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Circular economy, methane capture, and climate education in US HEIs

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Abstract

Purpose – This study aims to analyze the involvement of US colleges and universities in methane capture projects in the waste sector and their related educational initiatives aiming to build circular economies and reduce greenhouse gas (GHG) emissions.

Design/methodology/approach – The authors compiled a subset of 22 "early adopting" institutions – those that received media attention for solid or liquid waste methane capture projects from 1999 to the present. The authors included all cases found within a reasonable number of queries. The institutions fell into two groups: (1) schools directly involved in gas capture projects, and (2) schools that purchased third-party offsets tied to landfill gas (LFG) projects. The authors assessed transparency and accountability, which the authors determined as fundamental to GHG mitigation and climate education. The authors expanded on five innovative cases from our subset to illustrate pathways to improve equity and circularity in waste flows.

Findings – US higher education institutions (HEIs) can measure and educate more transparently about waste streams. While institutions using LFG offsets range in size, curriculum and geography, there were few methane capture projects supplying energy directly to campuses. Although HEIs generally rely on third-party providers for waste management, cases demonstrate how universities can play a role in methane use, and be incubators for climate action and related employment.

Practical implications – Illustrative cases demonstrate the educational and institutional benefits from methane use.

Social implications – HEIs can generate pathways of a "just" transition to a fossil-free circular economy.

Originality/value – To the best of the authors' knowledge, this is one of the first comparative studies examining waste sector methane capture and the potential for high-impact educational practices and sustainability training in US HEIs.

Keywords Circular economy, Climate education, "Just" transition, Methane, Waste colonialism

Paper type Research paper

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Abbreviations

EPA = Environmental Protection Agency;
GHG = greenhouse gas;
HEI = higher education institution;
LFG = landfill gas;
LFGTE = landfill gas to energy;
PFAS = perfluoroalkyl and polyfluoroalkyl substances;
PPA = Power Purchasing Agreement;
REC = renewable energy credit;
SIMAP = Sustainability Indicator Management & Analysis Platform; and
STARS = Sustainability Tracking, Assessment & Rating System.

Introduction

People in the USA send approximately five pounds of waste per person per day to landfills, much of which could be recycled or repurposed (Lee and Lee, 2022). The EPA (2022) estimates landfills to be the third largest US source of methane; however, recent research suggests landfill emissions are considerably higher than prior reports (Cusworth *et al.*, 2024). The same is true for wastewater emissions, now thought to be twice as high as previous estimates (Moore *et al.*, 2023). Climate impacts of landfills and wastewater are receiving greater regulatory scrutiny since the greenhouse gas (GHG) emitted is mainly methane, which has more than 80 times greater global warming potential than carbon dioxide in a 100-year timeframe (Mar *et al.*, 2022). Waste streams generate high social costs along with ecological consequences. Landfills and wastewater treatment facilities are often located in low-wealth areas and communities of color, thus creating a pattern of waste colonialism, which refers to how groups with wealth and power dispose of their garbage in marginalized communities (Liboiron and Lepawsky, 2022). In contrast, the "just" transition increases social equity while replacing fossil fuels and operationalizing climate mitigation, such as in a circular economy with synergies from renewable energy (Kristia and Rabbi, 2023). Circular economies reduce material use, redesign materials and products to be less resource-intensive and recapture "waste" as a resource to manufacture new materials and products – in this case, energy – while providing healthy green jobs (Padilla-Rivera *et al.*, 2020; Mies and Gold, 2021).

For renewable energy to provide a base for a circular economy requires policy support and integration of disparate efforts to accelerate fuel transition (Nunes *et al.*, 2023). Meanwhile, higher education institutions (HEIs) seek clean energy sources that are affordable, accessible and ethically sourced. Spurring a clean circular economy imbues fertile ground for high-impact educational practices (Kowasch, 2022; Vergani, 2024), which include collaborative problem-solving and community-based learning (American Association of Colleges and Universities (AAC&U), 2024). An essential role of higher education is to generate knowledge to help meet today's great challenges (Compagnucci and Spigarelli, 2020). Indeed, HEIs have a responsibility to train students and staff in sustainable technologies and pursue transparent climate action (Jebari *et al.*, 2021). To understand current efforts related to the potent GHG methane, our research sought to understand how institutions educate about and use emissions from waste flows. We asked two interconnected questions:

Q1. Do HEIs transparently account for and educate about campus waste and related GHG emissions?

Q2. How can HEIs participating in methane capture from waste become green training and knowledge incubators while benefitting community partners?

This paper begins with context about HEI waste sector methane capture and use. Next, we explore a subset of 22 institutions directly or indirectly involved in methane capture from liquid or solid waste. Then, we examine educational and training initiatives in five pathbreaking cases (Appalachian State University, the Council of Independent Colleges in Virginia, Stanford University, University of New Hampshire and University of Vermont) to explore circular economy options providing community co-benefits. Finally, we provide seven recommendations for expanding methane education and outreach in HEIs.

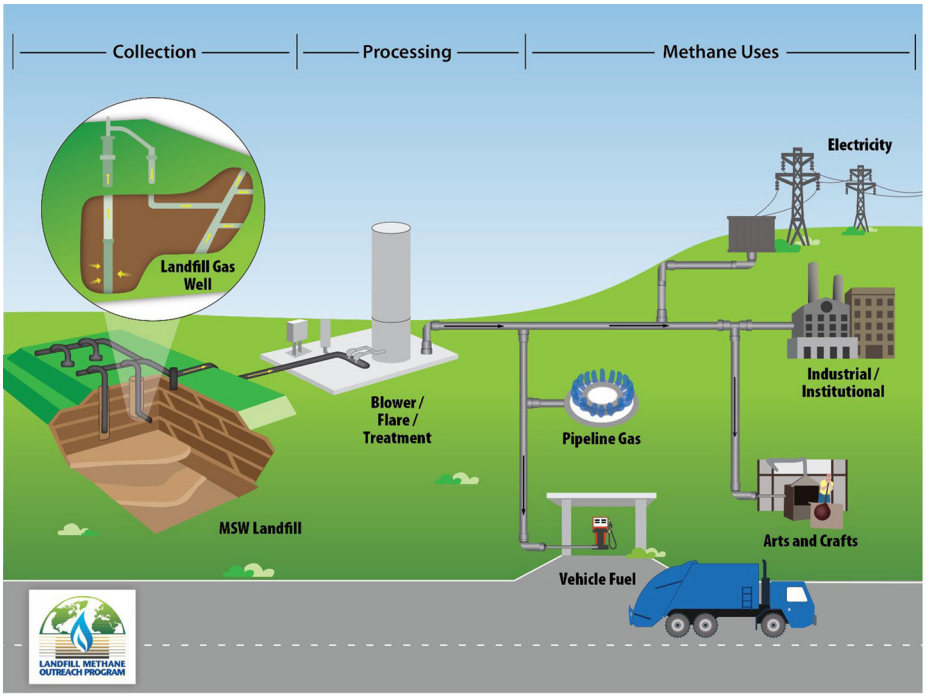
HEI waste flows and methane emissions

With methane receiving increased federal and state regulatory attention in recent years, the policy landscape is dynamic. Capture of methane emissions from wastewater is relatively novel, yet there are thousands of suitable US municipal facilities (Ha *et al.*, 2022). The US Environmental Protection Agency (EPA) requires control devices at large landfill sites with surface methane readings over 500 parts per million and releases of nonmethane organic compounds greater than 34 Mg per year (Jenks and Dobie, 2024). A few states have developed more stringent guidelines. GHG emissions from smaller landfills and closed landfills that continue to emit are often inadequately counted.

Methane is produced in landfills when organic wastes decompose anaerobically. LFG can be combusted in engines to generate electricity, which reduces the need for open gas flaring (Figure 1).

Waste revenue streams are increasing with consolidation and profitable landfill gas to energy (LFGTE) projects (Dezember, 2022). LFGTE technology is readily available and gaining popularity (Traven, 2023). There is a downside – LFG projects emit pollutants, often where populations are already burdened. Residing near landfills can increase birth defects, cancer and respiratory illnesses (Yu *et al.*, 2018). While public relations departments for landfill operators may make landfills and LFGTE operations seem environmentally conscious (Kreydatus, 2022; Mullis and Finley-Brook, 2022), systems create significant harm in host communities by polluting the air and tainting drinking water (Carey, 2023; Ernstson and Swyngedouw, 2023). Landfill odors lower quality of life. Landfills are disproportionately sited in minority-majority and low-income areas (Bullard, 2018; Devakumar *et al.*, 2020; Finley-Brook *et al.*, 2022; Liboiron and Lepawsky, 2022). Landfills produce leachate when water that percolates through the waste stream picks up contaminants (Ahmad *et al.*, 2018; Kamboj *et al.*, 2020). Even small amounts of certain chemicals commonly found in landfills can be harmful (Duan *et al.*, 2021; Pisharody *et al.*, 2022). The quality and condition of the liner and the range of materials accepted into the landfill can influence the extent of the health risks (Vaverková, 2019).

Remote sensors such as those on satellites and drones help detect previously uncalculated GHG emissions from waste facilities (Zhang *et al.*, 2023). Material evidence of methane generated from waste facilities has created a new regulatory landscape, propelling markets for GHG capture. These shifts create opportunities for HEIs but also highlight responsibilities. HEIs have an important role in education about the material and ethical consequences of waste produced by faculty, staff and students (Renfors, 2024). While recycling and compost projects are established on many campuses, a massive flow of waste to landfills and wastewater facilities still occurs. There is insufficient attention to this in current campus sustainability tracking and reporting efforts. For example, the Sustainability Tracking Assessment & Rating System (STARS) platform used by hundreds of HEIs



Source: (U.S. EPA Landfill Methane Outreach Program, 2023)

Figure 1. Collection and processing of LFG

highlights waste diversion from construction and hazardous waste but does not require reporting on wastewater. Likewise, in the Sustainability Indicator Management and Analysis Platform (SIMAP), in widespread use by US HEIs, institutions group solid waste into a single category and some institutions choose to not report wastewater emissions at all.

Many HEIs offset GHG emissions. An offset is a specific activity or set of activities intended to reduce GHG emissions, increase the storage of carbon or enhance GHG removals from the atmosphere [Environmental Protection Agency (EPA), 2018]. HEIs that purchase offsets continue to produce emissions because offsets entail that the offsetting institution is engaging in activities with net-negative effects, such as fossil fuel combustion or waste incineration. Thus, offsetting can be viewed as a "pay to pollute" transaction (Patterson *et al.*, 2021). Moreover, fraud in carbon offsets is a global challenge (Chan *et al.*, 2023). Without adequate transparency and accountability, offsets do not assure net GHG reductions (Reilly, 2022). "Ghost" credits are defined as purchasable offsets that are not genuine carbon offsets (Richards, 2023). Given this context, we used Second Nature's (2016) framework to assess offsets for transparency and additionality (Table 1). Principles are interconnected and reinforcing.

Hird (2022) argued scholars and practitioners need to reframe waste as a social justice issue. Impacted groups – and especially environmental justice communities made up of people of color and socially and economically vulnerable groups – must meaningfully

Table 1. Principles of high-quality offsets

Criteria	Description of criteria	Concerns
Real and measurable	Offset GHG reductions are material, quantifiable and traceable	Offsets may be fictitious or inaccurate
Additional	GHG reductions would not have happened without this project	Reductions were already in the works, so there is no overall lowering of GHGs
Transparent	Entities are not trying to keep anything secret	Information may be hard to find or difficult to understand
Permanent	Offsets are not temporary or fleeting	Offset projects will experience some form of reversal, such as from fire
Verified and registered	Formalities are conducted by independent, reputable third parties	Offset projects may be informal and unverifiable
Accounts for leakage	Boundaries, scope, time and technical reasons for potential leaks	If there is leakage outside the project, overall reductions may not occur
Enforceable	Offsets are backed by legal contracts with sanctions for lack of compliance	Volunteer transactions (those without enforcement) can change over time
Not double counted	Offsets are only claimed by one entity	There will be more than one entity counting the GHG reduction
Retired	Once purchased, offsets are taken off the market	Offsets will enter back into circulation, perhaps allowing for double counting across time
Co-benefits	Offset projects create positive educational, social, economic development and resiliency	Carbon-centric projects may have unintentional negative tradeoffs and miss opportunities for public good

Source: Extended from Second Nature (2016)

participate in decision-making from the start of projects. We extend Second Nature's (2016) principle of co-benefits as a noncarbon-centric way of evaluating offsets by ensuring projects support local communities. Co-benefits can help redress harms of landfill pollution and advance just transition (Finley-Brook *et al.*, 2022).

Research methodology

With limited prior research existing to show US HEI ties to methane use from the waste sector, we designed this research to capture the institutional and physical landscape. Common HEI waste pathways include disposal to a landfill with or without LFGTE, to an incinerator or waste-to-energy plant, to facilities for recycling or composting and to facilities for wastewater treatment. All these waste streams benefit from a circular economy approach. Because recycling and compost initiatives have received considerable attention in waste minimization research for decades, we focused here on the garbage stream sent to landfills. We included food waste and other organic matter not separated before landfilling.

Using Second Nature's reporting platform, journal and newspaper databases and carbon registry searches, we identified institutions directly or indirectly involved in methane capture from solid waste or wastewater from 1999 to the present. We included all cases that received attention from multiple verified sources and found within a reasonable number and type of queries. Table 2 lists the 22 HEIs included in the study and the size of their student body alongside self-reported data from institutions participating in STARS regarding waste per campus user.

Table 2. Case studies: student body and waste

Institution	Student body*	Waste per weighted user (tons)**
University of California, Los Angeles	45,930	0.19
Appalachian State University	18,811	0.18
American University	16,079	0.15
Stanford University	16,914	0.69
University of Vermont	15,968	0.17
University of New Hampshire	13,680	0.19
Dartmouth College	6,342	NA
University of California, Merced	8,847	0.05
Bentley University	5,460	0.19
Mercyhurst University	2,900	NA
Colgate University	2,890	0.28
University of Lynchburg	2,692	NA
Colorado College	2,270	0.32
Mary Baldwin University	2,184	NA
Colby College	1,917	0.47
Bowdoin College	1,816	0.51
Emory & Henry College	1,292	NA
Central College	1,120	NA
Hollins University	821	NA
Randolph College	684	0.22
Sweet Briar College	457	NA
Mayland Community College	421	NA

Notes: * Student body includes undergraduate, graduate, resident and commuter; numbers were taken from the university website ** Waste per weighted user, according to the most recent STARS report. Weighted campus users = Campus residents + 0.75 (nonresident campus users)
Source: Compiled by authors

Our research drew data from STARS and the SIMAP. Table 3 shows Scopes 1, 2 and 3 emissions as recorded by the HEIs included in our study that select to report to SIMAP.

Most HEIs place boundaries around GHG emissions they are required to count (Scopes 1 and 2) and those from services purchased by an HEI (Scope 3). HEI emissions from the waste sector include:

- *Scope 1:* from waste facilities owned by the HEI operating on campus.
- *Scope 2:* from purchased energy sourced from waste, such as LFGTE facilities.
- *Scope 3:* from treatment and disposal of campus solid and liquid waste by third parties.

Institutions in Table 3 (above) vary regarding SIMAP benchmark year and time using the platform. Inconsistencies also exist because disposal and reuse options vary widely and can shift based on third-party contracts and other factors. We split our 22 HEIs into two groups: those directly involved in methane capture projects and those providing offsets. Our list included schools of various types and sizes located throughout the USA. Offset cases exhibit important differences (Table 4), including the timing of programs and the distance between the university and the offset site.

We found 28 LFG offset projects at 10 of our 22 HEIs. A few universities participated in multiple offsetting projects. In other projects, the landfill supplied offsets to multiple

Table 3. Emissions changes by scope

Institution	Benchmark year*	Change in Scope 1 and 2 emissions, Benchmark – 2023 (%)	Change in Scope 3 emissions, Benchmark – 2023 (%)
University of California, Los Angeles	1990	−66	NA
University of New Hampshire	2001	−45	−66
Bentley University	2004	−84	−36
American University	2005	−68	+111
University of Vermont	2007	−51	−53
University of California, Merced	2007	−17	−26
Hollins University	2007	−24	−3
Colorado College	2008	−72	−11
Bowdoin College	2008	−49	−75
Colgate University	2009	−36	−59
Randolph College	2017	+24	−33
University of Lynchburg	2019	−88	−99

Note: * Year of first report on SIMAP
Source: Compiled by authors

Table 4. Case studies of early LFG offset adopters

Institution	Year of first LFG offsets	State of institution	State of offset project
Colby College	2013	ME	ME, MA, CT
Mercyhurst University	2014	PA	PA
University of California System	2015	CA	CA, GA, KS, LA, MO, MT, NC, NE, OK, PA, TX, WI
Bentley University	2015	MA	MA
American University	2017	DC	FL
Bowdoin College	2018	ME	NH
Central College	2018	IA	IA
Colgate University	2019	NY	NY
Colorado College	2020	CO	CO

Source: Compiled by authors

universities. Twenty-five projects supplied documents on popular offset reporting platforms: American Carbon Registry, Verified Carbon Standard, Climate Action Reserve and Center for Resource Solutions.

For offsetting institutions, we assessed the adherence of each project to attributes of Second Nature's high-quality offsets (Table 1 above). Offsets must be developed and sold to offsetting institutions in a transparent manner codified by registration, validation and verification. Meanwhile, offsetting institutions must be transparent in claims they make about purchased offsets. The principle of retirement is intended to ensure a one-to-one

correspondence between offsets and claimed reductions. Without clear standards, offsets can mislead about progress toward carbon neutrality.

Illustrative cases of waste sector methane use and education

Prominent waste management cases in HEIs demonstrate avenues for educational engagement in political science, economics, physics, engineering, art and a variety of other disciplines in addition to sustainability and environmental studies. Cases selected highlight diverse pathways for HEI involvement: LFG projects, LGFTE offsets, wastewater gas-capture and improved Scope 3 accounting of waste emissions. Four of the five cases demonstrate capture and reuse of methane on campuses or performed with participation by faculty, staff or students. Three of the cases involve GHG offsets and accounting.

University of New Hampshire

University of New Hampshire is the first US HEI to obtain most campus energy from LFG. The ECOline LFGTE project pumps gas through a 12.7-mile pipeline from a preexisting local landfill to a campus co-generation facility. The main hurdle for the ECOline project was the $49m cost (Rodriguez *et al.*, 2021). The University sold renewable energy credits to help finance the project, recuperated investments in ten years and now pays only operational costs of $2–3m per year.

In classes, students tour the campus cogeneration plant and the processing plant at the landfill. Students explore technical, behavioral and economic considerations of renewable energy systems including options for energy storage and load management. Real-life training and educational opportunities in methane capture are key to wider use. The LFG project has become a source of pride for the campus community and is a cornerstone of the University of New Hampshire's positive media attention as a sustainable college. Nevertheless, waste flows remain high (see Table 2) and energy use reported to STARS also remains above average, highlighting a need for continued conservation education.

University of Vermont

University of Vermont supported an early LFGTE project that was curtailed. In Brattleboro, Vermont, Carbon Harvest Energy sold electricity to the grid from a waste-to-energy facility at a Windham Solid Waste Management District site. Carbon Harvest later expanded the project to provide heat to a greenhouse and aquaponics operation, which supplied fish and fresh vegetables to markets and the Vermont Foodbank. Carbon Harvest received a seed grant from the state as a job incubator and potential model for other sites and used Vermont's Feed-in Tariff program, which benefits long-term, fixed-price renewable energy contracts. Education was a key component, and Carbon Harvest established ties to HEIs throughout the area. Although seemingly gaining momentum at the project site, Carbon Harvest unexpectedly filed for bankruptcy in 2013, when a main financier hit a setback unrelated to the LFG project and withdrew support (Heikkinen, 2015). While this program ended, knowledge and equipment from this pilot contributed to other agricultural LFGTE projects.

The University of Vermont contributes to a circular economy in the greater Burlington area. Scraps from dining halls are collected and sent to Green Mountain Compost, a nearby industrial compost facility (Gilligan, 2022). The university received an EPA grant to study the ability of farm biodigesters to accept food waste. This program involves community outreach working with students from a local middle school (Rumph, 2022). Favorable state policy facilitated university progress toward methane mitigation and use (Lisle, 2020). In 2020, Vermont Act #148 (the Universal Recycling Law) banned food waste (Belarmino *et al.*, 2023).

Mayland Community College and Appalachian State University

In 1999 Mayland Community College in North Carolina spearheaded EnergyXChange to use LFG from a recently closed landfill to power four greenhouses and art studios for pottery and glasswork. This inspired Appalachian Energy Center's CommunityTIES initiative, which helped communities in North Carolina beneficially reuse LFG. Appalachian State University also ran a commuter offset program, which asked commuters to voluntarily donate to fund yearly maintenance on an LFG system.

CommunityTIES developed LFG systems at landfills that were not viable for commercial LFG development because they were small or closed (ASU News Service, 2015). Appalachian Energy Center drew on faculty expertise in setting up LFG systems and strengthening relations between campus and the community. Through 2015, the project had directly helped install LFG systems in six counties in North Carolina, powering an industrial park, a blacksmithing studio, artist residencies and food distribution programs. The projects were initiated, planned and executed by the university, in partnership with communities and made use of academic assets such as research, technical knowledge and outreach capabilities. However, private utility company Duke Energy was involved, and offsets were not independently registered, verified or validated (Hubbard, 2017).

Stanford University

Stanford University has ambitious waste diversion goals of zero waste (Tripathi *et al.*, 2024), yet waste streams remain high (see Table 2). Indirect LFG use has become commonplace for the university, with a market exclusion that ensures solid waste is deposited only in landfills with methane capture. As for wastewater, a research center has developed a pilot-scale facility that "scalps" sewage from the campus sewer, running an anaerobic process to generate methane (Stanford Engineering Staff, 2023). The experimental pilot project is not producing energy but monitors yields to model methane formation.

Off-campus, Stanford has helped pilot methane capture from municipal wastewater with public and private partners (Sustainable San Mateo, 2020). University personnel are helping design systems to remove methane from wastewater at a larger pilot facility, which is energy-positive: it generates more electricity than is used to purify the wastewater.

Stanford involves its business school in improved calculations of Scope 3 emissions that demonstrate the total amount of in this scope can be significant. Nevertheless, project advisors acknowledge the limitations and boundaries to existing methods. More efforts like this in HEIs will train professionals in comprehensive GHG accounting across the full lifecycle of energy and waste options. Other Stanford experts focus on methane mitigation from oil and gas. With concern over sending mixed messages, Stanford's flagship Doerr Sustainability School has faced controversy as a result of sponsorship by oil and gas firms (Knox, 2022).

Council of Independent Colleges in Virginia

Six small institutions in the Council of Independent Colleges in Virginia collaborated on LFG offsets. Together the colleges entered a Power Purchasing Agreement (PPA) with the company Ingenco, which provided power from LFG to the grid. Ingenco, one of the largest private LFG operators in the eastern USA, established long-term contracts at favorable terms at multiple sites across the mid-Atlantic. Acting through a consortium allowed these small colleges to pool resources and take greater action. For example, one member institution cited this PPA as the primary contributor to its claim of becoming the first carbon-neutral university in the state (Carey, 2021). Nevertheless, schools did not build educational and training program opportunities tied to the LFG or the offsets.

A decade of grants from the EPA and alliances with HEIs helped Ingenco expand. Vulnerable communities experience ongoing injustices with continued emissions from the landfills and LFG facilities. Ingenco was purchased by Archaea Energy in 2022, shortly before Archaea became a subsidiary of the global giant BP (Smalley, 2023), formerly called British Petroleum. Consolidation of LFGTE markets is ongoing with insufficient environmental justice screens or policy safeguards in place to assure landfill operators comply with best practices. Ingenco established a pattern of profiting from landfills with environmental injustices. For example, in Charles City County, Virginia, a rural, minority-majority community, Ingenco expanded LFG operations alongside an expanding mega-landfill (Kreydatus, 2022), which increased pollution exposures for African-American and Native American households nearby (Finley-Brook *et al.*, 2022; Mullis and Finley-Brook, 2022). In another example, the Bristol landfill in Virginia became mired in lawsuits after harming the health and well-being of local populations (Wade, 2021). Today, impacted populations living near the landfill pay higher costs for waste services to assume expenses for odor control. Nonprofit organizations help those who cannot afford air filtration (HOPE for Bristol, 2023). The city gave Ingenco rights to the LFG for free, a situation argued to be unfair to local residents (Jones, 2018).

Research results

We present seven key findings followed by recommendations.

Finding 1: Waste flows remain high; intensification of waste minimization efforts is integral to HEI climate action.

Justification – Technological and financial skills from HEIs add important expertise and accountability in the waste sector and create opportunities to train climate professionals on methane and waste streams. Current reporting can mask how HEIs contribute to climate and waste colonialism. US HEIs send large flows to landfills and wastewater treatment facilities. HEIs in our study (Table 2) reported waste diversion rates of around 20%–60% with a median of around 40%. Large universities in our illustrative cases had comparable waste per weighted user. All large universities except Stanford performed better than smaller schools in this study in diverting waste from landfills. With high levels of waste still produced, most HEIs can improve their waste diversion. Importantly, methane capture projects cannot be promoted in the absence of programs and policies to reduce consumption and reuse materials prior to disposal. Some campuses promote a culture of mending, fixing and exchanging goods to reduce waste. In STARS reports, many institutions reported waste diversion initiatives including standard recycling, bulk purchases of goods, supply exchanges and educational events, although fully developed procurement policies were infrequent. Hundreds of institutions compete to reduce landfill disposal in the Race to Zero Waste, previously called Recyclemania. This and other waste diversion efforts benefit from hiring staff to engage new participants and conduct waste audits. Nonetheless, opportunities abound for HEIs to increase outreach and education. Websites, press releases and newsletters show positive examples, but these often have limited reach on campuses because of inadequate HEI investment in sustainability staff. HEIs can appeal to student, alumni and donor interests in sustainability by educating about circular economies and just transition as successes in climate action.

Recommendations – Hire staff and enroll interns and volunteers to increase diversion rates from public events, where outreach and education is visible and where maintaining separate waste streams can be labor intensive. Expand use of print and digital media to disseminate digestible information for nonexpert stakeholders about social, ecological and economic benefits of circular waste economies.

Finding 2: Methane is underused from campus waste flows. There is insufficient research and inadequate training in gas capture.

Justification – Universities produce significant organic waste leading to methane production. Composting is a traditional approach to lowering landfill methane emissions and is expanding on many campuses but often covers only a portion of total potential. LFG programs can complement recycling and composting initiatives. LFG capture technology is not new, and there is substantial room to improve efficiencies through research to advance technology. Both Ingenco and Appalachian State University use modified automotive engines that were not designed specifically for LFG; Appalachian State University's engines were like those installed at EnergyXChange in 1999 and run at about 30% efficiency (ASU News Service, 2015; Rischar, 2022). While Stanford's wastewater methane capture programs are cutting edge and show great potential, they remain small and in pilot stages. Universities are institutions with human, financial and technical resources to generate GHG emissions reductions; however, these resources are underused when purchasing offsets. Educational opportunity for training about manipulation of carbon credits, an important experience for today's sustainability professionals. It is necessary for HEIs to advance GHG accounting, preferably involving students in GHG accounting as well as education and outreach.

Recommendations – Encourage HEIs to embrace their full potential to reduce emissions in circular economies with community co-benefits. Support methane capture projects in the proximate region to improve educational and training opportunities, allow regular engagement, improve transparency, reduce GHGs of trash transportation and lower distances for electrical transmission. Create hands-on educational opportunities such as class projects and internships in methane use.

Finding 3: Although direct methane use was higher at large, state universities, the involvement of a community college shows potential for broader applicability.

Justification – Case studies show a wide array of education and operational opportunities related to methane emissions from waste flows. Illustrative cases show advanced education and training: several projects were built drawing from faculty expertise and provided hands-on training to students. University of New Hampshire and University of Vermont used methane directly building regional expertise and generating forward and backward linkages in the local community. Appalachian State University created co-benefits with local energy co-generation and education. Methane projects can support business programs like at Stanford University and art initiatives like those supported by Appalachian State University. Stanford is shaping new modalities for wastewater treatment with global benefits and leading efforts to improve accounting for Scope 3 emissions. Attention to the full lifecycle of waste flows would address interplay between all three scopes of emissions to comprehensively identify net reductions without unforeseen tradeoffs.

Recommendations – Bring circular economy into classes beyond environmental studies and sustainability programs. Arts, business, engineering, geography, law, physics, political science and additional disciplines can engage with different aspects of circular economy, such as engagement on ethical aspects of consumption or offsets. Circular economies are relevant to HEIs ranging in size, location and specialty.

Finding 4: Landfill and LFG offset markets have grown and consolidated without addressing health risks of landfill-impacted communities.

Justification –The close ties between fossil fuel industry and many academic institutions has received scrutiny in recent years (Sharmina, 2022), but conflicts of interest in the waste sector receive less attention (Hird, 2022). Waste sector and LFGTE consolidation creates unequal power between national firms and local stakeholders. Campus waste flows and GHG

emissions from them often remain poorly accounted for. Not all sites have documented as much conflict with the community as Ingenco's sites in Charles City and Bristol, Virginia, yet these patterns extend to other LFG offsets in Table 4. For example, media coverage documented environmental injustice in LFG offsets in Robeson County Landfill in North Carolina, which has a relatively high Native and African American population living with a concentration of landfills, oil and gas infrastructure and other contaminating facilities (Song, 2023). LFGTE projects were too often sited in vulnerable and already heavily burdened communities, such as with forever pollutants like perfluoroalkyl and polyfluoroalkyl substances (Song, 2023; Coffin, *et al.*, 2023). Environmental injustice is also problem at wastewater facilities, and water treatments can create additional exposures for surrounding communities (Liddie *et al.*, 2023).

Recommendations – Social and environmental externalities highlight the need to improve assessments. HEIs must ask questions about locations and use the EPA's EJScreen and other tools before determining waste, offset or PPA contracts. Draw attention to waste colonialism created by landfills disproportionately sited in vulnerable areas and use research to help develop policy that can diminish environmental injustice in siting of landfills and mitigation projects.

Finding 5: Offsets require accountable and transparent reporting, oversight and education.

Justification – Offsetting was intended as a last step for institutions to compensate for emissions that cannot be directly avoided, reduced or replaced. Failing to assure accountable measurement, offsets can create a false sense of accomplishment. Few offsets examined in this research met rigorous criteria for additionality. Some HEIs justified additionality by the upgrade of a system from LFG capture to energy generation. One of the most common shortcomings for additionality was the lack of synchronicity – records of timing show that several universities did not become involved in the offset project until well after any system was installed. Moreover, in many of those cases, institutions purchased only one year of offsets. These partial efforts lack comprehensive accountability for actual net emission reductions and allow a gap between claimed efforts and actual climate impact. In most offsetting cases, the online record was focused on carbon accounting mechanisms, seldom providing other details regarding the LFG project.

Concerns such as these in offset markets make GHG mitigation uncertain and unverifiable. HEIs have vast training opportunities to train students and project stakeholders on avoiding pitfalls in offsetting that stymie net GHG gains during mitigation. Without complete lifecycle documentation, offsets with significant shortcomings may be counted, allowing false claims of emissions reductions to persist. Additional research is necessary on all three scopes of GHGs linked to waste.

Recommendations – For offset projects to provide real emissions reductions, transparency is vital to ensure claims are accurate. Conduct lifecycle assessments to address leakages and tradeoffs. If HEIs create GHG projects without formal registration and verification, use peer verification like Second Nature Offset Network (2024) to extend transparency and accountability.

Finding 6: State and federal incentive programs provide seed funds for HEIs to innovate circular economies, GHG education and climate education.

Justification – University of Vermont benefited from federal funding for GHG mitigation from waste to accelerate and extend campus success with outreach to public schools. Incentives from the US Inflation Reduction Act and EPA grants for waste reduction and diversion create cost-sharing opportunities for campuses. The federal government has established tax credits for producing energy from LFG.

Recommendations – Harness government financial incentives to fund research, build expertise and support outreach. Create programs to complement city or county efforts and involve community members including farmers, small businesses and student organizations. Create a mutual aid program to educate and engage the public in waste minimization and GHG mitigation.

Finding 7: Policy-oriented research could accelerate waste minimization in circular economies and address harms of excess consumption and waste colonialism.

Justification – As knowledge centers, universities can advance real, effective, sustainable solutions and sponsor research to document how a clean circular economy incentivizes public health, climate action and job creation. Few academic papers outline social and practical benefits from reducing the large waste flows from US college campuses and using remaining waste as feedstock for circular economy and sustainability training.

Recommendations – HEIs can move beyond passive education about waste and energy policy to provide hands-on experience working with methane capture and waste diversion. Research can guide federal, state and local policies, including those for feed-in tariffs and incentives.

Conclusion

Waste diversion is a core topic in sustainability in higher education. Yet waste colonialism and related environmental injustices continue. Most campuses send large quantities of waste to landfills, falling short of moral obligations and potential impacts. Programs that educate about reduction of harmful materials in our waste stream and safe handling of hazardous and toxic waste benefit communities living near landfills by reducing dangerous leachate and air emissions.

Wastewater projects like that at Stanford University can assist municipalities in purifying wastewater with energy from the wastewater itself. While energy production from municipal wastewater sources and LFG could be significant, there must be environmental justice policies and practices in place to avoid extending unfair harms and unequal benefits. This research demonstrates the important roles of institutional transparency and community-based research in promoting holistic climate education and GHG mitigation. HEIs can help address data limitations and promote more effective and widespread waste diversion and methane use. To extend this preliminary research, which is limited by small sample size, we encourage further investigation of waste diversion and methane capture for greener and more ethical circular economies. HEIs can advance tenets of circular economy as part of the just transition as they provide high-impact educational experiences.

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