacteria break down organic matter in the absence of oxygen (U.S. Environmental Protection Agency, 2015). Typically this process takes place in a sealed vessel, like Chomp's mini AD used for this case study, containing complex microbial communities to produce the biogas and digestate by-products. These vessels allow for co-digestion, meaning we can put different types of feedstocks (yard waste, manure, food waste, cooking grease, etc.) into the digester together to output biogas and digestate. The quantities of both by-products vary depending on the feedstocks used, as well as the nutrient value of the liquid digestate (or N-P-K ratio for fertilizer use) (U.S. Environmental Protection Agency, 2015). Due to this varying nature, the following calculations use approximate by-product quantities based on articles researched and Chomp's fact sheet. An overview of the flow of materials in this case study is shown in Figure 1 below.

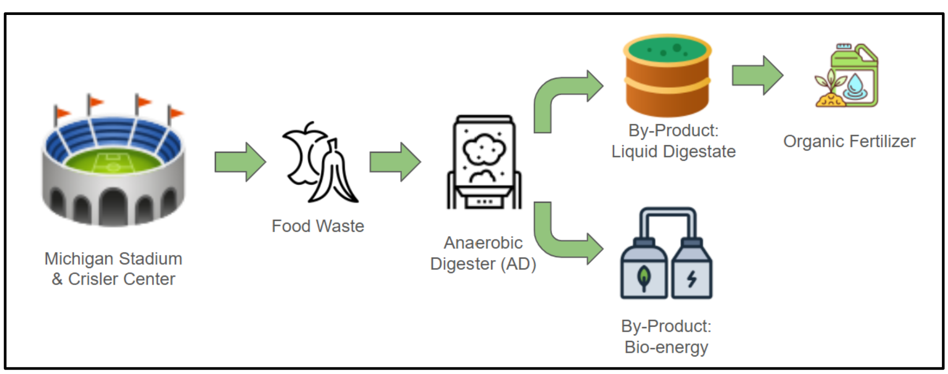

Figure 1. Michigan Athletics Case Study Waste Material flow

The goal of this case study was to determine if Michigan Stadium and the Crisler Center produce enough organic waste to financially justify an anaerobic digester and identify possible benefits of waste diversion. Each stadium and complex individually does not have the feedstock input to successfully run a mini anaerobic digester. However, the combination of both Michigan Stadium and Crisler Center would produce 26.7 metric tons of organic waste in one academic year which is an appropriate amount to run Chomp's mini anaerobic digester. Table 1 below provides an overview of this system's costs (initial investment and yearly maintenance) as well as its co-benefits (energy offset, dumpster removal, organic fertilizer sale, and organic fertilizer use).

Table 1. Cost-benefit analysis of adding an anaerobic digester at Michigan Stadium and the Crisler Center in Ann Arbor, Michigan

	Category	Cost/Value per Item	Quantity	USD ($)	Total Cost/Benefit
Costs	Anaerobic Digester Capital Investment	$222,257[1]	1	$222,257 (one time)	$222,257 (initial) + $21,000 (yearly)
	Yearly Maintenance & Operation	$21,000[2]	1	$21,000/yr	
Benefits	Energy Offset	0.13 $/kWh[3]	27,382 kWh/yr[1]	$3,745/yr	Fertilizer Sale: $95,009.62 (yearly) Fertilizer Use: $8,605.31 (yearly)
	Dumpster Offset	$95/dumpster /month[4]	3 dumpsters[5]	$3,420/yr	
	Organic Fertilizer Sale	$3.96/liter[2]	22,182 liters[6]	$87,843/yr	
	Organic Fertilizer Use	$642/ha[7]	1.8 ha [8,9,10]	$1,154/yr	

[1] (Chomp Energy, n.d.), [2] (Taylor, 2023), [3] (Facilities & Operations, 2020), [4] (Waste Management, 2024), [5] (Folsom and Sprague, 2023), [6] (Shimizu, 2014), [7] (Rauhe, 2023), [8] (ASHEE, 2022), [9] (GreenView, 2024), [10] (Song *et al.*, 2021)

The third and fourth benefits listed in Table 1 present two pathways for the liquid digestate by-product: sell the digestate to local farms and community green spaces, or use the digestate to fertilize green spaces around campus. If the university were to choose the liquid digestate sale pathway, this option would become economically beneficial after 4 years with total costs at $272,105 and total benefits at $337,659 (with a discount rate of 3% based on recommendation by the White House (The White House, 2024)). If the university were to choose the liquid digestate use benefit pathway, this option would not become economically beneficial in the next decade.

The greenhouse gas (GHG) emission savings were calculated as another source of encouragement for the university to transition away from fossil fuels and utilize the waste produced on campus to reach targets for a carbon neutral complex around scope 1 and 2 emissions as laid out in the carbon neutrality goals by the Office of the President. The total GHG emission savings from one football season and one year of sporting events at the Crisler Center would equal 24.7 MMT CO_2e (Krause *et al.*, 2023). This number was calculated under the assumption that the MSW and organic waste from one game are equivalent to the average for a single season, and the average food waste per person is the same at the Michigan Stadium and the Crisler Center. Organic waste sent to landfills makes up the majority of MSW and contributes to emissions from landfills. The emission savings were calculated under the premise that organic waste not entering landfills will reduce landfill emissions associated with university waste.

University athletics has the potential to scale this number up for all athletic events on campus and could benefit from utilizing an anaerobic digester for organic food waste on campus. It is important to note the limitations of this study, including the ability to access only data from a single football game for the 2023-2024 academic year. There were several assumptions made to come to these conclusions, and updates should be made when more information is available.

Sustainable Aviation Fuel

Sustainable aviation fuel (SAF) is a renewable liquid fuel derived from biomass feedstocks, offering a significant opportunity to reduce the aviation industry's carbon footprint. Depending on the feedstock and production process, SAF can be blended with conventional jet fuel at ratios of 10% to 50%. Since aviation contributes 2% of global CO_2 emissions and 12% of transportation-related CO_2 emissions, transitioning to SAF is a critical strategy for mitigating climate change impacts (Office of Energy Efficiency & Renewable Energy, 2024a).

1. Detroit's Opportunity in SAF Adoption.

Detroit faces dual challenges as a vital transportation hub: reducing aviation-related carbon emissions and promoting regional economic development. Aircraft operations at Detroit Wayne County Airport (DTW) generate 739,961 metric tons of CO_2 annually, accounting for 92% of the airport's emissions (Detroit Metropolitan Wayne County Airport, 2020). The Wayne County Airport Authority (WCAA) has committed to achieving net-zero emissions by 2050 through SAF adoption, aligning with its sustainability roadmap. This case study explores the feasibility of a pilot SAF program at DTW using locally sourced cherries and soybeans, emphasizing its alignment with Action 14 of the WCAA's roadmap: "Investigating SAF/Future Aviation Trends."

2. Feedstock Availability Assessment.

Michigan is uniquely positioned to support SAF production due to its abundant cherry and soybean crops. Cherries and soybeans provide high sugar and lipid content, making them ideal feedstocks for SAF under ASTM-approved pathways. Key agricultural statistics include:

1. Soybeans: Michigan's top agricultural export, yielding 113.68 bushels per hectare across 2,030,000 acres, providing a potential supply of 93,380,000 bushels annually (Mutschler, 2023).
2. Tart Cherries: Representing 74% of U.S. production, with an annual yield of 5 tons per acre on 1,000 acres, resulting in 54,665,914.6 kg annually (Mutschler, 2023; U.S. Department of Agriculture, 2023).

These crops' compatibility with existing processing infrastructure further enhances their viability as SAF feedstocks.

3. Conversion Pathways.

SAF production relies on advanced conversion technologies that transform biomass feedstocks into jet fuel. Two processes suited for Michigan's cherry and soybean feedstocks are:

1. Hydroprocessed Esters and Fatty Acids (HEFA): HEFA processes hydrogenate lipids from vegetable oils, waste oils, or fats into SAF. It involves hydrodeoxygenation and isomerization to produce paraffinic jet fuel suitable for blending up to 50% with conventional fuels (Gevo Sustainable Aviation Fuel Report, 2022; ASTM, 2023).
2. Fischer-Tropsch (FT) Synthesis: FT processes convert carbon-rich biomass into gaseous intermediates, which are reassembled into synthetic paraffinic kerosene (SPK). FT is

versatile, using feedstocks such as cherry lignocellulosic biomass, and supports a 50% blending ratio (Gevo Sustainable Aviation Fuel Report, 2022; ASTM, 2023).

While HEFA is more cost-effective for lipid-rich feedstocks like soybeans, FT synthesis broadens feedstock options, allowing diverse biomass utilization.

4. Economic Feasibility.

Techno-economic analysis (TEA) reveals the financial potential of SAF production from Michigan's feedstocks. The table below illustrates the key metrics.

Table 2. Sustainable aviation fuel (SAF) production metrics from Michigan agriculture feedstocks

Feedstock Type	Feedstock Input (kg)	SAF Production Output (MGGe)	Capital Investment (TCI)	Minimum Fuel Selling Price (MFSP)	Cost of Production
Soybeans Crude Oil	4,535,920 kg	802,631,720 liters	$1 billion	$0.99/liter	$5.2/gge ($1.37/lge)
Cherries Oil	680,388 kg	36,340,000 liters	$115 million	$1.42/liter	$12.1/gge ($3.2/lge)

While production costs currently exceed conventional jet fuel prices ($0.51/liter), economies of scale, policy incentives, and partnerships with renewable fuel producers like Zeeland Farm Services could lower costs.

5. Role of Stakeholders in SAF Deployment.

Airlines and airports are pivotal in SAF adoption. Partnerships between airlines like Delta and producers such as Neste exemplify long-term commitments to SAF integration. Delta's agreements to purchase millions of gallons of SAF annually are instrumental in meeting its 10% SAF usage target by 2030 (Harrington, 2022; Shell, 2023).

Airports like DTW can facilitate SAF deployment by collaborating with stakeholders to establish efficient supply chains. Utilizing existing terminals for SAF blending and leveraging Michigan's robust pipeline infrastructure could streamline SAF distribution while minimizing emissions (Commercial Aviation Alternative Fuels Initiative, 2024; IRS, 2024).

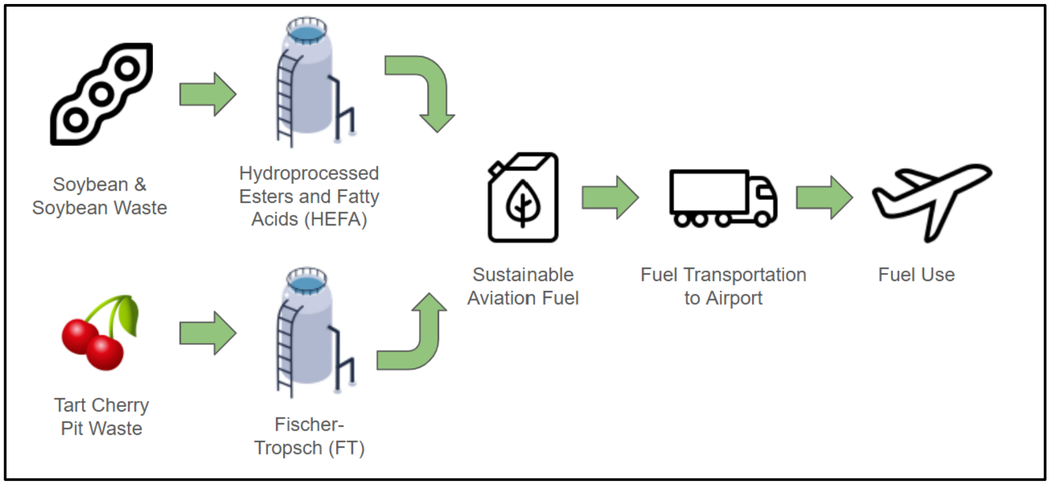

Figure 2. SAF Case Study Agriculture Waste Material Flow

DISCUSSION

Michigan Athletics Key Findings, Implications, and Recommendations

Michigan Stadium and Crisler Center generate an estimated 26.7 metric tons of organic waste annually, which can serve as feedstock for a mini-anaerobic digester. Under the fertilizer sale pathway, a mini-AD from Chomp would become financially beneficial to the university after four years. The total GHG emission savings from one academic year would equal 24.7 MMT CO_2e. To make anaerobic digestion more viable, we recommend the following:

- **Scaling Opportunities:** The University of Michigan (and similar institutions) should expand the collection of organic waste to all athletic and dining facilities around campus.
- **Professional Athletics:** Anaerobic digestion should be considered for professional athletic facilities; an example is major league baseball, which has 81 home games in a regular season.
- **Local Partnerships:** Universities and athletic facilities can create partnerships with local communities and farms to provide fertilizer and/or establish organic waste collection to combine waste as input for one anaerobic digester.

Diverting food waste from landfills not only decreases the GHG emissions associated with the waste, but also creates opportunities for new products to enter the market and simultaneously have positive community benefits.

Sustainable Aviation Fuel Key Findings, Implications, and Recommendations

Michigan's cherry and soybean feedstocks have the potential to produce 222 million gallons of sustainable aviation fuel (SAF) annually, meeting approximately 93 days of Detroit Wayne County Airport's (DTW) fuel demand [30]. While initial production costs remain higher than conventional jet fuel, strategic partnerships, economies of scale, and policy incentives can enhance economic feasibility. Additionally, adopting SAF at DTW could significantly reduce aviation-related emissions, aligning with the Wayne County Airport Authority's (WCAA) goal of achieving net-zero emissions by 2050.

To fully realize SAF's potential, the following steps are recommended:

- **Policy Support**: Advocate for subsidies, tax incentives, and grants to offset high production costs and attract investment in SAF technologies.
- **Infrastructure Investment**: Upgrade blending and distribution facilities to integrate SAF seamlessly into existing fuel supply chains.
- **Scaling Opportunities**: Expand feedstock research to include alternative biomass sources such as forestry residues and municipal waste, ensuring a more diverse and sustainable supply chain.

By addressing these economic and infrastructural challenges, SAF can play a transformative role in reducing emissions, supporting local economies, and advancing sustainable aviation at DTW and beyond.

Table 3. Case study of the economic and environmental benefits of an anaerobic digester in Ann Arbor for Michigan Athletics and sustainable aviation fuel in Detroit for the Detroit-Wayne County Airport

Case Study	Feedstock	Conversion Technology Used	By-Products	Organization Benefits	Community Benefits
Michigan Athletics	Food waste from university games	Anaerobic digestion	Bioenergy & Liquid digestate	Energy offset, dumpster removal, fertilizer use, profitable (after 4 years)	Fertilizer for local farms & community green spaces, landfill diversion, GHG emissions reduction
SAF for DTW	Tart cherry pit waste & soybeans	HEFA & FT[1]	Sustainable Aviation Fuel	90+ days of fuel, GHG emissions reduction	MI agriculture profits from waste, landfill diversion

[1]Hydroprocessed Esters and Fatty Acids & Fischer-Tropsch Synthesis

CONCLUSION

Organic waste is a global problem, and by-product development can simultaneously reduce carbon emissions and limit waste entering landfills. Michigan Athletics alone can support an anaerobic digester and, depending on the liquid digestate use case, can be economically beneficial from this investment in just four years and reduce GHG emissions by 24.7 MMT CO2e from landfills in Michigan during one year of athletics. Future research or applications should focus on athletic facilities and event arenas, both collegiately and professionally. Athletic stadiums across the country can not only support their financial investment in anaerobic digestion; they can also support local urban farms and community green spaces, divert tons of MSW, support additional jobs for AD operation, and decrease their carbon footprint.

For the U.S., the Department of Energy (DOE) released the 2023 billion-Ton Report, which estimates approximately 217 million tons of biomass MSW per year could be reallocated for by-product development (Office of Energy Efficiency & Renewable Energy, 2024b). This amount of waste could be used to produce roughly 25% of the total SAF needed to support U.S. aviation fuel demand—a by-product option this report presents. In this example alone, using biomass MSW for biofuel could cut not only landfill emissions but aviation emissions as well. SAF using cherry pits and soybeans as feedstock is currently not financially beneficial, but it can dramatically reduce GHG emissions from DTW and landfills. Future research could focus on creating technology for SAF that is more economically viable for airlines and airports to consider this as a transitory fuel. Many of the technologies employed in the case studies are commercially available but historically have had limited financial support and incentives. With increased federal and private investment, expanded education, and further research, a biomass circular economy will yield significant economic, social, and environmental benefits for communities worldwide.

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LITERATURE CITED

ASHEE (2022) Landscape Management | University of Michigan | Scorecard | Institutions | STARS Reports. *Sustain Track Assess Rat Syst STARS* https://reports.aashe.org/institutions/university-of-michigan-mi/report/2022-12-19/OP/grounds/OP-9/.

ASTM (2023) D7566: Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. *Compass ASTM* https://www.astm.org/d7566-22a.html.

Chomp Energy Chomp's Anaerobic Digester Product Line. *Chomp Energy* https://www.chomp.energy/product-line.

Commercial Aviation Alternative Fuels Initiative (2024) CAAFI - Home. *CAAFI* https://www.caafi.org/.

Craigen, A. (2021) For a truly circular economy, we need to listen to indigenous voices. *UNDP* https://www.undp.org/blog/truly-circular-economy-we-need-listen-indigenous-voices.

Detroit Metropolitan Wayne County Airport (2020) DTW Zero Emissions Roadmap. DTW, . https://www.metroairport.com/business/environment-sustainability/sustainability.

Facilities & Operations (2020) The University of Michigan Annual Report of Utilities: Fiscal Year 2020. *Univ Mich* https://utilities.fo.umich.edu/.

Folsom, K., and Sprague, K. (2023) Campus Farm experiments with composting stadium waste. *Univ Rec* https://record.umich.edu/articles/campus-farm-experiments-with-composting-stadium-waste/.

Gevo Sustainable Aviation Fuel Report (2022) *Gevo* https://gevo.com/.

GreenView (2024) Lawn Fertilizer Facts. *GreenView Fertil* https://www.greenviewfertilizer.com/articles/fertilizer-facts.

Harrington, T. (2022) Delta Air Lines to acquire 2 billion litres of alcohol-to-jet SAF from Gevo under a seven-year agreement. *GreenAir News* https://www.greenairnews.com/?p=2780.

IRS (2024) Active Fuel Terminals DTW. https://www.irs.gov/pub/irs-utl/tcn-db.pdf.

Krause, M., Kenny, S., Stephenson, J., and Singleton, A. (2023) Quantifying Methane Emissions from Landfilled Food Waste. *EPA* EPA-600-R-23-064.

Moriarty, K., Milbrandt, A., and Tao, L. (2021) Port Authority of New York and New Jersey Sustainable Aviation Fuel Logistics and Production Study. https://www.osti.gov/servlets/purl/1827314/.

Mutschler, E. (2023) 2023 Michigan Agriculture Facts & Figures.

Office of Energy Efficiency & Renewable Energy (2024a) Alternative Fuels Data Center: Sustainable Aviation Fuel. *DOE* https://afdc.energy.gov/fuels/sustainable-aviation-fuel.

Office of Energy Efficiency & Renewable Energy (2024b) 2023 Billion-Ton Report. U.S. Department of Energy, .

Rauhe, S. (2023) High fertilizer costs hit Michigan farmers. *Spartan Newsroom* https://news.jrn.msu.edu/2023/12/high-fertilizer-costs-hit-michigan-farmers/.

Shell (2023) Delta, Shell Aviation SAF agreement to fuel LAX hub and accelerate decarbonization within aviation | Shell Global. https://www.shell.com/business-customers/aviation/news-and-media-releases/news-and-media-2023/delta-shell-aviation-saf-agreement-to-fuel-lax-hub-and-accelerate-decarbonization-within-aviation.html.

Shimizu, H. (2014) Waste produced at the University of California is converted into campus energy. *UC Davis* https://fapesp.br/week2014/california/waste-produced-at-the-university-of-california-is-converted-into-campus-energy/.

Song, S., Lim, J.W., Lee, J.T.E., Cheong, J.C., Hoy, S.H., Hu, Q., *et al.* (2021) Food-waste anaerobic digestate as a fertilizer: The agronomic properties of untreated digestate and biochar-filtered digestate residue. *Waste Manag* 136: 143–152.

Taylor, S. (2023) Anaerobic Digestion at Western Washington University. Western Washington University (WWU), WWU. https://cedar.wwu.edu/cgi/viewcontent.cgi?article=1656&context=wwu_honors.

The White House (2024) Valuing the Future: Revision to the Social Discount Rate Means Appropriately Assessing Benefits and Costs | CEA. *White House* https://www.whitehouse.gov/cea/written-materials/2024/02/27/valuing-the-future-revision-to-the-social-discount-rate-means-appropriately-assessing-benefits-and-costs/.

U.S. Department of Agriculture (2023) USDA/NASS 2023 State Agriculture Overview for Michigan. *NASS USDA* https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MICHIGAN.

U.S. Energy Information Administration (2023) Biomass explained. *EIA* https://www.eia.gov/energyexplained/biomass/.

U.S. Environmental Protection Agency (2015) Basic Information about Anaerobic Digestion. *EPA* https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion.

U.S. Environmental Protection Agency (2017) National Overview: Facts and Figures on Materials, Wastes and Recycling. *EPA* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials.

U.S. Environmental Protection Agency, O. (2021) What is a Circular Economy? *EPA* https://www.epa.gov/circulareconomy/what-circular-economy.

U.S. National Renewable Energy Laboratory Biomass Energy Basics. *NREL* https://www.nrel.gov/research/re-biomass.html.

U.S. Office of Energy Efficiency & Renewable Energy Biomass Resources. *Energy.gov* https://www.energy.gov/eere/bioenergy/biomass-resources.

Waste Management (2024) Permanent Dumpster Sizes. *WM* https://www.wm.com/us/en/business/business-waste-recycling-pickup/permanent-dumpster-sizes.