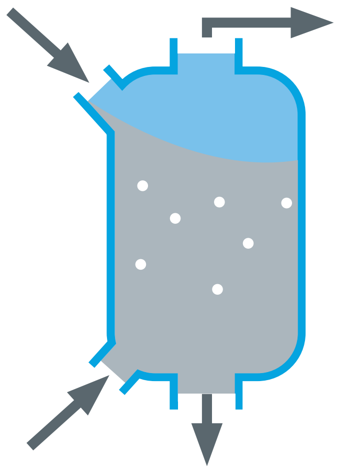
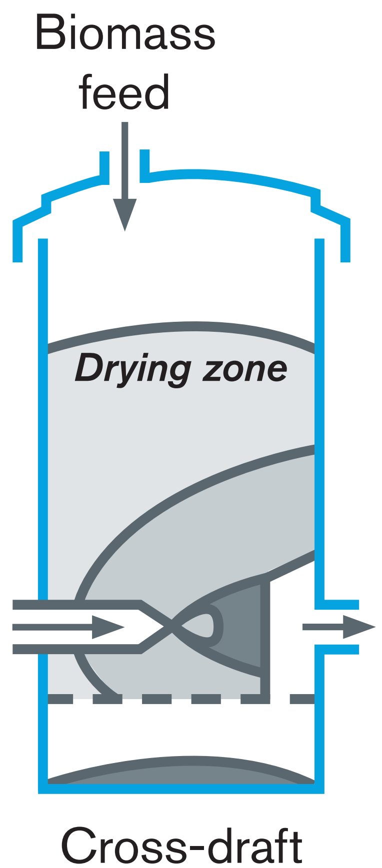
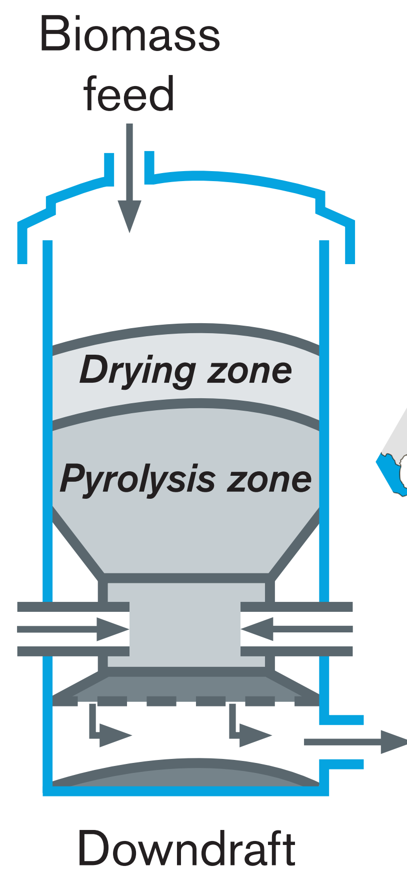
Sustainable Waste Management: E-Waste, Biogas and Syngas

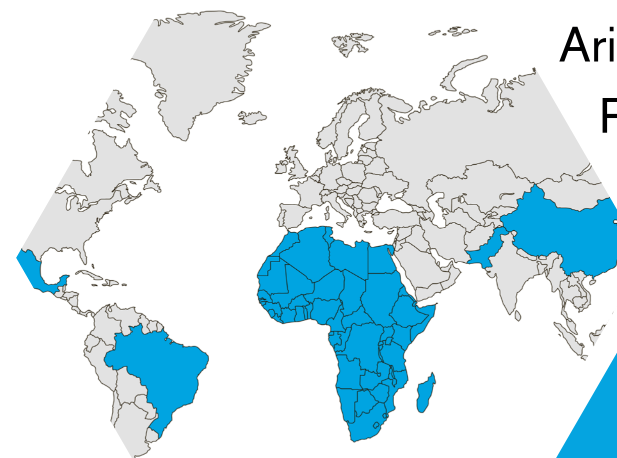
A Fall 2021 Collaborative Project with Arizona State University's Project Cities & the City of Peoria

ASU Sustainable Cities Network
Arizona State University
Project Cities
Peoria Arizona









PART 1:

Project and Community Introduction

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ACKNOWLEDGMENTS

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On behalf of the Julie Ann Wrigley Global Futures Laboratory, the Global Institute of Sustainability and Innovation, and the School of Sustainability, we extend a heartfelt thank you to the City of Peoria for enthusiastically engaging with students and faculty throughout the semester. These projects provide valuable real-world experience for our students and we hope that their perspectives shine light on opportunities to continuously improve Peoria's future livelihood and community well-being.

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links.asu.edu/PCPeoriaWasteManagement21F

ABOUT PROJECT CITIES

The ASU Project Cities program uses an innovative, new approach to traditional university-community partnerships. Through a curated relationship over the course of an academic year, selected Community Partners work with Project Cities faculty and students to co-create strategies for better environmental, economic, and social balance in the places we call home. Students from multiple disciplines research difficult challenges chosen by the city and propose innovative sustainable solutions in consultation with city staff. This is a win-win partnership, which also allows students to reinforce classroom learning and practice professional skills in a real-world client-based project. Project Cities is a member of Educational Partnerships for Innovation in Communities Network (EPIC-N), a growing coalition of more than 35 educational institutions partnering with local government agencies across the United States and around the world.

ABOUT SUSTAINABLE CITIES NETWORK

Project Cities is a program of ASU's Sustainable Cities Network. This network was founded in 2008 to support communities in sharing knowledge and coordinating efforts to understand and solve sustainability problems. It is designed to foster partnerships, identify best practices, provide training and information, and connect ASU's research to front-line challenges facing local communities. Network members come from Arizona cities, towns, counties, and Native American communities, and cover a broad range of professional disciplines. Together, these members work to create a more sustainable region and state. In 2012, the network was awarded the Pacific Southwest Region's 2012 Green Government Award by the U.S. EPA for its efforts. For more information, visit *sustainablecities.asu.edu.*

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ASU Sustainable Cities Network
Arizona State University

Project Cities

Sustainability through local action

ABOUT PEORIA

Ranked as the No. 1 place to live in Arizona by Money Magazine, the City of Peoria is currently home to over 191,000 residents. The City enjoys a reputation as a family-oriented, active community with an exceptional quality of life. Peoria entertainment and recreational amenities include attractions such as Lake Pleasant, trails, and community parks.

The City has also demonstrated a strong commitment to sustainability, as evidenced by its incorporation of LEED building design standards, a council-adopted Sustainability Action Plan, and the "Green Team" staff dedicated to managing organization-wide sustainability initiatives.

PEORIA TEAM

Project Cities Community Liaison

Sharon Roberson, Assistant to the City Manager, City Manager's Office

Peoria Project Leads

John Sefton Jr., Parks, Recreation, and Community Facilities Director

Jay Davies, Interim Public Works Director

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PEORIA ARIZONA

Peoria is the place
World class ▪ Sustainable ▪ Future Ready

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February 28, 2022

Dear Peoria community members,

On behalf of the City of Peoria, we would like to express our appreciation to all who have been involved with Arizona State University's (ASU) Project Cities program. Over the last year, our staff has had the opportunity to collaborate with faculty and students across several academic programs, benefitting from their insights, ingenuity, and diverse perspectives on a number of projects. Many of these entailed public participation, and you may have met some of these engaging students at a community event, or completed a community survey.

Project Cities is one of several partnerships we enjoy with ASU, and part of our ongoing strategy to connect with community partners to leverage our resources as we address the many challenges facing local governments. Working with students at an undergraduate, graduate and capstone project level brings a fresh perspective and resourcefulness to complex issues. This partnership has resulted in extensive research, recommendations, and deliverables that take several key initiatives to the next level. These include our efforts around increasing transit ridership, community engagement strategies, historic preservation and innovative recycling methods. Through this partnership, we have developed an understanding of the feasibility of each initiative much more quickly than we could have without their collaboration.

The results provided on each project position us to serve our community with cost-effective and innovative programs in the interest of continuous improvement. The city has already begun to incorporate the students' deliverables into next steps in advancing these projects. We look forward to continuing this work on additional projects in the coming year with such talented students and faculty.

The City of Peoria appreciates the ongoing and growing relationship with Arizona State University and the many ways in which the alliance provides mutual value.

Sincerely,

Cathy Carlat, Mayor

Jeff Tyne, City Manager

Peoria, Arizona

Proud partner of

ASU Sustainable Cities Network

Arizona State University

Project Cities

Rio Vista Recreation Center

Demographics

total population: **190,985**

median age: **35**

highly skilled and educated workforce of 85,252

11,997 veterans live in Peoria

78% of residents are homeowners

median property value: **$399,025**

33% of residents hold a Bachelor's degree or higher

median household income: **$79,700**

Schools

#3 of 131 Best School Districts for Athletes in Arizona

#5 of 40 Best School Districts in Phoenix Metro Area

#7 of 130 Best School Districts in Arizona

The Peoria Unified School District consistently receives high ratings and offers signature programs such as the Career and Technical Education programs. Deer Valley Unified School District has two highly-rated K-8 schools within the city, including an Academy of Arts.

Peoria is also home to Huntington University, a liberal arts college offering digital media education in animation, broadcasting, film, graphic design and other digital media arts.

Leading industries

Peoria, Arizona is not just a scenic suburb of Phoenix, but also a thriving economic development hub with an educated workforce and high-end residential living. There are over 4,000 employers and more than 75,000 people employed within Peoria. Leading industries include health care and social assistance, retail trade, and finance and insurance. Highest-paying industries include utilities, manufacturing and public administration. Beyond these industries, Peoria works actively to attract businesses from aerospace and defense, film and digital media, technology and innovation, hospitality and tourism, and research and development. Peoria is the place for business owners, developers and investors.

Health Care & Social Work
10,905 employees

Retail Trade
10,628 employees

Finance & Insurance
6,574 employees

History

Founded in 1886 by Midwestern settlers, Peoria is nestled in the Salt River Valley and extends North into the foothills around Lake Pleasant. Beginning as a small agricultural town, the economy received a major boost when a railroad spur line was built along Grand Avenue. The construction of the Roosevelt Dam in 1910 secured a reliable water supply, attracting more settlers to the area and business endeavors to the town center. Peoria's economy continued to have an agricultural focus for decades. Continually growing, Peoria assumed city status in 1971 with a population of 4,792. It has since grown into a city with a population over 190,000, and is renowned for its high quality of life and recreational amenities.

Sustainability

Peoria has demonstrated leadership in municipal sustainability efforts through a wide range of actions. Listed below are some of the City's sustainability accomplishments.

- Incorporation of LEED building design standards
- Appointment of a full-time city staff member who manages and coordinates sustainability initiatives
- Sustainable urban planning practices including open space planning and water management principles
- Sustain and Gain: Facebook page and brochures keep residents up to date on city sustainability efforts and ways to get involved
- Water Conservation Program: free public classes, public outreach at city events, and water rebate incentives for residents
- Council-Adopted Sustainability Action Plan: this strategic planning document, in its second iteration, ensures city departments are developing sustainability-oriented goals, tracking success metrics, and encouraging cross-communication in the preparation of Sustainability Update presentations made to the Peoria City Council on an annual basis
- Sustainable University: courses and workshops to empower residents to make small changes that make Peoria a better place to live; topics covered include residential solar, gardening, composting and recycling

Awards and recognition

- Number One City to Live, Work and Play in 2021 *(Ranking Arizona)*
- Received three Crescordia awards by Arizona Forward at the annual Environmental Excellence Awards in 2016
- 12th City for Green Space in the U.S. in 2019 *(Wallethub)*
- Top 15 Safest Cities in the U.S. 2017-2019 *(Wallethub)*
- 6th Wealthiest ZIP Code in 2020 *(Phoenix Business Journal)*
- Top 50 Hottest Hoods in 2018 *(Phoenix Business Journal)*
- 10th Best City to Raise a Family in 2018 *(Wallethub)*
- Top 100 Golf Course in U.S. 2017-2019 *(Golf Digest)*

Lake Pleasant

1886 – **2020**

- **1886** – Peoria founded by William J. Murphy
- **1889** – First school district formed
- **1919** – Chamber of Commerce organized
- **1954** – Peoria incorporated
- **1971** – Assumed city status with a population of 4,792
- **1977** – Brewers spring training begins at Greenway Sports Complex
- **1986** – Centennial celebration
- **1994** – Peoria Sports Complex opened
- **2007** – Theater for the Performing Arts and Rio Vista Recreation Center opened
- **2012** – 20-year extension spring training agreement with San Diego Padres and Seattle Mariners
- **2017** – Selected as site of new $70M health clinic for Maricopa County Integrated Health System

Livability

Peoria is renowned as a great place to raise a family and start a career. A plethora of local amenities and attractions contribute to Peoria's livability. Beyond the tourist attractions of Spring Training and Lake Pleasant, the City offers many community facilities and recreational opportunities for all ages and interests such as an extensive public park system and annual community events. Peoria's dedication toward livability is also evident in the City's latest General Plan which addresses sustainable water use, housing, public services and more.

Ranked as the No. 1 place to live in Arizona and one of the best cities in the United States.

-Money Magazine and Yahoo! Finance

Peoria Sports Complex

Peoria strives to uphold these six major livability priorities in order to maintain an exceptional quality of life for its citizens:

- Arts, Cultural and Recreational Enrichment
- Economic Prosperity
- Smart Growth
- Superior Public Services
- Healthy Neighborhoods
- Integrated Transportation

Community Facilities

- Peoria Community Center
- Rio Vista Recreation Center
- Peoria Sports Complex
- Peoria Center for the Performing Arts
- 39 neighborhood parks
- 2 libraries
- 3 swimming pools
- 5 golf courses
- 9 lighted multi-purpose ball fields
- 15 tennis courts

Lake Pleasant

Urban ecology, ecotourism and recreation

Skunk Creek

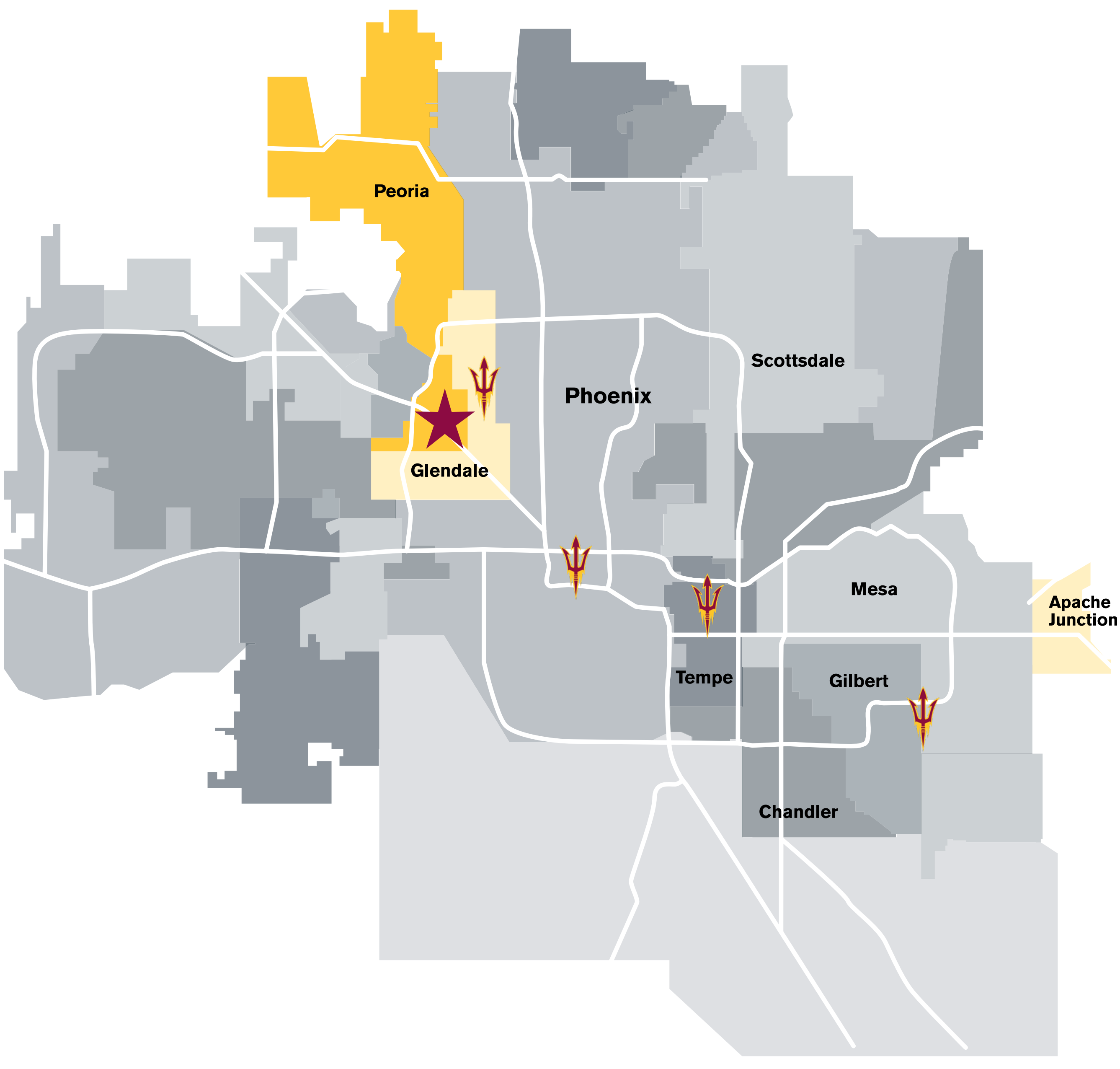
Peoria is surrounded by the natural beauty of the Sonoran Desert and is home to Lake Pleasant, a 23,000-acre park and major recreational asset to the North Valley. The transient Agua Fria River and New River flow through Peoria, as do a multitude of washes and creeks. Most notable perhaps is Skunk Creek — known for the recreational trails running alongside it — which forges a connection between Peoria and Glendale. Northern Peoria is home to beautiful mountains and buttes including Sunrise Mountain, Calderwood Butte and Cholla Mountain.

Boasting over 300 days of sunshine annually, Peoria's ecotourism opportunities are a steady industry for residents and visitors. The City features over 60 miles of trails for walking, biking and horseback riding, as well as 570 total acres of accessible park land.

Lake Pleasant Regional Park contains a full-service marina, providing opportunities for water-oriented recreation such as kayaking, water skiing and even scuba diving. Visitors can also go horseback riding, take gliding lessons, hike, camp and more.

Pleasant Harbor

MAP OF PROJECT CITIES PARTNER COMMUNITIES IN THE GREATER PHOENIX METROPOLITAN AREA



Peoria City Hall

ASU campus

The following report summarizes and draws highlights from work and research conducted by students in ERM 432/532 Sustainable Solid Waste Management, for the Fall 2021 partnership between ASU's Project Cities and the City of Peoria.

To access the original student reports, additional materials, and resources, visit:

links.asu.edu/PCPeoriaWasteManagement21F

Sustainable Cities Network
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Sustainability through local action

EXECUTIVE SUMMARY

Disposing of solid waste generated by residents is one of the more complex operations for a municipality. As one of the fastest-growing cities in Arizona, the City of Peoria has continually opted to remain on the frontline of providing sustainable waste management services for its residents, particularly for more challenging materials.

Electronic waste, or e-waste, has become the forefront of sustainable waste management in an increasingly technological age. Used and discarded electronics often end up in landfills where they can leach toxic chemicals into the environment. However, e-waste materials can be refurbished and reused for additional electronic products through material recovery practices. Due to the hazardous and expensive nature of recycling, e-waste is not typically offered as part of municipal waste programs provided to residents. The City of Peoria is interested in expanding its solid waste collection services to accommodate e-waste. Peoria is also seeking alternative fuel technologies to divert waste from third-party landfills, including biogas and syngas technologies.

Students in Al Brown's **ERM 432/532 Sustainable Solid Waste Management** course split into two groups to investigate the feasibility of an e-waste recycling program and a biomass gasification program. Students conducted a literature review of the two materials and identified potential municipal and private partners to expand its solid waste programs.

While e-waste and biomass gasification are two very different materials, the findings indicate that Peoria should consider partnering with other municipal and private entities to provide additional solid waste services to its residents. Additionally, students identified the need for community engagement in designing these services through public education and events that emphasize the importance of sustainably recycling these materials. The student research and recommendations provide the City of Peoria with baseline information to further investigate waste management practices for Peoria's more challenging materials.

KEY STUDENT RECOMMENDATIONS

Recommendations for e-waste recycling	Read more
Partner with electronic recyclers that are certified by an accredited, independent third-party auditor to assure they safely recycle and manage electronics. Consider partnerships with recyclers R2 or e-Stewards.	pp.33-37, 39
Develop education efforts to communicate the importance of disposing of e-waste properly.	p.39
Host additional e-waste drop-off events at monthly or quarterly intervals.	p.39
Consider partnerships with local vendors, such as Westech, ACE Recycling, Veolia, and R3eWaste.	pp.33-37, 39
Investigate the feasibility of adopting an e-waste curbside pick-up program for Peoria residents.	pp.23, 32-33, 39
Explore additional e-waste recycling tactics employed by other municipalities, such as the solid waste management team in McKinney, Texas. The municipality has developed its e-waste program through resident surveys to cater the program to residents' needs.	pp.32-33, 39

KEY STUDENT RECOMMENDATIONS

Recommendations for biomass gasification	Read more
Develop education-focused communication strategies for Peoria residents that emphasize the benefits of biomass gasification, such as the potential for reduced energy bills.	pp.77-78
Engage the public through events, such as a "Recycling Day," to encourage participation in sorting food waste.	pp.77-78
Partner with Peoria's "Sustainable U" composting class to conduct compost demonstrations at Peoria events.	pp.77-78
Consider partnerships with municipal entities, such as the City of Glendale and the City of Phoenix, to develop a curbside pickup program for food waste.	p.78
Develop partnerships with private companies like Avolta or Sierra Energy to dispose of Peoria's biomass waste.	pp.61, 78
Create a sorting system that presorts waste before it is used for alternative fuel technology.	pp.60, 78
Investigate the feasibility of constructing a dry anaerobic digester, on-site or in partnership with another entity.	pp.59-61, 78
Investigate the feasibility of on-site construction of a fixed-bed gasifier or in collaboration with another entity (recommended syngas technology.	pp.71-73, 78

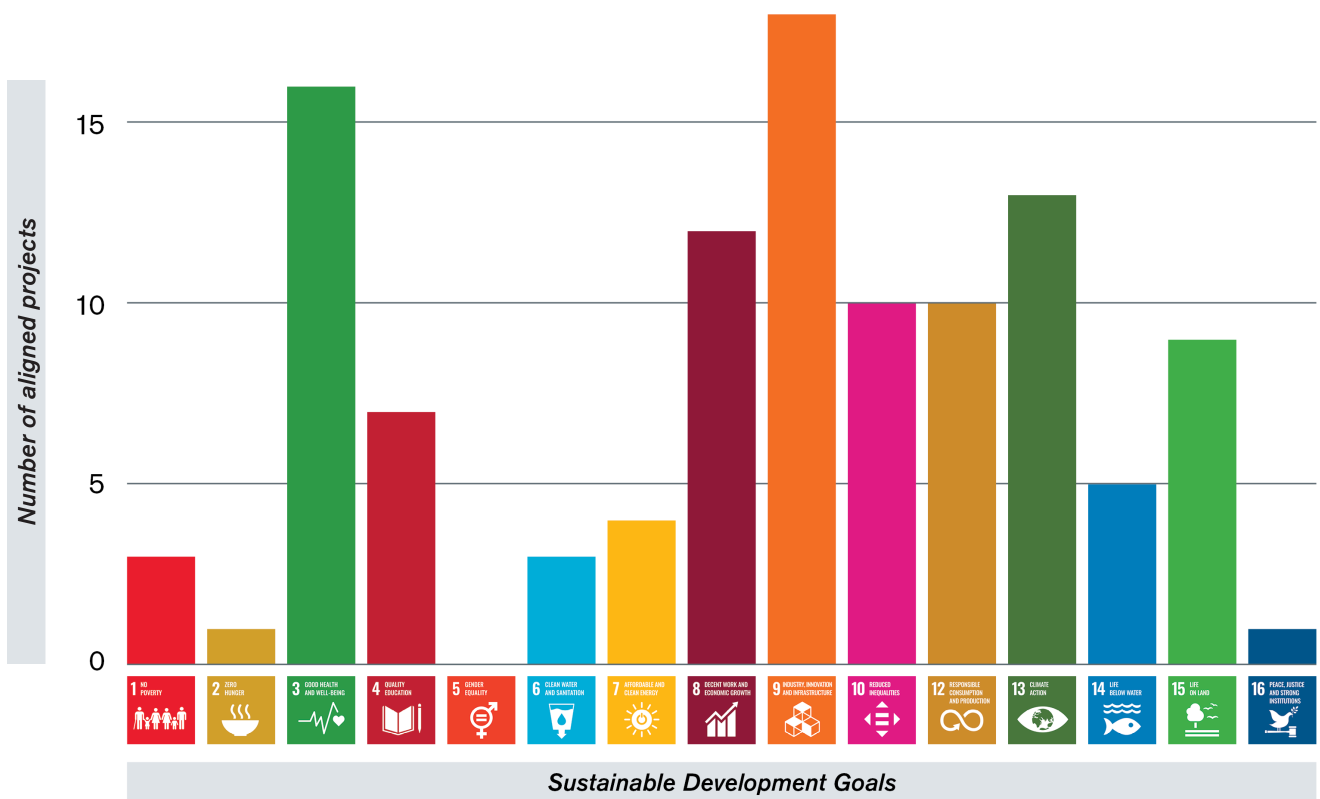
CITY OF PEORIA PROJECTS: ALIGNMENT WITH THE UNITED NATIONS'

SUSTAINABLE DEVELOPMENT GOALS

As the leading international framework for sustainable decision-making, the 17 Sustainable Development Goals (SDGs) lay out a path for partnerships toward global peace and prosperity. The SDGs provide a set of goals and metrics for project impact to be measured, offering an illustration of the benefits experienced by the cities, towns, and students who participate in a Project Cities partnership. For details on the SDGs, visit **sdgs.un.org/goals.**

Every project in the PC program aligns with SDGs 11 and 17.

The figure below illustrates SDG project alignment throughout the City of Peoria's partnership with Project Cities, through the Fall 2021 semester.



TOP THREE GOALS ADDRESSED IN THE FOLLOWING REPORT

This project provides base knowledge on recycling e-waste and biomass gasification, with the intent to inform City of Peoria leadership of potential new waste management practices. The student work aims to help Peoria continue growing as a regional leader in sustainability by examining cutting edge recycling and energy technologies.

Goal 12: Responsible Consumption and Production

"Ensure sustainable consumption and production patterns."

Recycling challenging materials and exploring alternative energy processes like biomass gasification can help further develop Peoria's already strong commitment to sustainability.

Goal 13: Climate Action

"Take urgent action to combat climate change and its impacts."

Recycling more waste categories and reducing reliance on landfills can help reduce demand for specific materials, and curb greenhouse gas emissions, resulting in a smaller municipal carbon footprint.

Goal 15: Life on Land

"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss."

The methods outlined in this project can reduce dependence on landfills, preserving habitats and open space.

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PART 2:

Municipal E-Waste Recycling Program Strategies

RECOMMENDATIONS FOR THE CITY OF PEORIA TO HANDLE CHALLENGING E-WASTE MATERIALS

ERM 432/532:
SUSTAINABLE SOLID WASTE MANAGEMENT

THE POLYTECHNIC SCHOOL

FACULTY
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ACKNOWLEDGMENTS

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INTRODUCTION

The City of Peoria is working towards a goal of offering e-waste recycling services to its residents and commercial customers. As a result, they are looking to form new partnerships with vendors or contractors willing to pick up and recycle e-waste. The rate of electronic waste recycling is expected to substantially increase over the next 50 years and demand for e-waste recycling options is increasing globally. Included within this report is a literature review that provides background information on the hazards of e-waste, a breakdown of best management practices, and applicable case studies. Students contacted potential vendors and regulatory agencies to find examples of available resources, and to provide potential vendor options to the City of Peoria. Some of these vendors may have the capacity to set up a new residential e-waste curbside pickup program, which is desired by the City of Peoria. The vendors included have provided feedback on their services and were vetted for their environmentally friendly and ethical recycling options. Students provided a qualitative analysis of each vendor that was contacted. This will provide the City of Peoria background information for services available should Peoria decide to pursue formal vendor proposals.

Figure 1 *E-waste collection site*

RESEARCH METHODS

Students assisted the City of Peoria to explore its interest in potentially adding an e-waste disposal option to the trash services already offered to residents. The City has begun offering more frequent e-waste drop-off opportunities to its residents and eventually would like to provide residents with an e-waste curbside pick-up program. Students conducted a literature review that explores the hazards associated with e-waste recycling and explores potential solutions to Peoria's e-waste collecting dilemma. As part of this exploration, students interviewed e-waste recycling vendors and investigated other resources.

FINDINGS & ANALYSIS

Background

E-waste is a term used to describe many types of electronics or electronic components that are no longer useful to consumers or businesses, meaning they have reached the end of their useful life and are ready to be discarded or abandoned (EPA, 2021a). In 2019, a global United Nations (UN) effort called Platform for Accelerating the Circular Economy (PACE), and World Economic Forum (WEF) collaborative initiative identified the various e-waste types that comprise the nearly 50 million tons of e-waste that are discarded annually around the world (Global E-Waste Monitor, 2017 as cited in WEF, 2019). Figure 2 lists common e-waste types and examples (Global E-Waste Monitor, 2017 as cited in WEF, 2019).

Common e-waste types and examples	
E-waste	***Examples***
Temperature exchange equipment	▪ Small air conditioning units ▪ Thermostats ▪ Household heating equipment & fans ▪ Hot plates, calorimeters, and other laboratory equipment
Screen-based tech	▪ TVs: Smart and Cathode-Ray Tube Based Screens (CRTs) ▪ Computer screens, laptops & tablets ▪ iPods and other small handheld screen-based technologies
Small IT	▪ Smartphones & cell phones ▪ Printers & scanners ▪ Keyboards & mice ▪ Circuit boards, cables, & Bluetooth based tech ▪ VCRs & DVD players
Large equipment (also known as White Goods)	▪ Microwaves, stoves & dishwashers ▪ Washing machines & dryers ▪ Refrigerators
Small equipment	▪ Lamps ▪ Electric water kettles ▪ Toasters & coffee makers ▪ Irons

Figure 2 *Common e-waste types according to the UN, PACE, and World Economic Forum*

E-waste is traditionally characterized by the materials they contain. If a device has a microchip, battery, or contains a circuit board it can be defined as e-waste. Items contained in Figure 2 are classified in this manner. Figure 3 demonstrates the various types of e-waste that are becoming increasingly problematic.

Figure 3 *E-waste dumping site in Birmingham, Alabama, via Wikimedia Commons*

E-waste toxicity and threats

Currently, e-waste is generated at accelerating rates. The UN & WEF anticipate that nearly 120 million tons per year of e-waste will be generated by 2050 (WEF, 2019). Only 20% of e-waste is estimated to be formally recycled and the other 80% is thrown into household waste, meaning it is “dumped, traded or recycled under inferior conditions” (WEF, 2019). In 2016, the US “generated an estimated 6.9 million tons of e-waste” or 42 pounds per person, most of which goes into the trash (Larmer, 2018). Discarded e-waste is estimated to represent 2% of all volume in US landfills (WEF, 2019). In addition, 66% of heavy metals contained in landfills originated from e-waste (WEF, 2019). The volume of e-waste generated is problematic, however, the greatest challenge affiliated with e-waste is its toxicity. E-waste contains many toxic chemicals. The list below is an example of some of the most prevalent toxins found in e-waste:

- Heavy Metals: Lead, Cadmium, Mercury, Beryllium, Lithium
- Epoxy, Plastics, & Chlorinated Dioxins
- Polychlorinated Biphenyls (PCBs)

- Brominated Flame Retardants (BFR) & Acrylonitrile Butadiene Styrene (ABS)
- Hydrochlorofluorocarbons (HCFs)
- Other Persistent Organic Pollutants (POPs) such as Per and Polyfluoroalkyl Substances (PFAS)

Toxic effects from these chemicals have been observed in populations in areas surrounding some of the largest e-waste landfills in the world. Globally, e-waste is commonly sent to China, Africa, Pakistan, Brazil, and Mexico (Figure 4). These countries lack solid waste management programs or hazardous waste infrastructure to dispose of e-waste properly. Consequently, much of the waste is burned in unregulated open pits and sits on land with no protective liners. Chemicals are leached and runoff into the surrounding waterways, groundwater, and soil causing bioaccumulation in drinking water, aquatic and terrestrial ecosystems, and food systems. In Accra, Ghana, home to the world's largest e-waste dumps, chickens grazing throughout the e-waste graveyard produce eggs containing enough chlorinated dioxins to "cause cancer and damage the immune system 220 times over" (Yeung, 2019). E-waste is openly burned or treated with acid to extract small amounts of precious metals to be resold, such as gold. Unregulated extraction and burning practices found commonly abroad "can lead to irreversible health effects, including cancers, miscarriages, neurological damage and diminished IQs" (EPA, 2021a). Damage to the liver, heart, nervous, and reproductive systems as well as other chronic and nefarious skin conditions have been documented at the Agbogbloshie e-waste dump in Accra (Yeung, 2019).

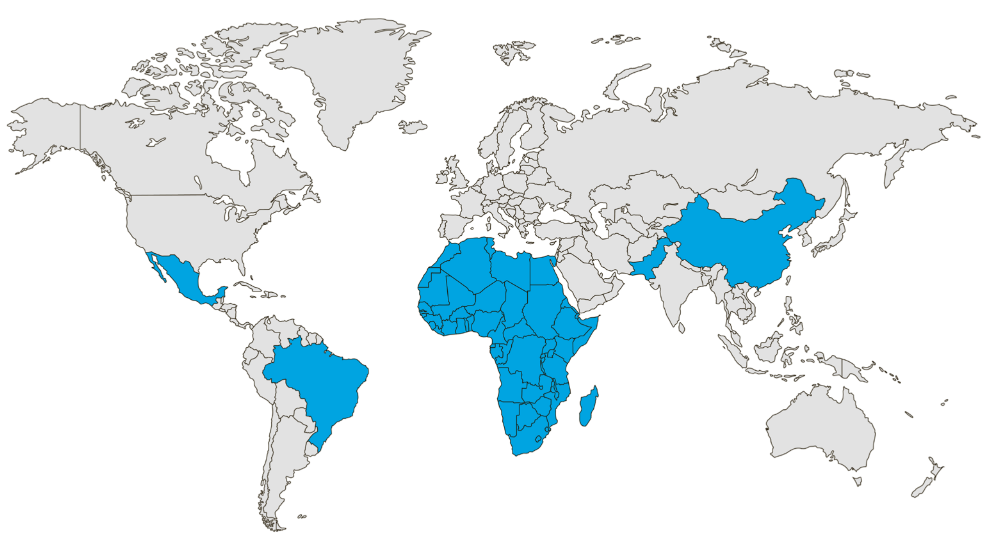

Figure 4 *Common countries that receive e-waste*

Figure 5 *Open e-waste burning leaving behind precious hard metals to be resold, in Accra, Ghana, at the Agbogbloshie dump, by BRS MEAS via Flickr*

Figure 6 *Informal physical extraction of precious metals, in Accra, Ghana, at the Agbogbloshie dump, by BRS MEAS via Flickr*

The United States is not removed from experiencing toxic effects from chemicals found in e-waste. Although electronic waste may "only account for 2% of the waste found in US landfills, it represents 70% of the overall toxic waste" found in landfills (ERI, 2017). Over time, e-waste chemicals and heavy metal leachate can percolate through liners and contaminate groundwater. **Lithium-ion batteries** pose significant dangers when not stored or handled properly. If mismanaged, these batteries are a potential fire hazard since they can combust or even explode when they encounter oxygen if the outer membrane is ruptured or damaged.

Editor's Note

Capstone student Justin Zysk researched safe battery storage in residential areas for his Fall 2021 Project Cities report. The final report and additional content is available at **links.asu.edu/PCPeoriaSafeBatteryStorage21F**

Recycling efforts

E-waste recycling efforts in the United States differ from those in Ghana. Additional protective equipment and safety measures are required, but these advanced recycling efforts are not without risk. The National Institute of Occupational Safety and Health (NIOSH) released a report in 2014 called the *Evaluation of Occupational Exposures at an Electronic Scrap Recycling Facility* that documented the dangers of professionally handling and recycling e-waste. The study found that workers at e-waste recycling facilities had abnormally high blood lead levels from overexposure to lead. Traces of lead were found in the air and on their clothing or skin. NIOSH suggested the findings demonstrate need for more strict regulation surrounding e-waste treatment, storage, disposal, and recycling to cope with the growing and unsafe issue (Electronics TakeBack Coalition, n.d.).

Many recycling centers focus on extracting valuable metals, batteries, and ink toners because these items have a market incentive for reuse. The leftover materials contain no resale value, so companies will send the remaining material through a shredder or ship it overseas (ERI, 2017). Electronic recycling facilities are expensive to operate, and shipping is less expensive in many cases. According to the Texas Commission on Environmental Quality, recycling facilities are costly because recycling facilities must adhere to strict federal and state laws. Any e-waste that is determined to be hazardous will be "subject to certain handling, recycling, and disposal requirements" (Texas Commission on Environmental Quality, 2021). Treatment and extraction costs mean that many organizations send the remaining e-waste overseas.

Many US-based companies ship e-waste overseas because the US has not ratified the Basel Convention. Companies have been caught shipping e-waste abroad under an alias to protect companies' reputations. Over the past ten years, e-waste from the US has been legally and illegally shipped from the country labeled as raw plastic, or as Bhutta et al. (2011) point out: "second-hand," reusable goods (Campbell, 2016).

The Basel Convention

The Basel Convention on Transboundary Movements of Hazardous Waste and their Disposal was passed in 1989 by the United Nations Environment Program (UNEP). This international law aimed to track the movement of hazardous waste around the globe to see where hazardous wastes are disposed of and to weaken developed nations' ability to ship their waste to developing nations. These goals suggest the Basel Convention hopes to create a sustainable hazardous waste management system that is regularly monitored and evaluated. More specifically, it aims to avoid public health crises that have arisen from improper disposal systems. Many countries receiving e-waste do not have adequate recycling facilities and solid waste management systems, which is why e-waste pollution deteriorates public health.

The US originally signed the Basel Convention in 1990 but has not formally ratified the treaty because ratifying it would indicate a commerce conflict. Not ratifying the Basel Convention has allowed the US to circumvent the Basel Convention's hazardous waste shipping restrictions. The Basel Convention attempted to stifle this loophole by stipulating that any non-Basel affiliated country cannot trade hazardous wastes with a country that has ratified Basel. However, the Basel Convention failed to address the countries that are members of the Organization for Economic Co-operation and Development (OECD) are allowed to trade or export/import goods with other countries that are also OECD party members (US Department of State, 2021). The US is an OECD member, meaning they can then ship e-waste to countries that are also OECD members if the trade agreement is consensual.

The current state of Peoria & e-waste

The lack of federal legislation in the US regarding e-waste management means businesses and municipalities are left to create their own disposal guidelines, structure, and practices. Despite the lack of an e-waste policy, the public has become increasingly aware of the pollution and dangers affiliated with e-waste at home and worldwide. This awareness means people want to dispose of their e-waste in an environmentally friendly and ethical way. The City of Peoria wants to provide its 191,000 residents with e-waste recycling services to divert the traditionally landfill-bound waste and meet the growing need to recycle e-waste safely.

As previously highlighted, e-waste disposal trends will continue to increase for the foreseeable future. New technology is notoriously making old tech obsolete, driving unsustainable consumption trends. The disposal of e-waste is not just an international problem, but it is a regional and local issue. The City of Peoria has witnessed an increase in the need for e-waste recycling options, which is why the City wants to find an e-waste recycling vendor to partner with for the foreseeable future. Peoria's Solid Waste Division handles all "residential and commercial waste collection…[including] trash, recycling, bulk trash, and household hazardous waste collection" (City of Peoria, n.d.). The facility itself does not have the infrastructure to recycle, store, or handle e-waste, nor are they looking to build out this infrastructure further because of the small size of the facility.

Coping with e-waste effectively means Peoria needs to work with certified e-waste recyclers to minimize the impact on the environment. None of the vendors contacted by the students, nor the research conducted by the students, were able to guarantee or fully certify that all aspects or elements of the e-waste were properly being disposed of in a way that is ethical and environmentally sustainable. Verified recyclers play an important role in recycling what they can, but this does not mean that e-waste recycling is the solution to fully addressing e-waste. Verified recycling will be discussed further below.

Recycling certification

E-waste recycling and disposal face many challenges; most e-waste is non-biodegradable and hazardous. Few incentives, subsidies, or laws exist to encourage sustainable practices, management, and disposal of e-waste in the United States. Recycling and reuse operations are common all over the country, however, large amounts of non-recyclable e-waste are sent overseas for disposal. Since the public has become more aware of the impacts of e-waste impacts, a new global outcry has emerged demanding sustainable and ethical e-waste recycling options.

J.B. Shaw, the Recycling Coordinator at the Arizona Department of Environmental Quality (ADEQ), advised that e-waste disposal should go to R2 or e-Steward certified recyclers (J. Shaw, personal communication, November 4, 2021). According to the e-Stewards Standard website, the e-Stewards Standard is the highest standard for globally responsible electronics recycling and reuse, because it prohibits the export of hazardous electronic waste from developed to developing countries while allowing viable technology to be reused. Furthermore, it includes the ISO 14001 standard and is a “one-stop-shop” for responsible used electronics management (e-Stewards, 2021). The e-Stewards Standard was published in 2009, created by the Basel Action Network, a contributor to important work of the Basel Convention. This certification provides assurance that e-waste going to an e-Steward certified recycler is not shipped overseas to developing countries and ensures toxic e-waste is not disposed of in municipal landfills. The student group was unable to find additional information regarding the disposal practices e-Steward certified recyclers use, nor was the team able to determine where waste from the recyclers ultimately ends up.

R2 certification is “referred to as [a] responsible recycling certification,” which was developed by the US EPA (Thomas Publishing Company, 2021). Acquiring R2 certification means recyclers must demonstrate a plan or protocol documenting how used electronics will be reused, recovered, or disposed of (Thomas Publishing Company, 2021). R2 certification is acquired through extensive audits conducted by an accredited institution called the ANSI-ASQ National Accreditation Board (ANAB). The team also had difficulties determining what standards and indicators R2 auditors use to certify recyclers. Moreover, there was no data regarding where e-waste from R2 certified recyclers ends up. As a result, entities such as the City of Peoria should conduct research into the vendors they want to work with to determine the types of certifications the vendors offer and whether or not they are environmentally friendly as they advertise.

By researching the R2 or e-Steward certifications, the City of Peoria can better inform its residents about the final disposition of their e-waste. Recycling e-waste with environmentally certified vendors does not solve the e-waste crisis. Instead, recycling with a certified vendor helps reduce the impact of e-waste disposal.

1. The R2 Technical Advisory Committee (TAC) discusses, identifies, and proposes revisions to the R2 Standard.
2. The Consensus Body (a subset of the TAC) aggregates and organizes those proposed revisions into a new version of the Standard.
3. The Consensus Body then distributes those proposals for public comment.
4. After the public comment period has ended, the TAC and Consensus Body respond to comments, and amend the proposed revisions. If changes are made, the public comment process is repeated.
5. When all public comments have concluded, the Consensus Body votes to submit the proposed version to the SERI Board. A Consensus Body vote can be appealed on procedural grounds by an interested party.
6. If the proposed version is approved by the SERI Board, it is submitted to ANSI for approval as an American National Standard.
7. The Standard Management Team (SERI staff) administers this process and ensures ANSI's process is followed.

Figure 7 *R2 development process as outlined by Sustainable Electronics at* **https://sustainableelectronics.org/r2/r2-standard-development/**

Case Study: McKinney, Texas, Solid Waste Services

Editor's Note
More information on the City of McKinney's e-waste collection is available at **www.mckinneytexas.org/792/Recycling#Ewaste**

The City of McKinney, Texas, is similar in size to the City of Peoria. McKinney has a population of 182,055 people and has a combined household median income of $93,354, which is slightly higher than the City of Peoria (DataUSA, 2019). The high demand for recycling e-waste services has led McKinney residential trash services to pioneer its own **e-waste collection system.** McKinney now offers e-waste pick-up services 12 times a year and the frequency of this pick-up schedule was determined based on the results of surveying surrounding residential areas. This is a strategy that the City of Peoria should investigate in the foreseeable future if they do end up looking to create a curbside e-waste pick-up program.

In McKinney, residents must fill out online forms to schedule a collection. The online form must be completed by 12:00 pm the day before the desired e-waste pick-up date. Once the form has been filled out, the residents are required to place their e-waste outside by 7:00 am on their scheduled pick-up dates. Smaller electronic waste and batteries must be packed in cardboard boxes and labeled with their contents.

This allows city workers to properly handle the waste during pick up. McKinney has strict restrictions in place regarding the amount of e-waste they are willing to pick up. E-waste will not be picked up if the box containing the e-waste weighs more than 50 pounds or if there are more than two boxes “larger than 20 inches long by 20 inches wide by 20 inches high per pick-up” (McKinney Texas Solid Waste Services, n.d.) Additionally, only one television or monitor is allowed per pick-up. Any excessive quantities of e-waste will not be collected and left on the curb. It is recommended that the City of Peoria contact the City of McKinney to discuss logistics and learn how to potentially implement a future e-waste curbside pickup program.

Potential partners

In October, the City of Peoria communicated to the ASU students that they were interested in finding a vendor that would be willing to take e-waste. Using this information, the students then reached out to Westech Recycling, VEOLIA Environment, ACE Recycling, and R3E Waste (R2). Additional vendors and stakeholders were contacted for more information about e-waste collection and services, but students did not receive many responses. The responses students did receive are not completely representative of the full range of services offered and the associated costs. However, the information will give Peoria an idea as to how to proceed with an e-waste program. Though the City of Peoria is already working with Westech recycling for their e-waste drop-off events, but the information provided will give the City more e-waste recycling contractors they could potentially work with in the future.

Arizona Complete Electronics (ACE) Recycling

Arizona Complete Electronics (ACE) Recycling was originally founded in 2012 as OCM recycling before being rebranded in 2019. ACE Recycling does not charge for e-waste pick-up, assessment management (inventorying), or data destruction; the company views the work as an essential service needed by communities. ACE recycling takes all e-waste that plugs in such as laptops, PCs, servers, small household appliances, retail equipment, phones, and tablets. The only cost for recycling occurs if the e-waste is a television or a Cathode-Ray Tube (CRT) monitor. The current cost for flat-screen TVs is $5/each, projection TVs $20/each, and CRT TVs & monitors $25/each. E-waste collection occurs twice a week, typically Wednesday and Thursday. Residents can drop off e-waste at the facility on weekdays from 8:00am-4:00pm at no cost for most items.

ACE Recycling has partnered with organizations to coordinate collection events, which includes providing tri-wall boxes and pallets for collection. E-waste collected is either re-sold, scrapped, or refurbished to be re-sold either through the company store or website. E-waste that is recycled is sent either to one of four CRT recyclers in North America or a metal scrap and reuse facility. ACE recycling has established contracts to reimburse a percentage of e-waste that is collected at some facilities from scrap and resale of material, so they are an ideal partnership candidate.

Westech

Westech Recyclers are an R2 certified recycling facility located in Phoenix, AZ. According to their website, Westech is also ISO 14001 and ISO 45001 certified and their program has been evaluated by a certifying body.

The City of Peoria recently partnered with Westech Recyclers during a drop-off e-waste recycling event. Westech provided services for this event at no cost to residents and minimal cost to the City of Peoria. Westech only charged a labor cost for this event. Westech also offers private residents free pick-up of electronics (for 10 or more items) and free data destruction. Westech charges a fee of $35 for the disposal of CRTs. Otherwise, their services are free to residents (Westech, 2021).

Once e-waste is received by Westech, the vendor separates out reusable electronics for testing. If they can be reused, the items will be refurbished and offered for sale. Otherwise, the products are dismantled and stripped of any usable parts or components for recycling and placed back into the supply chain through downstream vendors. Donations are accepted at Westech's facility Monday - Thursday from 7:30 am-3:00 pm, and Friday from 7:30 am - 2:00 pm. Residents also have the option to schedule a pick-up directly from the vendor's website.

R3E Waste

R3eWaste Electronics Recycling & Computer Recycling Company is an R2 (Responsible Recycling) certified e-waste recycler that has been certified since 2013. The company collects e-waste for no additional charge if the pick-up location is less than 10 miles from their facility location. If a pick-up location is more than 10 miles away from the company offices, a pick-up fee of $25 will incur. The company and its staff are R2 trained, fully insured, and provide pallet and wrapping services, as needed (Wilhelm, 2021).

Sensitive components found in data centers are carefully disassembled to ensure the total security of the data. All is packed, secured, and delivered directly to their facility. R3eWaste accepts all standard electronic components. Examples include servers and data centers, computers, monitors, printers, cell phones, batteries, cameras, audio equipment, UPS devices, credit card devices, and much more (Wilhelm, 2021). Examples of fees associated with electronic components can be found in Figure 8.

R3E waste example pricing		
Item	***Data destruction services***	***Charge***
1	Hard drive (each)	$7
2	Printer (small)	$5
3	Printer (large)	$60
4	Audio equipment	$5 (one-time fee)

Figure 8 *R3E waste example pricing*

Modern printers undergo destruction because of how multi-functional they are. For example, printers often also have scanning capability, and scanning requires these devices to retain sensitive information for it to be delivered electronically. R3eWaste specifically indicated to the student team they destroy all printers that come into their possession.

As an R2 certified company, R3eWaste tenants are to reuse, recycle, and only dispose of in a landfill as a last resort. R3eWaste also accepts drop-off e-waste material from Monday through Thursday 8:00 am - 3:30 pm and Friday from 8:00 am- 2:30 pm.

Materials collected from businesses go through two processes:

1. **Test, certify, and resale:** if items are ultimately not sold, they are dismantled for the commodity components.
2. **Recycle into commodities:** R3eWaste partners with downstream recyclers that are also R2 certified. R2 certified companies are audited yearly to ensure they are sending materials to be recycled at facilities that also follow the international standards of responsible recycling.

VEOLIA North America

VEOLIA North America is an R2 certified e-waste recycler that primarily provides pick-up and e-waste collection services. The cost for recycling waste is charged per pound, which does not include separate transportation and labor costs. CRT e-waste is $0.50/lb and all other e-waste is $0.36/lb. Veolia charges additional fees for items such as lamps and batteries. A more comprehensive breakdown of VEOLIA's e-waste pricing is available in the appendix of the original student content, at **links.asu.edu/PCPeoriaWasteManagement21F**.

VEOLIA provides many environmental solutions and services from onsite pick-up to final treatment or disposal. Veolia's flexibility allows for a wider variety of recycling solutions because it offers its customers cost-effective solutions for large and small quantities of lighting and electronic waste. VEOLIA's bulk recycling programs are designed for larger quantities of waste such as pallets or truckloads that can be picked up from businesses on a regular or scheduled basis. Some of the items that VEOLIA specializes in recycling are lamps, mercury waste, ballast, e-waste, electrical equipment, and batteries. Examples of pricing include U-Tube Lamps - $0.49 per lamp, neon Lamps $5.50 per lamp, and lithium-ion batteries $0.40 per lb. (Veolia, 2021).

VEOLIA also has systems in place, which assure safe and compliant handling of PCB, hazardous, universal, and non-hazardous waste during all company operations. These activities include the implementation of waste analysis and materials testing plans, waste disposal plans, personnel training plans, inspection plans, occupational health and safety plans, emergency/contingency plans, SPCC plans, and closure plans.

Economic benefits

Although there are significant health risks that accompany e-waste recycling, there are some economic benefits ascertained from e-waste recycling. Presently, consumer electronics hold the highest compound annual growth rate (CAGR), or rate of return. In other words, cellular phones, computers, and laptops have the highest resale value. This is partly due to the large percentage of recycling of these electronics. Batteries are also highly valued because of the global surge in electric car production, and the demand for recycled batteries and their components is projected to grow. In 2020, the global market for lithium-ion batteries was estimated to be $161.4 million (LTD, 2021).

Due to this demand and a limited supply of mined lithium, manufacturers are turning to recycled sources of lithium and other heavy metals used in battery production. Lithium alone is expected to have a CAGR growth rate of 19.9% between 2020-2030, equivalent to $991.5 million (LTD, 2021). Therefore, it is prudent to focus on battery recycling, especially lithium-ion, lithium-cadmium, or nickel-cadmium batteries.

Many of the chemical elements that are found in e-waste are rare and valuable, like gold, platinum, and copper. These materials are great conductors for electronic functionality and can be recycled and reused. From an economic perspective, disposing of these components to landfills is a lost revenue stream. According to a study conducted by the American Chemical Society (2018), it is cheaper to obtain metals through recycling than mining. The economics of e-waste recycling plays an important role in what services e-waste recycling offers and what they are willing to take, which the City needs to keep in mind when partnering with an e-waste recycler.

Transport and storage

Currently, the City of Peoria does not have a consistent method for collecting electronic waste on a regular basis; Peoria occasionally holds scheduled e-waste drop-off events for residents. E-waste is not accepted outside of these drop-off events by the City, meaning the public is referred to popular retail outlets, such as Best Buy, to drop off their discarded electronics. Peoria recently partnered with Westech Recyclers in Phoenix at their most recent e-waste drop-off event on November 6, 2021. The program was a huge success, yielding over 16,645 lbs. of electronics, including 35 CRTs. The success of the program indicates that collaborating with a recycling contractor regularly to host quarterly or monthly events will provide an outlet for residents to properly recycle their e-waste. Although the City of Peoria does not want to handle or store e-waste directly, it is important to note how residents and contractors will be handling and packaging this waste.

There are two approaches to consider when packaging e-waste:

1. Residents packaging e-waste for transport to a municipal facility
2. Municipal facility packaging for final disposition

Residents can utilize cardboard boxes to package small electronic devices. Batteries (lithium-ion or alkaline) should be removed from all devices and packed separately. Larger and breakable items, like computer screens or televisions, should be packaged in a box with paddings - such as foam or paper. Larger items that do not fit in boxes, like microwaves, large televisions, or appliances should be kept separate from other items. Battery terminals should be taped to avoid creating a short circuit to the battery.

Once a contracted vendor has collected the e-waste and reached the municipal reception facility, the e-waste will often be sorted and palletized. If enough of the same type of e-waste items are received, similar items will be packaged on pallets together. For example, computer screens should be placed on one pallet together, using a face-down, face-up alternating approach, which is evident in Figure 9.

Figure 9 *E-waste dropoff event where electronics are being packed for removal*

Computer towers are packed by placing computers flat at each corner of the pallet. The available space in the middle can hold horizontally-placed towers. This packing approach creates stability and more efficient use of space. Once items on the pallet reach approximately waist-high, stretch wrap is used to secure the load to the pallet by wrapping the plastic wrap around several times. Corrugated cardboard boxes, known as tri-wall or gaylord boxes, are also common receptacles used to transport e-waste. Transportation and storage of e-waste are logistics the City will need to discuss with a future vendor offering e-waste recycling services.

Recommendations

- Partner with electronic recyclers that are certified by an accredited, independent third-party auditor, that assures they meet specific standards to safely recycle and manage electronics. R2 and e-Stewards certified recyclers minimize the impact of discarded electronic waste because both certifications utilize best management practices and offer a way to assess the environmental, worker health, and security practices of entities managing used electronics. The ASU student group recommends verifying that vendors hold these certifications, and how these certification programs define safe e-waste disposal.

- Increase local educational efforts as to why e-waste should not be discarded in municipally bound waste and how to recycle e-waste more safely. See Figure 10 on the following page for a sample educational flyer produced by one of the group members as an example of what Peoria could create and disseminate.

- Provide residents additional opportunities to dispose of e-waste by increasing the number of e-waste drop-off events offered by the City of Peoria. Events are recommended at monthly or quarterly intervals.

- Explore the services of local vendors such as Westech, ACE Recycling, Veolia, and R3eWaste. This report gives Peoria a better idea as to the types of services that e-waste recycling vendors may offer.

- The student group recommends working with the solid waste management team in McKinney, TX. Their team can be contacted at 972-547-7385. This municipality has pioneered its own curbside e-waste program and has the knowledge and experience to better guide Peoria to develop a curbside program. From the case study research conducted by the student group, one of the most important elements on how McKinney developed an e-waste curbside pick-up program was through resident surveys. Surveying their residents allowed them to develop a program that provided the best fit for residential needs, allowing for more efficient planning, budgeting, and logistics. Subsequently, the student group recommends that Peoria conduct a similar survey before implementing any type of e-waste curbside pick-up program.

- Contact **other municipalities** offering e-waste pick-up through their household hazardous waste curbside collection programs. The City of Phoenix offers a similar service to residents. Consider contacting their team to work with them further.

Editor's Note
The City of Tempe also offers hazardous waste drop-off. More information on the service can be found at **www.tempe.gov/government/municipal-utilities/household-products-collection-center**

Figure 10 *Sample pamphlet designed by students as a media example for Peoria to consider distributing*

CONCLUSION

Given the toxic properties of discarded electronics in landfills, Peoria wants to provide viable reuse and recycling options to residents. Without recycling options, residents are forced to find e-waste recyclers on their own, use a retail store disposal site, or send their electronics to landfills. Peoria can reduce the amount of e-waste going into landfills by providing residents with alternative options for disposal and education. Educational programs can include publishing informational flyers and pamphlets to help inform residents of proper disposal procedures. Educating residents on e-waste can lead to increased resident participation in e-waste drop-off events and help gain public interest in a potential curbside e-waste pick-up program.

The ASU student group has suggested several potential vendors to Peoria for both e-waste drop-off events and a potential e-waste curbside pick-up program. Many of the local vendors the City has the opportunity to work with are R2 and e-Steward Standard certified. This certification ensures that e-waste is recycled and disposed of in a way that minimally impacts people and the environment. There is no perfect solution for dealing with e-waste, however, giving it to a responsible recycling vendor can reduce the probability of e-waste being shipped overseas to deteriorate public and environmental health.

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links.asu.edu/PCPeoriaWasteManagement21F

PART 3:

Biomass Gasification: Generating Energy Through Solid Waste

INNOVATIVE TECHNOLOGIES TO REDUCE LANDFILL DEPENDENCE IN THE CITY OF PEORIA

ERM 432/532:
SUSTAINABLE SOLID WASTE MANAGEMENT

THE POLYTECHNIC SCHOOL

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INTRODUCTION

Solid waste management is a pertinent discipline associated with collecting, storing, transporting, and processing solid waste within a city. Best management practices are utilized to ensure that economics, public health, and environmental factors are being considered during solid waste management. It must be considered that as cities grow, the solid waste produced within them will grow as well, and landfilling is not a long-term solution. The process of collecting solid waste for the purpose of generating renewable natural gas through alternative fuel systems is a more sustainable option for the city of Peoria since natural gas is already widely used in energy production infrastructure. There are many types of technologies that are utilized in alternative fuel systems; this research focuses on the technologies preferred by the City of Peoria staff.

Solid waste and municipal solid waste

Solid waste is an inclusive term for garbage or discarded materials; this waste can be from but is not limited to, industrial, commercial, or agricultural sources. The Resource Conservation and Recovery Act (RCRA) of 1976, states the specific criteria of solid waste and general guidelines for solid waste management, including hazardous waste. While municipal solid waste falls under solid waste, it is more specific (Gawali et al., 2020). It can be described as common everyday items, like food waste, newspapers, or yard waste, and generally comes from residential or commercial sources. Municipal solid waste (MSW) is either composted, repurposed, incinerated, or landfilled (Environmental Protection Agency, 2020b). Figure 1 details the composition of MSW (Environmental Protection Agency, 2020b). Interestingly, only 11.8 percent of total MSW was combusted for energy recovery in 2018 (Environmental Protection Agency, 2020b). Through the alternative fuel research presented below, the City of Peoria has the opportunity to contribute to energy recovery from MSW while also reducing their waste disposal in landfills. Another important category of waste to note is hazardous waste. Hazardous waste is explained in RCRA Subtitle C (RCRA, 2020) and can impose challenges for alternative fuel technologies. These risks can be properly mitigated by employing proper waste management practices, such as careful inspection, sorting, and processing.

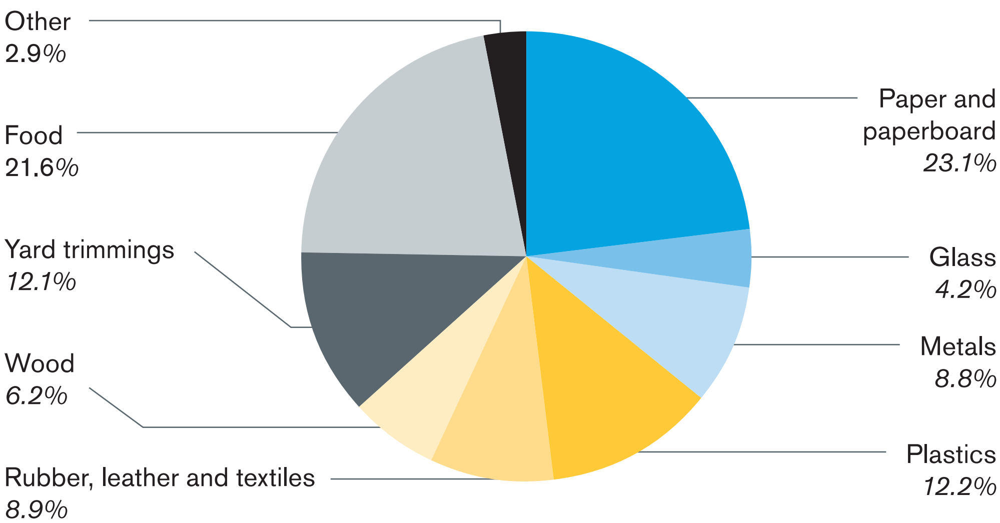

Figure 1 *Breakdown of MSW, by Environmental Protection Agency, 2020b*

Alternative fuels from organic waste

Alternative fuels are derived from sources other than petroleum. In this research, the primary focus is on biogas and syngas. These fuels are made from organic waste; in terms of MSW, this would include food waste and yard trimmings. Organic waste has a high carbon content which enables reactors or systems to produce renewable natural gas. However, different technologies may be more efficient with various feedstock combinations. An advantage is that they can potentially reduce greenhouse gas emissions. Landfills naturally produce methane and it is usually released into the atmosphere, rather than being captured. By diverting organic waste to alternative fuel technologies, the methane can be collected and utilized as an energy source; this would reduce overall greenhouse gas emissions from landfills.

Biogas

Biogas essentially means any fuel derived from the decomposition of organic matter. Its primary components are methane and carbon dioxide, with trace amounts of other gases (Tanigawa, 2017). Biogas production naturally occurs within landfills, but it can be accelerated in a controlled environment allowing the gas to be captured. Though the general process involves the decomposition of carbonaceous waste, it can be achieved through various technologies.

Syngas

Syngas is an abbreviation for synthesis gas and is a fuel mixture usually derived from the gasification of organic materials. It is predominantly made of carbon monoxide, hydrogen, and methane (Munasinghe, P. & Khanal, S., 2011). Organic waste is heated up to very high temperatures in a reactor and the resulting gas can be collected. The typical technology used for syngas production is called a gasifier. It should be noted that there are many varying factors in the technologies; different models may require a specific feedstock or have a unique design.

Regulatory requirements

Alternative fuel facilities will require varying permits depending on the site specifications. Alternative fuel production facilities have the potential to create hazardous waste, release air pollutants, and must abide by other pertinent rules and regulations. Municipal solid waste is regulated under RCRA Subtitle D and is categorized as non-hazardous solid waste. Additional regulations for general solid waste can be found in 40 CFR 239 through 259 (RCRA, 2021). It should be noted that potential byproducts should be evaluated by doing a waste determination, which would require compliance with RCRA Subtitle C. Since biogas and syngas facilities involve municipal solid waste, a solid waste permit is necessary. They must abide by federal, state, and county regulations. The Maricopa County Air Quality Department has jurisdiction over air pollution control permits in the Phoenix metropolitan area (Maricopa County, n.d.). Typically, this involves passing routine inspections, operating by their standards, and meeting construction requirements (Arizona Department of Environmental Quality, n.d.c).

Pollutant emissions permits will be required for a syngas or biogas facility because of the production and capture of natural gas. One example of a specific permit is a Class I or Class II permit. Depending on the size of the facility or the total emissions, these would be applicable for any facility emitting regulated air pollutants (Arizona Department of Environmental Quality, n.d.a). While federal requirements may be more lenient, state or county standards could be more stringent. It is important to follow the most stringent criteria for the site's location. Another example is if the facility utilizes a generator to convert natural gas into energy; it would then qualify as a power plant. According to ADEQ, a Generator's General Permit would be necessary (Arizona Department of Environmental Quality, n.d.b). These are only a few examples of possible permits that would be required; it is not all-inclusive and may be dependent on the site's operations.

With the alternative fuel industry growing, the EPA has been in the process of developing regulations on pyrolysis and gasification units (U.S. EPA, 2021). As these regulations become established, this could affect future projects and their permitting requirements as well.

Beyond permitting, there are other environmental health and safety requirements to consider when building an alternative fuel facility. For example, the National Fire Protection Association (NFPA) and the Occupational Safety and Health Administration (OSHA) have additional standards that need to be met. The generation of renewable natural gas has the risk of being flammable and explosive. NFPA has created standards for fuel storage tanks, and liquid propane (Environmental Protection Agency, 2011). While NFPA has not created standards for biogas or syngas facilities specifically, their collection of standards is applicable to specific types of equipment associated with the potential hazards of gas storage near an ignition source. The City of Peoria Fire Department should be consulted to identify pertinent fire code requirements. OSHA has rules for personal protective equipment and other precautions, specifically for toxic gas exposure. Some examples include respiratory protection, personal air monitoring devices, ventilation, confined space entry, lock-out/tag-out, and other worker safety measures within the facility (Environmental Protection Agency, 2020a).

Subject matter expert interview

The students interviewed Mr. Taimur Burki, the Global Green Building and Circular Economy Program Manager at Intel Corporation, and Mr. Joseph (J.B.) Shaw, the Recycling Coordinator at the Arizona Department of Environmental Quality. Figure 2 summarizes the interviews with Taimur Burki. Figure 3 summarizes the interview with J.B. Shaw and his opinion on public matters.

Interview with Taimur Burki from Intel Corporation		
Type of gas	***Issues***	***Benefits***
Syngas	▪ High capital costs ▪ Not as many small cell options ▪ More permitting and regulations ▪ Would likely need a Title V permit ▪ Finding areas to place these ▪ Finding willing partners	▪ Able to process more waste materials ▪ Less issues with small hazardous waste in the system because of the high temperatures relevant to the materials flash points
Biogas	▪ Requires diligent sorting ▪ Will only safely take food, and green waste as well as oil and grease ▪ Finding areas to place these ▪ Finding willing partners	▪ Lower capital costs ▪ Can be placed outside of schools, groceries, and restaurants to collect food waste ▪ Can generate liquid fertilizers that will benefit Arizona soil

Figure 2 *Advantages and disadvantages of alternative fuel technologies from subject matter expert interview with Taimur Burki on November 15, 2021*

Interview with J.B. Shaw from ADEQ	
Why haven't more cities implemented these systems?	The scale is the main struggle for cities that have looked into it and determine what size system is needed for matching what goes into it. Wastewater treatment plants have utilized it because they have designated feed and know the size of the facility needed.
How are they more beneficial than landfills?	In Arizona the climate makes it so that not enough methane is produced in a landfill to make it worth the cost of implementing methane capturing systems. With a biogas system, the process can be sped up and the methane can be used in an economically useful way.
What are ways to mitigate public concern?	Educating the public about the benefits of these systems will help the most such as capturing and turning methane into energy that can help power city buildings and homes rather than allowing it to pollute the environment.
As this technology progresses, how can we motivate the public to do their part in separation?	By first allowing those who are willing to do their parts such as implementing a drop off the program or a curbside pickup of the materials that will go into the system we can prevent the contamination that might come from public separation bins. Until technology allows for us to inspect bins regularly we will need to depend on the willing public.

Figure 3 *Summary of interview focused on public perspective and concerns from subject matter expert interview with J.B. Shaw on November 17, 2021*

RESEARCH METHODS

In this report, students investigate alternative fuel technologies in order to help the City of Peoria reduce their dependency on other cities' landfills. The students worked on several key objectives:

- Research alternative fuel mechanisms and technologies.
- Determine which technologies are most feasible for Peoria, while also taking into consideration environmental impacts.
- Evaluate the necessary financial investment required for building, operating, and maintaining the technology.
- Examine partnerships and local examples of technology being used.

FINDINGS & ANALYSIS

Literature review

Countries across the world are searching for more effective waste disposal methods. Landfilling and incineration are the bare minimum; there needs to be a better solution. Recently, alternative fuel technologies, like biogas and syngas, have become increasingly popular, but unfortunately, are still limited in use. Various companies, like Earthlee, are working towards making these systems more accessible.

Earthlee is a waste management service based in Kew East, Australia. They have designed a modular digester that is compact, mobile, and can process smaller feedstock volumes efficiently. The company has conducted five case studies that analyze various modular digesters and how they have been used to create methane fuel in cities (Earthlee, 2018). One specific example is Earthlee's partnership with Howard Tenens, a company located in Andover, England. They used a modular digester to process food waste at a small scale; this case study is similar to the recommendations presented in this report for the City of Peoria. Figure 4 provides additional information on various sizes of systems, tonnage, and other general information (Earthlee, n.d.). The system includes a gas mixing pod, biogas storage bladder, control panel, digestate storage, and a combined heat and power system (CHP). This specific system uses a wet anaerobic digestion process and is connected to a hot water boiler (Earthlee, n.d.). The water is used to liquefy the food waste and accelerate biogas production.

Modular digester comparison				
Feedstock	***System***	***Amount fed into digester per year***	***Biogas per year***	***CHP rating***
Food waste	1x20 ft.	183 tonnes	32,940 m^3	6kWe + 8kWth
	1x40 ft.	441 tonnes	79,380 m^3	15kWe + 21kWth
	2x40 ft.	882 tonnes	158,602 m^3	30kWe + 40kWth

Figure 4 *Comparison of different sized modular systems with food waste inputs, the amount of biogas produced, and CHP ratings, by Earthlee, n.d., available at* **https://www.earthlee.com/modular-digester**

This case study evaluated the specifications of the system. The digester is virtually automatic; the only manual operation required is placing the feed, or food waste, into the hopper. Once in the hopper, the food waste is automatically fed into the system. Then, based on the waste, the system calculates how much water is necessary, and injects the proper amount. Once the water and waste are added to the system, the hopper is responsible for liquefying and circulating the feed until the next batch of waste.

It was determined that after the feed was introduced into the system, it was only a matter of days until there was energy production (Earthlee, 2018). The system takes about ½ ton of food waste per day, and from that, every ton that is put into the system produces approximately 24,000 gallons of methane. The expected payback period for this system is eight years. Further, Figure 5 shows how compact the system is, and demonstrates how it is a feasible option for Peoria (Earthlee, n.d.).

Figure 5 *Modular digester used in the case study to process food waste, by Earthlee, n.d.*

Biogas

Chemical reactions in biogas

There are three different conditions that bioreactors can work under: aerobic, hybrid (aerobic and anaerobic), and anaerobic. Chemically, bioreactors take in raw products, or waste, and create two main products: biogas and sludge. Depending on the conditions, the production of biogas can vary.

Precipitation reactions involving CH_4, CO_2, and H_2, release gas molecules and result in biogas. Biogas capitalizes on the high amount of energy contained in specific bonds and these bonds are responsible for making methane. Consequently, the overall goal of the chemical processes is to use physical force to produce as much methane as possible. There are several types of biological, physical, and chemical conditions that can occur in bioreactors. In general, the processes in aerobic, anaerobic, and hybrid bioreactors are driven by various decomposer species of bacteria and archaea. Aerobic conditions signify the presence of oxygen while anaerobic conditions completely lack oxygen. Bacteria or archaea can either be obligate, fitting into a strict category of using oxygen or not or facultative, where they can switch processes and thrive in both aerobic and anaerobic conditions. The key chemical reactions taking place in a bioreactor under various conditions are described below (Weiss, 2021):

Aerobic conditions

1. Most aerobes oxidize organic carbon using oxygen as an electron acceptor.
    - **Example:** Organics (e.g., glucose) + $O_2 \rightarrow CO_2 + H_2O + e^-$
2. Nitrifying bacteria and archaea use ammonium, but some use nitrite as electron acceptors.
    - **Example:** *Nitroammonas* spp.: $NH_4^+ + O_2 \rightarrow NO_2^- + 4H^+ + 2e^-$
    - **Example:** *Nitrobacter* spp.: $NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$
3. Sulfur-oxidizing bacteria can directly oxidize sulfur/sulfide using oxygen. They can also oxidize nitrate using carbon dioxide indirectly.
    - **Example:** *Acidithiobacillus* spp.: $H_2S + 2O_2 \rightarrow SO_4^{2-} + 2H^+ + 8e^-$

Under aerobic conditions, phosphorus, nitrogen, and sulfur can be fixed by oxidation reactions. During this process, these elements are transformed from a gaseous state to an ionic form, where they are free to bind and precipitate as solids. The aerobic conditions are beneficial because it aids in creating purer methane gas, but this process alone will produce carbon dioxide, not methane. Instead, it provides free protons, which are important for the following anaerobic processes that are necessary to produce biogas.

Hybrid (aerobic and anaerobic) conditions

1. Some organisms can convert ammonia into nitrite and then into nitrate. This type of organism has the name Comammox (Complete Ammonia Oxidation). The chemical process results in nitrate with free protons.
   - **Example:** *Nitrospira* spp.: $NH_4^+ + O_2 + H_2O \rightarrow NO_3^- + 6H^+ + 4e^-$

Since aerobic digestion is unable to produce biogas itself, a hybrid system would be necessary. In a hybrid system, all aerobic reactions would happen at an aerated, top level of the system. Then, anaerobic reactions would follow at the bottom of the system, where oxygen is not present. Facultative bacteria are important because they can survive in the "in-between area," where the environment is not fully aerobic or anaerobic. In this space, they can convert ammonium directly into nitrate which is far more efficient compared to the two-step process aerobes must undergo. This demonstrates the process by which hybrid systems can produce methane for biogas.

Anaerobic conditions

1. Most anaerobes ferment organics to generate organic acids and carbon dioxide.
   - **Example:** *Clostridium* spp.: $C_6H_{12}O_6 + 4H_2O \rightarrow 2CH_3COO^- + 2HCO_3^- + 4H^+ + 4H_2$
2. Methanogens, mostly archaea, reduce carbon dioxide to methane.
   - **Example:** *Methanobacterium* spp.: $CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$
3. Denitrifying bacteria reduce nitrate.
   - **Example:** *Alcalignes* spp.: $2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$
4. Sulfate-reducing bacteria can produce sulfide.
   - **Example:** *Desulfobacterales* spp.: $SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$

A hybrid system requires multiple conditions, aerobic and anaerobic, to produce methane for biogas, but the anaerobic digester can produce methane under a single condition. Methanogenesis is a unique process that can only take place under anaerobic conditions. Specific organisms, methanogens, are able to reduce carbon dioxide to methane. Because they are obligate microorganisms, they can only survive in oxygen-free environments. These microbes are obligate anaerobic lithotrophic Archaea that produce energy from the biosynthesis of methane. It should be noted that the entire process produces mostly CH_4, with a manageable amount of residual CO_2.

Byproducts of biogas

Anaerobic digestion produces biogas as the primary product and digestate as a byproduct. Residual digestate is the product of microbial fermentation; it is nutrient-rich and has the potential to become fertilizer. In some areas, digestate may be used directly as a fertilizer but in North America, it is more common to dry the digestate first (RichenTek, n.d.). Consequently, for a larger scale operation, specific technology would be required for this process. Although fertilizer could be sold, these additional costs, the market demand, and potential environmental impacts should be considered first.

Biogas technologies

The two kinds of biogas systems studied are landfill bioreactors and digesters. A landfill bioreactor treats waste by using liquids, such as re-circulated leachate and other wastewater, to induce a microbial degradation of the solid waste. They are an interconnected reactor and landfill system that treats waste at one site. Additionally, landfill bioreactors are typically wet systems, meaning they must use some form of water in its process. Digesters are stand-alone systems that can only treat organic waste; they require waste to be sorted before being fed into the system. However, they do not need to be connected to a landfill and can also degrade solid waste through decomposers, like bacteria and archaea. Digesters can also be wet or dry systems, meaning they are not strictly dependent on water in their process.

Both systems can be done in aerobic, anaerobic, or hybrid conditions. As microorganisms degrade the solid waste, biogas and methane can be generated through either system. When compared to the traditional dry tomb landfills that only store waste, these are a better option because they can transform it into something usable.

Landfill bioreactors

Aerobic bioreactors use both air and liquids to promote waste degradation. Air is injected throughout the waste via horizontal or vertical wells and liquids are recirculated by a sump pump system. When air is introduced into this waste, the organic compounds in municipal solid waste can degrade at a much faster rate. Additionally, aerobic systems have "increased settlement [of particulates]" and "higher organic, nitrogen, and phosphorus...removal efficiencies" (Kumar et al., 2011). The waste also becomes stabilized more quickly and consequently, is ready to be transformed to biogas faster. However, aerobic bioreactors have a decreased total methane yield. Figure 6 illustrates what a general aerobic bioreactor looks like (Waste Management, 2007).

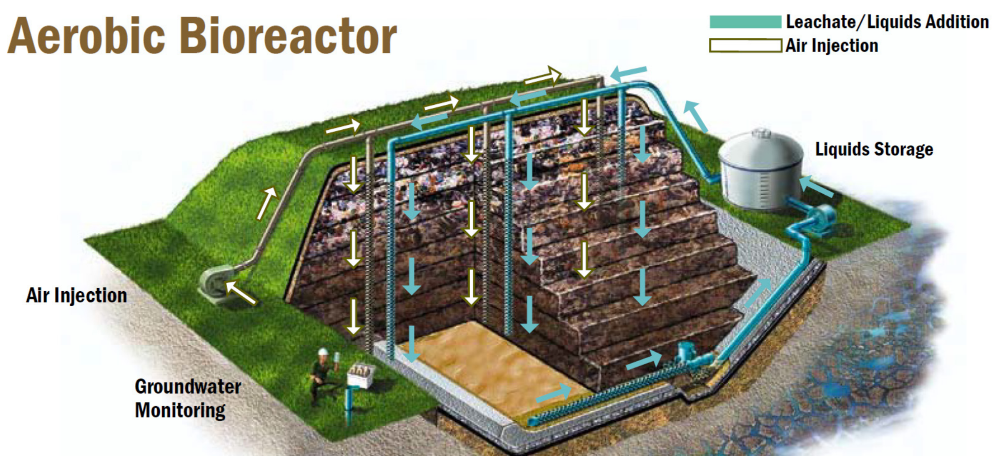

Figure 6 *Basic aerobic bioreactor diagram, by Waste Management, 2007, full brochure available at* **https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf**

Liquids, such as treated leachate, stormwater, and other non-hazardous wastewaters, are pumped throughout the bioreactor to create an anaerobic environment. This promotes the chemical processes that break down waste. While anaerobic bioreactors take much longer to degrade waste compared to aerobic systems, they have an "increase in methane generation" and consequently higher biogas yield (Grossule et al., 2018). Figure 7 portrays a general anaerobic bioreactor system (Waste Management, 2007).

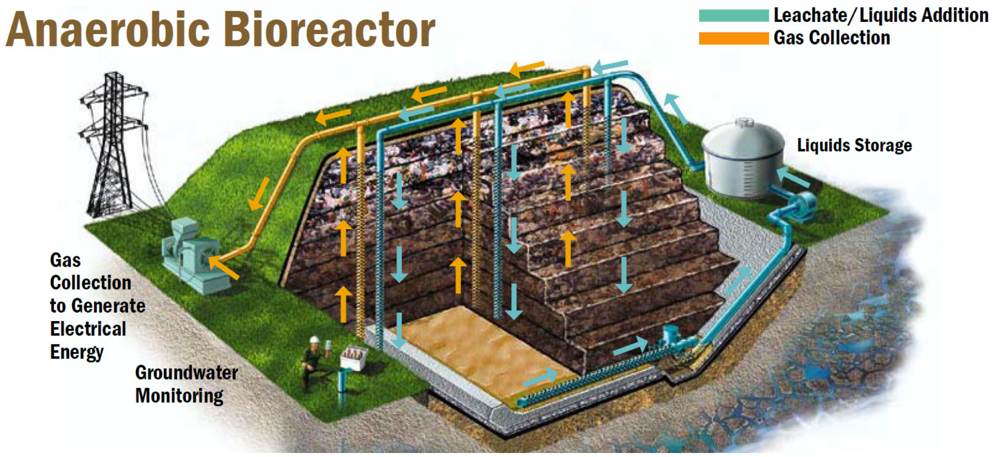

Figure 7 *Basic anaerobic bioreactor diagram, by Waste Management, 2007, full brochure available at* **https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf**

A hybrid bioreactor is a combination of aerobic and anaerobic processes. Air is circulated through the top portion of the waste, while the bottom portion remains oxygen-free. Gas is collected from the bottom, as the waste begins to degrade through anaerobic reactions. Berge et al. (2009) explain how this bioreactor is somewhat modifiable because the "aerobic and anaerobic conditions can be purposely alternated to enhance the methane production for energy recovery." The hybrid bioreactor is more complex though because it requires two different environments for decomposers. Figure 8 presents an example of a hybrid bioreactor (Waste Management, 2007).

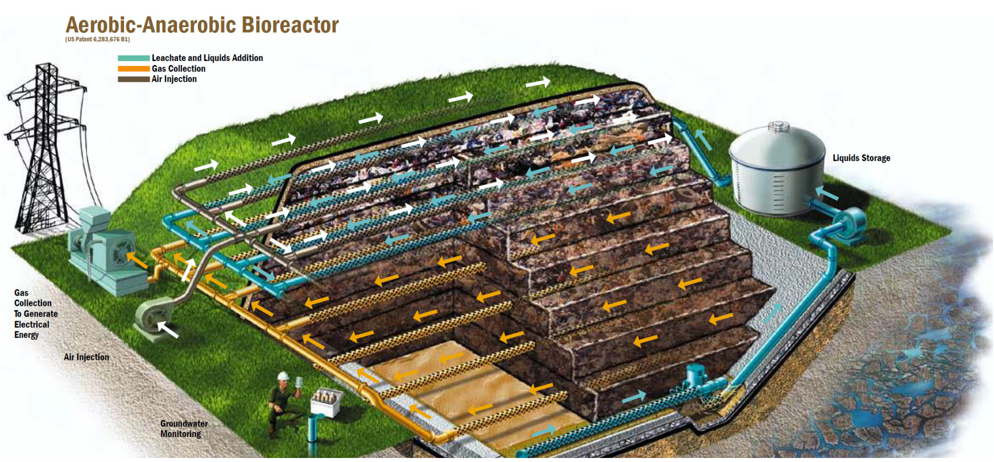

Figure 8 *Anaerobic-aerobic bioreactor diagram, by Waste Management, 2007, full brochure available at* **https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf**

Digesters

While landfill bioreactors can operate under various conditions, like aerobic or hybrid, biogas digesters can only work under anaerobic conditions. Anaerobic digestion of MSW can be achieved in a wet or dry environment. The general process that occurs, as depicted in Figure 9, is similar for both environments; therefore, they are treated similarly (Rocamora et al., 2020; Kraemer & Gamble, 2014). However, they do vary in the amount of solids they can process. Wet digesters can only utilize 10 to 20 percent of its volume for waste because the additional space is dedicated to water (Angelonidi & Smith, 2015). Further, the treatment of MSW through a wet process increases the rate of waste degradation; it also has a reasonable balance between waste input and energy output.

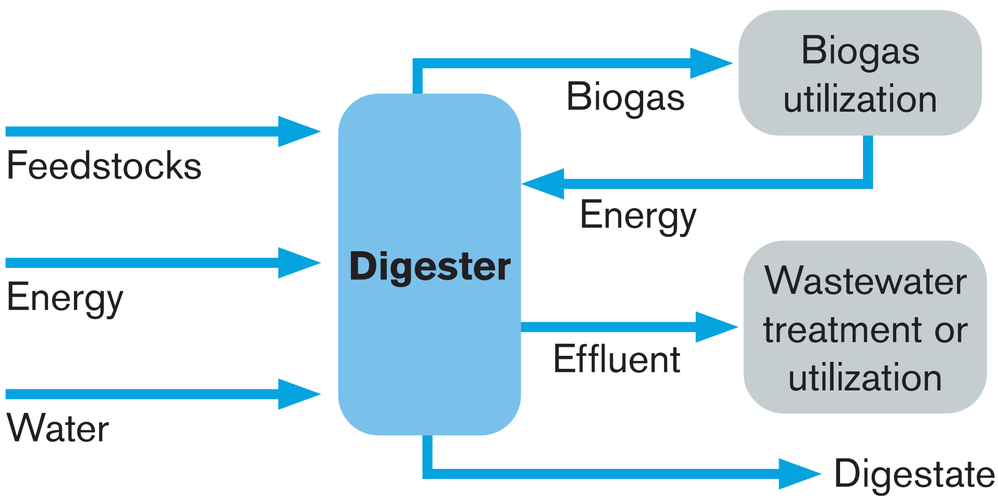

Figure 9 *Basic features of an anaerobic digestion system, by Kraemer and Gamble, 2014, via BioCycle, available at* **https://www.biocycle.net/integrating-anaerobic-digestion-with-composting/**

Dry digesters can operate using higher amounts of waste, as much as 20 to 40 percent of the digester volume (Rocamora et al., 2020). They have the advantage of a drastically reduced need for water and have a greater energy balance compared to wet systems (Riya, 2020). Dry digesters are also more flexible in design; they can be constructed as a batch or continuous flow reactor. Both of these systems work best when the solid waste tonnage is 20 to 40 percent of the total reactor volume, which makes the dry digester especially attractive (Guendouz et al., 2010).

Advantages of biogas technologies

Landfill bioreactors have the advantage of being connected to a landfill and utilizing various processes, like anaerobic or aerobic. The system can oftentimes produce more biogas because of the constant instream of food waste and does not require additional transportation. Digesters are beneficial because they do not require a landfill and can instead, be a stand-alone system. Both options are especially effective because they can produce energy. While the amount of energy produced usually depends on how much feedstock is input, it is still better than simply disposing of MSW. Dry anaerobic digesters also tend to be less odorous because it is an enclosed system with a lower chance of gases to escape (Angelonidi & Smith, 2015). This would reduce concerns about vermin in comparison to landfills. Though dry digesters can take a variety of feedstock combinations, it should be noted that potentially harmful or difficult to manage byproducts may generate when using MSW, other than food waste.

Disadvantages of biogas technology

There are some disadvantages to biogas technologies. Landfill bioreactors can be an impractical option for cities, like Peoria, without a landfill already constructed. It would require an excessive amount of space, planning, and a major financial contribution. When comparing dry and wet anaerobic digesters, the wet systems tend to be more troublesome. They can produce an effluent that would need to be treated and require a water supply; in places like Arizona, this can be quite difficult. Additionally, they are usually more expensive and have a higher chance of odor pollution. On the other hand, dry anaerobic digesters are cheaper but are more limited in the amount of waste they can take. They also need careful presorting of the feedstock before being added into the system to prevent harmful byproducts being produced.

Recommended biogas technology

In terms of choosing one of the systems described above, it is crucial to take into consideration a city's needs and available resources. According to Ritzkowski and Stegmann (2013), introducing liquids promotes nutrient and microbial movement. However, Arizona is a desert with limited water resources, so a wet system is not ideal. It is also important to note that Peoria does not have its own landfill, and consequently would be unable to build its own landfill bioreactors, which are typically wet systems. The degradation process of solid waste is still possible in a dry system, and instead requires different technology.

Ritzkowski and Stegmann (2013) continue to describe how introducing air accelerates decomposition. Aerobic systems are unable to produce methane without the aid of anaerobic species, and as a result, a hybrid system would be needed to produce biogas. Due to Peoria's limited space available for these systems, an anaerobic system would be best because it can convert waste into biogas on its own. Additionally, when compared to syngas technologies, dry anaerobic digesters consume less energy because they do not have any temperature requirements. Therefore, they emit less greenhouse gases. Overall, the dry anaerobic digester is the most feasible option for Peoria.

Biogas implementation examples

The Northern Oaks Recycling and Disposal facility opened in 1992 and is located in Harrison, Michigan. They accepted approximately 454 metric tons of MSW per day and utilized a bioreactor system to process waste (Zhao et al., 2008). The facility acquired a regulatory permit to recirculate leachate through-out its bioreactor cell and treat the MSW. The system was built using a RCRA Subtitle D composite liner, with the addition of secondary liners, to allow leachate drainage (Zhao et al., 2008). The leachate was then recollected with pipes to recirculate throughout the bioreactor again. The facility's design allowed Northern Oaks to reuse components while also producing biogas.

Avolta, a solar company based in Utah, has partnered with Butterfield and Milky Way dairy farms on a biogas project in Phoenix, Arizona. The farms have a high volume of feedstock, manure, from over 50,000 cows (Avolta, 2021). They utilized an anaerobic digestion process to transform the manure into methane. Once the fuel is generated, it is processed and injected into a pipeline. Annually, they produced over 675,000 metric million Btu of renewable natural gas (Avolta , 2021). Currently, they utilize the biogas as transportation fuel; however, later this year they will be delivering the gas to the Southwest Gas Pipeline. It should be noted that this system does not use MSW, but still demonstrates the potential of biogas facilities. A city's feedstock volume will be significantly smaller but will still be able to produce biogas and prevent additional waste from going into landfills.

Biogas economics

The average cost of building a typical dry anaerobic digester is $750,000. At this price, the digester would need approximately 600 m^2, or 6400 ft^2, of land. It would be able to process up to 2,000 tons of organic waste at a time. This cost only includes the construction of the digester, and not any other variables, such as a gas-purifying system, generator, slag disposal (Biogas World, 2021). This estimate is based on a small-scale operation compared to other larger options that can cost as much as five million USD. When considering the parameters of what Peoria was looking for, students decided a smaller operation would be most feasible.

Biogas cost analysis

The Solid Waste Division of the City of Peoria states that the total residential trash tonnage for 2021 is 67,087 tons (A. Redd, personal communication, November 10, 2021). Based on the landfill fees provided by Peoria, it costs $29 per ton of waste disposed of (R. Humbles, personal communication, September 23, 2021). The estimated annual cost of disposing of their total municipal solid waste (excluding recycling) is calculated below.

$$\frac{\text{68,087 tons of waste disposed}}{\text{Year}} \times \frac{\$29}{\text{Ton of waste disposed}} = \frac{\$1{,}945{,}523}{\text{Year}}$$

The calculated annual cost of disposing total residential waste is **$1,945,523.**

Since there is no specific data available for Peoria's MSW composition, the students are creating an estimate with a report from the EPA. According to the EPA, the total organic waste, primarily food waste, in MSW is 63.13 million tons and the total MSW generated is 292.36 million tons (2018). The first calculation below describes the percentage of organic waste in municipal solid waste. To be more applicable to Peoria, the second calculation estimates how much of its MSW is organic waste that can be used as feedstock for a dry anaerobic digester.

$$\frac{\text{63.13 million tons}}{\text{292.36 million tons}} = 0.2159 \times 100 = 21.59\%$$

$$\text{67,087 tons of waste disposed} \times 0.2159 = \text{14,484.083 tons of organic waste}$$

$$\text{14,484.083 tons of organic waste} \approx \text{14,484 tons of organic waste}$$

The approximate annual amount of organic waste within Peoria's MSW is **14,484 tons.**

Rather than going to a landfill, the organic waste could be diverted to a dry anaerobic digester. The cost analysis below shows the difference between the Total Annual Cost and the Annual Cost Without Organic Waste. Then, the potential savings per year can be calculated.

67,087 tons of waste disposed - 14,484.083 tons of organic waste = 52,603 tons of waste without organic waste

The tonnage of residential waste without organic waste is **52,603 tons.**

$$\frac{52{,}603 \text{ tons of waste disposed}}{\text{Year}} \times \frac{\$29}{\text{Ton of waste disposed}} = \frac{\$1{,}525{,}487}{\text{Year}}$$

The calculated annual cost of disposing residential waste excluding organic waste is **$1,525,587.**

$$\frac{\$1{,}945{,}523}{\text{Year}} - \frac{\$1{,}525{,}587}{\text{Year}} = \frac{\$420{,}036}{\text{Year}}$$

The calculated annual savings is **$420,036.**

As a general estimate, the City of Peoria could save $420,036 annually by using their organic waste for anaerobic digesters. Based on the average cost of a dry anaerobic digester, the students have created a tentative timeline for how long it will take Peoria to break even using $750,000 as the estimated initial capital cost.

$$\frac{\$750{,}000}{1} \times \frac{\text{Year}}{\$420{,}036} = 1.78 \text{ years}$$

According to the calculations above, it will take Peoria **1.78 years** to break even on capital costs; the savings are from fewer landfill disposal fees. Despite being a long-term investment, dry anaerobic digesters have promising potential. Further, these calculations do not address other means of profit.

The production of biogas creates methane which can be converted to electricity; this would save Peoria money on energy sources. Struvite, a byproduct of biogas production, can also be converted into fertilizer. While fertilizer sales are another potential option, it is not recommended unless substantive measures are taken to relieve environmental impacts. These additional options will require more equipment and consequently, further costs. It should be noted that additional, variable, costs of infrastructure, permits, real estate, operating, and maintenance are not included in this report. The dry anaerobic digester technology will produce less GHG emissions than the fixed-bed gasifier technology. Overall, dry anaerobic digesters have the capability of reducing landfill dependency and creating a means of economic growth for the City of Peoria.

Syngas

Chemical reactions in syngas

There are three primary processes that produce syngas: gasification, co-gasification, and pyrolysis. It involves the conversion of carbonaceous, or organic, feedstock into syngas with byproducts of tar and ashes. Depending on the specific process used, the chemical reactions may vary. Generally, though, these reactions occur between temperatures of 800-1000   and pressures of 1-20 bar. The general reaction of organic matter into syngas is described below (El Nagar & Ghanem, 2019).

$$\textit{Organic feedstock} + O_2 \rightarrow CO + H_2 + CO_2 + H_2O + CH_4$$

Generally, the conversion of organic feedstock into syngas begins with the thermochemical decomposition of the polymeric lignin and cellulose compounds in the feedstock to produce char and volatiles (Maschio et al., 1994). This step is where most of the ash byproduct is produced. Next, the resulting char and volatile compounds are typically introduced to heat and oxygen of some form, whether pure O_2 or air, to produce the raw syngas product (Maschio et al., 1994). However, syngas must be converted from its raw form to a usable state.

Raw syngas usually contains undesirable amounts of CO and other corrosive contaminants, like hydrogen sulfide, carbonyl sulfide, and carbon dioxide (Mondal et al., 2011). Consequently, raw syngas must be further processed for application purposes. This can be done through various processes like solvent absorption and adsorption (Mondal et al., 2011).

Further processing results in a greater H_2 to CO ratio, which is more ideal because H_2 is a highly valuable, carbon-free fuel product (Foong et al., 2021). Producing H_2 from organic feedstock as opposed to conventional processes is also more environmentally-friendly because it produces less CO_2 emissions compared to other processes (Foong et al., 2021). The CO can be converted to H_2 through a water shift reaction described below.

$$CO + H_2O \rightarrow H_2 + CO_2 \quad \Delta H_{298}{}^{0} = -41.1\ kJ/mol$$

For all processes, general preprocessing is required to separate the organic, combustible feedstock from the other components of municipal solid waste. This mainly involves screening, size reduction, and drying (Yang et al., 2021). Fortunately, this type of processing is already a fundamental part of solid waste management, so many facilities already have the tools to do so. But regardless of process type, feed composition, gas flow rate, etc., the factor that most affects the composition of the syngas product is the temperature (El-Nagar & Ghanem, 2019). Because of this, facilities can adjust the temperatures of their systems to manipulate the end-product composition.

Gasification

Gasification is a chemical process that oxidizes the organic matter in municipal solid waste at very high temperatures; usually at temperatures greater than 1500 °C. It performs incomplete combustion by adding high heat to feedstock with the addition of oxygen, carbon dioxide, and steam (Mondal et al., 2011; Yang et al., 2021). This is a relatively simple and safe process and does not require any other additional chemicals. According to Yang, gasification is an undervalued process, because it can produce higher yields of syngas and hydrogen gas compared to combustion or pyrolysis. Figure 10 summarizes the chemical reactions that can occur during the gasification process (Yang et al., 2021).

Gasification reactions		
Reaction name	***Chemical equation***	***Enthalpy change***
Boudouard reaction	$C + CO_2 \leftrightarrow 2CO$	ΔH = -172 kJ/mol
Dry reforming reaction	$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$	ΔH = +247 kJ/mol
Methanation	$C + 2H_2 \leftrightarrow CH_4$	ΔH = -75 kJ/mol
Oxidation of Char	$C + 1/2\ O_2 \leftrightarrow CO$ $C + O_2 \leftrightarrow CO_2$	ΔH = -111 kJ/mol ΔH = -394 kJ/mol
Oxidation of CO	$CO + 1/2\ O_2 \leftrightarrow CO_2$	ΔH = -283 kJ/mol
Oxidation of H_2	$H_2 + 1/2\ O_2 \leftrightarrow H_2O$	ΔH = -242 kJ/mol
Primary water-gas reaction	$C + H_2O \leftrightarrow CO + H_2$	ΔH = -131 kJ/mol
Secondary water-gas reaction	$C + 2H_2O \leftrightarrow CO_2 + 2H_2$	ΔH = -90 kJ/mol
Steam reforming reaction	$CH_4 + H_2O \leftrightarrow CO + 3H_2$	ΔH = +206 kJ/mol
Water-gas shift reaction	$CO_2 + H_2 \leftrightarrow CO + H_2O$	ΔH = -41 kJ/mol
Note: Enthalpy change of main reactions occurs during gasification. The positive sign indicates endothermic reaction, while the negative sign indicates exothermic reaction (Ramos et al., 2018; Sansaniwal et al., 2017; Werle, 2014).		

Figure 10 *Main reactions occuring during gasification and associated enthalphy changes, by Springer Nature Switzerland AG, available at* **https://doi.org/10.1007/s10311-020-01177-5**

Co-gasification

Co-gasification includes the same reactions as gasification but includes biomass material in addition to the traditional carbonaceous feedstock (Yang et al., 2021). Oftentimes, gasification and co-gasification are grouped together, since this is the only aspect that varies. The addition of biomass material is beneficial because it minimizes tar generation and results in a higher carbon conversion, meaning it is more efficient than conventional gasification. Further, there are virtually endless combinations of carbonaceous feedstock and biomass that can be used to produce syngas. Figure 11 provides examples of carbonaceous feedstock and biomass combinations (Yang et al., 2021).

Feedstock combinations			
Feedstock	***Temperature of gasification***	***Energy value of syngas***	***Reference***
Pig manure and wood chip	530-700 °C	14 MJ	Xiao et al. (2011)
Sewage sledge and woody biomass	550-850 °C	5.5 MJ	Seggiani et al. (2012)
Lignite and polyethylene	850 °C	19 MJ	Kern et al. (2013)
Palm kernel shell and polyethylene	650-800 °C	46 MJ	Moghadam et al. (2014)
Coal and switchgrass	700 °C	18 MJ	Masnadi et al. (2015, a, b, c)
Bituminous coal and pine sawdust	500-800 °C	11.4 MJ	Tursun et al. (2016)
Coconut shell and high-density polyethylene	600-800 °C	13.4 MJ	Esfahani et al. (2017)
Sewage sludge and residue from hydrolysis	600-800 °C	6.8 MJ	Chen et al. (2018)
Banana hydrochar and anthracite coal	850 °C	10.1 MJ	Zhu et al. (2019)
Gas-pressurized rice straw and coal	950 °C	23.8 MJ	Tong et al. (2020)
MJ = Megajoule			

Figure 11 *Example feedstock combinations and the resulting energy value of the syngas produced, by Springer Nature Switzerland AG, available at* **https://doi.org/10.1007/s10311-020-01177-5**

Pyrolysis

Pyrolysis is a process that involves inert, thermal degradation of organic feedstock that results in products of tar and syngas (Du et al., 2021). In comparison to gasification and co-gasification, tar is a valuable byproduct of this process, as it does not affect the efficacy of the reactor or machinery. Furthermore, catalyst choice is an important aspect of designing a pyrolysis process because it, like the composition of the feedstock, greatly influences the composition of the syngas product (Foong et al., 2021). Figure 12 goes more in-depth on the chemical reactions that occur (Foong et al., 2021). However, it should be noted that based on Peoria's preferences, the students in ASU's Project Cities did not research this technology as extensively as the other processes.

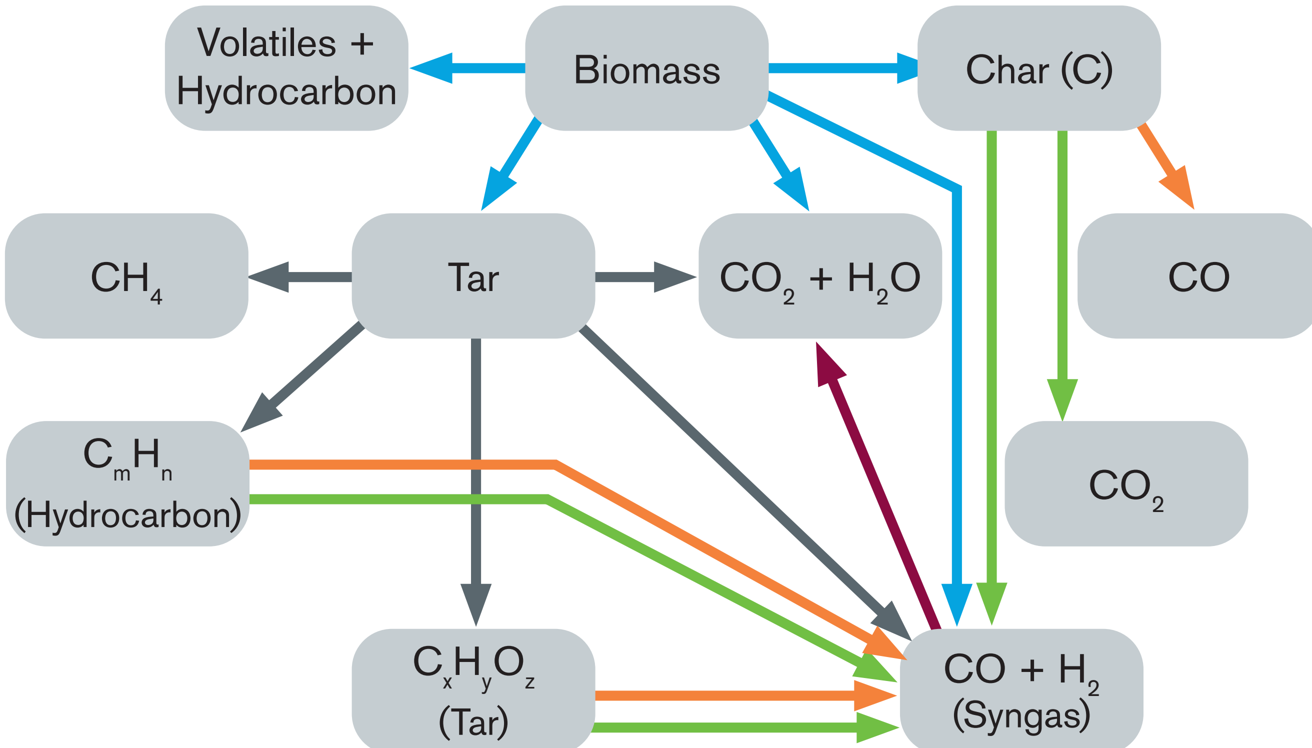

Figure 12 *Primary reactions during catalytic pyrolysis of feedstock, by Foong et al., 2021, Via Elsevier, available at* **https://doi.org/10.1016/j.biortech.2020.124299**

Byproducts of syngas

Unwanted byproducts that are typically produced from syngas production include tar, ash, nitrous oxides (NOX), and sulfur oxides (SOX). These byproducts are a result of both the solid lignin, cellulose, and plastic contents that are found in solid waste, and the nitrogen and sulfur elements present in air and catalysts. Tar is unwanted because it condenses at relatively low operating temperatures, 350 °C, and can adhere to machinery and cause blockages and malfunctions (Saleh et al., 2020). NOXs form from reactions with nitrogen in the air and they, along with SOX s, are undesirable because of their atmospheric warming properties and general harm to the environment (Maschio et al., 1994). However, they can be avoided by using pure O_2 in the system instead of air. Figure 13 provides additional information on the common and unwanted byproducts present in syngas production (Göransson et al., 2011).

Contaminant presence	
Contaminant	***Problems***
Alkali metals	Can cause high-temperature metal corrosion and defluidisation of the bed. Alkali metals exist in vapor phase.
Fuel-bound nitrogens	Forms NOx during combustion and causes potential emissions problems. Furthermore, the catalysts are sensitive to nitrogen compounds.
Particulates	Cause erosion of metallic components and environmental pollution. Originate from ash, char, bed material and condensing compounds.
Sulfur and chlorine	Could cause dangerous pollutants and acid corrosion of metals. The catalysts are sensitive to sulfur and chlorine compounds.
Tar	Clogs filters and valves and produces metallic corrosion. Tars exist in vapor phase in the syngas.

Figure 13 *Syngas production contaminants and associated problems, by Göransson et al., 2011, available at* **https://doi.org/10.1016/j.rser.2010.09.032**

Syngas technologies

Gasifiers repurpose waste by utilizing a pyrolysis process in a controlled environment. These systems come in various reactor designs, but all follow the same principles: design layout, chemical processes, and products. Although pyrolysis technically occurs within a gasifier reactor, the gasification process is still unique. It transforms carbon-based compounds into fuel, without relying entirely on combustion. Between all gasification technologies, the feedstock loading port and gas flow output areas are in different areas. When considering various designs, certain specifications, such as cost, gas outputs, and waste inputs, allow end users flexibility in choosing a system that best fits their needs. The three kinds of gasifiers studied are fixed-bed, fluidized bed, and entrained flow.

Fixed-bed gasifiers

There are three types of fixed-bed gasifiers that can be used to create syngas, all of which utilize the same principles. They include:

- Updraft gasifier
- Downdraft gasifier
- Cross draft gasifier

Figure 14 on the following page includes simplified diagrams for each type of gasifier.

In an updraft or counter-current, fixed bed gasifier, feedstock is loaded into the top of the reactor. Then, steam, oxygen, or air is injected into the bottom of the reactor. After the necessary chemical reactions occur, the syngas produced is funneled through the reactor and exits at the top of the reactor, adjacent to the feedstock loading port. (Dutta & Acharya, 2011).

In a downdraft, or co-current, gasifier, feedstock is loaded through the top of the reactor. Then, steam, oxygen, or air is added into the bottom of the reactor, above the oxidation zone. The resulting syngas exits at the bottom of the unit (Beohar et al., 2012).

In a cross-draft gasifier, feedstock is loaded into the top of the reactor. Uniquely, steam, oxygen, or air is injected into the side of the unit. The syngas product then leaves the system through the side of the reactor (Beohar et al., 2012).

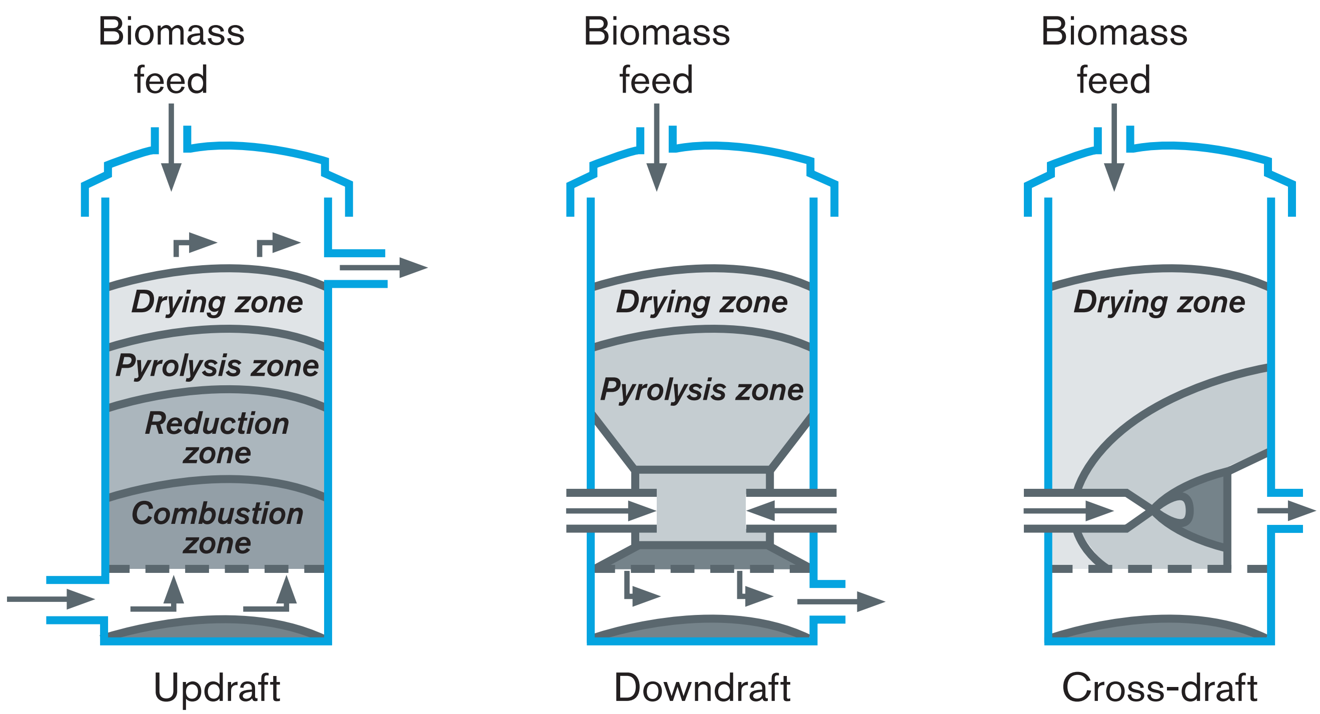

Figure 14 *Diagrams of different fixed bed gasifiers, including updraft (left), downdraft (center), and cross-draft (right), by Beohar et al., 2012, available at* **http://inpressco.com/wp-content/uploads/2012/03/Paper3134-140.pdf**

Fluidized-bed gasifiers

The most common type of fluidized bed gasifier is a bubbling fluidized gas bubbler (BFB). In this system, the bed material is agitated with a high velocity gasifying agent that is injected into the bottom of the reactor. Biomass, or feedstock, is added through the side of the unit and onto a hotbed, where it undergoes devolatilization. Ultimately, this creates syngas that exits via the top of the reactor. Many BFB units also have an additional gasifying agent injection port above the bed material, where additional amounts of gasifying agents can be added to ensure that as much biomass is converted to syngas as possible (Bermudez & Fidalgo, 2016). Figure 15 depicts the general setup of this system (National Energy Technology Laboratory, n.d.b).

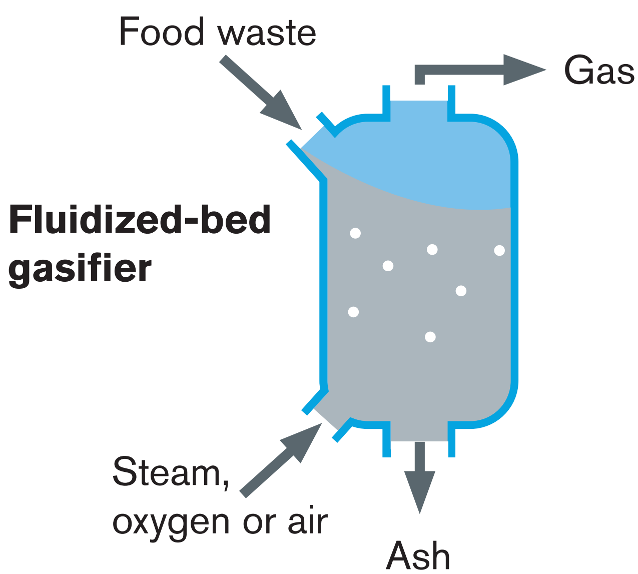

Figure 15 *Fluidized-bed gasifier diagram, by National Energy Technology Laboratory, n.d.b, available at* **https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/fluidizedbed**

Entrained flow gasifiers

Entrained flow gasifiers often utilize powdered biomass, or a biomass slurry, as a fuel for the system. Most commonly, this biomass is loaded into the bottom of the unit and placed under pressure. Then, it is mixed with a gasifying medium, such as air, steam, or oxygen. This causes combustion reactions to occur and ultimately produces syngas. If a system loads biomass into the bottom, the resulting syngas exits through the top of the unit. In systems that use a top loading mechanism, the syngas product exits through the bottom (Basu, 2013). Figure 16 illustrates two examples of entrained flow gasifiers (Basu, 2013).

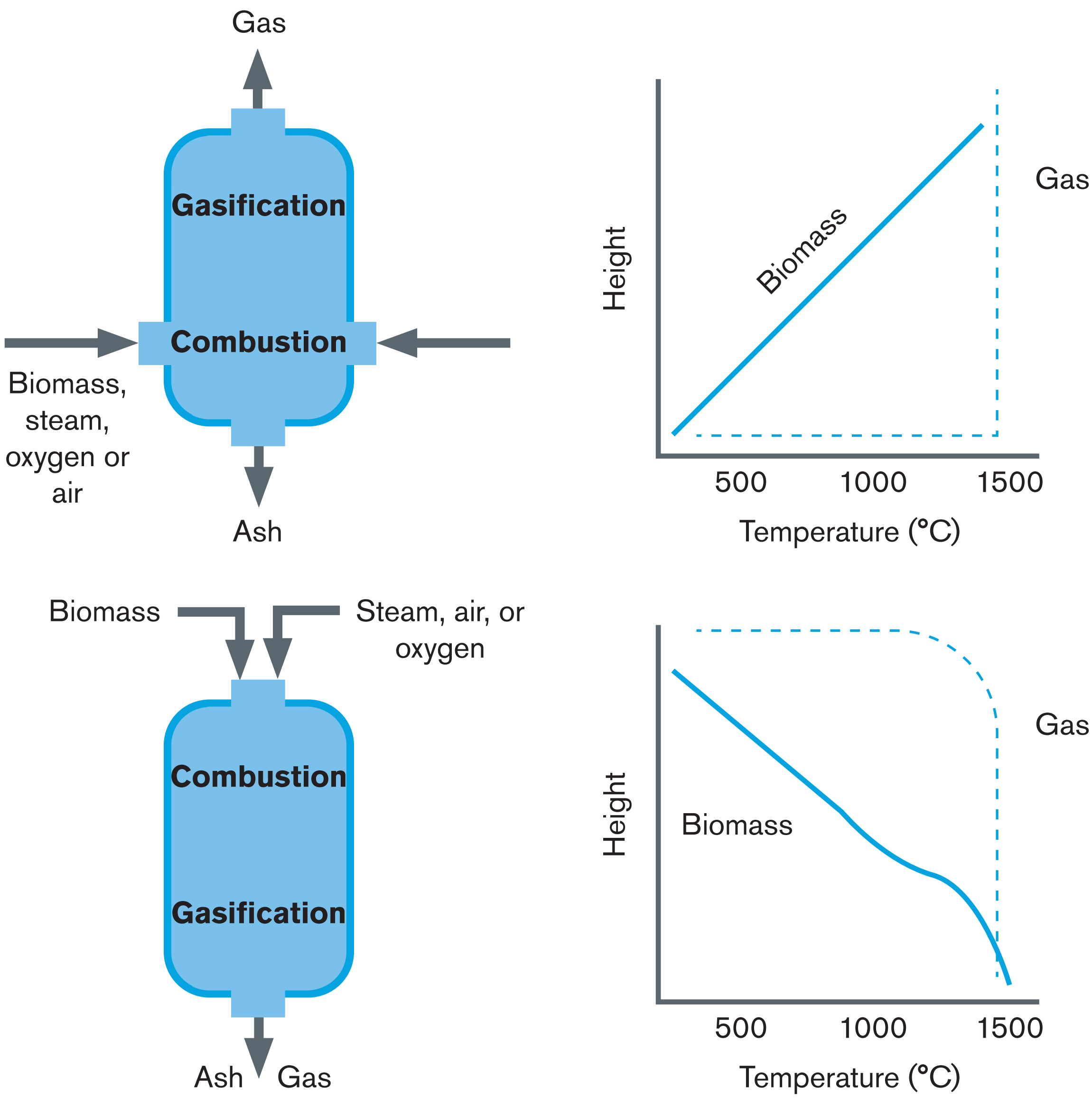

Figure 16 *Different setups for an entrained flow gasifier, by Basu, 2013, available at* **https://doi.org/10.1016/B978-0-12-396488-5.00007-1**

Advantages of syngas technologies

A key advantage of using gasification is that it utilizes waste materials, that would otherwise be discarded, and produces syngas. It is an effective alternative to traditional waste disposal systems, like landfills, and can be used to generate electricity (Mackaluso, 2007). Additionally, it has a 56.27 percent conversion efficiency of CO_2 at 1,000 °C and a 69.44 percent conversion at 1,100 °C; this is a higher conversion efficiency than other types of processes (Zheng et al., 2018). In comparison to typical coal combustion, gasification has significantly fewer pollutant emissions (National Energy Technology Laboratory, n.d.a).

Further, syngas is a renewable form of energy while coal is not (Filippis et al., 2004). Different technologies also have varying advantages. Using downdraft or updraft fixed bed gasifiers can result in less harmful byproducts (Beohar et al., 2012). Fixed bed gasifiers are also more flexible to one's needs; they can be adjusted for scale, materials, and the general setup. All of the technologies can produce a high heating value gas as well (Panda et al., 2010).

Disadvantages of syngas technologies

Despite the many advantages of gasification, there are drawbacks as well. Syngas, while being better for the environment, does not produce energy as efficiently as its counterpart, coal combustion (National Energy Technology Laboratory, n.d.a). This can make the transition to syngas especially difficult for communities who primarily rely on natural gas as an energy source. Other disadvantages can arise depending on the specific technologies used. Certain gasifiers, like the downdraft and updraft fixed bed, have limitations on the feed size (Beohar et al., 2012). Others, like the bubbling fluid bed and entrained flow, have an excessive amount of tar, slag, and other harmful byproducts (Panda et al., 2010).

Recommended syngas technology

When choosing a gasifier system for syngas production, variables such as efficiency, profit, and environmental concerns must be addressed. The City of Peoria has expressed its needs regarding available space and budget; consequently, certain gasifiers prove to be impractical for their application. Fluidized bed gasifiers are quite efficient with converting biomass to syngas, but they oftentimes require large-scale facilities. They typically operate using a high input volume, thus making it less feasible for Peoria (Panda et al., 2010). Entrained flow systems are a more attainable option based on space, however, they are more costly. They are more difficult to maintain because they operate at higher temperatures and generally have a shorter life span.

Fixed-bed gasifiers are the most achievable option for the City of Peoria. While they may not produce the most syngas, they have many benefits. They are lower in cost, can have diverse designs, and are able to be adjusted in scale. It is possible to make a smaller system that would best fit the city's needs. Additionally, they are versatile regarding input material; they are capable of taking food waste and yard trimmings as well. However, because of the high operating temperatures, fixed-bed gasifiers require more energy. This results in more greenhouse gas emissions and it should be considered when choosing an alternative fuel technology.

Syngas implementation

The Wabash River Coal Gasification Repowering Project operated for four years, through 1996 and 1999, and used gasification technology and operated using different fuels. The syngas composition remained relatively constant, but variations of coal used for the design resulted in reduced syngas and steam production (National Energy Technology Laboratory, n.d.c). Sudden changes to the feedstock can cause disruptions, but their method had a high H_2 to CO ratio. While this example utilizes coal as feedstock, the general process can be applied to MSW, specifically with food waste or yard trimmings. This will result in a lower fuel yield, but it is still an effective option.

In Australia, Logan City Council used a gasification process to shrink transported waste and produce syngas to power the facility (Arena, 2021). After treating wastewater, the remaining municipal solid waste was heated to high temperatures and ultimately created syngas. Logan City also plans to install solar power technologies, which will make the facility energy neutral. The residual biochar from the gasification process will serve as a marketable and environmentally friendly soil fertilizer (Arena, 2021).

Syngas economics

For the purposes of this report, the students researched a downdraft fixed-bed gasifier. It should be noted that other fixed bed systems, such as updraft and cross-draft, may also be considered as options; the only difference is preference in design. The average cost of building a typical downdraft fixed bed gasifier is $112,500 (Indrawan et al., 2020). The reactor can take up to 10 ton/hour of carbonaceous waste; this can also be adjusted to scale. The size of this reactor was decided upon based on the parameters given by the City of Peoria and was thought to be the most feasible option for what they are looking for. Figure 17 shows the cost breakdown of a downdraft fixed-bed reactor (Indrawan et al., 2020).

Equipment and materials for a downdraft gasifier		
Equipment	***Cost***	***Remarks***
Reactor, cyclone separator, and control system	$60,000	
Belt conveyor	$10,000	Bunting Magnetic Co.
Ash removal system (ash drum, screw conveyor, electric motor)	$10,000	
Air compressor	$10,000	Sullair air compressor
Gas scrubbing system (double gas scrubber, pump)	$4,500	The gas cleaning system consisted of water-acetone solution
Power generation unit (natural gas ICE)	$18,000	An ICE of 100 kW is used to accommodate total volume of syngas flow with an assumed capital cost
Total	$112,500	

Figure 17 *Suggested costs for constructing a downdraft gasifier system, by Indrawan et al., 2020, available at* **https://doi.org/10.3390/en13143703**

Syngas cost analysis

Referring back to the Biogas Cost Analysis, the total residential trash tonnage for Peoria in 2021 is 67,087 tons and the annual total cost for Peoria to dispose of total municipal solid waste (excluding recycling) is $1,945,523. As the City of Peoria has not provided specific data regarding Peoria's MSW composition, the students are creating an estimate based on a report from the EPA. According to the Environmental Protection Agency, the total organic waste in MSW, including food waste and yard trimmings, is 98.53 million tons and the total MSW generated is 292.36 million tons (2020b). The first calculation below expresses an estimate of what percent of MSW is usable for syngas production. To be more applicable to Peoria, the second calculation estimates how much of their MSW is organic waste that can be used as feedstock for a downdraft gasifier. Yard trimmings are included in this organic waste calculation because gasifiers are capable of processing it with little to no problems, while anaerobic digesters cannot.

$$\frac{98.53 \text{ million tons}}{292.36 \text{ million tons}} = 0.3370 \times 100 = 33.70\%$$

$$67{,}087 \text{ tons of waste disposed} \times 0.3370 = 22{,}608.319 \text{ tons of organic waste}$$

$$22{,}608.319 \text{ tons of organic waste} \approx 22{,}608 \text{ tons of organic waste}$$

The approximate annual amount of organic waste within Peoria's MSW is **22,608 tons.**

Rather than going to a landfill, the carbonaceous waste will be put towards the downdraft fixed-bed gasifier. The cost analysis below shows the difference between the total annual cost and the annual cost without carbonaceous waste, followed by the potential savings per year.

$$67{,}087 \text{ tons of waste disposed} - 22{,}608 \text{ tons of organic waste} = 44{,}479 \text{ tons of waste without organic waste}$$

The tonnage of residential waste without organic waste is **44,479 tons.**

$$\frac{44{,}479 \text{ tons of waste disposed}}{\text{Year}} \times \frac{\$29}{\text{Tons of waste disposed}} = \frac{\$1{,}289{,}891}{\text{Year}}$$

The calculated annual cost of residential waste disposal without organic waste is **$1,289,891.**

$$\frac{\$1{,}945{,}523}{\text{Year}} - \frac{\$1{,}289{,}891}{\text{Year}} = \frac{\$655{,}632}{\text{Year}}$$

The calculated annual savings is **$655,632.**

As a general estimate, the City of Peoria could save $655,632 annually by using its organic waste for this technology. Based on the average cost of a downdraft fixed bed gasifier, students created a tentative timeline for how long it may take Peoria to breakeven using $112,000 as the estimated initial capital cost.

$$\frac{\$112{,}500}{1} \times \frac{\text{Year}}{\$655{,}632} \times \frac{12 \text{ months}}{1 \text{ year}} = 2.05 \text{ months} \approx 2 \text{ months}$$

According to the calculations above, it will take Peoria only 2 months to breakeven on constructing a downdraft fixed-bed gasifier; the savings are from disposing of less waste to landfills. Although there are many capital investments, downdraft fixed-bed gasification shows promising potential. Further, these calculations do not address other means of profit. The production of syngas creates methane which can be converted to electricity. This would save Peoria money on energy sources. It should be noted that additional, variable, costs of infrastructure, permits, real estate, operating and maintenance are not included in this report. The fixed-bed gasification process produces more GHG emissions than the dry anaerobic digester technology. Overall, downdraft fixed-bed gasification is a promising option for reducing landfill dependency and creating a means of economic growth.

Recommendations

Education and public outreach

The first step in implementing a new alternative fuel technology is informing the public. The City of Peoria should present their preferred technology and its benefits to the community. It's critical to get the public onboard before making any major decisions. Some advantages that directly apply to the residents are potentially reduced energy bills. Since biogas and syngas are renewable natural gases, they may qualify for renewable energy credits or other incentives, such as reduced collection services fee. Additional concerns, like the location of the facility, can be addressed as well. The facility should be away from residential areas if possible, or be in a discreet region.

Education should also present alternative fuel technologies as an exciting opportunity. The City of Peoria should involve the public through events. Many communities have a "Recycling Day", but a "Food Waste Separation Day" could be beneficial too. It can emphasize the importance of properly sorting food waste and demonstrate how to do it. This can also be coordinated with the composting classes that Peoria already offers. This allows residents to feel important and can highlight their contribution to the biogas or syngas project. Further, children in schools can be taught about the importance of reducing landfill usage and how their own city is managing it effectively.

Waste sorting

Editor's Note
The Blue Lid Campaign is a good example of successfully reducing contamination through customer education. Waste sorting in this context could use a similar approach by investing in informational signage for bins.

Waste sorting within the community can allow feedstock to be added more quickly to the alternative fuel technology and reduce the time required for processing at another facility. Before implementing costly sorting systems, additional steps can be taken to better facilitate the process. The overall goal is to make the sorting process easier for the city, so they should take care when allowing the public to participate. For example, **proper education** can prevent people from putting unwanted trash in a designated food waste bin. Creating a program that allows residents to drop off food waste on their own is an easy first step to get the community involved; this could also be supplemented by incentives. If this is successful, creating a curbside pickup program could be a potential option in the future. Peoria would be able to slowly introduce this change in waste collection services and possibly mitigate sorting mistakes. As more food waste bins are introduced, it is critical to utilize the programs that check recycling bins for incorrect materials; this ensures no hazardous waste makes its way into the feedstock. Since these systems are already in place in Peoria, it is an easier transition.

Partnerships

The cost analysis and other research described in this report could be presented to potential partners to explain how this is a worthwhile investment for all parties involved. While Peoria does not have a significant amount of MSW, other cities or entities could contribute their own waste, produce more biogas, and have economic gain. See Appendix for a list of relevant entities.

Recommendations summary

- Construct a dry anaerobic digester, on-site, or in partnership with another entity (recommended biogas technology).
- Construct a fixed-bed gasifier, on-site, or in partnership with another entity (recommended syngas technology).
- Create effective education towards food waste and landfill usage (education and public outreach).
- Mitigate public concerns with information on alternative fuel technologies and its benefits (education and public outreach).
- Create designated drop off sites for food waste (waste sorting).
- Create a sorting system that presorts waste before it is used in the alternative fuel technology (waste sorting).

CONCLUSION

This research report presents the City of Peoria with a possible option of handling their municipal solid waste through alternative fuel technologies, biogas and syngas, and partnerships. Currently, Peoria utilizes other cities' landfills to dispose of their waste and has no means to manage it themselves. To alleviate some of the dependency on other cities, financial aspects, and environmental stress, the students in ASU's Project Cities conducted extensive research on how to reduce the amount of waste being sent to landfills. The students have provided examples and recommendations that will help Peoria make environmentally conscious decisions, the possibility of saving money, and most importantly, an alternative option to landfills.

The research highlighted the potential benefits that come from investing in a project like this. The primary focus was to show that by using biogas and syngas technology, the city of Peoria can save money on disposal fees from other landfills. Additionally, the students demonstrated how feasible of an option it is to have a City-owned, small-scale, waste management systems in place. Potential partnerships through existing facilities are another effective option because of the established waste transportation system in Peoria.

The students' goals are to encourage and aid Peoria in making municipal solid waste a long-term investment instead of a burden. By continuing with this project, Peoria will have the ability to lead the way, in Arizona and in the nation, by providing safer and more sustainable municipal solid waste options for the community.

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