HOW THE BREWING INDUSTRY CAN SUPPORT A CIRCULAR ECONOMY IN MECKLENBURG COUNTY, NORTH CAROLINA

by

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ABSTRACT

HEATHER M. HENDREN. How the Brewing Industry Can Support a Circular Economy in Mecklenburg County, North Carolina. (Under the direction of DR. JY S. WU)

This research investigates beer production in Mecklenburg County and its impact on water demand, and waste production, with a specific focus on how beer production fits into Charlotte's public strategy of a Circular Economy. Charlotte adopted a Circular Economy to not only provide environmental benefits, by reducing waste and recycling, but also to bridge the wealth divide and create opportunities for upward mobility through innovation and job creation. In this research, three questions are examined in relationship to beer production: investigate the impact of beer production on water demand in Mecklenburg County through 2065, quantify the impact of spent grain waste generated by beer production on the Circular Economy, and assess if and how breweries can support the Circular Economy in Mecklenburg County. The results of this research answers questions to knowledge gaps as to the impact the brewery industry has on water demand and solid waste in Mecklenburg County.

The first area of research is to investigate the long term water demand of the growing brewery industry in Mecklenburg County. In 2014, Catawba-Wateree Water Management Group (CWWMG) completed a Catawba-Wateree River Basin Water Supply Master Plan to protect, preserve and extend the water supply to the Charlotte region. At the time of the report there were limited breweries in operation in Mecklenburg County. Brewing beer is water intensive, requiring anywhere from 4L to almost 14L, depending on the brewery. By 2020, there were 35 breweries in operation. In addition, during this same time period Mecklenburg County experienced a significant growth in population. The research projected out the brewery growth and production, at different levels of production growth, through 2065, in alignment with the

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Catawba-Wateree River Basin Water Supply. The results show that while brewing beer is a water intensive industry, the greatest impact on the water demand is the population growth. The impact on the baseline net withdrawals in 2065 from the higher than anticipated population growth is a 20.4% increase in net withdrawals; however, the addition of the beer production at the average water-to-beer ratio at the base production level only adds an additional 0.41% increase. However, water savings achieved through reducing water demand by the breweries would benefit Mecklenburg County and the surrounding area. In 2020 breweries used more water than other industries in Mecklenburg County by a factor of 2.25 (Water Withdrawal (MGD)/Annual Payroll ($)).

The second area of research was to quantify the brewers' spent grain (BSG) that are produced by brewing beer and project those out over time. Brewers' spent grain is organic waste. Currently, because there is no organic waste ban in Mecklenburg County, the BSG are allowed to be landfilled with other municipal solid waste. In 2018, City of Charlotte adopted a Circular Economy strategy that includes goals to bring down the per capita waste going to the landfill, as well as to reduce the CO_2 equivalent per capita to 2 tons/person. Sending BSG to the landfill increases the per capita waste going to the landfill, particularly as the brewing industry continues to grow in Mecklenburg County. If the BSG is landfilled the contribution to the waste landfilled per capita in 2040 would increase approximately 1.5% to 2.5%. Also, by landfilling the BSG, they breakdown and contribute to an increase in CO_2 equivalent per person for the County. BSG that are disposed of as food waste will increase the tons CO_2E per capita from 0.6% to 1.49%. This percentage might not look significant, but the County needs to achieve an 83% reduction from the 2015 baseline emissions per capita. The research indicates that in order to support the

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goals of a Circular Economy the BSG must not be landfilled and must be treated or recovered to achieve a targeted reduction in the CO_2 ton equivalent per person.

The third area of research was to assess ways in which the BSG could be used to support the goals of the Circular Economy strategy. To do this the environmental, societal, and economic aspects of the BSG waste was analyzed. To analyze the environmental aspects of the BSG waste, the US EPA WARM model different greenhouse gas equivalents were calculated for different treatment options. Combustion of BSG provided the largest avoidance of greenhouse gas equivalents. However, BSG must be dried prior to combustion and there is not a food waste combustion plant in the County. Composting was the next highest option of treatment for the avoidance of greenhouse gas equivalents. The County currently operates a yard waste compost facility. To analyze the societal impact, an analytical hierarchy process (AHP) was performed setting priorities based on the Circular Economy strategy identified in the 2018 report. The following priorities were identified: treatment/disposal aligns with the food waste hierarchy, treatment/disposal reduces the carbon equivalent footprint in accordance with the circular economy strategy, and the treatment/disposal method is easy to implement. Utilizing BSG as human food, as an alternative to flour, and animal feed were the highest treatment options from the AHP analysis followed by composting. However, due to the quantity of BSG generated, the rapid spoilage time and the current low cost of alternative products human food and animal feed are not viable options at this time. Composting followed human food and animal feed in the AHP analysis. The last step was an economic analysis on the option that best supported the Circular Economy. The research supports composting the BSG is currently the best option for supporting the goals of the Circular Economy strategy. Other cities, like San Francisco, have implemented mandatory composting for food waste.

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The research indicates that the brewing industry in Mecklenburg County can support the population and economic growth in the County by working to reduce water demand. While other water demand reductions will need to take place to offset population growth, benchmarking can help the brewery industry continue to grow and minimize water demand. Through benchmarking and resulting process improvements an estimated 9-10% water demand reduction can be achieved. The research indicates that the breweries must be included by the County in a plan to achieve the goals of the Circular Economy strategy. The breweries can support the waste goals of the Circular Economy strategy by not sending BSG to the landfill. Furthermore, the research indicates that by composting the BSG, the breweries will support the goal of reduced waste landfilled per capita and reduce the CO_2 ton equivalent per capita that the Circular Economy strategy hopes to achieve for the area.

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DEDICATION

To Chuck, Carol, Travis, Charlie, and Vincent.

To my daily companions Frank and Tony.

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LIST OF ACRONYMS AND ABBREVIATIONS

AGR	Average Growth Rate
AHP	Analytical Hierarchy Process
BBL	US Beer Barrels (1BBL = 31 Gallons)
BSG	Brewers Spent Grain
Btu	British Thermal Units
C	Carbon
CBO	Congressional Budget Office
CE	Circular Economy
CH_4	Methane
C:N	Carbon to Nitrogen Ratio
CO_2E	Carbon Dioxide Equivalent
GHG	Greenhouse Gas
kg	kilograms
KPI	Key Performance Indicators
lb.	Pound
LFG	Landfill Gas
MGD	Million Gallons per Day
MSW	Municipal Solid Waste
$MtCO_2E$	Metric tons of Carbon Dioxide Equivalent
N	Nitrogen
NPV	Net Present Value
RNG	Renewable Natural Gas
SFDU	Single Family Dwelling Unit
St	Short Ton (1 short ton – 2,000 lbs.)
US EPA	United States Environmental Protection Agency
WL/C	Waste Landfilled per Capita
WtE	Waste-to-Energy

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WWTP	Wastewater Treatment Plan

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CHAPTER 1- INTRODUCTION

In 2018, the City of Charlotte approved a circular economy as a public sector strategy. In doing so, it became the first city in the United States to adopt such a strategy. A Circular Economy (CE) refers to an economy which is waste-free, decoupling economic development from natural resource use, and offers an alternative to the linear system of take-make-dispose (Gladek, Kennedy and Thorin, 2018; Pauliuk, 2017; Blomsma and Brennan, 2017). The goal of adopting this strategy is to balance economic growth while retaining natural resources (Williams, 2018). Charlotte, the largest city in North Carolina, is the county seat of Mecklenburg County, which also includes the towns of Cornelius, Davidson, Huntersville, Mint Hill, Matthews, Pineville, and Stallings.

In a Circular Economy, the value of products and materials is maintained in the economy as long as possible, and waste is minimized, with the ultimate goal of eliminating waste and developing a carbon neutral, resource-efficient and competitive economy. (European Commission, 2019). Charlotte's goal in implementing a Circular Economy strategy is to be a "zero waste and inclusive city." This new strategy, which is to be "waste-free," can eliminate negative environmental impacts and create new sources of value, but can also bridge the wealth divide and create new pathways for upward mobility in Charlotte (Gladek, Kennedy and Thorin, 2018). The large population growth, the amount of waste generated, the value lost in a linear environment and the strain on critical resources, including water, as population and demand grow has necessitated Charlotte's adoption of a circular economic strategy to eliminate negative impacts and create new sources of value (Gladek, Kennedy and Thorin, 2018).

1.1.1 Population Growth in Mecklenburg County

The need to focus on a Circular Economy is due to the large population growth in Mecklenburg County and the subsequent demand on resources. Mecklenburg County has experienced considerable population growth since 2000. Between 2000 and 2010 the Mecklenburg County population grew by 224,174, equating to an annualized growth rate of 2.83% (US Census Bureau Decennial Survey, 2000). The annualized growth rates from 2010 to 2020 was 1.95%, which exceeded those for North Carolina and for the United States. The increase in population between 2010 and 2020, Table 1.1, was 195,854 people, raising the population from 919,628 in 2010 to 1,115,482 in 2020 (US Census Bureau Decennial Survey, 2010; US Census Bureau Decennial Survey, 2020; NC Office of State Budget & Management (OSBM), 2022). The annualized growth rate for Mecklenburg County from 2010 to 2020 is 1.95%, as compared to 0.91% for the state of North Carolina. The projection for 2010 to 2030 is similar, shown in Table 1.2, with Mecklenburg County growing at an annualized growth rate of 1.84% compared to 0.95% for the state (US Census Bureau Decennial Survey 2020; NC OSBM, 2022).

Table 1.1 Deriving Indicators: Changes in Population 2010 to 2020

Area	2010	2020	Change 10-20	% Change 10-20	Annualized Growth Rate 10-20
Mecklenburg	919,628	1,115,482	195,854	21.30	1.95%
North Carolina	9,535,483	10,439,388	903,905	9.48	0.91%

Source: US Decennial Survey, 2010; US Census Bureau Decennial Survey, 2020

Table 1.2 Deriving Indicators: Changes in Population 2010 to 2030

Area	2010	2030	Change 10-30	% Change 10-30	Annualized Growth Rate 10-30
Mecklenburg	919,628	1,324,258	404,630	44.00	1.84%
North Carolina	9,535,483	11,527,150	1,991,667	20.89	0.95%

Source: US Census Bureau Decennial Survey, 2010; NC OSBM, 2022

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1.1.2 Beer Production Growth Mecklenburg County, North Carolina

In addition to population growth from 2010 to 2020, Charlotte experienced a boom in breweries. Between March 2009 and October 2016, 21 breweries opened in Mecklenburg County (Nilsson and Reid, 2019). By 2019, there were 32 breweries in Mecklenburg County (Williams, 2019) and another three opened in 2020, bringing the total to 35 breweries. The market is expected to grow even further with a recent change in regulations and the announcement of a large brewery in Charlotte from one of Germany's oldest beer producers. In March 2019, the NC House and Senate passed the NC Craft Beer Distribution & Modernization Act. The new regulations allow breweries to self-distribute up to 50,000 barrels of beer annually, the previous cap was 25,000 barrels annually, and if a company exceeds the 50,000 annual barrel production, but produces less than 100,000 barrels annually, the brewery can self-distribute the first 50,000 barrels (UNC School of Government, 2019). The change in regulations was demanded by brewers to allow growth without being locked into contracts with wholesalers (Kendall, 2019). It will also allow them to expand their market outside of the Charlotte area by giving them the flexibility to work with distributors that cover different areas (Jackson, 2019). In the summer of 2019, Gilde, a German based brewery since 1546, announced its first US location in Charlotte. The brewer planned to open a microbrewery in Charlotte by the end of 2021, with the ability to brew several thousand barrels of beer a year. With the Covid-19 pandemic, the opening was delayed, but the microbrewery opened in February-2022. In three years, Gilde plans to open a massive brewery in Charlotte that will have the annual capacity of 500,000 barrels of beer (Peralta, 2019).

Charlotte can expect additional brewery production growth due to its growing population, the current breweries, and the number of breweries per population. According to the Brewers

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Association, North Carolina ranked 17th in states for breweries per 100,000 adults 21 and older (Brewers Association, 2018). In fact, Charlotte did not rank in the top 25 cities for breweries per 50,000 people in 2018 according to C & R Research from Chicago (C & R, 2019). Ryan Self, Director of Sales at Olde Mecklenburg Brewery, stated that Charlotte was nowhere near a market bubble, as Charlotte trails behind many other cities with the number of breweries per capita (Barger, 2019). Currently, Charlotte has approximately 2 breweries per 50,000 people (US Census Bureau, 2017 and Williams, 2019). For comparison, Asheville, North Carolina, ranked second in the nation for the most breweries per capita, has 17 breweries per 50,000 people (C & R, 2019). In a recent publication by SmartAsset that ranked "Best Cities for Beer Drinkers -2021 Edition," cities with populations over 60,000 as of the 2020 Census and at least one brewery was ranked by the following five criteria: total number of breweries, total number of breweries per 100,000 residents, average number of beers per brewery, number of bars per 100,000 residents and average price of a pint of domestic draught beer as of January 2021. Asheville was ranked fifth, out of 366 cities and Charlotte, North Carolina was not ranked in the in the top fifty cities, indicating there is room in the market for brewery growth in Charlotte (Cutler, 2021; Villanova, 2021). While energy is also an important input in beer brewing, this research concentrated on the water impact and the BSG waste.

1.1.3 Beer Production Water Use

Brewing beer consumes huge amounts of water, so the source of water needs to be plentiful and reliable (Alworth, 2015). With the increasing population and demand for water, brewers will experience increased scrutiny and water risk and regulation (Brewers Association, 2017). Beer requires a significant amount of water to produce and generates a lot of waste. Typically, breweries use between 4 and 7 L of water to produce 1 L of beer (Olajire, 2012).

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Small breweries use much more water (Goldammer, 2008) and for less efficient breweries the ratio can go as high as 10L to 1L of beer (Agnew, 2016). The Brewer's Association found that the size of the brewery has the largest impact on water per liter of beer. Facilities with larger production volumes tend to have lower water use ratios (Brewers Association, 2017a). Also, through their 2016 sustainability survey, the Brewer's Association found that breweries in the Southeast used 4.7 L to 13.9 L of water per liter of beer and that water reduction is not typically driven by cost savings. Focus on water reduction tends to be driven by the need to support the image of a community based, sustainable business and to protect their source of water from future water risk (Brewers Association, 2017b).

1.1.4 Water Supply Charlotte

Clean water is important for any city, but particularly for cities with a brewery industry. Water is the most important raw material used in the production of beer. According to a European Industry report, water makes up, on average, 92% of beer (The Brewers of Europe, 2012). Charlotte, the largest city in North Carolina, is located in Mecklenburg County. According to a 2014 Water Supply Master Plan conducted by the Catawba-Wateree Water Management Group (CWWMG), Charlotte could reach unstainable water usage, when water demand exceeds water supply (Brown et al., 2019), in less than 50 years (CWWMG, 2014). Since the CWWMG Master Plan was published in 2014, the population growth has exceeded the baseline projections and Annualized Growth Rate. Furthermore, since completion of the Master Plan in 2014, Charlotte has seen a larger than projected population growth and an explosion in the Craft Brewery Industry through 2019. However, the craft brewery industry in Charlotte experienced a reduction in production volume with the onset of the COVID-19 pandemic in Spring 2020. The Brewer's Association estimates that the mid-Year 2020 volume of craft beer

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declined at least 10% from the same time in 2019. However, prior to the COVID-19 downturn, craft brewing production volume was up 3-4% at the beginning of 2020 compared to the same time in 2019 (Watson, 2020b). The Brewers Association reported an 8% growth in 2021 over 2020 (Gatza and Watson, 2022).

In 2018, Envision Charlotte, a public private plus cooperative, identified long term goals to extend water sustainability in Charlotte by 40 years. Benchmarking data were collected on 22 commercial buildings in Uptown Charlotte to identify potential water saving opportunities. The benchmarking was just the beginning to work towards long-term sustainable solutions (Itron, 2018). With the large amount of water used to brew beer, anywhere from 4L to 14L of water per liter of beer (Fillaudeau et al., 2006; Brewers Association, 2017b), the breweries need to be part of this benchmarking and analysis. The Colorado Department of Public Health and Environment provided breweries in Colorado state funded onsite benchmarking assessments to help identify opportunities for reducing environmental impact, including water use reduction (CDPHE, 2018). Because brewing beer consumes 3 to 7 times the amount of water contained in the beer, they recognized the importance of preserving the scare resource that is needed to support a growing city and drive industry (CDPHE, 2019). Population increase creates pressure on the water supply, which is further magnified by the growth of water intensive industry of brewing beer (Koop and van Leeuwen, 2017).

1.1.5 Waste Generation in Charlotte

Cities generate massive amounts of solid waste and managing this waste is a challenge to cities of all sizes all around the world (Koop and van Leeuwen, 2017). Cities are concentrated centers of production, and the resulting waste generated drive a host of environmental problems (Grimm et al. 2008). In 2018, the EPA reported that the total Municipal Solid Waste (MSW) was

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292.4 million (US short) tons, or 4.9 pounds per person per day. Of the 292.4 million tons, 63,130,000 tons, or 21.59%, was food waste. The same year 146.1 million tons of the MSW generated was landfilled, food waste comprising 24% of the MSW landfilled (USEPA, 2018a). For Mecklenburg County, the North Carolina Department of Environmental Quality reported in 2018 that the per capita rate was 1.30 tons per person, for a total of 1,425,782 tons of MSW that was sent to landfills. A 2018 report commissioned by the City of Charlotte and Envision Charlotte to study Charlotte's move to a Circular Economy, found that 18% of the MSW that was land filled was food waste.

Food waste is a major source of methane, a greenhouse gas (GHG). Methane has the global warming potential 28-36 times greater than CO_2 over a 100-year period (USEPA, 2021i). Landfills are the third largest contributor of human-related methane emissions in the United States, accounting for 15.1 percent of emissions in 2019 (USEPA, 2021e)

1.1.6 Beer Production Solid Waste Generation

In addition to using a large amount of water in production, beer production generates a large amount of waste, particularly solid waste. Typical solid waste includes spent grain, trub, spent yeast and diatomaceous earth (DE) slurry. The main side-stream of the brewing process is spent grain (BSG), representing approximately 85% of the organic by-products from brewing (Bolwig et al., 2019; Lynch et al., 2016; Witkiewicz, 2012). For every liter of beer produced, there is approximately 0.46 lbs. of BSG that are generated (Lynch et al., 2016; Assandri et al., 2021). BSG mainly consist of barley grain husks (Xiros and Christakopoulos, 2012) so it is considered food waste when disposed of as Municipal Solid Waste (MSW). The disposal of BSG is problematic due to the large quantities that are generated every time a batch of beer is brewed,

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the little to low market value of the waste, and the limited storage period prior to spoilage due to the high moisture content (Xiros and Christakopoulos, 2012; Assandri et al., 2021).

1.2 Research Objectives, Research Questions and Significance of Research

The overall purpose of this research is to investigate the role of the brewery industry in the planned Circular Economy in Charlotte, North Carolina. Three major questions are examined in relation to the growth in beer production: 1) What is the long term stress of additional water consumption? 2) What is the impact of the amount of food waste being generated by the production of beer on the Circular Economy strategy goal of being “waste free?” and 3) Can beer production support the proposed Circular Economy in a way that is beneficial to business, consumers, and the county? The objective of these separate but related analyses is to answer important questions that can guide future beer production and growth in Mecklenburg County.

1.2.1 Research Question 1: What is the Impact on Water Demand by Beer Production in Mecklenburg County?

Beer production is water intensive. In recent publications the impact of the Craft Brewery industry on the water supply has not been duly reported. This paper provides a review of the water demand of the breweries in Charlotte and surrounding Mecklenburg County. The intent is to assess the growth of the brewery industry, coupled with larger than forecasted population growth, on the CWWMG Master Plan water use projections. The overall objective of this portion of the research is to quantify the current water demand by breweries, and to project the water demand with anticipated brewery growth coupled with population growth. The main question would be: “Is the brewery growth sustainable with the projected water demand and what measures, if any, should the County implement to be able to support the growth of the industry?”

The current CWWMG plan was established before Mecklenburg County experienced the growth in the brewery industry. Also, the current City of Charlotte Circular Economy plan does

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not specifically address the growing water demand from the growing brewery industry. Sustainable and efficient water supply management is necessary due to the growing demand of the region.

1.2.2 Research Question 2: What is the Impact on the Circular Economy of Spent Grain Waste Generated by Beer Production in Mecklenburg County?

The brewing process, as compared to many other industrial processes, has an impact on the environment because of the huge amount of waste it generates (Amoriello and Ciccoritti, 2021). In 2016, it was estimated that 6 billion pounds of BSG was produced in the United States, and that much of that was disposed of in landfills (Zebell et al., 2016). Currently there are no government regulations or policies regarding any special treatment or disposal requirements for BSG. There are no specific food waste recovery requirements for the City of Charlotte or Mecklenburg County, while the Circular Charlotte plan has a goal to make Charlotte a Zero-Waste City by 2050. The Circular Charlotte plan proposes to terminate use of all landfills by 2040, minimize annual GHG emissions to 2 tons per person, recover maximum value from waste streams and ensure that nutrients from all organic waste streams are returned to natural cycles. However, there is no specific mention of the BSG generated at the breweries and how the waste should be treated.

The current City of Charlotte Circular Economy plan does not specifically address BSG when identifying waste streams and food waste. This research will attempt to quantify the amount of BSG generated by the breweries in Mecklenburg County and identify how the waste is currently being managed through a waste survey of the individual breweries.

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1.2.3 Research Question 3: Can Breweries Support the Circular Economy in Charlotte, North Carolina?

Currently there is no documented plan for how the breweries can support the Circular Economy initiative in the City of Charlotte. Several goals of the Circular Economy are impacted by the growing brewery industry. These include, but are not limited to, the termination of all landfill use by 2040, minimizing GHG emissions to 2 tons per person by 2050, recovering maximum value from waste streams, ensuring that all nutrients from all organic wastes are returned to natural cycles, improving its new resource efficiency, maintaining clean water and ensuring that all residents have access to healthy food (Gladek, Kennedy and Thorin, 2018). Can breweries support the Circular Economy initiative in Charlotte, North Carolina and to what extent?

To meet the established goals of the Circular Charlotte initiative, a plan for the water consumption and solid waste of beer production needs to be included. An analysis of the current consumption and waste disposal will be conducted with potential steps to support the Circular Economy, based on the published goals.

1.3 Dissertation Organization

This dissertation consists of six chapters. Chapter 1 contains background information for the brewery industry in Mecklenburg County. The research questions are proposed in terms of knowledge gaps and justifications for the research. Chapter 2 provides a literature review conducted to understand the current research and practices and to identify the unknowns as it relates to beer production, water use and waste generation in Mecklenburg County. Chapters 3, 4 and 5 present the data collected, the methodology and the analysis completed to obtain results. Chapter 6 connects all three research questions to the Circular Economy. References are provided at the end of the paper. The research uses published data, collected data, multi-criteria

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decision analysis and cost analysis to meet the established objectives and to answer the research questions.

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CHAPTER 2 – LITERATURE REVIEW

The existing literature is reviewed for topics including water use in beer production, waste generated in Charlotte breweries and analysis of breweries supporting Charlotte's Circular Economy initiative.

2.1 Perspectives on Water Use in Beer Production

"Freshwater is essential for life. Water is public health. Water is food. Water is energy," said Arjen Hoekstra, creator of the water footprint concept, to emphasize the importance and scarcity of water and the need for sustainable allocation. He argues that "freshwater is a renewable resource, but finite, and to a large extent has the characteristics of a non-reproducible resource (Hoekstra, 2020)." Water is important in brewing beer, and high consumption of good-quality water is necessary in brewing beer (Goldammer, 2008). Water shortages occur when the water demand exceeds the water available to meet that demand. Traditionally, the water demand and supply were balanced by an ability to adapt, these adaptation measures included reservoir storage, instream flow removals and groundwater mining. However, projections for many areas of the United States indicate that population growth and projected climate change will likely cause water shortages, and although continued improvements in water use efficiency will help reduce water demand, those improvements will be insufficient to avoid future water shortages (Brown et al., 2019).

2.1.1 Beer Industry Benchmarking and Reduction in Production Water Consumption

The need to reduce water consumption in Mecklenburg County has been established by the 2014 Water Supply Master Plan conducted by the Catawba-Wateree Water Management Group (CWWMG (CWWMG, 2014). While the growing brewery industry supports economic development in the County, it is also a large consumer of water, which will increase as the

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industry grows. Sustainable development measures, such as benchmarking, can assess trends and promote improvement, to support policy decision making before economic, societal, and environmental thresholds are met (Tokos et al., 2012). Benchmarking can answer whether a brewery is efficient compared to others and if not, what practice can be improved (Goncharuk and Lazareva, 2017). Benchmarking identifies potential improvements but requires data and specific knowledge of the production (Kubule et al., 2016). Small and privately owned breweries often do not have the resources to collect, analyze and report benchmarking data (Bumblauskas, 2015). Data collection and reporting can be time-consuming.

Water consumption per unit of production is a tool that is used to determine the performance of a brewery in comparison to other breweries (Fillaudeau et al., 2006). In 2017, Colorado Department of Public Health and Environment (CDPHE) started a Sustainable Brewery Initiative. The focus on sustainability helps businesses to meet the resource needs of today without compromising the ability of future generations to meet their needs, and specifically for businesses to reduce their overall environmental impact. In 2017, the Brewery Initiative focused on 22 craft brewery facilities that produced nearly 400,000 barrels of beer. At the beginning the program offered no-cost, sustainability assessments, not only focused on water benchmarks but also energy and waste. At the conclusion of the assessment, the program recommended simple, cheap measures, focusing on low capital projects with a three year or less Return on Investment (ROI). These measures included recommending tracking water usage through locally available utility audits. At the onset of the initiative, only half of the breweries were tracking water usage. The breweries were provided industry benchmarking data available through the Brewers Association. For example, one water saving suggestion was reusing hot water from their heat exchanger for the next brew or for cleaning purposes. At the onset of the

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initiative only 27% of the breweries had implemented this process (CDPHE, 2018). The barriers identified in the Brewery initiative included costs associated with recommended actions and time needed by staff to collect data and analyze (CDPHE, 2018).

Envision Charlotte began a similar program in Charlotte, not for breweries but for twenty-two commercial buildings in downtown. Envision Charlotte had completed a similar benchmarking project for energy consumption. A 19 percent reduction in energy consumption in commercial buildings was achieved by those that participated in the program. Similar to the CDPHE Sustainable Brewery Initiative, the Envision Charlotte water benchmarking project began collecting data on water usage. The usage data and comparative industry benchmarks were given to building managers to encourage analyzing water usage and identify water-saving opportunities. The future goal is to use the usage information to implement sustainability programs and reduce water usage (CDPHE, 2018; Itron, 2018).

2.1.2 Safe Yield of Water

While there are many definitions of 'safe yield,' it is commonly defined as the maximum quantity of water that can be continuously withdrawn from a groundwater basin and the annual amount of recharge, without adverse effect (Sophocleous, 2000). Safe yield is a useful baseline for planning and water management because it sets a long-term groundwater extraction goal from the basin while taking into account climate change and population growth. The long-term extraction rate avoids adverse impacts to groundwater and is widely used as a sustainability management tool (Loáiciga, 2017). Sustainability is commonly defined as the ability to meet the needs of the present without compromising the ability to meet needs in the future (Sophocleous, 2000). The two concepts are aligned, as safe yield has been expanded over time to include not only the environment, but also economic and water quality concepts for society. Water

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sustainability is not purely a scientific concept, but should be used to frame development decisions that require a tradeoff between water used for consumption and those subsequent impacts on the environment. Basin withdrawals cannot be identified as safe or sustainable without looking at their long-term implications and even then, need to be evaluated on a continuum range from weak to strong incorporating the environment, economy, and societal implications (Alley and Leake, 2004).

Safe yield can be a useful baseline number to establish a long-term goal for water usage, with sustainability overlayed. The reason behind joining the two is because there is an ambiguity to safe yield that has given it a contentious profile. This includes who should determine what the safe yield value is and also, how do you estimate it over such a long time period while factoring in the uncertainties of climate change, population growth and demand growth? Safe yield is important and widely used as a benchmark (Loáiciga, 2017). There is increasing competition for access to water, which has created a public policy dilemma for managing water resources. For sustainable resource management, the sustainable yield must be considerably less than the recharge, which is why safe yield alone is a flawed concept (Sophocleous, 2000).

2.2 Circular Economy and Waste

2.2.1 Implementing a Circular Economy

As a way to combat resource scarcity and environmental degradation, China implemented a policy goal to create a Circular Economy (Geng et al., 2009). In 2002, China advocated that economic systems could operate “according to the materials and energy cycling principles that drive natural systems” and introduced a Circular Economy policy goal as a new development model so that it could “leapfrog” past environmental damage that is typical as countries industrialize (Geng and Doberstein, 2008; Suet al., 2013). China implemented a national strategy

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by promoting a top-down approach (Ghisellini et al., 2015) and issued a “Cleaner Production Promotion Law (CP)” in 2002. The CP addressed the generation of pollution as well as a strategy for efficiently using resources at the different stages of production (Su et al., 2013; Hicks and Dietmar, 2007).

The successful implementation of a Circular Economy in China is on the three levels of micro-, meso-, and macro-economies (Yuan et al., 2006, Su et al., 2013; Geng et al., 2009) and focuses on four main areas including production, consumption, waste management and other support which includes policies and laws, and NGOs (Su, 2013; Naustdalslid, 2014). At the micro or corporate level, the four main focus areas change in parallel, and an individual firm is encouraged, or required, to make changes (Su et al., 2013; Yuan and Moriguichi, 2006; Geng and Doberstein, 2008). At the meso, or inter-firm level, the four main focus areas also change in parallel but with multiple firms an industrial symbiosis, a waste from one firm becomes a benefit to another, or an eco-industrial network is created (Su et al. , 2013; Yuan, et al. 2006). Also, at the meso level the utilization of integrated resources between multiple firms is needed (Su et. al. 2013). The macro level is a city, province, or state level that would create a regional eco-industrial network. The alternative to the top down, national strategy applied in China is a market-based approach applied in Europe, Japan, and the United States (Ghisellini et al. 2016). The bottom-up market-based approach differs because there is an economic demand for more environmentally sustainable products and supporting legislation that connects the public and private sectors (Ghisellini, et al. 2016; Naustdalslid, 2014).

Barriers to implementing the Circular Economy are common to both the top-down and bottom-up approaches. The first barrier is the need to have industry incentives for sustainable production and consumption. This can include waste reduction and waste reclamation. The

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second challenge is the financial cost of implementing Circular Economy processes. The third challenge is the lack of public awareness and participation concerning the nature of a circular system and how to adjust system conditions (Webster, 2017; Su et al. 2013; Geng et al. 2009).

2.2.2 Circular Economy Plan in Charlotte

In 2018, the City of Charlotte and Envision Charlotte commissioned Metabolic, a consulting firm specializing in sustainable solutions, to analyze Charlotte's waste production and propose a strategy to transform Charlotte into a Circular Economy. According to the Metabolic report, 11.5% of materials in the Charlotte waste stream are recycled. Also, 16% of the waste that Charlotte sends to landfills is food waste. The report notes that Charlotte lacks free organic waste recycling programs that provide alternatives to landfills (Gladek, Kennedy and Thorin, 2018). Currently, Charlotte and Mecklenburg County provide no food waste recovery programs to residents and there are no mandatory programs for food recovery from commercial businesses.

As part of the Circular Economy planned for Charlotte, food waste is incorporated into the short-term, medium term and long-term planning recommended in the Metabolic report (Gladek, Kennedy and Thorin, 2018). The following food waste plan is proposed in the report:

Short-term (0-5 Years) – Campaign for food waste reduction and prioritize waste streams

Medium-term (5-10 Years) – Provide refunds or credits to incentivize recycling behavior and ban food wastes generated by restaurants.

Long-term (10-15 Years) – Pay-as-you-throw Programs – rates set for the amount of waste individuals dispose in order to increase participation in reduction and recycling programs.

The report claims that 56,620 tons of organic waste is currently composted. In addition, the report proposes a plan to upcycle food waste into feed stock. By diverting 55,000 tons, from the 250,000 tons produced annually, of food waste from the landfill to black soldier fly larvae that

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will eat the waste and produce animal feed, $1.65 million in tipping fees will be saved and 90,000 tons of annual CO_2E emissions prevented (Gladek, Kennedy and Thorin, 2018). CO_2E is "a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2) (USEPA, 2022i)." The revenue from the feed will be used to expand food waste collection programs (Gladek, Kennedy and Thorin, 2018). The report does not separately address the amount of brewery waste currently produced in Mecklenburg County. The spent grain from breweries is food waste that is rich in organics, consisting of mainly barley grain husks that are rich in fiber and protein (Lynch et al., 2016; Xiros and Christakopoulos, 2012; Jackowski et al., 2020). Currently the water ordinances for Charlotte do not specifically address brewery waste. The report also does not mention alternatives to the larvae upcycle and what other communities have already developed successful food waste recovery programs. As a note to the long term waste plan in the Circular Economy plan for Charlotte, Pay-as-you-throw programs are not always successful. For example, in Seattle, Washington when the City imposed a large landfill rate increase, residents increased the average pounds of garbage in each collection container by 11.3% to avoid paying the additional fees (Craig, 1995).

2.2.3 Waste Hierarchy in a Circular Economy

A 2015 report from the Ellen MacArthur Foundation and the McKinsey Center for Business and Environment defined the Circular Economy as "an economy that provides multiple value-creation mechanisms which are decoupled from the consumption of finite resources (Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015a)." Similarly, a Circular Economy is defined as "a regenerative system in which resource input and waste, emission and energy leakage are minimized by slowing, closing, and narrowing material and

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energy loops (Geissdoerfer et al., 2017). Waste management plays an important role in the European Commission Action Plan to transition to a Circular Economy. In 2008, the European Commission created a waste hierarchy to address waste management (Figure 2.1). The focus is on preventing waste from the start. The last and most unappealing option is disposal. This includes sending waste to a landfill or to an incinerator without energy recovery (European Commission, 2016).

Figure 2. 1 European Commission Waste Hierarchy (European Commission, 2016)

The Circular Economy gives the framework for how the Waste Hierarchy should be applied. The priority is to prevent waste, reuse, recycle and recover energy and as a last option dispose of the waste (European Commission, 2015). The goal of the waste management is to avoid the loss of resources through landfilling. The waste hierarchy provides the framework for linking environmental and economic goals of the Circular Economy (European Commission 2015). The US EPA has a similar waste hierarchy, aimed at reducing the amount of disposable waste and preserving the valuable, limited landfill space (USEPA, 2018b). The EPA also promotes sustainable management of food with a Food Recovery Hierarchy (Figure 2.2) that can be applied to the food waste at breweries. The EPA estimates that 24% of all solid waste that is landfilled is food waste (US EPA, 2021d).

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Sustainable management of food helps businesses and consumers save money, it helps support people in the community without enough to eat, and it conserves resources which support society (USEPA, 2019).

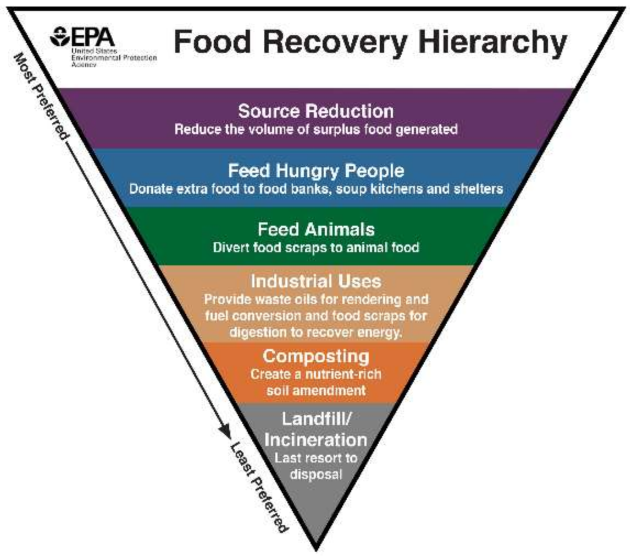

Figure 2. 2 US EPA Food Recovery Hierarchy (USEPA, 2019)

2.2.4 Food Waste within the Circular Economy

The Food and Agriculture Organization (FAO) of the United Nations estimated in 2011 that roughly one-third of food produced in the world for human consumption is lost or wasted (Gustavsson et al, 2011; EUFIC, 2021). In 2019, the United Nations estimated that 931 million tons of food waste was generated (UNEP, 2021). If the emissions from food loss and waste were measured as a country's emissions, it would be the third biggest source of greenhouse gas emissions behind China and the United States (EUFIC, 2021). In 2011, the annual average per capita greenhouse gas (GHG) emission from food loss and waste was 323 kg CO_2E, or 711 lb. CO_2E (Porter et al., 2016). In the United States, food waste is the most common material that is landfilled, comprising 24 percent of material landfilled (US EPA, 2021d).

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From 1961 to 2011 there was a 44% increase in emissions per capita due to food loss and waste, estimated at 225 kg CO_2E to 323 kg CO_2E, an annual growth rate of 0.7% (Porter et. al, 2016). The wasted amounts differ based on the income level of the country: high-income countries produce more than two times the food waste than upper-middle-income countries and four to six times higher than low-income countries (Chen et al., 2020). During this period, North America showed the lowest cumulative food loss and waste emission growth at 10%, partially because the per capita waste was so high in North America (Porter et al., 2016). The US waste is estimated at 492 to 1,032 pounds per person per year (223 kg to 468 kg per person per year), higher than any other country (Chen et al., 2020; USEPA, 2021d).

Moving to a circular economy has become critical for many cities and countries for several reasons including the growing demand for food and consumption of finite resources (Klitkou et al., 2019; Ellen MacArthur Foundation, 2015). Faced with these challenges there has been a paradigm shift in resource and environmental management, which in turn has resulted in adoption of the circular economy concept (Nghiem, et al., 2017). The United Nations in their 2030 Agenda for Sustainable Development identified seventeen (17) Sustainable Development Goals (SDG) that were adopted by the member states in 2015. Goal 12 is to "Ensure sustainable consumption and production patterns," and specifically related to food waste, and subsequently food waste from breweries, Goal 12.3 is to halve per capita food waste and losses by 2030 (United Nations, 2015).

In 2015, the European Union published their action plan for implementing a Circular Economy to "develop a sustainable, low carbon, resource efficient and competitive economy." The benefits from addressing waste included reduced landfilling and increased reuse and recycling of waste. However, the plan identified barriers such as a limited secondary market for

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recycled products and the lack of data or reliable measures for food waste (European Commission, 2015). In the plan, the European Union identified that there is “no harmonized, reliable method to measure food waste,” which made addressing the problem of reducing food waste a challenge (European Commission, 2015). Similar to the European Union, the United States currently does not have a harmonized and reliable method to measure food waste (USDA, 2022). The EPA and USDA both use 2010 as the baseline estimate, but neither estimate provides a comprehensive measure of food loss and waste. The EPA 2010 estimate, based on 2010 baseline, is 218.9 pounds of food waste per person sent for disposal. The USDA 2010 baseline estimate is 31 percent of the food supply, equaling 133 billion pounds (USDA, 2022). Similar to the barriers identified by the European Union, brewers spent grain is not currently measured at a community level and has a limited secondary market due to the large quantity produced by each brew, little to no market value and limited storage period (USDA, 2022; Xiros and Christakopoulos, 2012; Assandri et al., 2021).

In the United States in 2019, the U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (USEPA) and the U.S. Food and Drug Administration (USFDA) signed a joint agreement entitled “Winning on Reducing Food Waste Initiative (USDA, USEPA, USFDA, 2018).” Similar to the United Nation’s Sustainable Development Goal 12.3, and the European Commission Circular Economy plan of 2015, the initiative set a national goal of reducing food loss and waste by 50% by 2030 (USDA, USEPA, USFDA, 2018). In their 2019 report, the Ellen Macarthur Foundation found that “less than 2% of biological nutrients in food by-products and organic waste is composted or otherwise valorized.” Also, by 2050 it is expected that 80% of all food will be consumed in cities (Ellen MacArthur Foundation, 2019). This gives cities, including Charlotte, a unique opportunity to support the goal of a

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circular economy. Specifically for food, there are three defined objectives for a city to support a circular economy. They are 1) to source food grown regeneratively and locally, when possible, 2) make the most use of food, which means designing out food waste, and 3) design and market healthier food products (Ellen MacArthur Foundation, 2019). Reducing and then valorizing food waste will be key for cities to be able to meet the above objectives.

2.3 Managing Food Waste

In the United States, food represented 21.6% of total municipal solid waste (MSW) generated in 2018 (USEPA, 2020a). There are several options for managing food waste. The common methods for dealing with general food waste are: landfilling, composting, anaerobic digestion, animal feed and incineration. All of these can be applied to beer spent grain. In addition, the beer spent grain can be transformed into products for human consumption, which will be discussed in waste valorization. Table 2.1, from the US EPA, summarizes the MSW disposal methods used in the United States, by decade, from 1960 to 2018 (USEPA, 2020a).

Table 2. 1 Generation, Recycling, Composting, Other Food Management Pathways, Combustion with Energy Recovery and Landfilling of MSW 1960 to 2018 in the United States (Million tons)

Activity	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	88.1	121.1	151.6	208.3	243.5	253.7	251.1	262.1	268.7	292.4
Recycling	5.6	8.0	14.5	29.0	53.0	59.2	65.3	67.6	67.0	69.1
Composting*	neg.	neg.	neg.	4.2	16.5	20.6	20.2	23.4	27.0	24.9
Other Food Management**	-	-	-	-	-	-	-	-	-	17.7
Combustion with Energy Recovery***	0.0	0.5	2.8	29.8	33.7	31.7	29.3	33.5	34.2	34.6
Landfilling and other disposal****	82.5	112.6	134.3	145.3	140.3	142.2	136.3	137.6	140.5	146.1

Details might not add to totals due to rounding. Negligible (neg.) = less than 5,000 tons or 0.05 percent. A dash in the table means that data are not available.

*Composting of yard trimmings, food and other MSW organic material. Does not include backyard composting.

** Other food management pathways include animal feed, bio-based materials/biochemical processing, codigestion/anaerobic digestion, donation, land application and sewer/wastewater treatment.

*** Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery of source separated materials in MSW (e.g., wood pallets, tire-derived fuel).

**** Landfilling is what remains after recycling, composting, other food management and combustion with energy recovery are accounted for. Landfilling includes other disposal methods such as combustion without energy recovery.

Source: Reproduced from USEPA, 2020a

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2.3.1 Landfilling of Food Waste

Landfilling is the most common way of disposing of food waste in the United States. It is the sixth, or lowest level, of the EPA's Food Waste Recovery Hierarchy. Landfills are managed facilities for the disposal of waste (USEPA, 2021c). Landfills for non-hazardous Municipal Solid Waste, including food waste, are regulated by Subtitle D of Resource Conservation and Recovery Act (RCRA). RCRA sets minimum federal criteria for the operation of municipal waste landfills, including design criteria, location restrictions, cleanup corrective actions and closure requirements (USEPA, 2021h). Landfills accounted for 14.5% of human-related methane emissions in 2020. This total represents the equivalent of GHG emissions from 20.3 million passenger vehicles driven for a year or the CO_2 emissions of energy use from 11.9 million homes for one year (US EPA, 2022b). In 2018, the US EPA estimated that 33% of commercial food waste was sent to a landfill (USEPA, 2020c).

When waste is placed in a landfill, initially there is little methane production because oxygen is present. As time passes, typically less than a year, anaerobic conditions are established, and methane-producing bacteria begin to decompose the waste and the methane production increases (USEPA, 2022f). Over time, the methane production exceeds the carbon dioxide production (Figure 2.3). The gas composition changes in each phase as the waste decomposes. The emitted landfill gas (LFG) can be captured and used as energy. The gas can be used to generate electricity through reciprocating internal combustion engines, turbines, microturbines and fuel cells. The electricity generated can be used on-site and/or sold to the grid. The gas can also be used directly to offset the use of another fuel, like coal or fuel oil. Lastly, it can be treated and upgraded to renewable natural gas (RNG) to generate electricity or used as fuel for vehicles (US EPA, 2022b).

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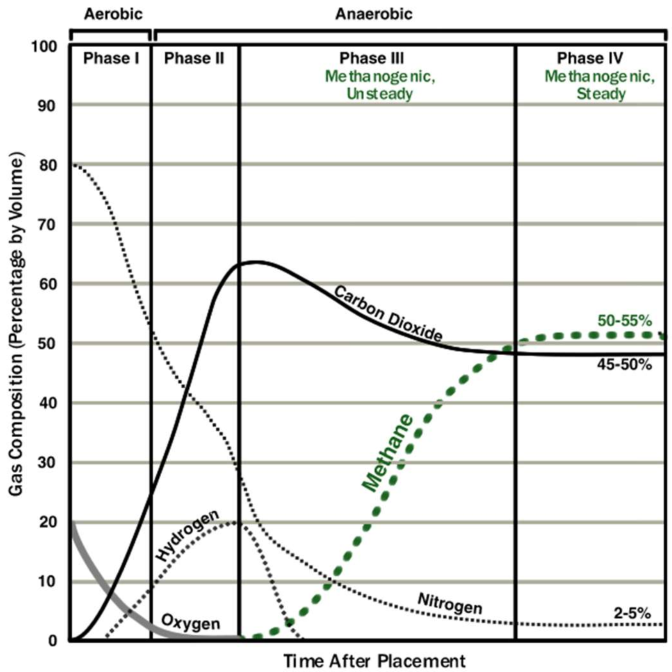

Figure 2. 3 Greenhouse Gas Emissions from Landfills Over Time (USEPA, 2022f)

2.3.2 Composting of Food Waste

Composting is the decomposition of organic waste by microorganisms in an aerobic, oxygen present, process. The resulting material is a soil-like byproduct that resembles humus. Composting is a controlled process that requires energy input but does not generate energy that can be utilized like LFG. There are five areas that must be controlled during composting: feedstock and nutrient balance, particle size, moisture content, oxygen flow and temperature (USEPA, 2022h). A summary of the different composting system options is provided in Table 2.2.

Composting is promoted as a scalable, flexible approach that can reduce carbon-dioxide equivalent greenhouse gas emissions by 50% (Project Drawdown, 2022). General benefits derived from the production and application of compost are the reduction and/or elimination of chemical fertilizers, higher yields of agricultural crops, improved marginal soils, enhanced water

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retention of soils, and carbon sequestration (USEPA, 2022h). For healthy soils, the balance between carbon inputs and carbon mineralization is in equilibrium. Disturbed soils have low carbon and will have higher rates of net carbon sequestration than less disturbed soils. The application of compost to disturbed soils allows carbon to accumulate until equilibrium conditions are reached (Morris, 2014).

The characteristics of a batch of compost can vary greatly and the result of feedstock used and the composting process. The most important characteristic for plant growth is the carbon (C) to nitrogen (N) ratio (C:N). For compost with a C:N < 20, a percentage of the N is plant-available the first year, if C:N is between 20 and 30 there is no N released during the first year, and compost with a C:N greater than 30 will render the soil nitrogen deficient, as a result of nitrogen immobilization, and thereby reduce crop yield in the short run (Gale et al., 2006; Morris, 2014; Hills et al., 2019). Concerns about contamination often reduce the demand for compost. Contamination of compost by heavy metals and micro- and nanoplastics can introduce toxins into the food chain and that contamination can outweigh the potential soil health and yield benefits and provide a resistance to use of compost (Hills et al., 2019; Weithmann et al., 2018; Pathan et al., 2020).

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Table 2. 2 Summary of Composting Systems

Composting Systems	Description	Benefits or Positive Aspects	Challenges or Negative Aspects
On-Site Composting	Yard trimmings and small quantities of food scraps can be composted on site in a compost pile.	Low cost - little time or equipment	Only good for a small amount of wasted food Food scraps need to be handled properly to not cause odors or attract animals and insects No animal products Time - compost can take up to two years, manual turning can reduce the time to three to six months
Vermicomposting	Red worms in bins feed on organic matter, including food scraps, and yard trimmings to break the material down into a high quality compost called castings. It takes three to four months to produce castings	Bins are easy to construct or purchase One pound of worms can eat up to half pound of organic material per day	Worms are sensitive to temperatures and must be provided sufficient food N_2O emissions from strongly nitrifying conditions in the processing beds combined with the presence of de-nitrifying bacteria within the worm gut.*
Aerated (Turned) Windrow Composting	Organic waste is formed into rows of long piles called "windrows" and aerating them periodically by manually or mechanically turning. Piles should be between 4 to 8 feet high with a width of 14 to 16 feet.	Good for large volumes - example communities, restaurants Large amounts of compost produced	Requires large tracts of land, equipment, labor Windrows in warm climates must be covered to prevent water from evaporating Produces leachate that must be collected and treated Odors need to be controlled Compost must be tested for bacterial and heavy metal content Large amounts of compost that must be distributed or sold
Aerated Static Pile Composting	Organic waste is mixed in a large pile. Bulking agents are added to aerate the pile. The piles can also be placed over equipment that delivers air to the pile or draws air out.	Good for large generators of yard trimmings and compostable municipal solid waste (i.e. food scraps), such as local governments. It is most suitable for homogenous mix of organic waste.	Does not work well for composting animal byproducts or grease from food processing industries. In warm climates, piles must be covered to prevent water from evaporating. There may be significant equipment costs for blowers, pipes, sensors and fans CH_4 emissions due to created anaerobic zones*
In-Vessel Composting	Organic materials are placed into a drum, silo, concrete-lined trench, or similar equipment. The material is mechanically turned or mixed to aerate.	Good for large amounts of any type of organize waste Does not take up as much space as Windrow Composting The size of the vessel can vary based on capacity. Produces compost in just a few weeks and once the microbial activity is balanced and the pile cools it is ready for use. Little odor or leachate produced. Requires less land and labor than windrow composting.	Expensive and requires technical expertise to operate.

Source: All from USEPA, 2022h except *Hobson et al., 2005

2.3.3 Anaerobic Digestion of Food Waste

Anaerobic digestion (AD) is the breakdown of organic materials by microorganisms in a closed space in the absence of oxygen. The process takes place in a digester, and the feedstock can be animal manures, food scraps, fats, oils, and greases, industrial organic residuals, and

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sewage sludge, also known as biosolids. There are two products created through the process: biogas and digestate. Biogas is mainly methane and carbon dioxide, in addition to small amounts of water vapor and other gases. The biogas can be collected, the CO_2 and the other gases removed, leaving CH_4. How the biogas is used depends on its quality, but it can be used for powering engines, heating and/or electricity generation, run alternative-fuel vehicles and be distributed through the natural gas pipelines for use in homes and businesses (USEPA, 2021b). Biogas is capable of running all devices that can run on natural gas, but it is necessary to adjust for the lower Btu content (Moriarty, 2013). The digestate created is a wet mixture that is rich in nutrients that are approximately 30% biosolids and 70% liquids. The solids and liquid are typically separated, and the liquid is applied directly to land as a low-grade fertilizer. The remaining solids can be composted or used as animal bedding (Moriarty, 2013).

Anaerobic digesters have different configuration options depending on the type of feedstock, the type of loading, the number of process stages and the temperature within the digester (USEPA, 2022c). The feedstock is considered wet or dry, even though all feedstock has moisture contents above 70%. Feedstock with solid content from 3%-10% is referred to as low solid, while high solid feedstock has >15% solid content. Wet digesters are more common than dry digesters, where wet digesters process low solid feedstock and are often used at WWTPs. A dry digester processes high solid feedstock. There are two methods for feedstocks to be loaded into the digester: batch or continuous. In a batch digester, the feedstock is loaded in all at once, then, following the time period for digestion to occur, the digester is emptied and readied for the next batch. The more common method is a continuous flow digester, where feedstock is continuously added into the digester and digested material is continuously removed. Anerobic digester systems are designed to run within two different temperature ranges: the mesophilic (86-

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100°F) and thermophilic (122-140°F) ranges. Typically, thermophilic digesters are more difficult to operate but produce more energy. In the United States, most digesters that are used at WWTPs and farms are mesophilic and dedicated food waste digesters, commonly used in Europe, are thermophilic (Moriarty, 2013; US EPA 2021b). The length of time for complete degradation of food wastes in a digester, known as residence time, is a function of the feedstock, temperature, and processing system. The residence time for mesophilic systems ranges from 15-30 days. The residence time for thermophilic systems is about 14 days, the shorter duration is due to higher temperatures (Moriarty, 2013). The barrier to adopting anaerobic digestion can be its high capital costs and operating costs (Moriarty, 2013; USEPA, 2022c). In addition, the biogas that is produced must be treated before it is used to generate heat and electricity, requiring additional costs (Moriarty, 2013).

2.3.4 Animal Feed of Food Waste

Food that is no longer edible for humans, but is still safe and wholesome, should be diverted to feed animals. The EPA food recovery hierarchy lists feeding animals as the third tier, ranked lower than feeding hungry people, but above industrial uses, composting and the lowest option of landfilling or incineration (Harvard Food Law and Policy Clinic, 2016). In 2002, the European Union prohibited feeding food waste to animals and then in 2009 updated the ban by prohibiting using kitchen leftovers and catering waste for feed. These rules stemmed from veterinary diseases possibly related to food waste in animal feed (Kim and Kim, 2010; European Commission, 2002; European Commission, 2009). Similar federal and state laws were enacted in the United States due to disease outbreaks and greatly reduced the amount of food waste fed to animals (Harvard Food Law and Policy Clinic, 2016). In 2015, the European Union's Circular Economy Action Plan indicated the need to increase the use of surplus food as feed without

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compromising the feed and food safety (European Commission, 2015; Refresh, 2019). In 2019, EU project REFRESH, determined that 16% of total food that becomes waste could become animal feed by updating the EU legislation per the goals of the Circular Economy Action Plan. This would not only reduce feed costs, but it would also reduce land use for farming, reduce carbon emissions, and provide greater food security by decoupling Europe's feed supply from global commodity prices (Refresh, 2019). Based on the success achieved in Japan, which turns 52% of their surplus food into animal feed, the European Union would need to use a combination of heat treatment and acidification, which is fermentation or adding lactic acid, to ensure safe feed (FAO, 2017; Refresh, 2019). In the United States several laws, including The Ruminant Feed Ban Rule of 1997 and Swine Health Protection Act of 1980, provide protection from food waste contamination by using heat treatment.

In North Carolina, the feeding of animal-derived waste to swine must be heat treated and permits are required. Heat treatment requires heating to 212 degrees Fahrenheit for at least 30 minutes (Harvard Food Law and Policy Clinic, 2016). In 2013 the FDA proposed a rule under the Food Safety Modernization Act (FSMA) to monitor animal feed more closely to prevent food borne illnesses, which would have regulated the feeding of spent grain generated in the brewing process (USFDA, 2020; Sexton, 2014b). The Food Safety Modernization Act passed in 2011, reformed food safety laws, the largest reform in 70 years (USFDA, 2020; Sexton, 2014a). The 2013 proposal under Good Manufacturing Practice (GMP) and Hazard Analysis and Risk-Based Preventive Controls for Food for Animals, would require additional regulations and treatment of brewers spent grain. Brewers argued that they would incur additional costs with equipment and paperwork and make the practice of giving or selling the grain as animal feed prohibitive (USFDA, 2020; Sexton, 2014a; Sexton, 2014b). In 2014, the USFDA clarified that spent grain

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would not be subject to the new requirements under animal feed and John Dillard clarified the following for the Agricultural & Food Law Consortium, “animal food facilities that are already in compliance with human food safety requirements (e.g., brewers, distillers) do not need to implement additional CGMPs or preventive controls when supplying a by-product (e.g., wet spent grain, liquid whey, or fruit or vegetable peels) for animal food, except to prevent physical or chemical contamination when holding or distributing the by-product. The requirement to prevent contamination applies regardless of whether the facility donates or sells by-products as animal food (Dillard, 2016; USFDA, 2020).”

2.3.5 Other Treatment Methods of Food Waste

Other disposal methods of MSW are incineration, gasification, and pyrolysis.

Incineration is the combustion and conversion of waste materials into heat and energy (Pham et. al, 2015). Pyrolysis is the process of decomposing materials at moderately elevated temperatures in an oxygen-free environment. Gasification uses small amounts of oxygen to provide heat to facilitate the process (USEPA, 2021g). Incineration was the most widespread WtE technology worldwide, but due to the low electricity efficiency, 22-25%, other options are gaining research attention (Dong et al., 2018). Lu, J,-W. et al. found that in 2015, there were 1,179 MSW incineration plants around the world, with a capacity of 70,000Mg/d (Mg is Megagram; 1 Mg equals a metric ton) (Lu, J.-W., 2017). In France in 2015, 28% of their MSW was incinerated, and of this 38.4% was organic waste (Beylot et al, 2018). Incineration was a popular option because solid waste volume could be reduced up to 80-85% (Pham et al., 2015). The environmental performance of different WtE options depends on emission levels, energy efficiencies, end-use applications, and energy source (Dong et al., 2018). Typically, food waste is mixed in with general MSW and incinerated because of its high moisture content (Pham et al, 2015). In Korea the food waste is dried before being mixed with general MSW and then

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incinerated, this drying pre-treatment requires additional electricity (Pham et al, 2015). In comparison, a pre-treatment of waste is also needed for pyrolysis and gasification. Pyrolysis and gasification reduce CO_2 emissions and have lower operating costs, as compared to incineration. However, both require a feedstock that is homogeneous and has low moisture content. In this regard, food waste is a challenge for pyrolysis and gasification and requires shredding and drying (Pham et al., 2015; Dong et al., 2018). Pyrolysis and certain types of gasification, transform biosolids into biochar, a carbon rich material, and generates a hydrogen-rich synthetic gas (syngas). Biochar can be used as a soil amendment that can increase the soil's ability to hold water and nutrients. Syngas can be used to supplement the fuel needed to dry biosolids, and offset additional energy needs (US EPA, 2021h). Both pyrolysis and gasification require significant financial investment. There is considerable interest in both pyrolysis and gasification, not only for food waste but also for the potential for per- and polyfluoroalkyl substances (PFAS). PFAS are widely used, long lasting chemicals that breakdown slowly over time. PFAS have been found in residual streams from WWTP. As further research is conducted on PFAS and the contamination of biosolids it might lead to requirements for incineration, or possibly pyrolysis and gasification (US EPA, 2021f).

2.4 Food Waste Policy Supporting A Circular Economy

The European Union began addressing food waste in 1999 with the Landfill Directive which required all member countries to reduce the volume of biodegradable municipal waste to 35% by 2016 (European Commission, 1999). Germany began to look at waste as a resource as early as 1996 when it adopted the German Closed Cycle Management Act (Kreislaufwirtschaftsgesetz, KrWG). In 2005, Germany banned all biodegradable waste from landfills (Nelles et al., 2016). Landfilling and incinerating waste are not compatible with the

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concept of a circular economy (Nghiem, at al., 2017). In 2012, the German Closed Cycle Management Act was updated to be harmonious with the EU and the adoption of the Circular Economy Act in 2015 (Nelles et al., 2016). In the United States several states and municipalities have recognized the need to address food waste. By removing food waste from MSW, the need for landfill space is reduced due to a smaller waste quantity and because food waste is readily biodegradable; also, methane gas production is reduced. It is estimated that for each kg of food waste that 0.1 m^3 of methane gas is generated (Eriksson et al., 2015).

To implement a circular economy in a community there are two main strategies, reduce waste and find the most sustainable solution to managing the residual waste (Garcia-Garcia et al., 2019). The generation of food waste can have implications for all three pillars of sustainability, which are economic, social, and environmental, in a community (Vandermeersch et al., 2014). Based on the waste hierarchy, prevention is always preferential, followed by feeding humans and then feeding animals, and then other recovery options. While it is increasingly accepted that food waste needs to be managed more sustainably, the method to achieve the most sustainable option is not clearly defined. State and municipal organic waste bans and mandatory recycling laws are summarized in Tables 2.3 and Tables 2.4, respectively. In 1991, North Carolina banned yard wastes from landfills (NC DEQ, 2022), but there is no state or local ban on food wastes.

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Table 2. 3 State Organic Waste Bans & Mandatory Recycling Laws

State Legislation	Food Waste Generators Covered	Waste Production Threshold	Distance Exemption	Compliance	Enforcement
California - California Mandatory Commercial Recycling Law, AB 1826	Any business - commercial or public entity such as a firm, partnership, corporation, or association organized as a for profit or nonprofit entity	2016: 8 cubic yards/week organic waste 2017: 4 cubic yards/week organic waste 2019: 4 cubic yards/week solid waste 2020: Additional entities pahsed in if statewide organic waste disposal has not been reduced to 50% of the level in 2014 2022: 2 cubic yards/week of solid waste and recycling[1]	Local govenments of rural jurisdictions (population 70,000 or fewer) can exempt their jurisdictions from law	Subscribing to organic waste recycling services, processing organic waste on-site, or selling or donating surplus food	The law grants local jurisdictions discretion with respect to enforcement.
Connecticut - Commercial Organics Recycling Law	Commercial food wholesaler or distributor, industrial food manufacturer or processor, supermarket, resort or conference center.	2014: 104 tons/year 2020: 50 tons/year 2022: 26 tons/year[2]	20 miles	Sending food waste to a composting or AD facility or animal feed operation, donation for human consumption, on-site treatment, or reducing waste generated below threshold	There are no fines for violating the law. DEEP can pursue enforecement measures.
Massachusetts - Commercial Food Material Disposal Ban (Regulation)	Any entity, including a partnership, association, firm, company, corporation, department, agency, group or public body that produces commercial organic material	2014-2021: 1 ton/week 2022: 0.5 ton/week[3]	None	Sending food waste to a composting or AD facility or animal feed operation, donation for human consumption, on-site treatment, or reducing waste generated below threshold	Massachusetts Department of Environmental Protection can take enforcement actions against violators.

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Table 2.3 (Continued)

New York State - Environmental Conservaion Law	Businesses, nonprofits, government entities, and other organizations including supermarkets, food service businesses, higher education institutions, hotels, food processors, correctional facilities, and entertainment venues	2 tons/week	25 miles	Separating and transporting food scraps to an organic recycler (including animal feed)[4] or processing organics on-site. Generators must separate edible surplus food for donation to the extent possible.	The New York Department of Environmental Conservation (DEC) is responsible for enforcement, but penalties have not been identified.
Rhode Island - General Laws 23-18.9-17	Commercial food wholesaler or distributor, industrial food manufacturer or processor, supermarket, resort or conference center, banquet hall, restaurant, religious institution, military installation, prison, hospital or other medical care institution, casino, or covered educational facility	2016: 104 tons/week 2018: 52 tons/week for covered educational facilities 2023: 30 tons/week for covered educational facilities[5]	15 miles	Sending food waste to a composting, AD, or other authorized recycling facility, including an animal feed operation, or on-site treatment	Violators may be subject to a civil penalty up to a maximum of $25,000.
Vermont	Any individual, partnership, company, corporation, association, unincorporated association, joint venture, trust, municipality, the State of Vermont or any agency, department or subdivision of the State, federal agency, or any other legal or commercial entity	2014: 104 tons/week 2015: 52 tons/week 2016: 26 tons/week 2017: 18 tons/week 2020: Food scraps banned from landfill	20 miles (until 2020)	Source reduction, donation for human consumption, sending food waste for agricultural use, composting, AD, or energy recovery, or on-site treatment	The Vermont Department of Environmental Conservation (DEC) can issue violations and fines against haulers and businesses.

Source: Sandson et al., 2019 unless otherwise noted

[1] Waste Management, 2022

[2] CT DEEP, 2022

[3] MassDEP, 2022

[4] Rosengren, 2019

[5] Rhode Island State, 2016

Note: In 2021, Maryland passed House Bill 264 Solid Waste Management - Organics Recycling and Waste Diversion - Food Residuals - however breweries and restaurants are not included. (Maryland State Laws, 2021)

Table 2. 4 Municipal Organic Waste Bans and Mandatory Recycling Laws

City or Metro Area	Food Waste Generators Included in Requirements	Requirements
Austin, Texas	Food Enterprise that holds a food permit	1. Transporting the recyclable and organic materials to a materials recovery or composting facility authorized by law; or 2) contracting with a City-licensed recycling service provider to transport the recyclable and compostable materials to a materials recovery or composting facility authorized by law; or 3) transporting recyclable or organic material, as permitted and required by City Code, to a material recovery facility, food bank, processor, material broker, urban farm, urban ranch, rural farm, rural ranch, community garden, or a facility that prioritizes the hierarchy beginning with the most beneficial as follows: feeding hungy people, feeing animals, providing for industrial use, composting. [1]
Boulder, Colorado	Any business, residential property owner or manager, or special event permit holder	All properties, businesses and waste haulers to provide composting, recycling and landfill collection services to tenants, residents, customers and employees. The ordinance also requires business owners to separate recyclables and compostables from trash, place bins for each waste stream, post signs on or above all waste bins and train employees on proper sorting[2]
Hennepin County, Minnesota	Businesses including: restaurants; grocery stores; food wholesalers, distributors and manufacturers; hotels; hospitals; sports venues; event centers; caterers; nursing and residential care facilities; office buildings with dining services; farmers markets; food shelves and food banks; colleges and universities with dining services; shopping centers; airports; golf clubs and country clubs; and rental kitchens or shared use commercial kitchens.[3]	Covered Generators must implement a Collection program to divert food and Food Scraps from Back-of-House for Beneficial Use. Beneficial use includes: 1. Donation of edible food for human consumption (must be done in combination with other management methods) 2. Collection of food and Food Scraps for Food-to-Animal Programs (this may include either Food-to-Livestock or Food-to-Animal-Feed Processing). 3. Collection of food, Food Scraps and other Compostable materials for Composting at a Commercial Composting Facility. 4. Collection of food, Food Scraps, and other Compostable materials accepted for Anaerobic Digestion at an Anaerobic Digestion facility. Additional methods may be included but must be reviewed and approved.[3]

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Table 2.4 (Continued)

Metro Portland, Oregon	Businesses that cook, assemble, serve or sell food.	Local governments must require (1) covered businesses in their jurisdiction to source separate and recover business food waste; (2) delivery of collected business food waste to a facility authorized by Metro; and (3) persons who provide space to a covered business to allow the source separation and collection of food waste[4]
New York City, New York	Food service establishments in hotels with 100 or more rooms; arenas and stadiums with a seating capacity of 15,000 or more people; food manufacturers with a floor area of 25,000 sq ft or more; food wholesalers with a floor area of 20,000 sq ft or more; food service establshments with floor areas of at least 7,000 sq ft; food service esablishments that are part ochains with at least 2 locations; food retailers with floor areas of at least 10,000 sq ft.; Catering establishments with attendance of 100 persons or more; food preparation with area of 6,000 sq ft or more and sponsors of a temp event.[5]	Entities must separate their organic material and either send to a composting, aerobic or anaerobic digestor, or other processing facility, or process it on-site.
San Francisco, California	All businesses, governmental entities, residences and individuals.	All waste must be separated by compostables, recyclables and trash and all entities subscribe to composting collection services.
Seattle, Washington	All residences and businesses.	Businesses and individuals must separate food waste and subscribe to compost collection services.

Source: Sandson et al., 2019 unless otherwise noted
1 City of Austin, Texas (2016)
2 City of Boulder, Co (2019)
3 Hennepin County Minnesota (2018)
4 Metro Portland, Oregon (2018)
5 New York City, New York (2022)

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2.4.1 Soil

In 2021, the European Union issued a Soil Strategy for 2030 because "soil and the multitude of organisms that live in it provide food, biomass and fibers, raw materials, regulate the water, carbon and nutrient cycles and make life on land possible." (European Commission, 2021). The strategy works in synergy with other EU policies including the 2015 EU Action Plan for the Circular Economy. The 2015 EU Action Plan recognizes the benefit of organic waste material derived from food waste that can be returned to soils as fertilizers. The sustainable use of organic waste material reduces the need for mineral-based fertilizers (European Commission, 2015). "Today's agriculture does not allow the soil to enrich itself, but depends on chemical fertilizers that don't replace the wide variety of nutrients plants and animals need," according to Dr. Tim Lobstein, Food Commission Director in the UK (Lawrence, 2006 & Ellen MacArthur Foundation, 2013).

Soil degradation is estimated to affect one-third of the 1.5 billion hectares of land that are cultivated. Degraded soil is less fertile, less able to retain water, and more prone to erosion (Webster, 2017). Loss of soil carbon is a problem because carbon supports soil texture, water retention and nutrient delivery to roots (Ellen MacArthur Foundation, 2013). Through the agricultural process and the removal of organic matter from soil, carbon is removed from the soil and emitted to the atmosphere. The soil acts as a carbon sink, and the soil contains approximately 40 times more carbon than that contained in the crops growing on it (Masullo, 2017). The EU Soil Strategy relies on carbon removal through the restoration and renewal of soils to absorb emissions. Between 2013 and 2018, the EU saw that net carbon removal from soil was reduced 20% due to soil degradation. To address the heavy use of chemical fertilizers, the EU Soil Strategy has set a goal to reduce nutrient losses by at least 50%, the overall use and risk of

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chemical pesticides by 50% and the use of more hazardous pesticides by 50% by 2030 (European Commission, 2021).

As populations continue to grow, so does agricultural demand. Previous growth has been met with technological advances including irrigation, mineral fertilizers, and pesticides (Ellen MacArthur Foundation, 2013). However, due to soil degradation, water scarcity, and climate change, a decrease in agricultural production is occurring where no further productivity per acre can be achieved (USDA, 2021a; Ellen MacArthur Foundation, 2013). The United States has acknowledged the need for improved fertilization technologies and supports research and development into soil improvement, but has not established a comprehensive plan similar to the European Union. Also, in October 2021, the USDA announced a $10 million initiative with Conservation Reserve Program to monitor soil carbon (USDA, 2021b). Soil health can be improved by adding compost or digestate which returns nutrients needed for food production back to the soil.

2.5 Perspectives on Waste in Beer Production

The existing literature is reviewed for topics related to waste in beer production.

2.5.1 Solid Waste Produced in Beer Production

Beer produces a significant amount of solid waste in the brewing process. These include spent grain, trub, spent yeast and diatomaceous earth (DE) slurry (Goldammer, 2008). Brewer's spent grain (BSG) represent 85% of the organic by-products from the brewing process, see Figure 5 (Bolwig et al., 2019; Xiros and Christakopoulos, 2012). BSG is high in water content (70-85%) and the remaining solid matter is primarily fiber and protein (Jackowski et al., 2020 and Colby, 2021). The protein content of the dry matter is 19-30% and the fiber content is 60-70% (Jackowski et al., 2020; Amoriello and Ciccoritti, 2021; and Colby, 2021). The high protein

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and fiber content of the BSG make it extremely perishable and it spoils quickly. The BSG can be stored for a limited number of days before smell and health hazards become an issue (Bolwig et al., 2019 and Jackowski et al., 2020).

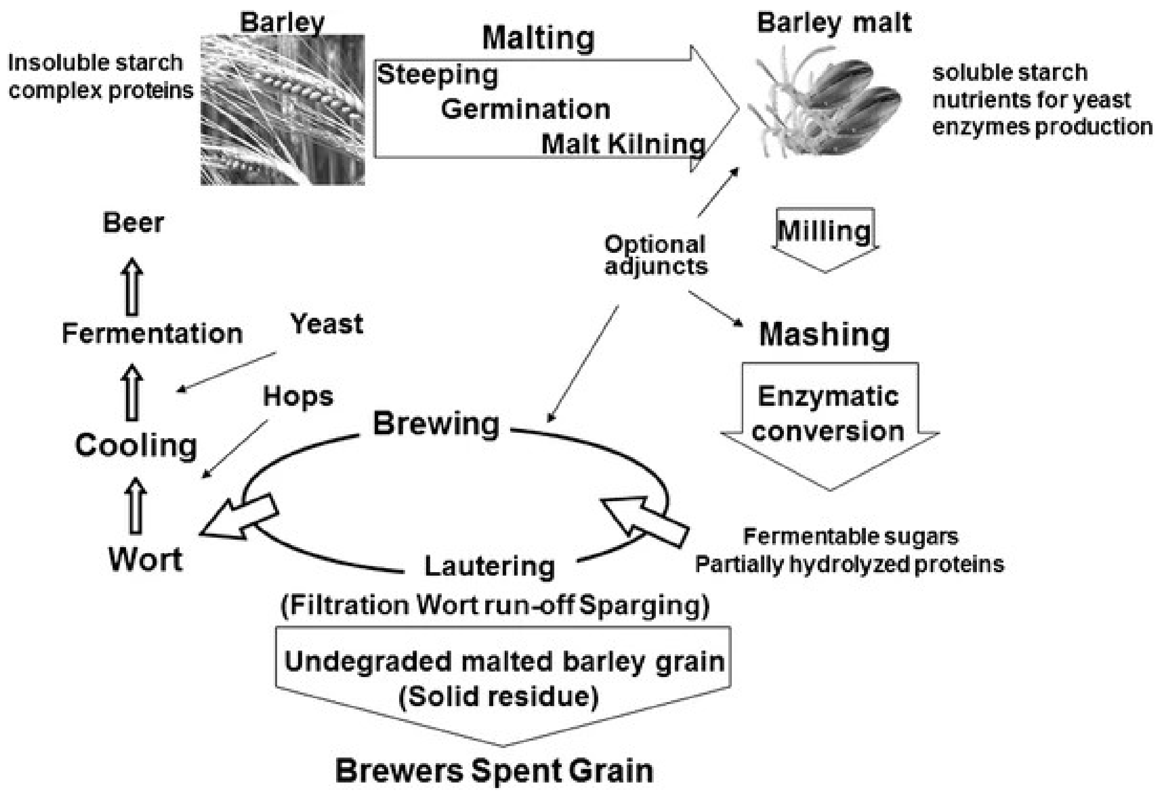

Figure 2. 4 Generation of brewers spent grain during the brewing process (Source: Xiros and Christakopoulos, 2012)

While larger breweries can separate the by-products, including trub and spent yeast, smaller breweries do not have the ability to segment the different products. Generally, many of the small breweries either market or give away the spent grain. Spent grain is wet, but can be dried and marketed or sold as a dry product. Sugars and starches are removed from the barley grain during the malting and mashing process of brewing, the remaining spent grain is higher in fiber, protein and other minerals that are found in grain. The nutrition breakdown is summarized in Table 2.5 (Westendorf and Wohlt, 2002).

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Table 2. 5 Nutrient analysis of brewing byproducts

Byproduct	DM (%)	TDN (%)	NE_L (Mcal/lb)	CP (%)	EE (%)	ADF (%)	Ash (%)	Ca (%)	P (%)
Dried brewers grains	92.00	60.00	0.61	22.20	6.30	29.00	4.10	0.29	0.54
Wet brewers grains	21.00	66.00	0.68	25.40	6.50	23.00	4.80	0.33	0.55
Brewers dried yeast	93.00	79.00	0.83	46.90	0.90	4.00	7.10	0.13	1.49
Malt sprouts	94.00	71.00	0.74	28.00	1.40	18.00	7.00	0.23	0.75
Dried spent hops	89.00	37.00	0.35	23.00	4.50	30.00	7.00	1.60	0.60

Source: Waller, 2019; Westendorf and Wohlt, 2002

Abbreviations: DM, dry matter; TDN, total digestible nutrients; NE_L, net energy for lactation; CP, crude protein; EE, ether extract (crude fat); ADF, acid detergent fiber; Ca, calcium; P, phosphorus.

2.5.2 Brewers Spent Grain Disposal

BSG has traditionally been used for animal feed as a method of disposal (Ikram et al., 2017). BSG are produced in breweries at every brew cycle, but because of the high moisture content are expensive to transport and, also due to the high moisture content, have a spoilage shelf life of 5 to 7 days uncovered, or of 7 to 10 days in containers (Westendorf and Wohlt, 2002; Ikram et al., 2017). Typically, if the BSG do not go to a farmer for animal feed they are composted or disposed of as MSW and go to the landfill (Jay et al., 2008; Westendorf and Wohlt, 2002).

As demonstrated above in Table 2.5, wet brewers' grain is a good source of protein and therefore can be used as feed. Drying the BSG is an alternative to preserve the value as a feedstock past the 7 to 10 days. Drying the BSG reduces the volume of the product, thereby decreasing the storage and transportation costs; however, drying the grain takes additional equipment and energy (Mussatto et al., 2006). Currently, the most common way to dry BSG is a two-step process: the first step is to press the grain to reduce the moisture level to 65% or below, and the second step is to use rotary dryers to reduce the moisture content below 10%. The process is very energy intensive. Currently, there are many studies in the literature investigating

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more economically viable methods of drying the grain, that do not affect the nutritional quality (Ikram et al., 2017).

The protein, fiber, and energy content of wet BSG, make them a suitable supplement in a variety of diets. For ruminant diets, animals that have four compartment stomachs like cattle and sheep, only limited amounts of brewers' grain can be added to the diets without performance decrease and a decrease in dry matter intake (Westendorf and Wohlt, 2002). The BSG can replace soybean meal and corn gluten meal as protein supplements in beef cattle, and provide diet fiber for dairy cows (Thomas et al., 2019). BSG can also be fed to non-ruminant animals, those with a single-compartment stomach, such as swine, poultry, horses, dogs, and humans. Food waste fed to swine must be heat treated per the 1980 Swine Health Protection Act (Westendorf and Myer, 2019). There has been limited research on feeding swine wet BSG. In studies, swine were fed up with 23% brewers dried grain without a reduction in weight gain or a decline in quality of the animal (Westendorf and Wohlt, 2002; Westendorf and Myer, 2019). However, with wet BSG the high moisture content results in a low dry matter intake and slower weight gains (Westendorf and Myer, 2019). There has been limited research into wet BSG for feeding poultry and horses, however both have successfully been fed dry BSG; for poultry this cannot exceed 30% of diet dry matter and in horses up to 40% dry matter (Westendorf and Wohlt, 2002).

2.6 Valorization of Waste

Cities need to look at waste, which traditionally represents a cost to the economy, as a resource with value. To support a transition to a sustainable and circular economy, the ways streams of organic waste can be transformed into valuable products needs to be explored. Substances that represented a cost to companies and communities are now becoming assets

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(Klitckou et al., 2019). Valorization should be explored in an industry that produces food waste because the waste can provide economic value and the waste can be available in large amounts (Garcia-Garcia et al., 2019). Even if there is a small economic value to the food waste it can have a significant economic value, because of the quantity of the food waste produced (Garcia-Garcia et al., 2019). In all likelihood, there would be more than one valorization option possible for food waste that will have different economic, social, and environmental impacts for the producer and greater community (Stone et al., 2019). Valorization of food waste can increase food security, promote resource and energy conservation, and help mitigate climate change (USEPA, 2021d).

2.6.1 Valorization of Beer Waste

A 2019 study performed on the food industry in the UK, specifically on Molson Coors Brewing Company, concluded that the valorization of spent grain was worth exploring because of their high availability and that the valorization may provide a more sustainable performance, both economically and environmentally, than the more common practice of using the grain in animal feed (Garcia-Garcia et al., 2019). The brewing industry is often considered somewhat circular because the spent grain is used as animal feed, as opposed to disposed of as food waste. However, often it is given away to farmers for free, bringing little to no monetary benefit to the brewery. This also prevents further valorization of the waste, or resource (Bolwig et al., 2019). As the number of breweries grow and the amount of BSG increases, research is needed into the options that are available for the use and disposal of BSG. They are produced in every brew cycle, but because of the high moisture content and quick spoilage rate animal feed has been the default option. As the trend for adopting Circular Economy policies grows, options to add value to brewery by-products need to be explored (Bolwig et al., 2019; Jackowski et al., 2021; Ortiz et al., 2019).

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CHAPTER 3 – WATER DEMAND, BENCHMARKING AND WATER SAVINGS IN BEER PRODUCTION

3.1 Introduction

Charlotte is the largest city in North Carolina, and is located in Mecklenburg County. Charlotte is the county seat of Mecklenburg County, which also includes the Towns of Cornelius, Davidson, Huntersville, Mint Hill, Matthews, Pineville, and Stallings. In 2018, The City of Charlotte approved a circular economy as the public sector strategy. In doing so, it became the first city in the United States to adopt such a strategy. The goal of adopting this strategy is to balance economic growth while protecting natural resources (Williams, 2018). To achieve a circular economy, four areas of performance were identified. Two of these relate to sustainable water, specifically, Charlotte as Zero Waste City and Charlotte as a Resilient and Healthy City. The circularity of these performance areas will be evaluated based on seven pillars, one of which is that water is extracted at a sustainable rate and resource recovery is maximized (Gladek, Kennedy and Thorin, 2018).

Previous to the adoption of a circular economic strategy, the Catawba-Wateree Water Management Group (CWWMG) completed a Catawba-Wateree River Basin Water Supply Master Plan in 2014 to protect, preserve and extend the water supply to the Charlotte region. The CWWMG is a collective of regulatory officials, from both North and South Carolina, and outside stakeholders. The water supply of the Catawba-Wateree River Basin, see Figure 3.1, provides water to Charlotte and Mecklenburg County, as well as to surrounding counties. Previous to the 2014 Master Plan, studies indicated that safe yield for many of the Basin's reservoirs would be exhausted by 2050 (HDR and McKim & Creed, 2014a).

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The Master Plan recommendations promote the effective management of the Basin's water supply and improves the safe yield and extends the water yield by 40-50 years. To develop

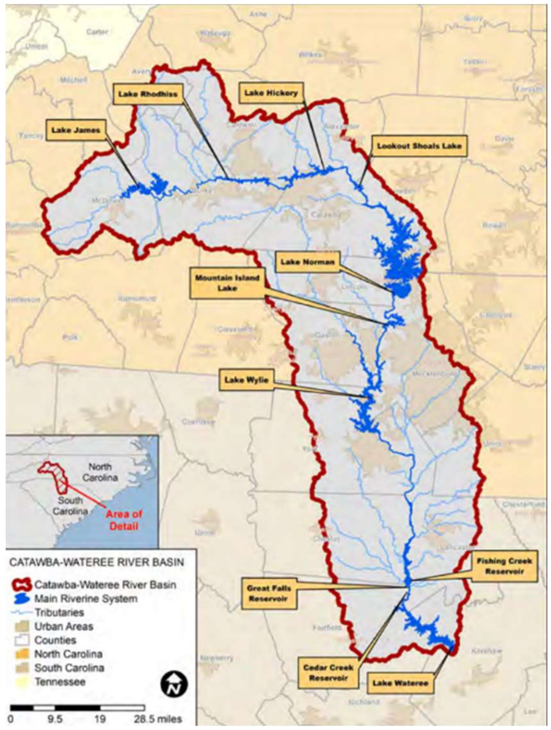

Figure 3. 1 Catawba-Wateree River Basin (Source: HDR and McKim & Creed, 2014a)

the recommendations, twenty-six individual future operating scenarios were evaluated in eight distinct categories, which included population growth sensitivity. From these scenarios, 10 integrated scenarios were developed, and multiple scenarios and strategies were combined. Three classifications were established: Base Case, Planning Case and Worst Case. The Base Case scenario included lower population growth, and subsequently lower water demand, and no impact of climate change. The Worst Case scenario included higher population growth, and with its higher water demand, and a greater impact of climate change. After all the scenarios and strategies, the CWWMG recommended a Mitigated Planning Case which included Baseline Population Growth. This scenario and its water yield enhancements improve the safe yield by 204 mgd (from the Safe yield of 660-719 mgd) and extend the water yield by 40 years, Table 3.1.

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Table 3.1 CWWMG WSMP Recommended Planning Scenario

Scenerio	Description	Safe yield (mgd)	Projection year to reach safe yield
MP-01	Planning Case A Climate Change: Moderate: Includes gradual temperature increase of 0.6^{0}F per decade (11% increase in lake evaporation between Base Year and 2065 Population Change: Total Basin AGR was 1.49%; for Charlotte Water specific the following AGR was used based on OSBM (at the time of publication) population projections through 2030: AGR of 1.63 used for Mecklenburg County projected through 2025; AGR of 1.20 used for years 2026 thru 2045; AGR of 0.9 used for 2046 thru 2065	660-719	2055 - 2065
Scenerio	**Integrated Planning Scenarios**	**Change in Safe yield vs Planning Case (mgd)**	**Yield enhancement vs Planning Case (years)**
MP-01M	Mitigated Planning Case A	139	30
	Includes Planning Case plus conservation, etc		
MP -01Mb	**Mitigated Planning Case B (Recommended WSMP)**	**204**	**40**
	Planning Case: Baseline population; Mitigated Planning Case + Lower Mountain Island Lake Critical Intake		

Source: HDR and McKim & Creed, 2014a

The population largely drives the demand for water (Blomenhofer et al., 2013; HDR and McKim & Creed, 2014a). The CWWMG used population growth projections based on historical growth patterns and projection data from the North Carolina Office of State Budget and Management (NC OSBM) based on 2014 data, these are summarized in Table 3.2. Based on the Historic Population included in the recommended plan, the AGR used for Mecklenburg County population growth was 1.63% through 2025, 1.20% for 2026 thru 2045, and 0.90% for years 2046 thru 2065 (HDR and McKim & Creed, 2014b).

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Table 3. 2 Historical Population Data & Population Projections

	Base Year	2010	2030	AGR
Historical Data (US Census Bureau) Mecklenburg Population Change 1970-2010	354,656	919,628		2.41%
Population Projections (NC OSBM) Mecklenburg County Population Projectiom - 2010-2030		919, 628	1,270,222	1.63%
Total Basin AGR thru 2065				**1.49%**

Source: HDR and McKim & Creed, 2014a

There were three withdrawal scenarios based on population change: slow population growth, baseline population growth and rapid population growth. Included in the report were the change in basin net withdrawals if the population growth outpaced the baseline growth, or was below the baseline growth, Table 3.3.

Table 3. 3 Population Growth Scenarios - Comparison of Basin Net Withdrawals

	Baseline	Rapid Growth		Slow Growth	
Year	(mgd)	(mgd)	% Difference	(mgd)	%Difference
Base	188.7	188.7	0.0%	188.7	0.0%
2015	194.6	239.1	+22.8%	189.4	-2.7%
2025	220.7	274.3	+24.3%	205.4	-6.9%
2035	248.4	309	+24.4%	223.4	-10.1%
2045	322.9	393.7	+21.9%	273.8	-15.2%
2055	385.7	470.3	+21.9%	326.4	-15.4%
2065	419.5	514.5	+22.6%	353.1	-15.8%

Soource: HDR and McKim & Creed, 2014a

Looking at future water scarcity using the World Resources Institute (WRI) Aqueduct tool, a water risk mapping tool, for Mecklenburg, North Carolina shows that the area is in medium-to-high Stress by 2030, Figure 3.2. Water risk accounts for physical risks, which include quality and quantity, and regulatory risk. The projections for 2030 account for how much freshwater is available and the demands, including population, on the water source. Using the same WRI Aqueduct Tool for projections to 2040, Charlotte remains a medium-to-high Stress location, Figure 3.3 (WRI, 2022).

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Figure 3. 2 WRI Projected Water Stress 2030 for Mecklenburg County, North Carolina (Reproduced from WRI, 2022)

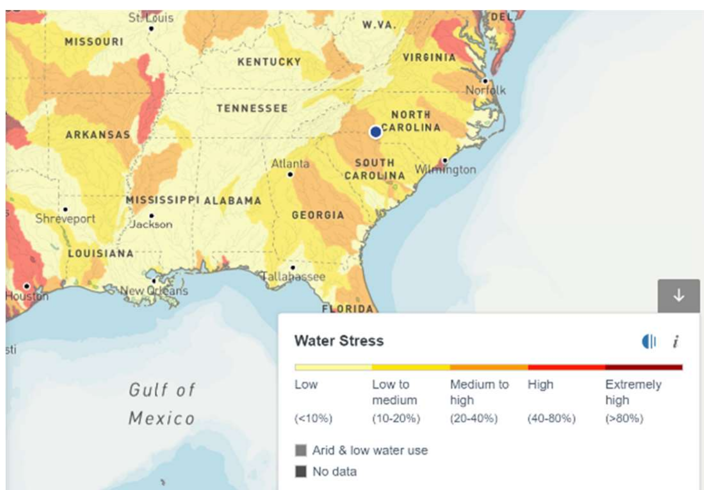

Figure 3. 3 WRI Projected Water Stress 2040 for Mecklenburg County, North Carolina (Reproduced from WRI, 2022)

3.2 Production Data Mecklenburg County, North Carolina

Production data were collected for craft breweries within Mecklenburg County from 2010/2011, the Base Year of the CWWMG Master Plan, thru 2020, Table 3.4. The production data were collected to calculate the water demand from the breweries. The breweries report their annual barrel production to The Brewers Association. The Brewer's Association is the trade

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Table 3. 4 Mecklenburg County Brewery Production Base Year to 2020

Name	Market Segment	First Year Production Data	Closed	2010/2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Armored Cow Brewing	Brewpub	2019										393	535
Ass Clown	Micro	2011		NA	NA	NA	NA	350	500	850	850	750	640
Birdsong Brewing Co	Micro	2011			747	2,037	3,300	4,870	6,070	7,218	7,435	7,542	5,876
Blue Blaze Brewing	Taproom	2016							332	1,300	1,500	1,500	1,275
Bold Missy Brewery	Brewpub	2017	2020							505	800	700	90
Brewers @ 4001 Yancey[1]	Regional	2019										9,174	10,000
Catawba Brewing[2]	Regional	2017								3,000	3,000	3,000	2,460
D9 Brewing Company	Micro	2014				12	41	1,478	3,004	5,000	8,700	9,760	5,663
Devil's Logic	Brewpub	2019										8	500
Divine Barrell Brewing	Taproom	2019										650	1,270
Fonta Flora Brewery [a]	Taproom	2020											
Four Friends[3]	Taproom	2010	2014	NA	700	700							
Edge City Brewery	Taproom	2020											250
Eleven Lakes Brewing Company	Brewpub	2017							0	203	385	495	427
Free Range	Taproom	2015						165	333	356	287	288	289
Heist	Brewpub	2012			NA	NA	NA	800	800	800	1,000	1,875	1,700
Legion Brewing	Micro	2015						220	1,863	4,061	6,214	6,856	6,539
Lenny Boy Brewing Co	Taproom	2012			NA	NA	150	400	1,000	1,250	1,625	2,000	1,700
Lower Left Brewing Co	Taproom	2019										115	285
Middle James Brewing	Brewpub	2019										250	600
NoDa Brewing[4]	Regional	2011		702	1,650	4,005	9,100	13,010	15,265	15,650	15,580	15,600	16,270
Olde Mecklenburg Brewery	Regional	2009		4,897	7,032	10,000	14,500	19,100	21,270	21,579	20,335	19,653	20,500

Table 3.4 (Continued)

Name	Market Segment	First Year Production Data	Closed	2010/2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Petty Thieves	Taproom	2020											155
Pilot Brewing	Taproom	2018									89	233	256
Protagonist	Brewpub	2019										80	252
Red Clay Ciderwork	Taproom	2015						NA	NA	NA	NA	NA	NA
Resident Culture	Taproom	2017								450	1,205	1,485	2,300
Rock Bottom Restaurant & Brewery	Brewpub	1997	2019	NA	NA	NA	NA	498	538	487			
Salty Parrot Brewing Inc [5,6]	Taproom	2020											NA
Salud Cerveceria	Brewpub	2016							200	140	325	350	300
Seven Jars	Taproom	2017								10	15	20	15
Suffolk Punch[7]	Brewpub	2017								415	943	1,414	1,389
Sugar Creek Brewing Co	Micro	2014					575	2,160	4,125	5,085	5,002	5,541	4,524
Sunstead Brewing	Taproom	2020											325
Sycamore Brewing	Regional	2013				NA	180	1,865	2,908	4,750	6,600	14,069	19,977
Thirsty Nomad Brewing	Taproom	2016	2020						63	131	135	135	45
Three Spirits	Taproom	2015	2019					13	350	NA	275	75	
Town Brewing Company	Brewpub	2019										700	650
Triple C Brewing	Taproom	2012			350	1,800	3,150	4,500	6,000	6,000	5,876	4,787	3,771
Traust Brewing	Taproom	2020											NA
Unknown Brewery[8]	Micro	2013				55	2,000	DNP	7,500	8,400	9,000	9,861	10,685
Wooden Robot	Brewpub	2015						1,200	2,500	3,800	3,800	DNP	2,178
Total Estimated Production (US Barrels) [9, 10, 11]				**5,599**	**10,479**	**18,609**	**32,996**	**50,629**	**74,621**	**91,440**	**100,976**	**118,967**	**123,691**
Annual Increase					**87%**	**78%**	**77%**	**53%**	**47%**	**23%**	**10%**	**18%**	**4%**

Source of Data Unless Otherwise Noted: The Brewers Association, with permission, (2016, 2019, 2020, 2022a)

(1) Artisanal Brewing Ventures umbrella company of Victory Brewing, Sixpoint Brewery, Southern Tier Brewing & Distilling Co., and Bold Rock Cider. 10,000 annual barrel capacity. Source: Brewers at 4001 Yancey, 2021

(2) Figure for Charlotte production is based on an estimate provided by the brewery in 2017 (Shapiro, 2018, 2019, 2020)

(3): Production values estimated (Hartis, 2013)

(4): 2019 & 2020 Production not published. Estimate based on 2017 and 2018 production growth

(5): Southern Soltice Brewing, Sunstead Brewing, Salty Parrot Brewing Company (Bowman, 2020)

(6): Salty Parrot Brewing in Sunstead Brewing (Hartis, 2020)

(7) Formerly Hyde Brewing, rebranded 2018 (Simmons, 2018)

(8): 2019 & 2020 Production not published. Estimate based on 2017 and 2018 production growth

(9) Barking Duck Brewing Company and Bayne Brewing Closed were not included. Both closed in 2018 and production is unknown (Ramsay, 2018; Untapped, 2022)

(10) Primal Brewery (Opened 2016) and Seaboard Brewing (Opened 2018) were unintentially omitted from data

(11) Lost Worlds Brewing opened May 2020, production not reported to Brewers Association (Lost Worlds Brewing, 2021)

(a) Brewed outside Mecklenburg County

association representing small and independent American craft brewers. To be a craft brewer the following criteria apply: 1) Small – annual production of 6 million barrels of beer or less 2) Independent – less than 25% of the craft brewery is owned or controlled by a beverage alcohol industry member that is not itself a craft brewer and 3) brewer has a TTB Brewer's (Alcohol and Tobacco Tax and Trade Bureau) notice and makes beer (Craft Beer.com, 2020). The following definitions used for market segments are taken directly from The Brewers Association :

1. **Microbrewery:**

   A brewery that produces less than 15,000 barrels of beer per year and sells 75 percent or more of its beer off-site. Microbreweries sell to the public by one or more of the following methods: the traditional three-tier system (brewer to wholesaler to retailer to consumer); the two-tier system (brewer acting as wholesaler to retailer to consumer); and directly to the consumer through carry-outs and/or on-site taproom or restaurant sales.

2. **Brewpub:**

   A restaurant-brewery that sells 25 percent or more of its beer on-site and operates significant food services. The beer is brewed primarily for sale in the restaurant and bar, and is often dispensed directly from the brewery's storage tanks. Where allowed by law, brewpubs often sell beer to-go and/or distribute to off-site accounts.

3. **Taproom Brewery:**

   A professional brewery that sells 25 percent or more of its beer on-site and does not operate significant food services. The beer is brewed primarily for sale in the taproom, and is often dispensed directly from the brewery's storage tanks. Where allowed by law, taproom breweries often sell beer to-go and/or distribute to off-site accounts.

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4. Regional Brewery

A brewery with an annual beer production of between 15,000 and 6,000,000 barrels.

3.3 Methodology

The following methodology will be used for estimating future beer production and subsequent water demand and brewer spent grain (BSG) production in this chapter and following chapters of this research. The methodology was derived from production actuals reported from the breweries directly to the Brewers Association. The production data are used with written permission from the Brewers Association. The current beer production in Mecklenburg County is used to determine the water demand for current beer production and then projections for future water demand. The same methodology for current beer production and future beer production is used to calculate the brewers' spent grain generated currently and estimates for the future. The current and future water demand is needed to analyze the research question, "what is the impact of water demand of beer production in Mecklenburg County?" The current and future production of brewers spent grain is needed to analyze the research question "what is the impact of waste by beer production in the Circular Economy?"

From the production data and additional industry sources, production data were estimated for 2021 through 2065 to assess the impact on The Catawba-Wateree River Basin, and to determine the impact of the growing industry on the projection year to reach safe yield. Four different scenarios were established to assess the effect of different production levels on the water demand. The 2020 production data were unique due to COVID-19. During 2020, The Brewers Association report that nationally, breweries with typical annual production under 2,500 barrels, saw a decrease of 16% for the first 6 months of the year, and a recovery of 3% for the second 6 months of the year, as COVID-19 restrictions were eased in certain areas. For

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breweries with typical annual production over 2,500 barrels, the first 6 months in 2020 were down 10% and had a 3% recovery in the second 6 months (Watson 2020a; Watson 2020b). However, Mecklenburg County experienced a growth of 3.97% in production in 2020 over 2019, Table 3.4. This can be attributed to the different COVID-19 rules per state. North Carolina closed bars and restaurants on March 17, 2020, with Executive Order #118. By May 20, 2020, restaurants were allowed to open with limited capacity, but bars remained closed. Outdoor seating was opened in bars by Executive Order #169 on October 2, 2020. Bars were opened with limited capacity on February 24, 2021, Executive Order 195. Executive Order 216, on May 14, 2021, eliminated many remaining capacity issues for restaurants and bars. As a comparison, New York removed capacity requirements for bars and restaurants in July of 2021, two months after North Carolina (NC.gov, 2022). New York did not allow indoor dining until September 30, 2020, four months after North Carolina, which would affect alcohol sales (New York Government, 2020).

Assumptions are:

a. For 2021 Production Estimates (Brewers Association, 2022c):

   The overall craft industry saw a volume increase of 7.9% from 2020 (Watson, 2021). According to the Brewers Association, 2021 volume was up but still behind 2019 growth (Watson, 2021).

b. For the four scenarios the following production assumptions were made:

   1. Base Production: The Compound Annual Growth Rate of production, 12.37%, for the last four years (2016-2019) was used to grow production annually from 2021 to 2030. From 2031 through 2040, a Maturing Market Rate of 9% Growth was used (Watson, 2020c), from 2041 to 2050, a 5% stable market growth was used

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and from 2051 to 2065 (Brewers Association, 2017c), the annual population compound annual growth rate (CAGR) was used.

2. Longer COVID Market Recovery: A 4% annual recovery was assumed for 2022 and 2023 (Watson, 2020a), followed by the Production Compound Annual Growth Rate, 12.37%, for (2016-2019). With the slower recovery the Production CAGR was continued to 2032 and then the growth followed the Base Production scenario.
3. Aggressive Growth

   To estimate the growth for years 2022 to 2030:

   i. The population over 21 years of age, legal drinking age in the United States, was determined to be 72.9% of the 2019 population. That percentage population was used with the 2030 population estimate from the North Carolina Office of State Budget & Management (OSBM) to determine the estimated population +21 years of age. Currently, Charlotte has approximately 2.2 breweries per 50,000 people over 21 years old (US Census Bureau, 2019 and Williams, 2019). For comparison, in 2019, Asheville, North Carolina, ranked second in the nation for the most breweries per capita, has 17 breweries per 50,000 people (C & R, 2019).

   ii. The average brewery production in 2019 was 3,500 barrels/brewery. Assuming, Charlotte grows to 9 breweries per 50,000 people in 2030, a Compounded Growth Rate of 15.8% was determined to reach this level and applied to the production volume. This was used as the growth until 2030.

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iii. From 2031 to 2040, it was assumed that Mecklenburg County would get to 13 breweries per 50,000, which is 75% of Asheville. From 2041 to 2050, the 9% maturing market rate was used, followed by the 5% market growth from 2051 to 2065.

4. Aggressive Growth with Gilde Brewery is the same growth as Scenario 3, but with Gilde Brewery added in 2025. In the summer of 2019, Gilde, a German based brewery since 1546, announced its first US location in Charlotte. In three years, Gilde plans to open “a massive brewery in Charlotte that will have the annual capacity of 500,000 barrels of beer” (Peralta, 2019). This brewery addition was announced before the Coronavirus (COVID-19) pandemic, so there is the potential that this volume may be delayed or adjusted.

3.4 Results and Discussion

When the CWWMG Master plan was released in 2014, the report utilized baseline water years 2010/2011. At that time in Mecklenburg County there were five breweries in Mecklenburg County producing under 10,000 US barrels (US bbl.) annually. By 2014, when the Master Plan was released, there were twelve breweries producing 32,996 US bbl., and by 2019 this had grown to thirty-one breweries producing over 114,000 US bbl., an increase of 1948% in gallons of water use for production, Table 3.5. The growth in the brewery industry was not included in the water projections in the Master Plan in 2014, which used water data from 2010/2011.

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Table 3. 5 Mecklenburg County Beer Production (US bbl.) Water Demand Growth WSMP Base Year (2010/2011) to 2019

	2010/2011	2012	2013	2014	2015	2016	2017	2018	2019
Total US Barrel Production (bbl)	**5,599**	**10,479**	**18,609**	**32,996**	**50,629**	**74,621**	**91,430**	**100,961**	**114,662**
Total Liters of Beer Produced (L)	657,030	1,229,687	2,183,725	3,872,007	5,941,200	8,756,608	10,729,106	11,847,548	13,455,330
Estimated Water Liters (Low 4.7 L) Used for Production	3,088,042	5,779,530	10,263,505	18,198,432	27,923,640	41,156,056	50,426,799	55,683,475	63,240,049
Estimated Water Liters (High 13.9 L) Used for Production	9,132,719	17,092,653	30,353,772	53,820,896	82,582,680	121,716,846	149,134,577	164,680,914	187,029,080
Estimated Water Liters (Avg 9.3 L) Used for Production	6,110,380	11,436,091	20,308,639	36,009,664	55,253,160	81,436,451	99,780,688	110,182,194	125,134,565
Gallons of Water (gal) Used for Production Based on Avg 9.3L of Water/Liter of Beer	**1,614,192**	**3,021,096**	**5,364,975**	**9,512,747**	**14,596,341**	**21,513,234**	**26,359,269**	**29,107,056**	**33,057,054**
% Increase (Base Year 2010/2011 to 2019)									**1948%**

Source: Brewers Association with permission, 2016, 2019; Shapiro, 2018, 2019, 2020; Hartis 2013, 2020; Bowman, 2020.

Without this new industry demand incorporated into the plan, the projected year that safe yield was reached was 2065. With the proposed integrated plan in the Master Plan, the safe yield was improved by 200 mgd and the water yield was extended 40-50 years. However, the mitigated plan that extended the life 40-50 years was based on baseline projected population growth, Table 3.1, and with limited brewing production, as noted above, in years 2010/2011.

The goal of this research was to evaluate what impact the growth of the brewery industry has on water demand in Mecklenburg County, with the addition of the population growth in Mecklenburg County. The water demand for the different beer production scenarios through 2065 is summarized in Table 3.6.

Table 3. 6 Horizon of Water Change (MGD)

	Base Production	**Longer COVID Recovery**	**Aggressive Growth**	**Aggressive Growth with Gilde**
Water Use 4.7 L/L Beer	0.9	0.8	1.8	2.0
Water Use 13.9 L/L Beer	2.6	2.3	5.3	5.9
Water Use 9.3 L/L Beer	1.7	1.6	3.5	3.9

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The combined results of the AGR, calculated at 1.84%. and the beer production at the base production with average water use (9.3 L/L Beer) are shown in Table 3.7. By adjusting the population Annual Growth Rate from 1.49% to 1.84%, which is the Mecklenburg County growth rate updated and adjusted by the same amount the CWWMG Master Plan adjusted and adding in the Base Production of Beer in 2065 at the average water consumption, the change in yield is increased by 20%, Table 3.7.

Table 3. 7 Comparison of Base Net Withdrawals 2065 Adjusting for Population Growth and Beer Production

Year	Baseline (mgd)	CWWMG Rapid Growth		Population Impact Revised AGR		Additional Beer Production Demand	
		(mgd)	% Difference	(mgd)	% Difference	mgd	% Difference
Base	188.7	188.7		188.7			
2065	419.5	514.5	22.65%	505.1	20.4%	1.7	20.81%

This would reduce the Mitigated Planning Case change in safe yield by 42 mgd, and reduce the yield enhancement to closer to 30 years. If the aggressive growth case of beer production is used the Mitigated Planning Case change in safe yield is reduced by 43 mgd, further reducing the yield enhancement to closer to 30 years. Isolating the water demand for the different production scenarios, Table 3.8 summarizes the additional percentage impact that the brewery water demand for all of the production scenarios that are presented in Table 3.6 has on the impact of water demand (mgd) from the growth in population in 2065.

Table 3. 8 Additional Impact On Water Demand From Brewery Production Scenarios on the Population Increase in Demand on Base Net Withdrawals

	Base Production		Longer COVID Recovery		Aggressive Growth		Aggressive Growth with Gilde	
	mgd	% Impact	mgd	% Impact	mgd	% Impact	mgd	% Impact
Water Use 4.7 L/L Beer	0.9	0.21	0.8	0.19	1.8	0.43	2.0	0.48
Water Use 13.9 L/L Beer	2.6	0.62	2.3	0.55	5.3	1.26	5.9	1.41
Water Use 9.3 L/L Beer	1.7	0.41	1.6	0.38	3.5	0.83	3.9	0.93

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The actual water withdrawals were less than the WSMP projected. Between 2011 and 2019, the WSMP predicted a 9.4% increase and between 2011 and 2020 the WSMP projected a 10.6% increase in water withdrawals. However, the actual water withdrawals from 2011 to 2019 decreased by 0.2% and from 2011 to 2020 decreased by 5.4%. The Catawba-Wateree Annual Water Use (CWAWU) report, produced by HDR and Duke-Energy, on Annual Water Use for the Year 2020, attributes the lower net withdrawals, as compared to 2011 and to 2019 due to the relatively wetter conditions for the basin, causing a greater return (HDR and Duke-Energy, 2019; HDR and Duke-Energy, 2020). For 2020, there were relatively wetter conditions than originally anticipated in water projections, causing a greater return, but also attributed to "2020 being a unique year for communities and industries due to the effects of the COVID-19 pandemic." (HDR and Duke-Energy, 2020). Between 2018 and 2019, the net water withdrawals increased by 1.9%, likely due to the increased consumption for power generation and continued growth in the region (HDR and Duke-Energy, 2019). The WSMP Report and the World Resource Institute both predict an impact from increasing temperatures in future years on evaporation and water stress. The wetter conditions and the reduced water demand from the COVID-19 pandemic cannot be relied upon in future years for reduced water consumption. Rather, the actuals between 2018 and 2019 with increased consumption due to power generation and growth should be more indicative of the trend going forward (HDR and McKim & Creed, 2014; World Resource Institute, 2022).

Water for Mecklenburg County is provided within the Catawba River Basin from Mountain Island Lake and Lake Norman. Water from Mountain Island Lake goes to Franklin and Vest Water Treatment Plants and water from Lake Norman is treated at Lee S. Dukes Water Treatment Plant (Charlotte Water, 2022). The actual demand from Lake Norman and Mountain

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Island Lake, the supply for Mecklenburg County, for the years 2019 and 2020 is shown in Table 3.9.

Table 3.9 Mecklenburg County Water Demand (MGD) Actuals for 2019 and 2020 Compared to 2014 WSMP

Lake Norman	**2014 WSMP, MGD for 2019**	**2019 CWAWU Report, MGD**	**Difference, MGD**	**% Change**	**2020 CWAWU Report,**
Charlotte Water	19.5	16.1	-3.4	-17.44%	17.9
Power - Duke	36.3	32.9			22.9
Agriculture/Irrigation	8	8.14			7.2
Other	12.1	11.2			10.2
Total Withdrawals	**75.9**	**68.4**	**-7.5**	**-9.88%**	**58.2**
Net Withdrawals	74.7	67.1	**-7.6**	-10.17%	56.7
Mountain Island Lake	**2014 WSMP, MGD for 2019**	**2019 CWAWU Report, MGD**	**Difference, MGD**	**% Change**	**2020 CWAWU Report, MGD**
Charlotte Water	104.1	92.6	-11.5	-11.05%	90.2
Power - Duke	0.5	0			0
Agriculture/Irrigation	0.7	0.7			0.7
Other	21.9	23.6			21.2
Total Withdrawals	**127.2**	**116.9**	**-10.3**	**-8.10%**	**112.1**
Net Withdrawals	121.5	111.1	**-10.4**	-8.56%	106.1

Source: HDR and Duke-Energy, 2020

For the total Catawba Basin, Lake Norman and Mountain Island Lake represented 48% of the total withdrawals in 2019 and 90% of the Net Withdrawals. If the 2065 Net Withdrawals are adjusted isolating Mecklenburg County and the supplying sources of Mountain Island Lake and Lake Norman, the impact would be a 34% change in yield and a reduction of over 10 years off the yield enhancement. Table 3.10 summarizes the additional percentage impact that the brewery water demand for all of the production scenarios that are presented in Table 3.6 has on the impact of water demand (mgd) from the growth in population in 2065 from Lake Norman and Mountain Island Lake.

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Table 3. 10 Impact of Brewery Production Scenarios on the Population Impact on the Base Net Withdrawals for Lake Norman and Mountain Island Lake

	Base Production		Longer COVID Recovery		Aggressive Growth		Aggressive Growth with Gilde	
	mgd	% Impact	mgd	% Impact	mgd	% Impact	mgd	% Impact
Water Use 4.7 L/L Beer	0.9	0.24	0.8	0.21	1.8	0.48	2.0	0.53
Water Use 13.9 L/L Beer	2.6	0.69	2.3	0.61	5.3	1.40	5.9	1.56
Water Use 9.3 L/L Beer	1.7	0.45	1.6	0.42	3.5	0.93	3.9	1.03

3.5 Conclusions

This paper has presented the additional challenges facing the water security in Mecklenburg County, North Carolina. The growth in breweries and population have increased the demand for water in the County with a higher than projected annual growth rate in population and a brewery industry that was not predicted in the 2014 CWWMG Master Plan. The results provide an answer to the first research question of what impact beer production in Mecklenburg County has on the water demand in Mecklenburg County. The answer is that beer production, while water intensive, does not have a significant impact on water demand. This is particularly true when the beer production water demand is projected out to 2065 with the population growth. These results were summarized in Table 3.7, the impact on the baseline net withdrawals from the higher than anticipated population growth is a 20.4% increase in net withdrawals. The addition of the beer production at 9.3 L water/L of beer at the base production level adds an additional 0.41% increase, Table 3.7. Even at the most aggressive production of beer level in 2065 at the high end of water use 13.9 L/L of beer, adds an additional 1.41% increase to net withdrawal over the baseline plan, Table 3.8. The analysis indicates that the population growth will reduce the yield enhancement in the CWWMG WSMP plan from 40 years to 33.6 years, a significant reduction. However, when the beer production water demand is added, the yield enhancement only changes from 33.6 years to 33.2 years.

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Water for Mecklenburg County is provided by Mountain Island Lake and Lake Norman. Isolating these two sources, the impact on the baseline net withdrawals from the higher than anticipated population growth is a 33.8% increase in net withdrawals. The addition of the beer production at 9.3 L water/L of beer at the base production level adds an additional 0.45% increase. Even at the most aggressive production of beer level in 2065 at the high end of water use 13.9 L/L of beer, adds an additional 1.56% increase to net withdrawal over the baseline plan, Table 3.10. The analysis indicates that the population growth will reduce the yield enhancement in the CWWMG WSMP plan from 40 years to 29.4 years, a significant reduction. However, when the beer production water demand is added, the yield enhancement only changes from 29.4 years to 28.9 years.

While the results show that the impact of the growing beer industry is small on the overall water demand, but coupled with the population growth, the impact of reaching safe yield even ten years earlier can be significant for the County's long term planning and sustainability. If the projection year to reach safe yield is reduced from the 40 additional years due to yield enhancement, by ten years due to the higher annual growth rate in population and the addition of a growing brewery industry, the research signals a need for a water consumption reduction plan. While a water consumption reduction plan for the Catawba-River Basin is out of the scope of this research, the research into the beer brewing industry provided insight into the need for data collection and benchmarking. Water demand was reduced in Colorado by the public sector, The Colorado Department of Public Health & Environment (CDPHE), working with the private breweries. In Mecklenburg County, Envision Charlotte Energy Reduction Program achieved a 19% energy consumption reduction by working with private commercial buildings on benchmarking and resulting changes to use. The Beverage Industry Environmental Roundtable

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estimates 9-10% water demand reduction can be achieved through benchmarking data and resulting processing improvements in breweries. These reduction measures can be low cost items such as a leak detection program, to higher cost items such as equipment upgrades and submeters (CDPHE, 2018). For Mecklenburg County breweries this could result in up to 215 million gallons annually in demand reduction. These are examples of public and private collaborating to collect benchmarking data and using that data to achieve demand reduction. From the research, it is recommended that a private and public collaboration for benchmarking is a necessary step to reduce water consumption and promote sustainable growth in the brewery industry.

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CHAPTER 4 – WASTE GENERATION BEER PRODUCTION MECKLENBURG COUNTY

4.1 Introduction

In 2020, the Brewers Association reported that 23,069,854 barrels were produced in the United States by craft brewers (Brewers Association, 2021). Spent grain are the byproducts after the mash has extracted most of the sugars, proteins, and nutrients in the malting and lautering processes (Brewers Association, 2022d; Witkiewicz, 2012). The spent grain represents around 85% of the total by-products generated (Xiros and Christakopoulos, 2012). Brewers spent grain are food waste. Why look at brewers' grain as a component of food waste in Mecklenburg County? For every liter of beer produced approximately 0.441 lbs. (200 kg/m^3) of spent grain is generated (Amoriello & Ciccoritti, 2021; Weger et. al, 2017; Ortiz et al, 2019; Mussatto, Dragone, and Roberto, 2006). For the United States that would equate to 1.1 billion pounds and for Mecklenburg County 6.4 million pounds, 3,200 tons of spent grain in 2020. Currently, Mecklenburg County produces approximately 250,000 tons of food waste annually, BSG would represent 1.3% of the total food waste (Hamm, 2022).

Brewers spent grain are not specifically identified or addressed in the 2018 Circular Charlotte report by Metabolic commissioned by the City of Charlotte and Envision Charlotte; however, making Charlotte a zero waste city by 2050 is one of the primary goals of the circular economy strategy (Gladek, Kennedy and Thorin, 2018). The report found that 16% of the waste that is landfilled in Charlotte is food waste. The report attributed this partly to the fact that the city offers no free organic waste recycling programs that provide an alternative to landfilling. As part of the zero waste by 2050, the circular economic plan includes the following three goals directly related to the generation and disposal of food waste: 1) terminate all use of landfills by 2040, 2) minimize annual GHG emissions to 2 tons of CO_2 equivalent per person and 3) ensure

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nutrients from all organic wastes are returned to natural cycles (Gladek, Kennedy and Thorin, 2018). In 2015, the City of Charlotte did a baseline emissions inventory and the GHG emissions were 12 tons of CO_2 equivalent per capita. The Charlotte Strategic Energy Plan (SEAP) identified five stages to achieve a GHG emissions of 2 tons of CO_2 E by 2050: 1) shifting energy demand, 2) reducing energy consumption, 3) changing energy consumption away from fossil fuels, 4) generating energy on-site and 5) meeting the remainder of energy requirements through energy purchasing. The SEAP was developed by The City of Charlotte and Envision Charlotte to meet the goals of the Global Covenant of Mayors (GCoM), ensuring that Charlotte grows sustainably (City of Charlotte, 2018).

4,2 Spent Grain Data Mecklenburg County, North Carolina

As in Chapter 3, beer production data were collected to determine the spent grain produced in Mecklenburg County, North Carolina, Table 3.4. The BSG in Mecklenburg County grew from 289,720 lbs. (144.9 tons) from a 5,599 US Barrels production, in 2010/2011, to over 6.4 million pounds (3,200 tons) in 2020, from 123,691 US barrel production, an increase over 6 million pounds and 2000%. The growth of BSG in Mecklenburg County between 2010/2011 – 2020 is summarized in Figure 4.1.

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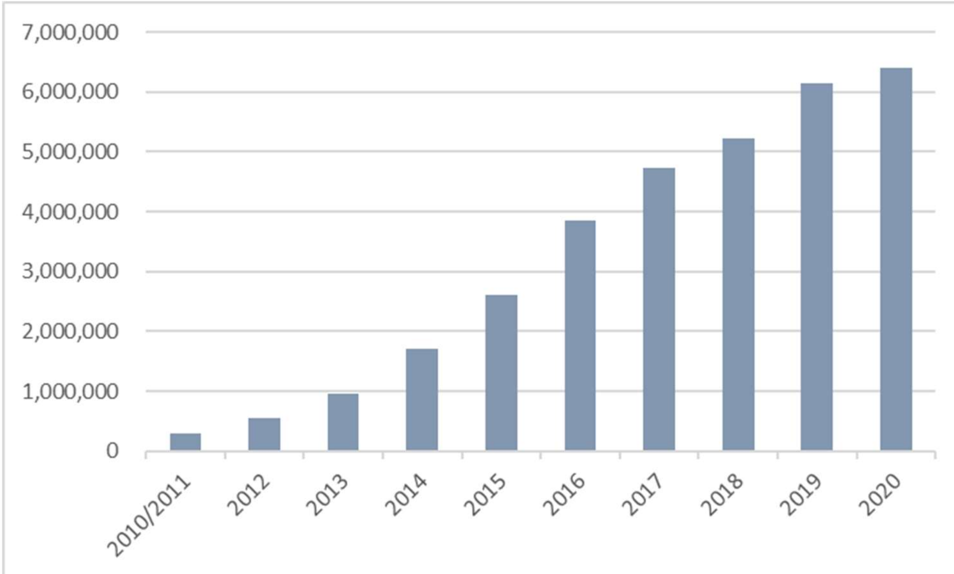

Figure 4. 1 BSG (lbs) Generated in Mecklenburg County, NC 2010-2020

4.3 Methodology

4.3.1 Brewers Spent Grain Produced

Assumptions are synonymous with Section 3.3 for calculating the amount of BSG produced in Mecklenburg County and projected production through 2065 for four different production scenarios: Base Case, Longer COVID-19 Recovery, Aggressive Growth and Aggressive Growth with Gilde.

4.3.2 Potential Greenhouse Gas (GHG) Emissions

The EPA Waste Reduction Model (WARM) was used to provide an estimate of the potential GHG emissions produced by landfilling the BSG generated from the breweries in Mecklenburg County, NC. WARM is a tool based on a database developed in open life cycle assessment (OpenLCA) software (USEPA, 2022a). Open LCA is a free, open-source software for lifecycle assessment (USEPA, 2022b). WARM recognizes 60 material types, including food waste (non-meat). The current WARM tool used in the analysis is WARM Version 15, which was released May 2019 and updated in November 2020 (USEPA, 2022b). Food waste falls under

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the category of “organics” in WARM. Specifically, “food waste (non-meat)” is the weighted average of the three non-meat food type emission factors: including grain, fruits and vegetables, and dairy products. The emission factors estimated specifically exclude emissions from “food waste (meat only)” and “mixed organics category, “ which includes food waste and yard trimmings. The WARM estimates the greenhouse gas emissions, in $MtCO_2E$, beginning at the point of waste generation, when material is discarded. Within the model, parameters are based on national averages, or can be updated to be specific for Mecklenburg County. For example, to account for the avoided electricity related to emissions for landfilling and combustion, the electricity grid mix emission factor is used for the state of North Carolina (USEPA, 2022). In addition, Mecklenburg County averages over 41.6 inches of precipitation annually according to the National Weather Service (National Weather Service, 2022). For WARM, over 40 inches of precipitation annually increases the moisture conditions to “Wet” and the decay rate is 0.06. The decay rate is the rate of change per year for the decomposition of organic waste in landfills (OpenLCA, 2020).

4.4 Results

The following BSG were calculated for Mecklenburg County using the production for Mecklenburg County provided in Table 3.4 and the production projections established in the Methodology in Section 3.3. The total BSG in short tons is summarized in Table 4.1 and the growth between 2020 and 2065 is graphically shown in Figure 4.2.

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Table 4. 1 BSG (Short Tons) Produced in Mecklenburg County Projected to 2065

Year	Base Case	Longer COVID Recovery	Aggressive Growth	Aggressive Growth with Gilde
2020	3,200	3,200	3,200	3,200
2021	3,453	3,453	3,453	3,453
2035	17,050	15,522	19,645	32,581
2045	33,482	30,480	39,591	52,526
2055	46,811	42,615	71,325	84,261
2065	56,173	51,137	116,181	129,117

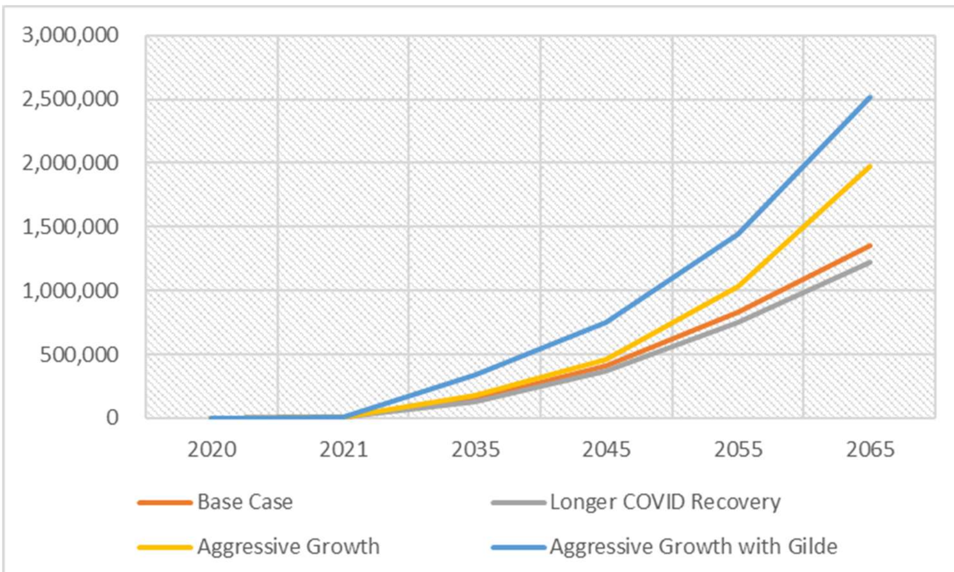

Figure 4. 2 BSG (Short Tons) in Mecklenburg County Projected to 2065

Using the WARM tool provided by the USEPA, the $MtCO_2E$ emissions were calculated based on the BSG, or “food waste (non-meat)” generated and projected generation in Mecklenburg County through 2065, Table 4.2 (OpenLCA, 2020).

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Table 4. 2 $MtCO_2E$ Generated by BSG Produced in Mecklenburg County Based on National Average Parameters

Year	2020	2021	2035	2045	2055	2065
Base Case	1,591.94	1,717.80	8,482.01	16,656.62	23,287.53	27,944.94
Longer COVID Recovery	1,591.94	1,717.80	7,721.88	15,163.19	21,200.11	25,439.63
Aggressive Growth	1,591.94	1,717.80	9,772.99	19,695.73	35,482.76	57,797.72
Aggressive Growth with Gilde	1,591.94	1,717.80	16,208.39	26,130.63	41,918.16	64,233.12

Source: OpenLCA, 2020

Table 4.2 is a summary based on the WARM national averages. Table 4.3 shows the same $MtCO_2E$ for Mecklenburg County, including the updated electricity grid mix for North Carolina and the increased decay rate for organic materials based on the average precipitation rate for Mecklenburg County. Figure 4.3 is a graphic summary of Table 4.3 showing the large increase of $MtCO_2E$ in later years as production increases. Figure 4.4 provides each production scenario individually with the $MtCO_2E$ shown in relationship with the increasing BSG generated. All the additional data presented is based on the specific conditions for Mecklenburg County in WARM.

Table 4. 3 $MtCO_2E$ Generated by BSG Produced in Mecklenburg County Based on Area Specific Parameters

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.17	44,506.40	68,199.20

Source: OpenLCA, 202

Note: Specific Parameters include electricity grid mix for North Carolina and increased decay rate of organic materials due to precipitation rate for Mecklenburg County, North Carolina.

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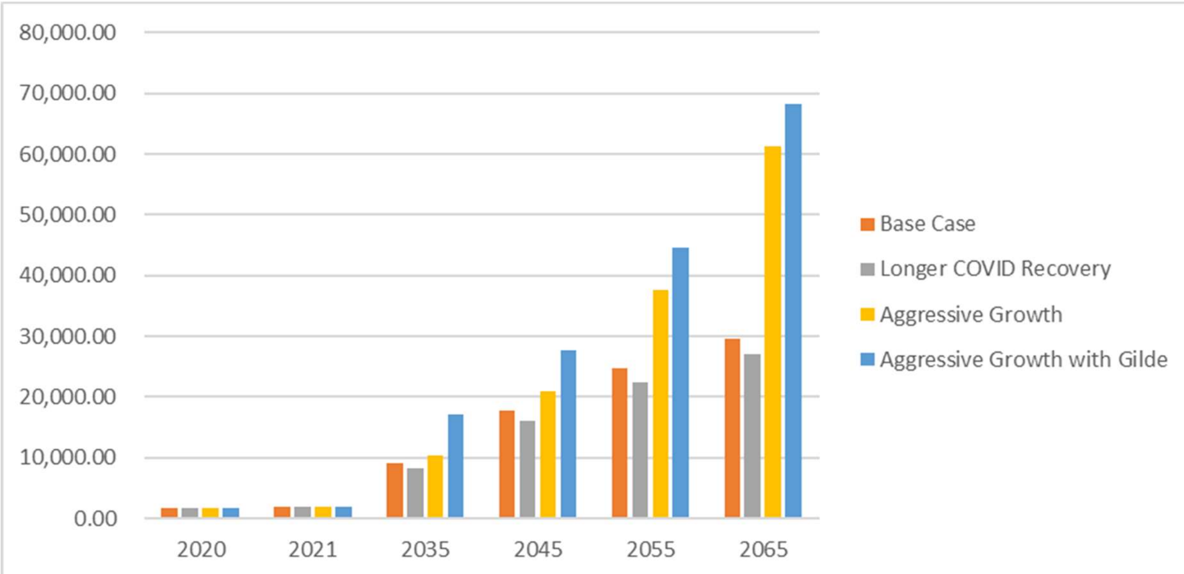

Figure 4. 3 $MtCO_2E$ from BSG (Short Tons) Produced in Mecklenburg County Projected to 2065 Based on Area Specific Parameters (Open LCA, 2020)

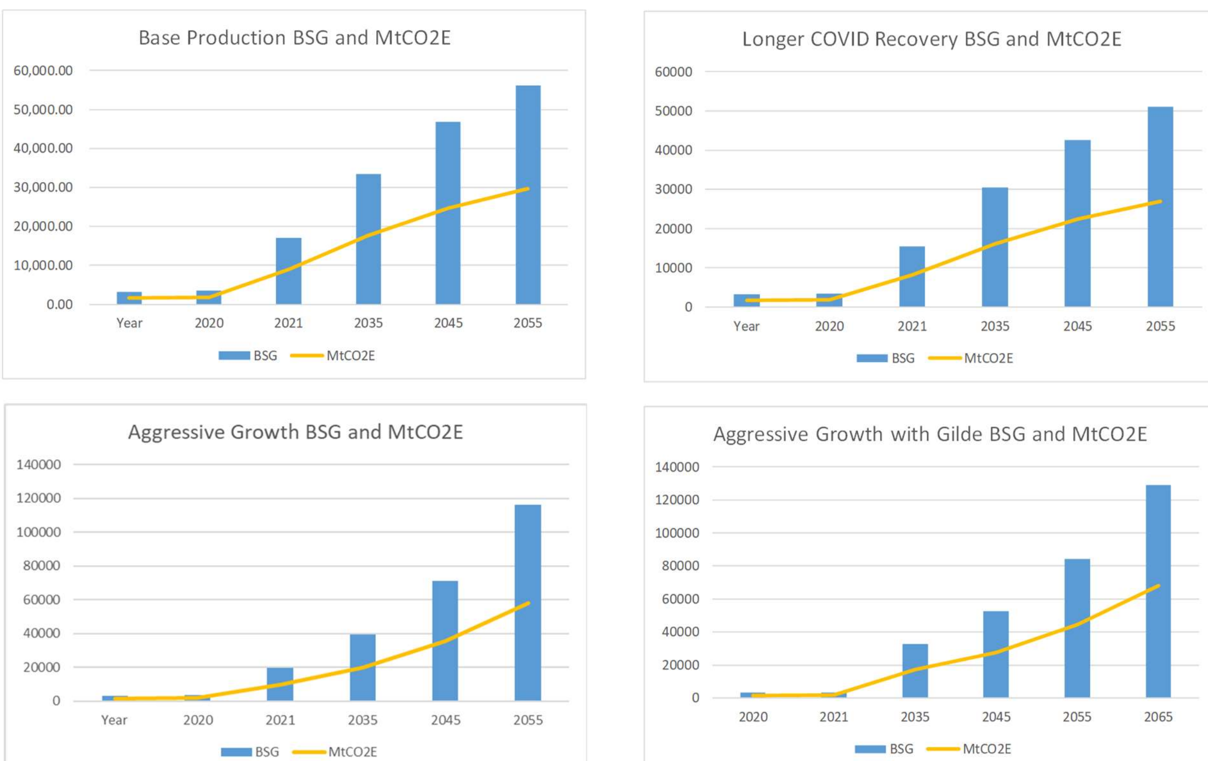

Figure 4. 4 BSG and $MtCO_2E$ Generated Based on Four Production Scenarios (OpenLCA, 2020)

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To determine the impact of beer production on Charlotte's goal to be a zero waste city, as part of the circular economic strategy, the annual growth rate was applied to the 2020 population through 2065 and the tons of BSG per capita, as well as pounds (lbs.) per capita, were calculated (Gladek, Kennedy and Thorin, 2018). The results are summarized in Table 4.4.

Table 4. 4 BSG Tons/Capita and lbs./capita for Mecklenburg County

	2020	2021	2035	2045	2055	2065
Population	**1,115,482**	**1,136,007**	**1,466,353**	**1,759,634**	**2,111,574**	**2,533,904**
BSG Tons/Capita						
Base Case	0.0029	0.0030	0.0116	0.0190	0.0222	0.0222
Longer COVID Recovery	0.0029	0.0030	0.0106	0.0173	0.0202	0.0202
Aggressive Growth	0.0029	0.0030	0.0134	0.0225	0.0338	0.0459
Aggressive Growth with Gilde	0.0029	0.0030	0.0222	0.0299	0.0399	0.0510
BSG lbs/Capita						
Base Case	5.74	6.08	23.26	38.06	44.34	44.34
Longer COVID Recovery	5.74	6.08	21.17	34.64	40.36	40.36
Aggressive Growth	5.74	6.08	26.79	45.00	67.56	91.70
Aggressive Growth with Gilde	5.74	6.08	44.44	59.70	79.81	101.91

The Circular Charlotte strategy established in 2018 set key performance indicators (KPIs) that can be used to measure Charlotte's progress towards circularity. The KPI related to the goal of Charlotte as a zero waste city and terminating the use of landfills by 2040 is tons of waste going to the landfill annually per capita, WL/C (waste landfilled/capita). In 2018, the Circular Charlotte report indicated Charlotte's current WL/C as 1.12. The report does not identify a specific reduction value, but highlights the City of Austin is 0.95 WL/C (Gladek, Kennedy and Thorin, 2018). The percentage increase of in the WL/C indicator due to beer production is summarized in

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Table 4.5. The annual growth rate was applied to the 2020 population through 2065. The $MtCO_2E$ BSG per capita, as well CO_2E tons per capita, were calculated, Table 4.6.

Table 4. 5 Percentage Increase in WL/C due to BSG Production

	2020	2021	2035	2045	2055	2065
% Increase in KPI - Charlotte 1.12 WL/C						
Base Case	0.26%	0.27%	1.04%	1.70%	1.98%	1.98%
Longer COVID Recovery	0.26%	0.27%	0.95%	1.55%	1.80%	1.80%
Aggressive Growth	0.26%	0.27%	1.20%	2.01%	3.02%	4.09%
Aggressive Growth with Gilde	0.26%	0.27%	1.98%	2.67%	3.56%	4.55%

Table 4. 6 $MtCO_2E$/capita & Tons of CO_2E/capita Mecklenburg County

	2020	2021	2035	2045	2055	2065
Population	**1,115,482**	**1,136,007**	**1,466,353**	**1,759,634**	**2,111,574**	**2,533,904**
MtCO2E/capita						
Base Case	0.0015	0.0016	0.0061	0.0101	0.0117	0.0117
Longer COVID Recovery	0.0015	0.0016	0.0056	0.0091	0.0107	0.0107
Aggressive Growth	0.0015	0.0016	0.0071	0.0119	0.0178	0.0242
Aggressive Growth with Gilde	0.0015	0.0016	0.0117	0.0158	0.0211	0.0269
CO2E (tons)/capita						
Base Case	0.0017	0.0018	0.0068	0.0111	0.0129	0.0129
Longer COVID Recovery	0.0017	0.0018	0.0062	0.0101	0.0118	0.0118
Aggressive Growth	0.0017	0.0018	0.0078	0.0131	0.0197	0.0267
Aggressive Growth with Gilde	0.0017	0.0018	0.0129	0.0174	0.0232	0.0297

Source: OpenLCA, 2020

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As part of the Circular Charlotte strategy, the goal is to have a net annual CO_2E emission of less than two tons per person. By shifting to a zero-waste system, between 0.08-0.34 tons of CO_2E per person can be reduced according to the Circular Charlotte report (Gladek, Kennedy, and Thorin, 2018). With the production of BSG the tons of CO_2E per person ranges from an additional 0.0017 in 2020 to a range of 0.0118 to 0.0297 tons of CO_2E in 2065.

4.5 Conclusions

As of 2018, 16% of waste that went to the landfills in Mecklenburg County was food waste. There is no free organic waste recycling program in the County, or any public policy that requires food waste to be collected or recycled (Gladek, Kennedy and Thorin, 2018). The second research question was to evaluate the impact of BSG on the Circular Economy. To do this the three goals of the Circular Charlotte plan directly related to the generation and disposal of food waste were evaluated with the production of BSG. Two of the goals are linked, to terminate the use of landfills and ensure nutrients from organic waste are returned to natural cycles, which does not occur when the waste is landfilled. The third goal is to reduce annual GHG emissions to 2 tons of CO_2 equivalent per person. To evaluate the impact of the food waste generated through beer production on the Circular Economy goals, the quantity of BSG currently produced and projected to be produced in Mecklenburg County was calculated through 2065 and summarized in Table 4.1. The analysis provided shows that a significant amount of food waste in the form of BSG will be produced as the beer production grows in the County.

As part of its public strategy to achieve a Circular Economy, Charlotte has set a goal to close its landfills by 2040 and reduce the WL/C. The Circular Charlotte report established a Key Performance Indicator of waste landfilled/capita (WL/C). At the time of the report in 2018 this was 1.12 WL/C. If the BSG is landfilled the contribution to the WL/C by 2040, would increase

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the current WL/C anywhere from approximately 1.5% to 2.5%. Not requiring the BSG nutrients be returned to natural waste cycles, allowing food waste into landfills, does not support the Circular Economy. Currently, there is no public facility in Mecklenburg County that accepts and recycles food waste. In 2018 Mecklenburg County moved to a new compost facility, called Compost Central & Recycling Center. Residents were concerned about odors near the facility, Jeffrey Smithberger, the director of solid waste management in Mecklenburg County, promised "we would not do food waste composting." The facility accepts and processes only yard waste (Maile, 2020).

In 2015, the City of Charlotte did a baseline emissions inventory and the GHG emissions were 12 tons of CO_2 equivalent per capita. Charlotte plans to minimize GHG emissions to 2 tons per person by 2050, a reduction of 83%. BSG that are disposed of as food waste will increase the tons CO_2E/capita from 0.6% to 1.49%. While the percentage may look insignificant, every percent is significant when trying to achieve an 83% reduction. The Charlotte Strategic Energy Plan (SEAP) did not incorporate reducing waste emissions, food or other, in their plans to achieve GHG emissions of 2 tons of CO_2 by 2050 (City of Charlotte, 2018).

To achieve the Circular Economic goals of closing landfills, ensuring nutrients from organic wastes return to natural cycles, and reducing the tons of CO_2E per person, the recommendation would be for Charlotte to implement a policy that incorporates the BSG into an overall food waste management or recovery plan. To achieve an approximately 80% reduction in CO_2E/capita many changes will need to be implemented, including a ban on landfilling food waste. In 1991, North Carolina banned yard wastes from landfills (NC DEQ, 2022). Between 1999 and 2013, the per capita yard waste diverted from landfills increased from 75 lbs. to 229 lbs., an increase of 205% (Gerlat, 2014; Mecklenburg County Government, 2014). In 2009 San

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Francisco passed an ordinance making composting food waste mandatory. In 2010, they recovered 400 tons/day and by 2013 recovered 600 tons/day, a 50% increase (Howard, 2013). Further research is needed into specific waste management recovery plans that would incorporate BSG. Management or recovery plan options are explored in Chapter 5.

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CHAPTER 5 – SUPPORTING THE CIRCULAR ECONOMY STRATEGY

5.1 Introduction

In Chapter 4, the amount of BSG produced and projected in Mecklenburg County was established. As previously discussed, Mecklenburg County does not require food waste separation or provide separate food waste collection. There is separate yard waste collection for residential homes and compost from the yard waste is available for purchase. The county provides no free organic waste recycling programs that provide an alternative to landfilling waste. Commercial businesses must contract with private waste haulers for their solid waste collection (Gladek, Kennedy & Thorin, 2018).

A Circular Economy promotes the efficient use of resources with the ultimate goal of balancing the economy, the environment and society responsibility (Ghisellini, et al., 2015). In this Chapter the environmental, societal, and economic implications of the projected BSG are evaluated, to determine the best option for BSG to support the Circular Economy. The overall goal is to find a solution that aligns all three pillars, environmental, social, and economic, to find the best solution to integrate BSG into the zero waste plan.

5.2 Spent Grain Data Mecklenburg County, North Carolina

The beer production data for Mecklenburg County was used to determine the amount of BSG produced through 2065. A summary of the production can be found in Table 3.4, in Chapter 3.

5.3 Methodology

5.3.1 BSG Production through 2065

The methodology presented in Chapter 3 was used to project the BSG production through 2065, using the four established scenarios.

5.3.2 Environmental – MtCO_2E

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To evaluate the environmental impact of the BSG, the WARM model was used to determine the $MtCO_2E$ for the different disposal/treatment methods. The following scenarios were analyzed: landfilling, composting, combustion, anaerobic digestion, animal feed and use as human food. The GHG savings are calculated by comparing an alternate scenario with the current waste treatment method, landfilling. Each method has emissions associated with the treatment and then those two values are compared for a net savings or a net gain (WARM, 2022a).

5.3.2.2 Human Food and Animal Feed Using WARM Emission Factors

Utilizing BSG as food avoids the emissions from landfilling that would occur if the BSG are disposed of as waste. In addition, there is an upstream benefit due to the potential that using BSG for food products offsets the demand for similar food. However, the US EPA recognizes there is uncertainty to what extent converting food waste into food products avoids upstream demand for food. The US EPA provides low- and high-end estimates for the GHG emissions avoided by using BSG as food, converting into usable food, and animal feed. The high-end estimate includes the GHG emissions avoided by not landfilling the waste, as well as an estimate for the substitution of BSG for the food that does not need to be produced. BSG can be dried, milled, and used as flour, therefore avoiding the production of the same amount of equivalent flour. It should be noted that a portion should be estimated for spoilage, particularly that BSG have a very short spoilage timeframe due to the high sugar and protein content (Bolwig et al., 2019). For all food types, the USEPA calculates an average donation loss rate of up to 3% based on a nationwide estimate of food banks (USEPA, 2021f). The low-end estimate includes the avoided GHG emissions by avoiding landfilling the waste. Using the WARM model for animal feed, the USEPA recommends using the low-end estimate of just the avoided landfill emissions.

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There are no data as of now on the impacts from food sent to farms to feed animals and the upstream benefit of avoided GHG emissions. (USEPA, 2021f).

Several scenarios were run for the animal food and food options. Beginning with BSG for animal feed, a scenario was run with zero spoilage. There is the possibility that the BSG could be stored after production and transported for animal feed before any spoilage takes place. Next, a spoilage rate of 3% was simulated in WARM. This is based on the USEPA national average for food donation loss (USEPA, 2021f). Low-and high-end data simulation was performed in WARM on the BSG generated at 3% spoilage. To determine the impact of higher spoilage, but also a real world scenario where some BSG is used as animal feed or converted into human food, two more scenarios were run with 10% spoilage and 30% spoilage to observe the impact on $MtCO_2E$.

5.3.3 Societal Analysis

For the societal analysis, the analytic hierarchy process (AHP) was utilized to conduct pairwise comparisons to reach a decision as to the best treatment/disposal option of the BSG generated by the brewing process. Priorities were set as 1) treatment/disposal aligns with the food waste hierarchy, 2) treatment/disposal reduces the carbon equivalent footprint, in accordance with the circular economy strategy, and 3) the treatment/disposal method is easy to implement. Once the priorities were set, the various options were compared with pairwise matrices using a scale of numbers that indicate how many more times one element dominates over the other element with respect to the criterion to which they are compared. The scale in Table 5.1, established by Thomas L. Saaty was used in the pairwise comparisons (Saaty, 2008). For the first priority, align with the food waste hierarchy, the options were scaled based on where they were ranked by the US EPA Food Waste Hierarchy (US EPA, 2019). For the second

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priority, reducing the carbon footprint, the cumulative results from WARM for the avoided $MtCO_2E$ was used to scale the options. The last priority, easy to implement, was scaled based on research of the various options if they are currently used for BSG and if they are currently used in Mecklenburg County.

Table 5. 1 AHP - The Fundamental Scale of Absolute Numbers

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Source: Reproduced from Saaty, 2008

5.3.4 Economic Analysis

A market assessment was completed first to determine the potential market for compost created from BSG. A potential agricultural market was identified by the total farm acres for Mecklenburg County and surrounding Counties in North Carolina (USDA, 2019). Based on industry publications, application of compost was assumed at 20 tons/acre/year. For the number

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of acres that would need, or want, compost a conservative 5% was assumed. Of the 5% of acres that would use compost, a 30% market capture was assumed (Coker, 2022c). To determine a residential landscape market the total Single Family Dwelling Units was calculated for Mecklenburg County and surrounding counties in North Carolina from the 2021 ACS US Census Bureau Survey (US Census Bureau, 2021). Based on industry publications, each SFDU was assumed to have 250 sq ft of available land that would require compost. For the land, it would need 3 yd^3/1,000 sq ft/year. Assume that 10% of the SFDU would use compost, and of that potential market a 30% market capture was assumed (Coker, 2022c). The next step was to determine how much compost the BSG would yield at the different production levels. The BSG need to be mixed with an additional feedstock to achieve a desired C:N ratio. Through the composting process the feedstock shrinks 30% in volume. Once curing begins, the volume would shrink another 10%. The compost is then put through a screening process and 20% would be lost to overs, which is oversized pieces that would not fit through the screen (Coker, 2022a).

The economic value of the compost created from the BSG and feedstock was assessed by calculating the Net Present Value (NPV) for different production levels. The NPV of the future cash flows is a measure of the projects value. In this case, land costs and tax effects are not considered. Currently, the County processes yard waste at Compost Central (Maile, 2020). The assumption is made that the BSG could be processed by expanding and modifying Compost Central by adding Covered Aerated Static Pile (ASP) composting ability to the existing windrow composting process that is already in place (Maile, 2020). To estimate the capital costs required, industry publications were used and then modified for the comparable BSG volumes that would need to be processed by ASP at Compost Central. Also, annual fixed and variable costs for operating an ASP were obtained and then the labor rates were adjusted to North Carolina labor

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rates (US BLS, 2021). The sale price of compost was determined from current internet searches for the market cost of compost. The inflation rate used was 2.3%, based on the long term CPI index from the Congressional Budget Office (CBO) (CBO, 2022). The discount rate of 3.8% is based on the 10-Year Treasury note (CBO, 2022).

Additionally, economic data were collected to determine the cost and value of the products produced from the various treatment options. To use a consistent production value, the BSG for 2021 were used for all various treatment options. Pricing data were collected, including energy data, to aid in comparing different options and any benefits of the products produced. All dollar values were adjusted to 2021 values using the US BLS CPI inflation calculator (US BLS, 2022a).

5.4 Results and Discussion

5.4.1 Environmental Results

Results from the WARM are included for the different treatment options for combustion, composting, anerobic digestions and then animal feed and converting to human feed. When looking at a comparison of results between landfilling BSG or treating the waste through combustion, composting, or anaerobically digesting, combustion provided the greatest offset of $MtCO_2E$. WARM results of these three options, as compared to landfilling, are provided in Tables 5.2, 5.3, and 5.4 in Metric tons of CO_2 equivalent, $MtCO_2E$.

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Table 5. 2 Change in $MtCO_2E$ Combustion versus Landfill of BSG

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,101.59)	(2,267.75)	(11,197.56)	(21,989.25)	(30,743.05)	(36,891.53)
Longer COVID Recovery	(2,101.59)	(2,267.75)	(10,194.04)	(20,017.69)	(27,987.33)	(33,584.14)
Aggressive Growth	(2,101.59)	(2,267.75)	(12,901.82)	(26,001.32)	(46,842.58)	(76,301.68)
Aggressive Growth with Gilde	(2,101.59)	(2,267.75)	(21,397.51)	(34,496.36)	(55,338.27)	(84,797.37)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

Table 5. 3 Change in $MtCO_2E$ Compost versus Landfill of BSG

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,060.10)	(2,222.98)	(10,976.48)	(21,555.11)	(30,136.08)	(36,163.17)
Longer COVID Recovery	(2,060.10)	(2,222.98)	(9,992.78)	(19,622.47)	(27,434.77)	(32,921.08)
Aggressive Growth	(2,060.10)	(2,222.98)	(12,647.10)	(25,487.97)	(45,917.75)	(74,795.23)
Aggressive Growth with Gilde	(2,060.10)	(2,222.98)	(20,975.06)	(33,815.29)	(54,245.71)	(83,123.19)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

Table 5. 4 Change in $MtCO_2E$ Anaerobic Digestion versus Landfill of BSG

Year	2020	2021	2035	2045	2055	2065
Base Case	(1,864.18)	(2,011.57)	(9,932.60)	(19,505.18)	(27,270.09)	(32,723.99)
Longer COVID Recovery	(1,864.18)	(2,011.57)	(9,042.45)	(17,756.34)	(24,825.67)	(29,790.23)
Aggressive Growth	(1,864.18)	(2,011.57)	(11,444.34)	(23,064.02)	(41,550.90)	(67,682.09)
Aggressive Growth with Gilde	(1,864.18)	(2,011.57)	(18,980.29)	(30,599.40)	(49,086.85)	(75,218.04)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

WARM was also used to evaluate using the BSG as animal feed and converting into human food. A 0% spoilage scenario was run only for the option of animal feed. If the BSG are stored appropriately and transported in a timely manner, there could be a scenario where there is no loss. The results of avoided M_tCO_2E from 0% Spoilage and 3% Spoilage are summarized in

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Appendix A and graphically shown in Figure 5.1. Assuming a 3% loss is based on the USEPA recommendation for average loss for food banks (USEPA, 2021f). Additional runs were done with a 10% spoilage and a 30% spoilage to see the impact this would have on the $MtCO_2E$. The avoided $MtCO_2E$ for 10% spoilage are summarized in Appendix A and graphically shown in Figure 5.2. The avoided $MtCO_2E$ for 30% spoilage are summarized in Appendix A and graphically shown in Figure 5.3. For each level of spoilage, a low- and high-end scenario was generated from the model. For animal feed, the US EPA only recommend using the low-end estimates as there is not enough data on the upstream food that is replaced. For human food, BSG can be a direct substitute for flour in products (Mussatto, 2014).

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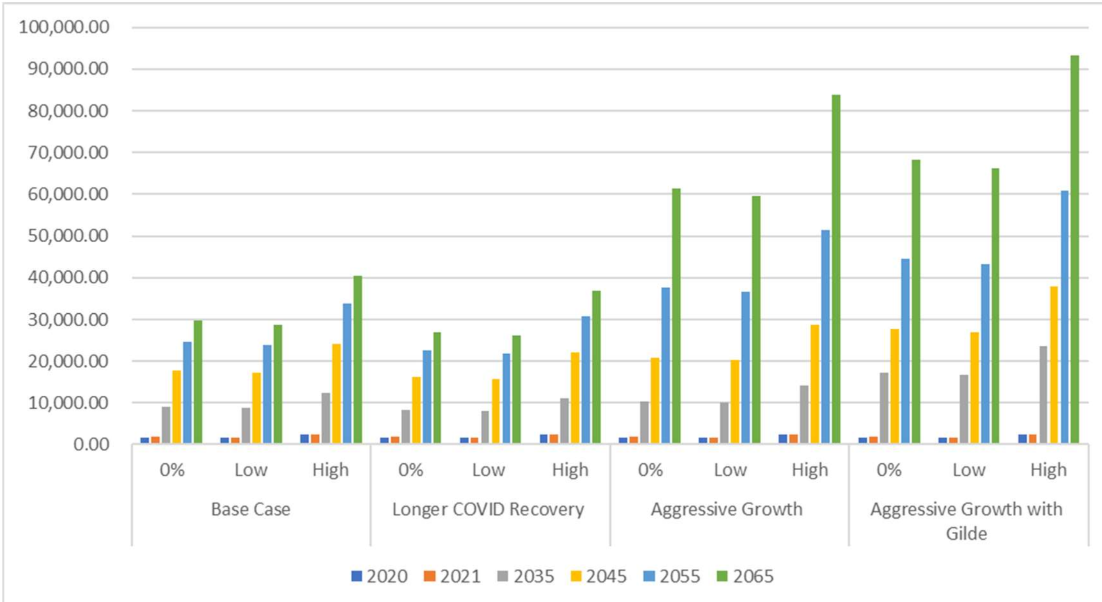

Figure 5. 1 $MtCO_2E$ Avoided Utilizing BSG as Animal Feed or Human Food - 0% Spoilage and 3% Spoilage (Open LCA, 2020)

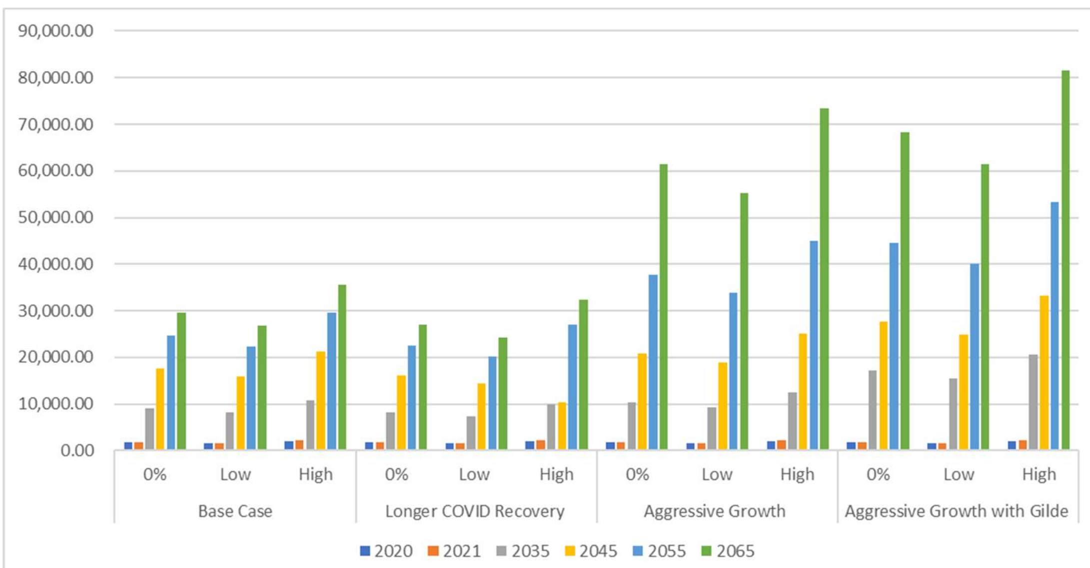

Figure 5. 2 $MtCO_2E$ Avoided Using BSG as Animal Feed or Human Food - 0% Spoilage and 10% Spoilage (OpenLCA, 2020)

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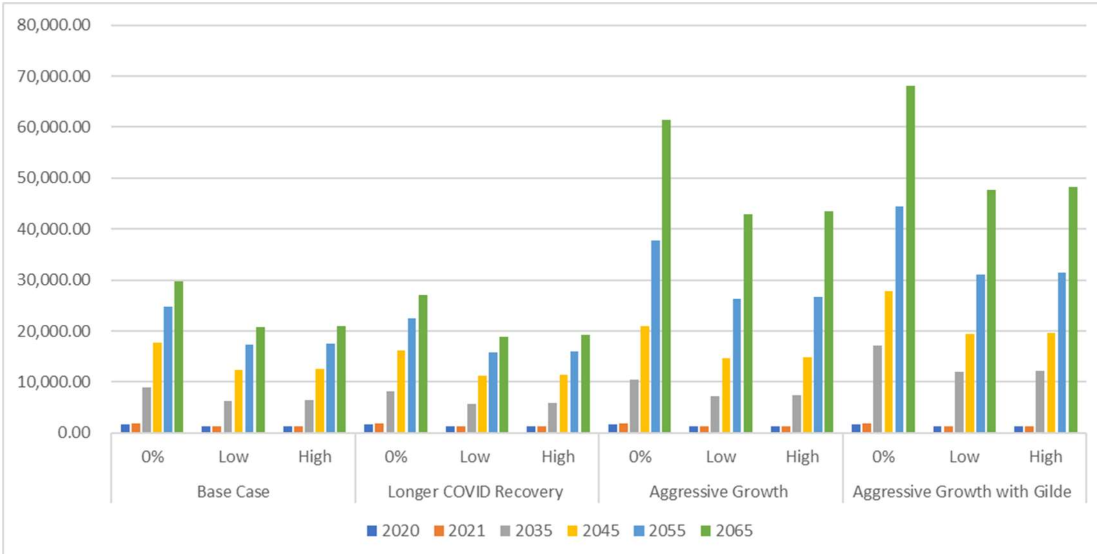

Figure 5. 3 $MtCO_2E$ Avoided Utilizing BSG as Animal Feed or Human Food - 0% Spoilage and 30% Spoilage (OpenLCA, 2020)

To summarize the $MtCO_2E$ data to be used with the economic and social responsibility data, the cumulative total of $MtCO_2E$ avoided as compared to landfilling the waste was calculated for 2065. This was then converted to $MtCO_2E$/capita and CO_2E (tons)/capita, similar to Chapter 4, to see the impact of different treatment/disposal options of BSG. The results of the cumulative total of $MtCO_2E$ avoided and the per capita summary are shown in Table 5.5 for all treatment options.

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Table 5. 5 Summary of Avoided MtCO2E by Treatment Options

	Combustion	Composting	Anaerobic Digestion	0% Spoilage	3% Spoilage		10% Spoilage		30% Spoilage	
					Low	High	Low	High	Low	High
Base Case	(886,528)	(869,025)	(786,379)	(713,000)	(691,610)	(1,688,044)	(641,700)	(1,566,226)	(499,100)	(1,308,177)
Longer COVID Recovery	(804,965)	(789,073)	(714,031)	(647,402)	(627,980)	(1,532,740)	(582,662)	(1,422,130)	(453,181)	(1,106,100)
Aggressive Growth	(1,296,348)	(1,270,754)	(1,149,903)	(1,042,602)	(1,011,324)	(2,468,384)	(938,342)	(2,290,254)	(729,821)	(1,781,308)
Aggressive Growth with Gilde	(1,653,164)	(1,620,525)	(1,466,411)	(1,329,575)	(1,289,688)	(3,147,800)	(1,196,617)	(2,920,639)	(930,703)	(2,271,608)
$MtCO_2E$/Capita										
Base Case	(0.3499)	(0.3430)	(0.3103)	(0.2814)	(0.2729)	(0.6662)	(0.2532)	(0.6181)	(0.1970)	(0.5163)
Longer COVID Recovery	(0.3177)	(0.3114)	(0.2818)	(0.2555)	(0.2478)	(0.6049)	(0.2299)	(0.5612)	(0.1788)	(0.4365)
Aggressive Growth	(0.5116)	(0.5015)	(0.4538)	(0.4115)	(0.3991)	(0.9741)	(0.3703)	(0.9038)	(0.2880)	(0.7030)
Aggressive Growth with Gilde	(0.6524)	(0.6395)	(0.5787)	(0.5247)	(0.5090)	(1.2423)	(0.4722)	(1.1526)	(0.3673)	(0.8965)
CO_2E (tons)/Capita										
Base Case	(0.3857)	(0.3780)	(0.3421)	(0.3102)	(0.3009)	(0.7343)	(0.2792)	(0.6813)	(0.2171)	(0.5691)
Longer COVID Recovery	(0.3502)	(0.3433)	(0.3106)	(0.2816)	(0.2732)	(0.6668)	(0.2535)	(0.6187)	(0.1971)	(0.4812)
Aggressive Growth	(0.5639)	(0.5528)	(0.5002)	(0.4536)	(0.4400)	(1.0738)	(0.4082)	(0.9963)	(0.3175)	(0.7749)
Aggressive Growth with Gilde	(0.7192)	(0.7050)	(0.6379)	(0.5784)	(0.5610)	(1.3694)	(0.5206)	(1.2706)	(0.4049)	(0.9882)

Source: OpenLCA, 2020

Note 1: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

Note 2: The low-end estimate includes the GHG emissions avoided by not landfilling. The high-end estimate includes the GHG emissions avoided by not landfilling the waste, as well as an estimate for the substitution of BSG for the food that does not need to be produced.

5.4.2. Societal Analysis

The AHP analysis is included in Appendix K. The ranking of options based on the AHP: 1) Human Food, 2) Animal Feed, 3) Composting, 4) Combustion, and 5) Anerobic Digestion.

For the first priority, the US EPA Food Waste Hierarchy was used to scale the options. The hierarchy provided in Figure 2.2, gives the highest priority to feeding humans, feeding animals, industrial uses, composting and then landfilling. The cumulative WARM results used to scale the second priority, reduce the carbon equivalent footprint, are found in Table 5.5. The third priority, treatment/disposal method is easy to implement, used data and information collected in literature, in addition to parameters specific to Mecklenburg County to scale the options. AHP is useful in this environment because the model allows judgements to derive tangible values to provide credence for judgements when intangibles are involved (Saaty, 2008). The following information contributed to the piecewise comparison of options for the third priority.

5.4.2.1 Combustion

To be used in combustion, BSG must be dried to <= 55% moisture content (Mussatto et al. 2006; Mussatto, 2014). It is possible for a brewery to produce energy by combusting the BSG to produce steam energy. This process does generate emission particles and toxic gases that must be treated or collected. The process of combustion does reduce the volume of BSG to a greatly reduced volume of ash, but does require significant capital investment in equipment (Mussatto, 2014).

5.4.2.2 Compost

BSG is not suitable for direct composting, but can be mixed with other carbon-rich-byproducts to increase the C/N ratio and replace the chemical fertilizers that are more expensive

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and do not contribute to the closed loop emphasis of the circular economy (Assandri et al., 2021). Currently, Mecklenburg County does not pick up food waste, but it does in certain areas, based on town or city, collect yard waste. This would be a carbon-rich source to mix with the BSG for compost. All residents in Mecklenburg County can also self-haul their yard waste to full-service recycling centers, currently 4 centers in the County. This can be free to residents, or a fee is charged, based on the quantity. Also, there are private food waste collection services that provide collection services for commercial businesses and residences for a fee. The food waste, according to David Valder, co-Owner Crown Town Compost (personal interview, November 12, 2021), is taken to industrial farming facilities to compost and create soil.

5.4.2.3 Anaerobic Digestion

BSG cannot be used as a mono substrate in anaerobic digestion, meaning that it must have additives (Bougrier et al., 2018). An example would be co-digestion with animal waste. Also, because the brewing process is not continuous at local breweries, there might not be a continuous supply of BSG to feed the digester (Sturm, B. et al., 2012). There are also significant capital costs and operating costs for an anaerobic digester. In 2021, the US EPA published a survey of digester processing food waste by state in 2017 and 2018, and for North Carolina there were two digester (USEPA, 2021a). There is a private digester owned by Blue Sphere Corporation in Charlotte, North Carolina that processes food waste and is connected to the electrical grid through Duke Energy (Whatley, 2016).

5.4.2.4 Animal Feed

Based on information obtained directly from breweries in Mecklenburg County, brewers often give their BSG to farmers, at no charge. That is the brewery allows the farms to take the BSG for free, and this can be used as a supplement to feed. The farmer is responsible for

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transporting the BSG from the brewery after the brew cycle. BSG contains 74% water on average. Due to the high water content, mature cows should be limited to 30 to 50 pounds per cow per day. This is equivalent to 7.8 to 13 pounds of dry matter feed per cow per day, or 30% of their dry feed (Thomas et al., 2019).

5.4.2.4.1 Farms in Mecklenburg County and Surrounding North Carolina Counties

For brewers spent grain, the current strategy of animal feed might not be the most sustainable, at least on a longer timeline. An analysis of farms in Mecklenburg County and surrounding counties in North Carolina was performed. A map of North Carolina showing Mecklenburg County and surrounding counties is shown in Figure 5.4. Between 2012 and 2017, the number of farms and then number of farmed acres have decreased by 7%, Table 5.6. A comparison of the number of farms and the number of acres in Mecklenburg County as compared to surrounding counties for 2012 and 2017 are shown in Figure 5.5 and Figure 5.6, respectively. While using feed for animals is helpful for keeping it out of the landfill, and a cheap source of food for the farmer to use as animal feed. If the declining trend in the number of farms and the farm acres continues, using all the BSG as animal feed will not be sustainable. Due to the heavy weight and the quick spoilage rate, it only makes sense to transport to local farmers. In 2013, Mussatto found that the cost to transport BSG to farms was $16/ton for 5 miles, this would be $20.59/ton for 5 miles in 2022 dollars, or $4.07/ton/mile (US BLS, 2022a).

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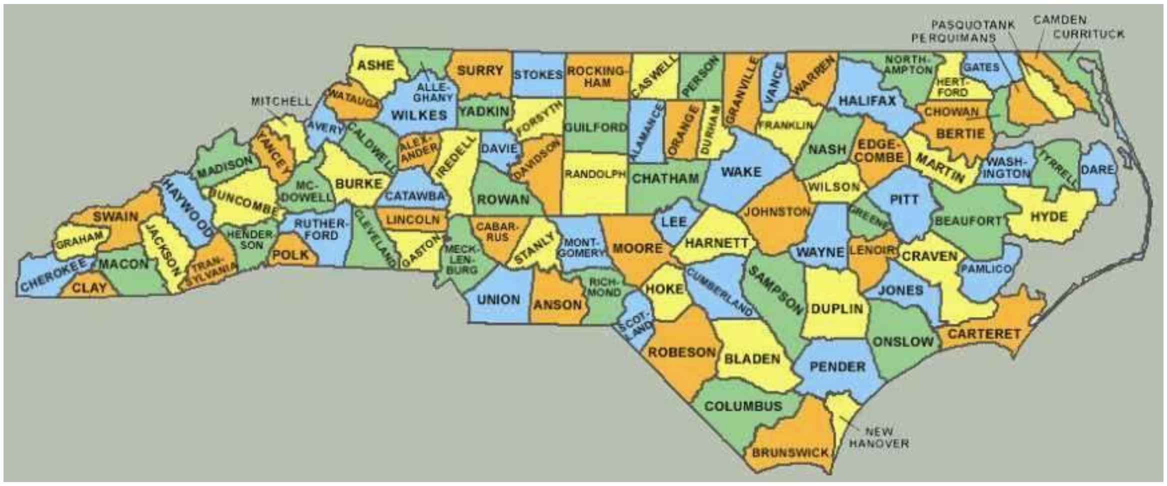

Figure 5. 4 County Map of North Carolina (Blogspot, 2015)

Table 5. 6 Number of Farms and Land in Farms (Acres) in Mecklenburg County and Surrounding Counties in North Carolina

	Number of Farms			Land in Farms (Acres)		
	2012	**2017**	**% Change**	**2012**	**2017**	**% Change**
Mecklenburg County	237	216	-9%	15,361	11,674	-24%
Catawba County	701	638	-9%	66,874	63,530	-5%
Cabarrus County	588	629	7%	66,320	63,667	-4%
Gaston County*	520	522	0%	41,923	37,695	-10%
Iredell County	1,199	1,055	-12%	151,530	133,346	-12%
Lincoln County	653	614	-6%	55,753	54,080	-3%
Rowan County	1,016	925	-9%	121,341	118,914	-2%
Union County	1,063	957	-10%	200,673	186,626	-7%
Total	**5,978**	**5,556**	**-7%**	**719,773**	**669,532**	**-7%**

*Data from USDA, 2019, except Gaston County 2012 data provided CEFS, 2012

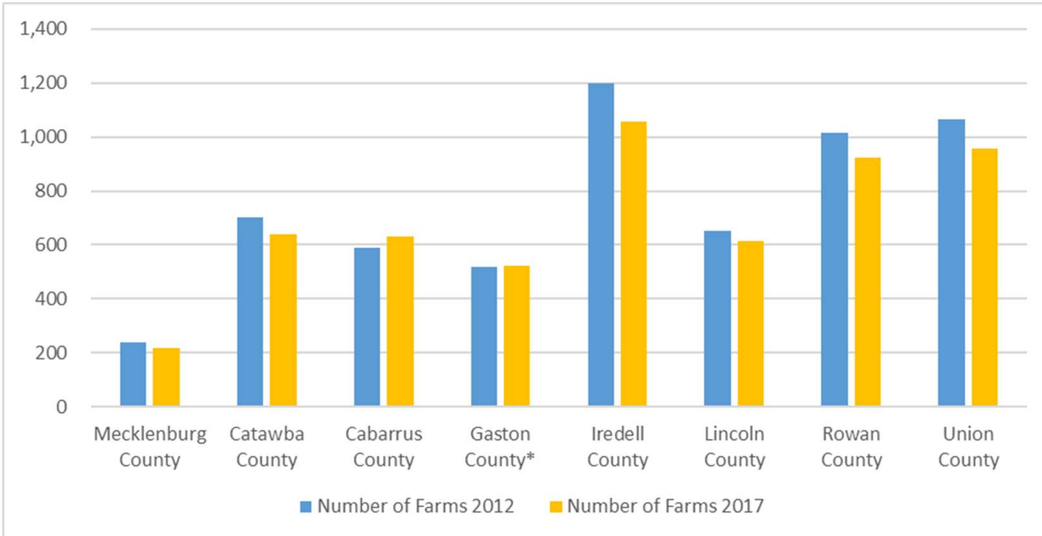

Figure 5. 5 Number of Farms in Mecklenburg County and Surrounding Counties, NC 2012 & 2017 (USDA, 2019)

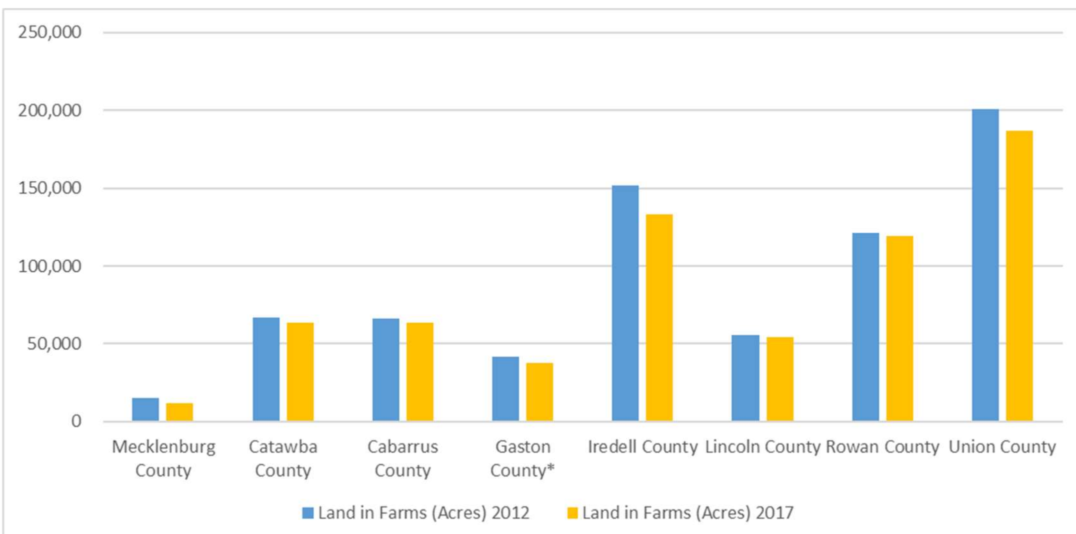

Figure 5. 6 Land in Farms (Acres) Mecklenburg County and Surrounding Counties, NC 2012 & 2017 (USDA, 2019)

5.2.2.5 BSG for Human Food

BSG deteriorates quickly due to the high moisture content and sugar content. To preserve it longer it can be freeze dried, oven dried and frozen. Oven drying is considered the most effective preservation (Ikram et al., 2017; Mussatto et al., 2006). While oven drying preserves the BSG and reduces the weight to transport the BSG (reducing the weight of water), it is very

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energy intensive (Lynch et al., 2016). Once the BSG is dried, it can be converted into flour and used in bakery products such as breads, muffins, and cookies. However, only small amounts can be incorporated into products to avoid changing the texture and color of the final products (Mussatto, 2014). Because of brownish color and higher than conventional flour moisture adsorption, only 5 -10% can be substituted for flour replacement (Mussatto et al., 2006; Lynch et al., 2016).

5.4.3 Economic Analysis

The potential demand market for compost was calculated from the agricultural acres for Mecklenburg County and surrounding counties plus the SFDU in Mecklenburg County and surrounding counties. The total potential market was compared to the potential volume of compost that could be produced by composting the BSG with an additional feedstock to determine if compost was produced would there be a potential market demand. The potential market and the volume of compost produced is summarized in Table 5.7. The potential market, including the surrounding counties, is larger than the projected amount of compost that could be generated by all the different production scenarios. The detail on the production volume of BSG, the additional feedstock and the resulting compost product can be found in Appendix M.

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Table 5. 7 Market Potential of Compost and Expected Compost Production from BSG

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Market Potential										
Agricultural Market for Compost (Tons/Year)										
Mecklenburg & Surrounding Counties	129,954	129,954	129,954	129,954	129,954	129,954	129,954	129,954	129,954	129,954
Mecklenburg County Only	2,620	2,620	2,620	2,620	2,620	2,620	2,620	2,620	2,620	2,620
Residential Market for Compost (Tons/Year)										
Mecklenburg & Surrounding Counties	5,788	5,788	5,788	5,788	5,788	5,788	5,788	5,788	5,788	5,788
Mecklenburg County Only	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total Potential Market for Compost (Tons/Year)										
Mecklenburg & Surrounding Counties	135,743	135,743	135,743	135,743	135,743	135,743	135,743	135,743	135,743	135,743
Mecklenburg County Only	5,020	5,020	5,020	5,020	5,020	5,020	5,020	5,020	5,020	5,020
Compost Production (Tons/Year)										
Base Production	14,283	16,049	18,034	20,264	22,771	25,587	28,751	32,307	36,303	39,570
Longer CoVid Recovery	12,235	13,748	15,448	17,359	19,506	21,918	24,629	27,675	31,097	34,943
Aggressive Growth	15,174	17,575	20,355	23,575	27,305	31,625	36,628	42,423	49,134	51,859
Aggressive Growth with Gilde	15,174	17,575	62,733	65,953	69,683	74,003	79,006	84,801	91,512	94,237

Source Notes:

The following sources were used to obtain data : Agriculture Acres (USDA,2019); Compost Volume and Application (Coker, 2022c); Residential SFDU (US Census Bureau, 2021); Compost Feedstock, Shrinkage & Volume (Coker, 2022a)

The NPV was calculated based on the potential volume of compost produced by the BSG. Sensitivity analysis was completed for each production level based on different compost selling prices. An example of the NPV analysis is included in Appendix N. The prices would be determined by market demand, so a range of prices were used and the resulting NPV is summarized in Table 5.8. The NPV is positive at a selling price between $80-$81/Ton. Current market rates of high quality compost can range from $40-$150/Ton (Nauta, 2022). Currently, inflation is at a 40-year high, 8.2% in September 2022 (Russel, 2022). Inflation at this rate would cause the Selling Price $/Ton for all production scenarios to increase to above $81/Ton. For the Base Case and the Longer COVID recovery case it would require the selling price to increase to $82-$85/Ton.

Table 5. 8 Summary of Resulting NPV by Different Compost Selling Prices ($/Ton)

	$50	$60	$70	$80	$90
Base Production	(4,040,383)	(2,550,771)	(1,061,158)	428,454	1,918,066
Longer CoVid Recovery	(3,916,748)	(2,635,380)	(1,354,011)	(72,643)	1,208,726
Aggressive Growth	(4,511,478)	(2,649,463)	(787,448)	1,074,567	2,936,583
Aggressive Growth with Gilde	(5,672,627)	(1,854,829)	1,962,970	5,780,768	9,598,566

Note: A negative value in parenthesis indicates the expected rate of return earned on the investment is less than the discount rate.

Results of general economic and cost information of the end products for the various treatment options analyzed in AHP performed in Section 5.4.2 are compiled in Appendix O. All referenced prices have been adjusted to 2021 dollars (US BLS, 2022a)

- **AHP Rank 1 – Human Food** – The pricing for using BSG directly in baking goods or milling as flour is multiples higher than the conventional baked goods and flour. Only 65g of BSG (Spent Grain Company, 2022) can be used directly in a standard loaf of bread without altering the texture or flavor, the remaining flour (335g-435g) would be conventional flour. To utilize all of the BSG produced in the County, 48 Million loaves could be produced, that is 42 loaves per person in 2021. However, the cost of the loaves

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is $7/loaf (Hewn, 2022) as compared to a conventional loaf of bread that is $1.50/loaf (In2013dollars.com, 2022). The same is true for milling BSG as flour. The BSG must be dried and milled. The cost of this results in the flour price of $8.77/lb. (Zimbaroff, 2018) as compared to conventional flour of $0.48/lb. (US BLS, 2022b).

- **AHP Rank 2 – Animal Feed -** Currently, breweries allow farmers to pick up BSG at no charge to the farmer. Commercial feed for cattle is $406.53/ton (Scully, 2014). The BSG can be used directly as animal feed, assuming they are not allowed to spoil, can be used for 1/3 of the needed feed, without causing adverse effects to the animal. In the analysis, large breweries, in other areas of the country, sold the BSG as feed at $116.15/ton (Scully, 2014). This results in a $96.79/ton savings to the farmer. Depending on the distance of the farm to the brewery and the amount of BSG available, this could be economically beneficial to the farmer.
- **AHP Rank 3 – Composting –** Every ton of food waste yields 1 – 1.5 cubic yards of compost (Atlas, 2018). Mecklenburg County charges $28.03/ton for disposing of organic waste directly at the recycling center. The County does compost organic waste and sells the resulting waste for $18.02/cubic yard. This results in a net end product loss.
- **AHP Rank 4 – Combustion –** As of 2021, there was no food waste combustion plant in Mecklenburg, North Carolina. Building a plant would take millions of dollars in capital costs. In addition, combustion emits measurable nitrous oxide (USEPA, 2022b). The analysis only looks at the resulting energy produced by combusting waste. For each ton of waste 550 kwh of energy is produced (USEPA, 2022d). Selling the resulting energy does result in a positive end product value.

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- **AHP Rank 5 – Anaerobic Digestion –** As of 2021, there was one organic waste anaerobic digester operating in Mecklenburg County. It is privately owned and contracts with Duke Energy to sell the resulting energy to the grid. Anaerobic digestion of organic waste results in 273-436 L CH_4/kg, liters of methane per kilogram food waste, (Gladchenko et al., 2017) of gas. Assuming all the BSG generated in 2021 had been treated in the anaerobic digester, the gas generated results in a positive end product value.

5.5 Conclusions

It is important to investigate how BSG can be integrated into the Circular Economy strategy. Food waste does not belong in a landfill and disposal of food waste offers the City and County an opportunity to help meet some of the waste goals laid out in the Circular Economy Strategy. Environmental, societal, and economic aspects of the disposal of BSG were analyzed to determine how BSG fit into a Circular Economy. For the environmental aspects, the WARM analysis was used to determine the $MtCO_2E$ avoided by the different treatment options. All options are better than landfilling the BSG. This would suggest that a policy restricting the disposal of food waste in landfills would be beneficial to Mecklenburg County in an environmental context. A summary of all the results is shown in Table 5.7. Combustion of BSG would avoid the greatest amount of $MtCO_2E$, followed by composting, anerobic digestion, animal feed, and then human food with 3%, 10% and then 30% spoilage, respectively. However, human food, regardless of the spoilage rate, with the EPA high estimate of food production avoided, meaning the BSG did offset flour production, had the greatest offset to $MtCO_2E$. Within the WARM model the EPA identifies a high level of uncertainty for the high-end estimate of food donation. There is currently not enough research as to the degree that the donated food decreases the upstream food production, and no identified research within WARM for BSG

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specifically. Also, the WARM results for food donation do not include the transportation, processing, and storage of the BSG (US EPA, 2021f).

The MtCO_2E avoided from combustion within the WARM model is primarily from the assumed avoided utility emissions. In the United States, most WtE (waste-to-energy) plants produce electricity. Within North Carolina there is one commercial waste combustor in Haw River for hospital, medical and infectious waste, not food waste (US EPA, 2022g). Also, due to the high moisture content of BSG, the avoided MtCO_2E does not include any method for drying the spent grain to a moisture level for combustion (Mussatto et al. 2006; Mussatto, 2014). The MtCO_2E avoided by composting is generated by the fertilizer offset and soil carbon storage. Compost from food waste applied to soils can offset the use of synthetic fertilizer and therefore the emissions from producing/generating the fertilizer. The degree to which compost offsets fertilizer use depends on the health of the soil. Fertilizer is applied when certain nutrients are not present in the soil. Over time compost improves the health of the soil and would offset additional fertilizer. Soil restoration, improved nutrients, and water retention are not possible with chemical fertilizers (Oyetunji, O. et al., 2022; Tabatabai, S. et. al., 2020; Ohlson, 2014), When compost is applied to soil it can act as a carbon sink. The decomposition of the carbon within the compost can take years to decompose. The EPA identifies a lack of research on carbon storage associated with composting as a limitation within the WARM model (US EPA, 2020b). The storage and sequestration of carbon by soil is currently of great interest to researchers. There is current research that indicates that increasing soil quality, in part through compost, can increase the carbon storage and sequestration capacity to help offset climate change (Ohlson, 2014; Tickell and Tickell, 2020). The USDA is reviewing a new standard, 808-CPS-1, called the Soil Carbon Amendment that require the use of soil organic carbon amendments, like compost, to improve

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soil conditions and increase carbon storage (USDA, 2020). The $MtCO_2E$ avoided by anerobic digestion also include the emission savings from avoided synthetic fertilizer and the soil carbon storage, similar to that of compost. However, the WARM model does not include new research into the potential long term and damaging effects of per- and polyfluoroalkyl substances (PFAS) that been found in residual streams from WWTP. Current research is on-going on PFAS and the contamination of biosolids from anaerobic digestion (US EPA, 2021f).

For the societal impact of BSG, the analytic hierarchy process (AHP) was utilized to conduct pairwise comparisons to reach a decision. This WARM environmental data were incorporated into the AHP, along with piecewise comparisons to see which options best align with the US EPA Food Waste Hierarchy and which methods could be easily implemented. After completing the AHP analysis, the options were ranked as follows: 1) Human Food, 2) Animal Feed, 3) Composting, 4) Combustion, and 5) Anaerobic Digestion. Currently, using BSG as human food, either directly in baking products or milling as flour, presents some economic challenges. The second option of using the BSG as animal feed, is currently, the most likely treatment option other than landfilling. Because BSG are considered food waste many breweries allow farmers to pick up the BSG for animal feed for free. However, the number of farms close to Charlotte and Mecklenburg County is decreasing. As the brewing industry continues to grow this is not necessarily a sustainable option, particularly because of rapid spoilage rate of the spent grain. The third option of composting also presents some economic challenges; however, there is already an existing compost location for Mecklenburg County. Central Compost handles over 100,000 tons of yard waste annually for the County (Maile, 2020). The yard waste could be used as feedstock for the food waste.

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A Net Present Value analysis was performed for composting, considered the most feasible option given the environmental and societal aspects. Capital costs were included to incorporate aerated static pile method of composting for food waste into the Central Compost location. Selling at a market rate of $70-80/ton the base case production would have a positive NPV. However, the analysis does not include any additional land costs for Central Compost or taxes. In addition, the amount of BSG that would need to be composted would require the entire feedstock of yard waste annually being processed at Central Compost. Currently, the County sells the yard waste compost for $25.23/ton, which is not calculated in the cash flows of processing the BSG. However, the food waste compost sells for a higher price because of the quality. Yard waste compost is not considered a valuable soil amendment (Ohlson, 2014).

The research is limited by several factors including $MtCO_2E$ offsets in the WARM model and if composting BSG at a central location operated by the County would be a feasible option the County would be willing to explore. The EPA lists limitations of the WARM which were mentioned above in the research, including the upstream emissions avoided by using the BSG as human food, the potential additional benefits of soil carbon storage and the avoided utility emissions from combusting the BSG. The composting capital costs, fixed and variable costs are scaled from 2022 industry research. Additional research would need to be conducted with the County on converting Central Compost into a food waste compost facility.

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CHAPTER 6 – SUMMARY OF CONCLUSIONS AND IMPLICATIONS FOR CIRCULAR ECONOMY AND MECKLENBURG COUNTY, NORTH CAROLINA

6.1 Summary of Conclusions

The goals of this research project were to analyze three questions in regard to the brewing industry in Mecklenburg County. The three questions are examined in relation to the growth in beer production: 1) what impact beer production has on water demand, 2) what the impact does the spent grain waste generated by beer production have on the Circular Economy strategy, and 3) can breweries support the circular economy. Ultimately, the environmental, social, and economic performance of an option must be balanced with the technological maturity as well as with a company's or community's goals (Stone et al., 2020).

6.1.1 Water Demand in Beer Production

The production of beer requires a significant amount of fresh water, anywhere from 4.7 L/L to 13.9 L/L (liters of water per liter of beer) . Through past, current, and projected beer production, future water demand needs were projected through 2065. The research presented the additional challenges facing the water security After the analysis, the growing brewery industry does not present a significant impact on the water demand directly. However, the projected growth in the brewing industry is at least, partially driven by the projected growth of population in the County, which will have significant impact on the water demand in Mecklenburg County. In the 2014 the Catawba-Wateree River Basin Water Supply Master Plan, the growth in the brewery industry was not predicted. Also, the population growth has been higher than the population growth planned for in the 2014 CWWMG Master Plan.

The research was limited by the data published by the Catawba-Wateree Water Management Group Master Plan in 2014. This was the most recent plan published predicting the long term safe yield and population growth projections. This research included updated water

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demand as published by Catawba-Wateree Annual Water Use (CWAWU) for 2019 and 2020, but there is no update if any additional mitigation measures have been put in place that would affect the safe yield reductions calculated in Chapter 3.

The results in Chapter 3 show that the impact of the growing beer industry is small on the overall water demand, the impact of the population growth on reaching safe yield will be significant. At the most aggressive beer production schedule, and with the highest water use of 13.9 L/L (liter of water per liter of beer), the addition of the brewery production only changes the safe yield from 33.6 years to 33.2 years. The population growth however, reduced the CWWMG WSMP plan from 40 years to 33.6 years, a significant reduction. Even isolating the water supply for Mecklenburg County by Mountain Island Lake and Lake Norman, the brewery industry adds an additional 1.56% increase in 2065. However, recognizing that the brewery industry is water intensive and projecting the impact of population growth, the research indicates a need for a water consumption reduction plan. While a water consumption plan for the Catawba-River Basin is out of the scope of this research, water demand reduction was achieved in the beer industry in Colorado. It is recommended that the County partner with breweries to form a Sustainable Initiative, similar to the Colorado Department of Public Health & Environment (CDPHE), to put in place best practices to ensure that the water demand by breweries is as efficient as possible to support the growing industry. This is further supported by the work Envision Charlotte completed with their Charlotte Energy Reduction Program, which achieved a 19% energy consumption reduction. The Beverage Industry Environmental Roundtable estimates a 9-10% reduction in water demand can be achieved through benchmarking and process improvements. Focusing on water demand reduction for breweries would be a logical place to start because in

2020 breweries used more water than other industries in Mecklenburg County by a factor of 2.25 (Water Withdrawal (MGD)/Annual Payroll ($)).

However, these results are very production size dependent (BIER, 2022). Further research is recommended into the private and public collaboration that can work on benchmarking data collection for individual breweries so that water demand can be minimized while still promoting brewery growth in Mecklenburg County.

6.1.2 Brewery Waste in a Circular Economy

Three specific goals were identified in the Circular Economy plan commissioned by the City in 2018 that relate directly the BSG generated by beer production in Charlotte, even though beer production is not directly addressed in the report. The three goals: 1) terminate all use of landfills by 2040, 2) minimize annual GHG emissions to 2 tons of CO_2 equivalent per person, and 3) ensure nutrients from all organic wastes are returned to natural cycles (Gladek, Kennedy and Thorin, 2018). In Chapter 4, the significant amount of organic waste, BSG, was projected through 2065 based on different brewery production levels. The waste cannot be landfilled if the first goal of the Circular Economy Plan is going to be achieved by 2040. The Circular Charlotte report in 2018 estimated the waste landfilled/capita (WL/C) at 1.12 WL/C. If the projected BSG is landfilled it would increase the WL/C from 1.5% to 2.5%, depending on production levels.

The second goal of the Circular Economy plan is to minimize annual GHG emissions to 2 tons of CO_2 equivalent per person ((Gladek, Kennedy and Thorin, 2018). In 2015, the City of Charlotte calculated the GHG emissions were 12 tons of CO_2 equivalent per capita, this would require an 83% reduction in per capita emissions by 2050. BSG that are disposed of as food waste will increase the CO_2E/capita by 0.6% to 1.49%, depending on the brewery production volume.

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Mecklenburg County does not have a ban on food waste going to landfills. Therefore, there is no requirement for BSG nutrients to be returned to natural waste cycles, which is the third goal of the Circular Economy plan. In 1991, North Carolina banned yard wastes from landfills (NC DEQ, 2022), but there is no state or local ban on food wastes. The research indicates that to achieve the goals set out in the Circular Economy Plan the BSG generated cannot be landfilled and the County should investigate a policy to restrict the landfilling of BSG. This is supported by the North Carolina ban on yard wastes, which saw the per capita yard wastes diverted from landfills increase from 75 to 229 lbs. (Gerlat, 2014 and Mecklenburg County Government, 2014). In addition, the San Francisco ordinance making composting food waste mandatory increased the recovered food waste from 400 tons/day in 2010 to 600 tons/day in 2013 (Howard, 2013).

6.1.3 Supporting the Circular Economy

Given the projected growth in the beer industry, the BSG generated will need to be incorporated into the overall waste plan for the City and County. It is important for the CE strategy that the BSG do not go to the landfill. Treatment of BSG needs to be incorporated into the City's planning to achieve a zero waste goal. Environmental, societal, and economic aspects of the disposal of BSG were analyzed to determine how BSG fit into a Circular Economy. For the environmental evaluation, the WARM analysis was used and combustion of BSG avoided the greatest amount of $MtCO_2E$, followed by composting, anaerobic digestion, animal feed and then human feed. However, within North Carolina there is one commercial waster combustor, and the high moisture content of BSG require drying before combustion.

Based on an AHP analysis the options were ranked as follows: 1) Human Food, 2) Animal Feed, 3) Composting, 4) Combustion, and 5) Anaerobic Digestion. Human Food ranks at the top of the Food Waste Hierarchy but the market cost of creating human food products from BSG is much higher than conventional products. Animal Food is ranked second. It is an easy option for farmers, however, as the amount of BSG generated continues to grow and the trend for farms close to Mecklenburg County declines, it might not be a sustainable option. Composting was ranked third in the analytical hierarchy process (AHP) analysis.

A net present value (NPV) analysis was performed for composting given that it was the most feasible option of the environmental and societal analysis. The NPV analysis assumed that the Central Compost location could be modified to accept food waste. Currently, the volume of yard waste composted at the central location could be used as feedstock for the BSG. The resulting compost has an expected market value that is higher than the yard waste compost, currently sold by the County, due to the quality of the final compost.

6.2 Recommendations

For the growing water demand, due to the brewery growth, but more importantly the population growth, a water consumption reduction plan should be implemented by the County. Industry examples were given from public and private collaborating to collect benchmarking data and using that data to achieve demand reduction. From the research, it is recommended that a private and public collaboration for benchmarking is a necessary step to reduce water consumption and promote sustainable growth in the brewery industry. A limitation of this research was the brewery water demand was based on benchmarking data provided by the Brewers Association. There is no database for the individual breweries in Mecklenburg County and their individual water demand. Data on private establishments is difficult to obtain and much of this information would be time-consuming to collect. However, water demand savings will be necessary to extend the safe yield for Mecklenburg County and the surrounding areas.

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Currently, there are no food waste recovery laws in place for the City or County. While a farmer might come pick up the BSG, if they do not the only available option is to landfill the waste. The City and County need to consider implementing mandatory laws to ensure food waste is kept out of landfills. As documented in Table 2.3 and 2.4, several states and municipalities have implemented bans on landfilling food waste. With the growing population in Charlotte and the projected growth in the brewing industry, mandatory food waste laws could be a feasible solution to ensure that BSG are not sent to landfills. Connecticut is modeling their food waste ban after San Francisco, and recommending that fees for trash collection are ten times higher than for food waste. This could help make the options of turning BSG compost more economically feasible (Fife, 2020). However, in 2006, the City of Oakland, California set a Zero Waste Goal, they put financial incentives in place to ensure that landfilling costs more than composting. However, even given the price difference, the landfill rates and compost rates have been stagnant the last few years (Hoffman, 2021).

Limitations of this research include the $MtCO_2E$ offsets in the WARM analysis. There are significant uncertainties with the degree to which food recovery offsets upstream foods production, the level of carbon storage created with soil amendments, and the true impact of food donated to feed animals (US EPA, 2021f). The amount of compost that could be absorbed into the market was set at 30% of 5% use for agricultural and 10% for single family dwelling units. There are no data on how price dependent these assumptions are and if they are understated or overstated. Also, the assumptions made in the NPV analysis are based on a food waste recovery composting operation. However, no land or tax costs was included. It is also assumed that the Central Compost facility in Mecklenburg County could be modified to compost BSG. There were also no costs associated with collecting and transporting the BSG.

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6.3 Future Research Needs

What is important to recognize is the economic benefit of craft brewery production in the economic growth of an area (Nilsson, Wartell and Reid, 2020). In this case Mecklenburg County, which had 35 breweries operating in 2020. For water demand, future research into how data could be compiled and analyzed on the individual breweries to assess the level of water savings that could be achieved. This would need to be on a brewery by brewery basis to look at their operations and volume to determine what changes could be implemented and the cost-benefit of these changes. For waste recovery of the BSG, the actual capital costs for modifying Central Compost facility, or locating another facility need to be quantified for a more accurate NPV analysis. Also, the potential market for the BSG compost needs to be further defined and potential ways that the compost could be sold at a more cost-competitive price than landfilling the waste. These next steps are in alignment with the 2020 Organics Recycling Study for the State of North Carolina that was done by NC DEQ that concluded the capital costs required to expand diversion efforts needed to be quantified and that markets for compost need to be more competitive than landfilling. In addition, they found that the state should compare job creation between landfilling and composting operations (NC DEQ, 2020).

If the recommendation to ban food waste from landfills is pursued, additional research would be required in to how this could be successfully implemented in Mecklenburg County. Additional research would be needed as to how the County could be incentivized to make the change. Currently, as in many areas, landfilling waste is the lower cost option. In addition, while additional revenue could be a possibility by selling the higher value food waste compost, the County would forego the current revenue stream from the yard waste compost. Implementing the change would not be as simple as increasing landfill dumping costs. As mentioned earlier in the

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research, pay-as-you-throw programs do not always achieve the desired outcome of reducing landfilled waste. In order to be successful, the municipalities must agree the benefits are worth the costs. Consumers must also understand the pricing, or economic incentives. The pricing of waste is an important part of pay-as-you-throw program and even in the long-term if pay-as-you-throw is cost-saving the economic benefits might not be great enough to incentivize municipalities to adopt the change in municipal solid waste management (Gradus, R. et al., 2019; Ukkonen and Sahimaa, 2021).

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APPENDIX A

Avoided MtCO2E Utilizing BSG as Animal Feed or Human Food At Various Spoilage Rates

Table A.1 Avoided MtCO2E Utilizing BSG as Animal Feed or Human Food 0% Spoilage and 3% Spoilage (OpenLCA, 2020)

		2020	2021	2035	2045	2055	2065
Base Case	0%	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
	Low	1,639.52	1,768.93	8,735.85	17,154.25	23,983.31	28,779.87
	High	2,311.43	2,493.65	12,316.23	24,184.08	33,811.74	40,573.93
Longer COVID Recovery	0%	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
	Low	1,639.52	1,768.93	7,952.53	15,616.67	21,833.55	26,200.15
	High	2,311.43	2,493.65	11,211.44	22,016.88	30,781.03	36,937.51
Aggressive Growth	0%	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
	Low	1,639.52	1,768.93	10,065.32	20,284.35	36,543.83	59,525.68
	High	2,311.43	2,493.65	14,190.46	28,597.09	51,520.56	83,920.61
Aggressive Growth with Gilde	0%	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20
	Low	1,639.52	1,768.93	16,692.61	26,912.16	43,171.12	66,153.50
	High	2,311.43	2,493.65	23,533.23	37,941.67	60,863.33	93,264.67

Note: The low-end estimate includes the GHG emissions avoided by not landfilling. The high-end estimate includes the GHG emissions avoided by not landfilling the waste, as well as an estimate for the substitution of BSG for the food that does not need to be produced.

Table A.2 MtCO2E Avoided by Utilizing BSG as Animal Feed and Human Food - 0% Spoilage and 10% Spoilage (OpenLCA, 2020)

		2020	2021	2035	2045	2055	2065
Base Case	0%	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
	Low	1,521.21	1,641.64	8,105.18	15,916.69	22,252.94	26,703.00
	High	2,022.65	2,182.95	10,776.93	21,163.50	29,588.34	35,504.82
Longer COVID Recovery	0%	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
	Low	1,521.21	1,641.64	7,378.91	14,489.50	20,257.94	24,309.74
	High	2,022.65	2,182.95	9,811.37	10,265.74	26,935.36	32,323.48
Aggressive Growth	0%	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
	Low	1,521.21	1,641.64	9,338.52	18,820.18	33,906.54	55,229.85
	High	2,022.65	2,182.95	12,416.53	25,023.44	45,083.61	73,435.59
Aggressive Growth with Gilde	0%	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20
	Low	1,521.21	1,641.64	15,488.32	24,969.98	40,055.81	61,379.65
	High	2,022.65	2,182.95	20,593.86	33,201.31	53,259.66	81,612.93

Note: The low-end estimate includes the GHG emissions avoided by not landfilling. The high-end estimate includes the GHG emissions avoided by not landfilling the waste, as well as an estimate for the substitution of BSG for the food that does not need to be produced.

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Table A. 3 MtCO2E Avoided Utilizing BSG as Animal Feed or Human Food 0% Spoilage and 30% Spoilage (OpenLCA, 2020)

		2020	2021	2035	2045	2055	2065
Base Case	0%	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
	Low	1,183.16	1,276.65	6,304.03	12,379.35	17,307.43	20,769.23
	High	1,197.57	1,292.12	6,380.78	12,529.76	17,517.61	21,022.01
Longer COVID Recovery	0%	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
	Low	1,183.16	1,276.65	5,738.86	11,269.61	15,756.11	18,907.34
	High	1,197.57	1,292.12	5,808.42	11,406.81	15,947.56	19,137.60
Aggressive Growth	0%	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
	Low	1,183.16	1,276.65	7,263.24	14,637.92	26,371.82	42,956.67
	High	1,197.57	1,292.12	7,352.57	14,815.60	26,693.25	43,479.87
Aggressive Growth with Gilde	0%	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20
	Low	1,183.16	1,276.65	12,046.59	19,420.74	31,154.64	47,739.49
	High	1,197.57	1,292.12	12,193.47	19,657.03	31,534.15	48,320.77

Note: The low-end estimate includes the GHG emissions avoided by not landfilling. The high-end estimate includes the GHG emissions avoided by not landfilling the waste, as well as an estimate for the substitution of BSG for the food that does not need to be produced.

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APPENDIX B
Select WARM Data for Compost

Table B.1 Select WARM Data for Compost

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Compost - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	(369.87)	(399.12)	(1,970.72)	(3,870.02)	(5,410.65)	(6,492.76)
Longer COVID Recovery	(369.87)	(399.12)	(1,794.11)	(3,523.03)	(4,925.66)	(5,910.67)
Aggressive Growth	(369.87)	(399.12)	(2,270.67)	(4,576.13)	(8,244.10)	(13,428.78)
Aggressive Growth with Gilde	(369.87)	(399.12)	(3,765.88)	(6,071.22)	(9,739.31)	(14,923.99)

Change

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,060.10)	(2,222.98)	(10,976.48)	(21,555.11)	(30,136.08)	(36,163.17)
Longer COVID Recovery	(2,060.10)	(2,222.98)	(9,992.78)	(19,622.47)	(27,434.77)	(32,921.08)
Aggressive Growth	(2,060.10)	(2,222.98)	(12,647.10)	(25,487.97)	(45,917.75)	(74,795.23)
Aggressive Growth with Gilde	(2,060.10)	(2,222.98)	(20,975.06)	(33,815.29)	(54,245.71)	(83,123.19)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

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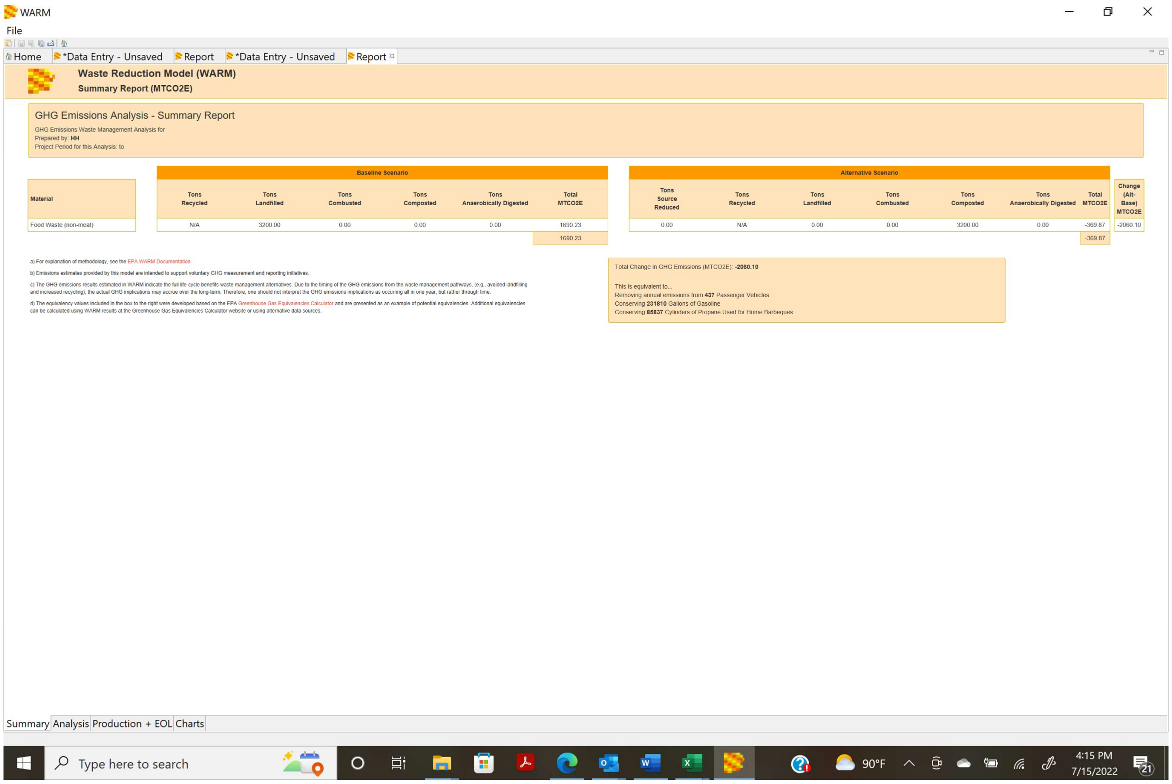

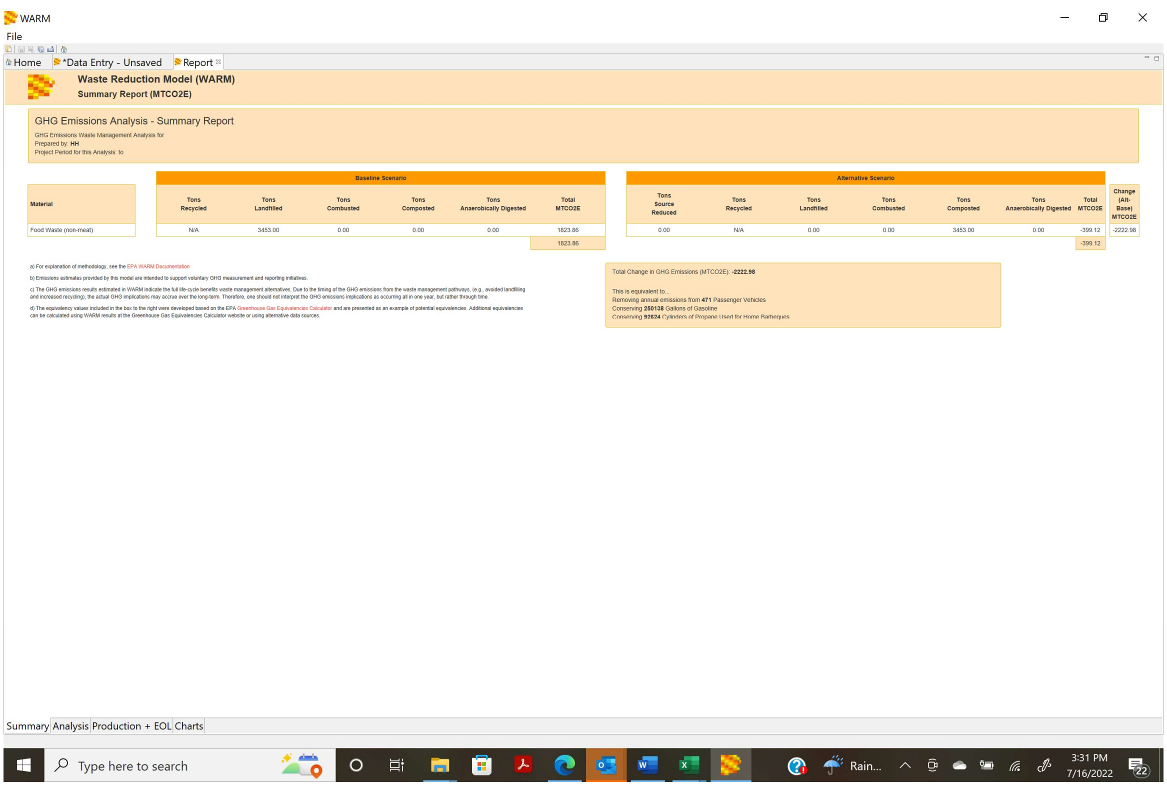

Figure B.1 – WARM Model Inputs

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APPENDIX C
Select WARM Data for Combustion

Table C.1 – Select WARM Data for Combustion

Landfill - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Combustion

Year	2020	2021	2035	2045	2055	2065
Base Case	(411.36)	(443.89)	(2,191.80)	(4,304.16)	(6,017.62)	(7,221.12)
Longer COVID Recovery	(411.36)	(443.89)	(1,995.37)	(3,918.25)	(5,478.22)	(6,573.73)
Aggressive Growth	(411.36)	(443.89)	(2,525.39)	(5,089.48)	(9,168.93)	(14,935.23)
Aggressive Growth with Gilde	(411.36)	(443.89)	(4,188.33)	(6,752.29)	(10,831.87)	(16,598.17)

Change

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,101.59)	(2,267.75)	(11,197.56)	(21,989.25)	(30,743.05)	(36,891.53)
Longer COVID Recovery	(2,101.59)	(2,267.75)	(10,194.04)	(20,017.69)	(27,987.33)	(33,584.14)
Aggressive Growth	(2,101.59)	(2,267.75)	(12,901.82)	(26,001.32)	(46,842.58)	(76,301.68)
Aggressive Growth with Gilde	(2,101.59)	(2,267.75)	(21,397.51)	(34,496.36)	(55,338.27)	(84,797.37)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

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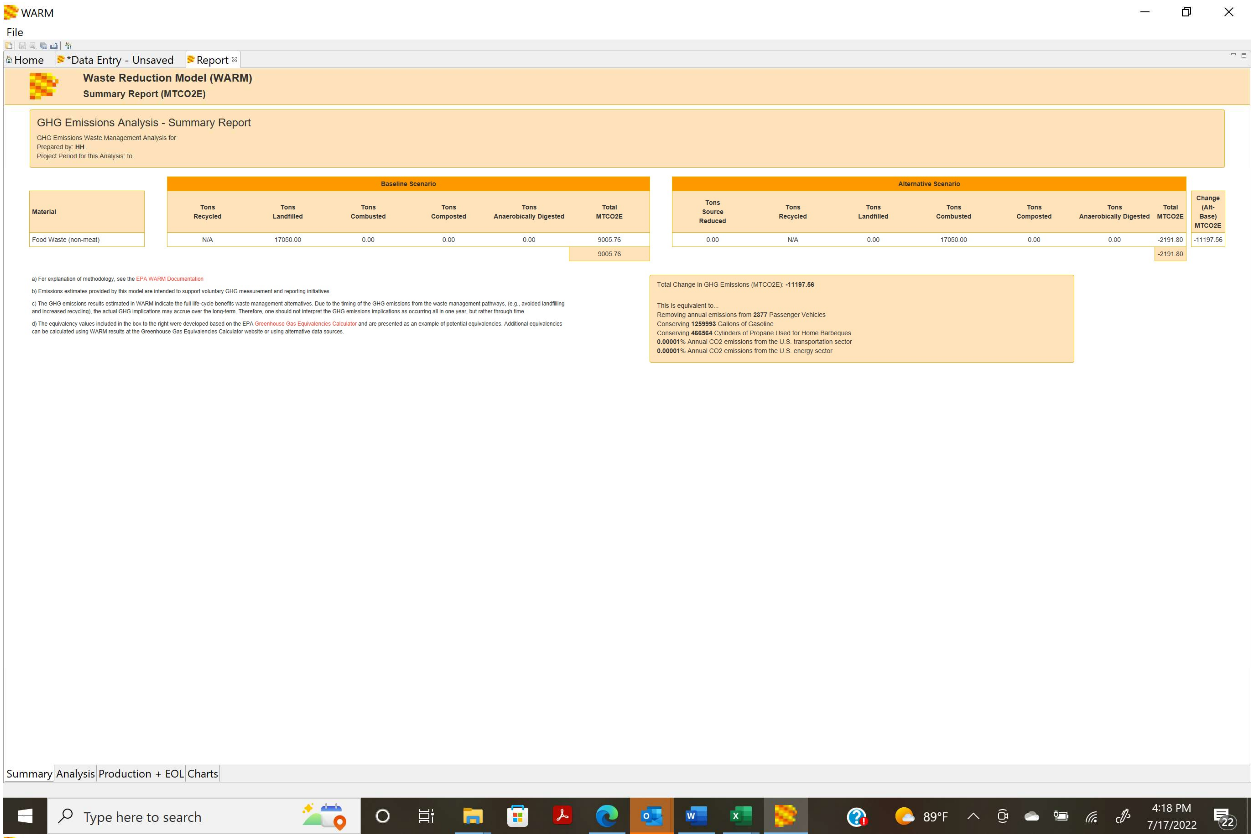

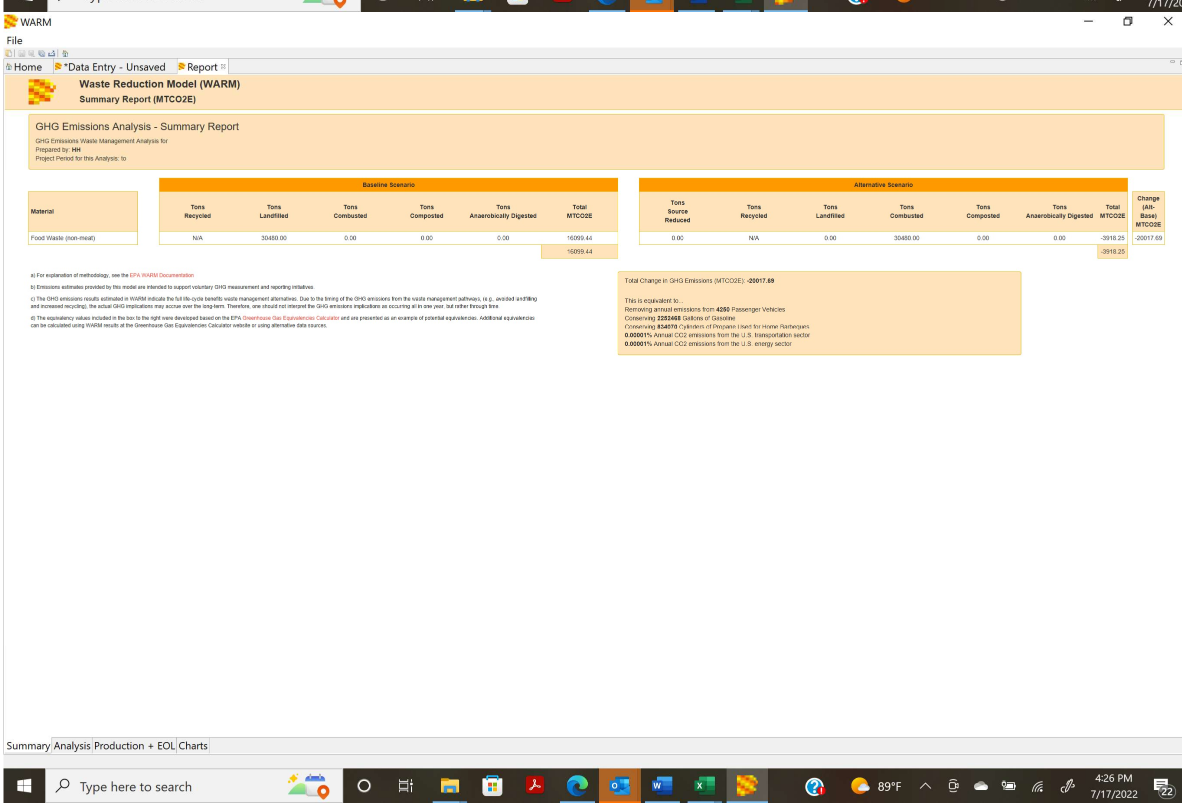

Figure C.1 WARM Model Inputs

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APPENDIX D
Select WARM Data for Wet Anaerobic Digestion

Table D.1 – Select WARM Data for Wet Anaerobic Digestion

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Wet AD

Year	2020	2021	2035	2045	2055	2065
Base Case	(173.95)	(187.71)	(926.84)	(1,820.09)	(2,544.66)	(3,053.58)
Longer COVID Recovery	(173.95)	(187.71)	(843.78)	(1,656.90)	(2,316.56)	(2,779.82)
Aggressive Growth	(173.95)	(187.71)	(1,067.91)	(2,152.18)	(3,877.25)	(6,315.64)
Aggressive Growth with Gilde	(173.95)	(187.71)	(1,771.11)	(2,855.33)	(4,580.45)	(7,018.84)

Change

Year	2020	2021	2035	2045	2055	2065
Base Case	(1,864.18)	(2,011.57)	(9,932.60)	(19,505.18)	(27,270.09)	(32,723.99)
Longer COVID Recovery	(1,864.18)	(2,011.57)	(9,042.45)	(17,756.34)	(24,825.67)	(29,790.23)
Aggressive Growth	(1,864.18)	(2,011.57)	(11,444.34)	(23,064.02)	(41,550.90)	(67,682.09)
Aggressive Growth with Gilde	(1,864.18)	(2,011.57)	(18,980.29)	(30,599.40)	(49,086.85)	(75,218.04)

Source: OpenLCA, 2020

Note: Numbers in parentheses are negative values which are avoided GHG emissions by using the selected management practice

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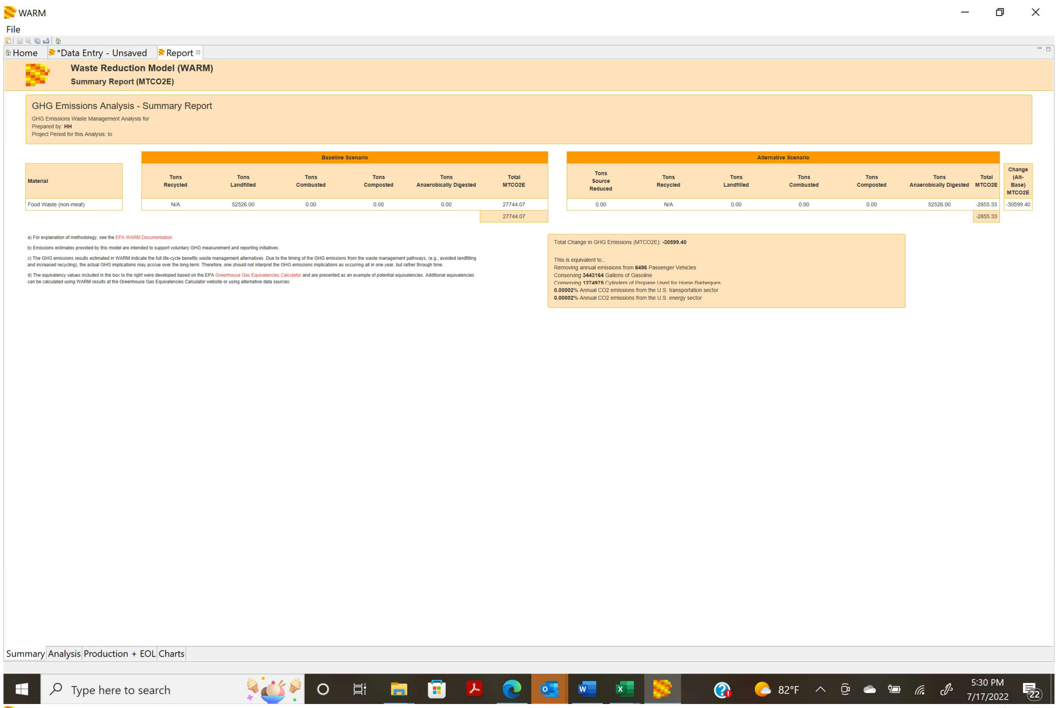

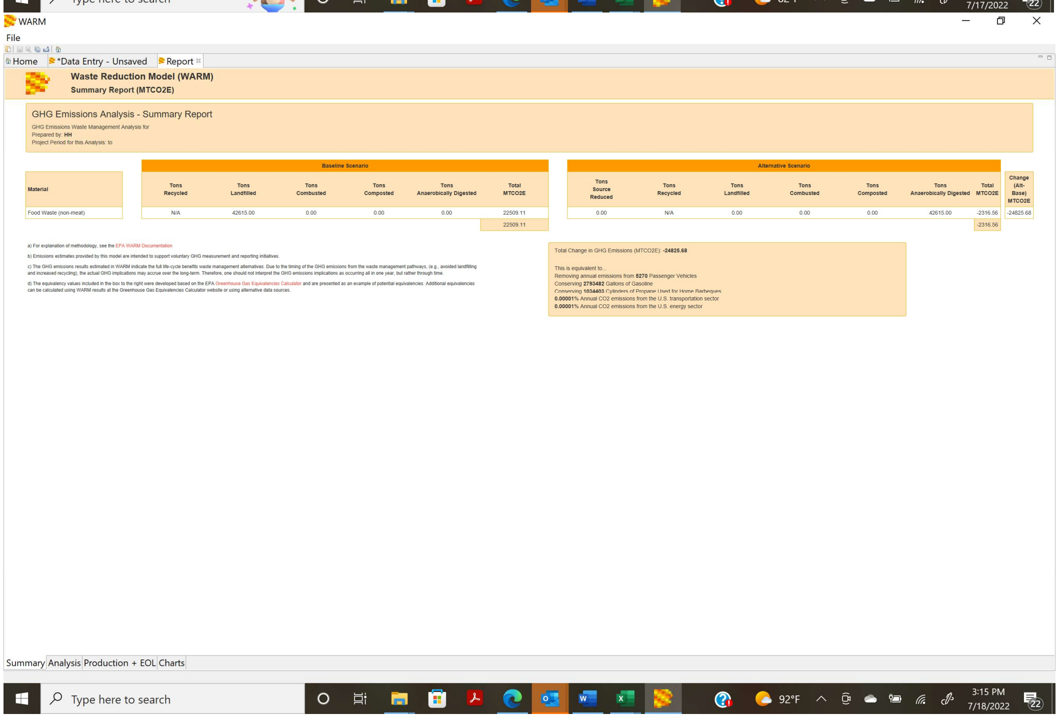

Figure D.1 – WARM Data Inputs

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APPENDIX E
Select WARM Data for Animal Feed – no spoilage

Table E.1 – Select WARM Data for Animal Feed – no spoilage

Landfill - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Low End - MtCO2 avoided

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

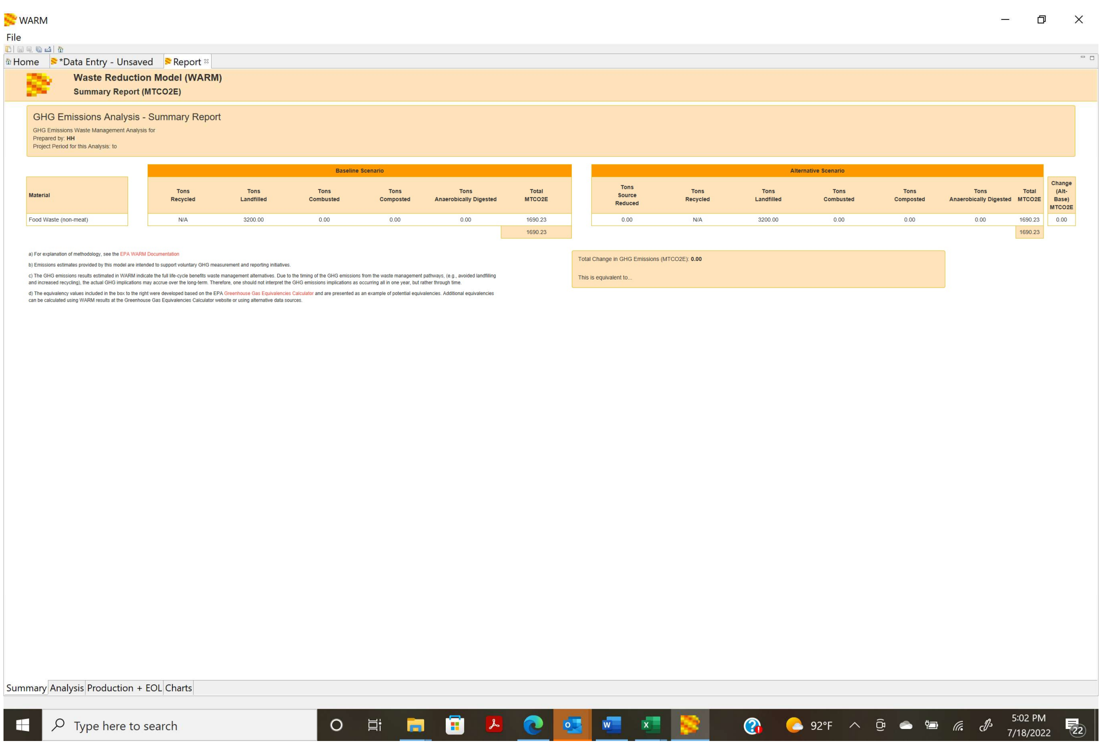

Figure E.1 – WARM Model Inputs

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APPENDIX F
Select WARM Data for Food Donation 3% Spoilage Low End Estimate

Table F.1 – Select WARM Data for Food Donation 3% Spoilage Low End Estimate

Landfill - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	1,639.52	1,768.93	8,735.85	17,154.25	23,983.31	28,779.87
Longer COVID Recovery	1,639.52	1,768.93	7,952.53	15,616.67	21,833.55	26,200.15
Aggressive Growth	1,639.52	1,768.93	10,065.32	20,284.35	36,543.83	59,525.68
Aggressive Growth with Gilde	1,639.52	1,768.93	16,692.61	26,912.16	43,171.12	66,153.50

Food Donation 3% Spoilage - Low Estimate - AVOIDED

Year	2020	2021	2035	2045	2055	2065
Base Case	1,639.52	1,768.93	8,735.85	17,154.25	23,983.31	28,779.87
Longer COVID Recovery	1,639.52	1,768.93	7,952.53	15,616.67	21,833.55	26,200.15
Aggressive Growth	1,639.52	1,768.93	10,065.32	20,284.35	36,543.83	59,525.68
Aggressive Growth with Gilde	1,639.52	1,768.93	16,692.61	26,912.16	43,171.12	66,153.50

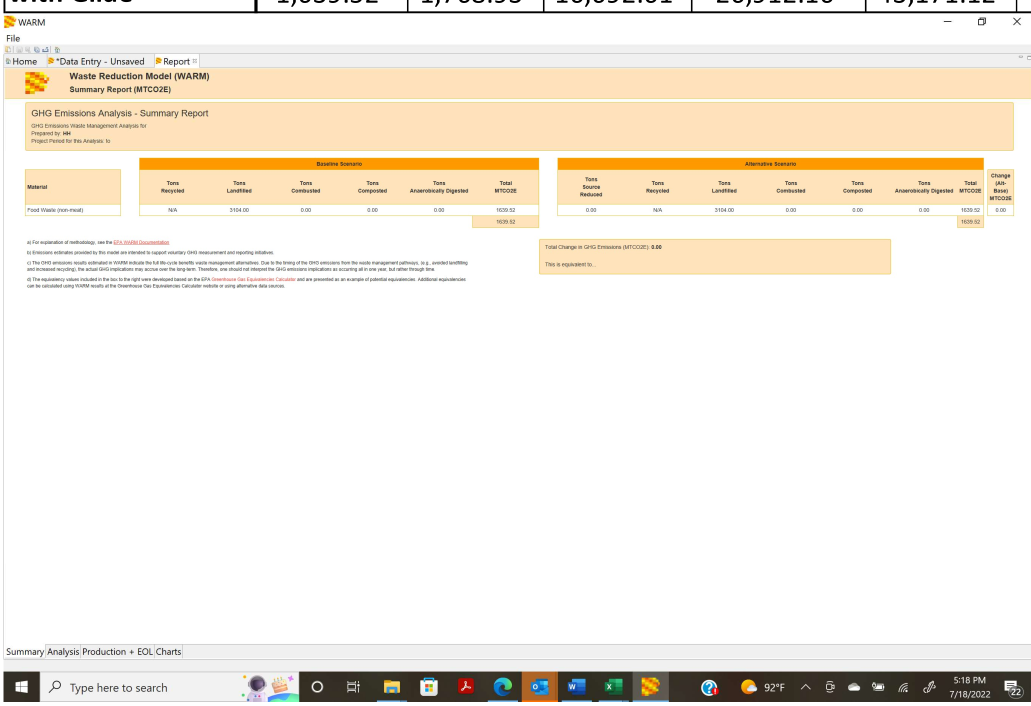

Figure F.1 – WARM Data Inputs

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APPENDIX G
Select WARM Data for Food Donation 3% Spoilage High End Estimate

Table G.1 – Select WARM Data for Food Donation 3% Spoilage High End Estimate

Landfill - NC

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Food Donation 3% Spoilage - High Estimate - Source Reduction (97%) & Landfill (3%)

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,311.43)	(2,493.65)	(12,316.23)	(24,184.08)	(33,811.74)	(40,573.93)
Longer COVID Recovery	(2,311.43)	(2,493.65)	(11,211.44)	(22,016.88)	(30,781.03)	(36,937.51)
Aggressive Growth	(2,311.43)	(2,493.65)	(14,190.46)	(28,597.09)	(51,520.56)	(83,920.61)
Aggressive Growth with Gilde	(2,311.43)	(2,493.65)	(23,533.23)	(37,941.67)	(60,863.33)	(93,264.67)

Difference

Year	2,020.00	2,021.00	2,035.00	2,045.00	2,055.00	2,065.00
Base Case	(4,001.66)	(4,317.51)	(21,321.99)	(41,869.17)	(58,537.17)	(70,244.34)
Longer COVID Recovery	(4,001.66)	(4,317.51)	(19,410.11)	(38,116.32)	(53,290.14)	(63,947.92)
Aggressive Growth	(4,001.66)	(4,317.51)	(24,566.89)	(49,508.93)	(89,194.21)	(145,287.06)
Aggressive Growth with Gilde	(4,001.66)	(4,317.51)	(40,742.41)	(65,685.74)	(105,369.73)	(161,463.87)

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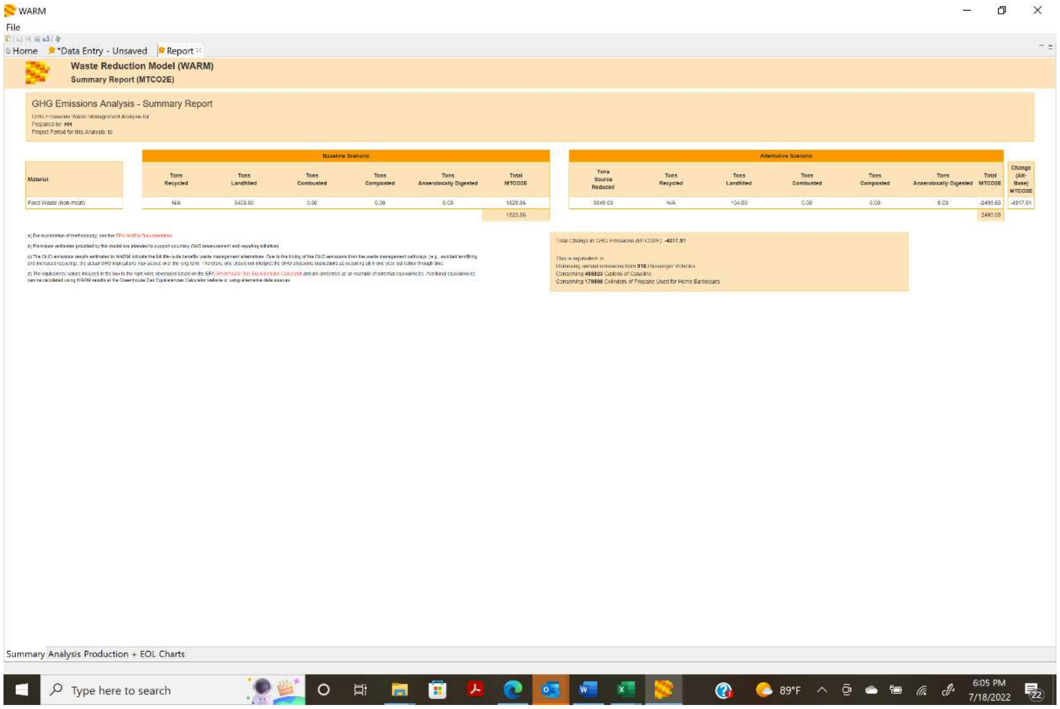

Figure G. 1 – WARM Data Inputs

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APPENDIX H
Select WARM Data for Food Donation 10% Spoilage Low End Estimate

Table H.1 – Select WARM Data for Food Donation 10% Spoilage Low End Estimate

Landfill - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	1,521.21	1,641.64	8,105.18	15,916.69	22,252.94	26,703.00
Longer COVID Recovery	1,521.21	1,641.64	7,378.91	14,489.50	20,257.94	24,309.74
Aggressive Growth	1,521.21	1,641.64	9,338.52	18,820.18	33,906.54	55,229.85
Aggressive Growth with Gilde	1,521.21	1,641.64	15,488.32	24,969.98	40,055.81	61,379.65

Food Donation 10% Spoilage - Low Estimate

Year	2020	2021	2035	2045	2055	2065
Base Case	1,521.21	1,641.64	8,105.18	15,916.69	22,252.94	26,703.00
Longer COVID Recovery	1,521.21	1,641.64	7,378.91	14,489.50	20,257.94	24,309.74
Aggressive Growth	1,521.21	1,641.64	9,338.52	18,820.18	33,906.54	55,229.85
Aggressive Growth with Gilde	1,521.21	1,641.64	15,488.32	24,969.98	40,055.81	61,379.65

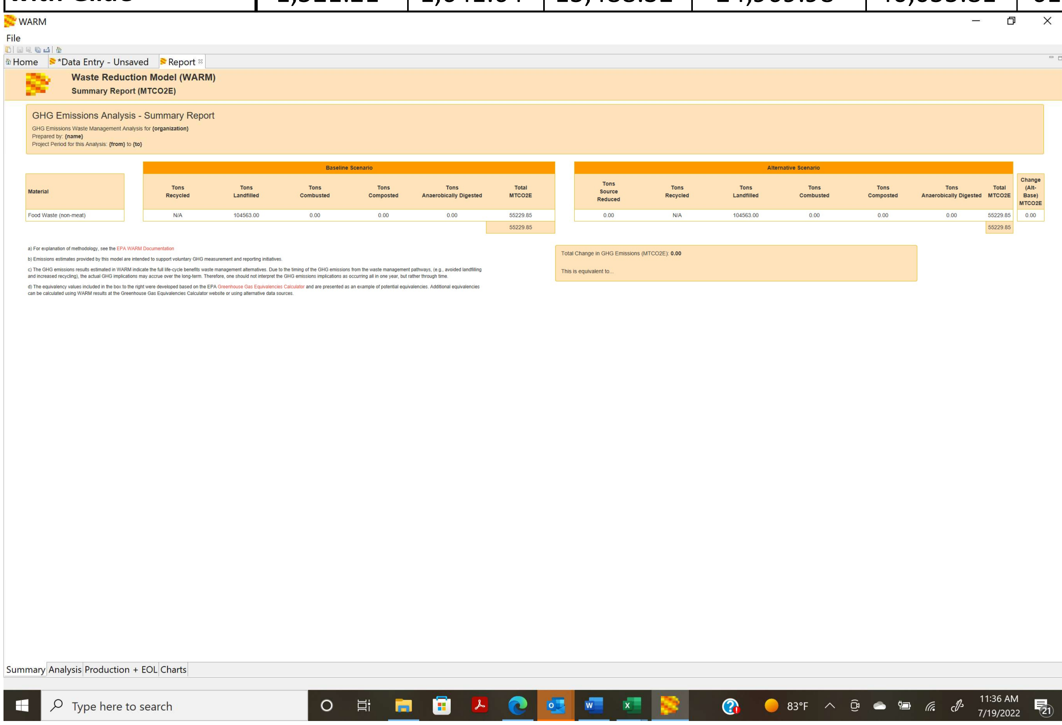

Figure H.1 – WARM Data Inputs

APPENDIX I
Select WARM Data for Food Donation 10% Spoilage High End Estimate

Table I.1 – Select WARM Data for Food Donation 10% Spoilage High End Estimate

Landfill - NC

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Food Donation 10% Spoilage - High Estimate - Source Reduction (90%) & Landfill (`10%)

Year	2020	2021	2035	2045	2055	2065
Base Case	(2,022.65)	(2,182.95)	(10,776.93)	(21,163.50)	(29,588.34)	(35,504.82)
Longer COVID Recovery	(2,022.65)	(2,182.95)	(9,811.37)	(10,265.74)	(26,935.36)	(32,323.48)
Aggressive Growth	(2,022.65)	(2,182.95)	(12,416.53)	(25,023.44)	(45,083.61)	(73,435.59)
Aggressive Growth with Gilde	(2,022.65)	(2,182.95)	(20,593.86)	(33,201.31)	(53,259.66)	(81,612.93)

Difference

Year	2,020.00	2,021.00	2,035.00	2,045.00	2,055.00	2,065.00
Base Case	(3,712.88)	(4,006.81)	(19,782.69)	(38,848.59)	(54,313.77)	(65,175.23)
Longer COVID Recovery	(3,712.88)	(4,006.81)	(18,010.04)	(26,365.18)	(49,444.47)	(59,333.89)
Aggressive Growth	(3,712.88)	(4,006.81)	(22,792.96)	(45,935.28)	(82,757.26)	(134,802.04)
Aggressive Growth with Gilde	(3,712.88)	(4,006.81)	(37,803.04)	(60,945.38)	(97,766.06)	(149,812.13)

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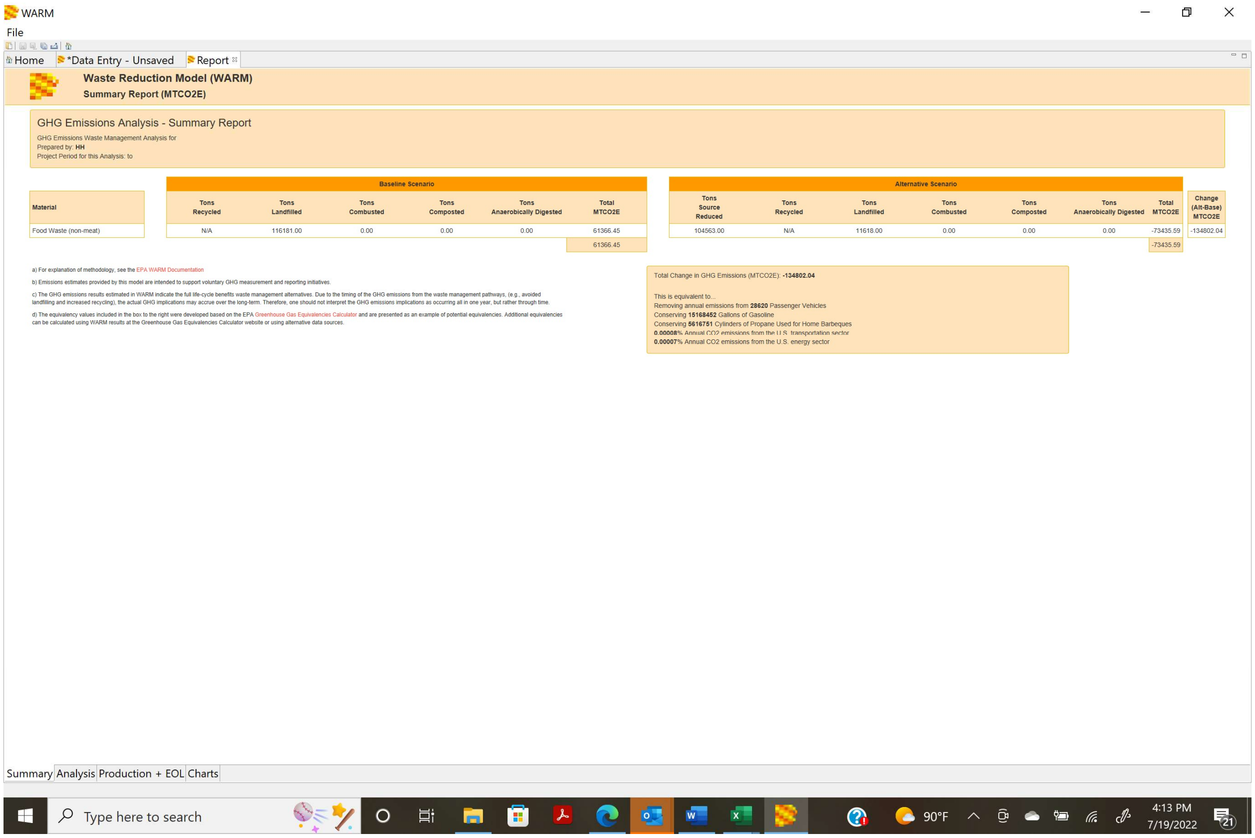

Figure I.1 – WARM Data Inputs

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APPENDIX J
Select WARM Data for Food Donation 30% Spoilage Low End Estimate

Table J.1 – Select WARM Data for Food Donation 30% Spoilage Low End Estimate

Landfill - NC - Wet

Year	2020	2021	2035	2045	2055	2065
Base Case	1,183.16	1,276.65	6,304.03	12,379.35	17,307.43	20,769.23
Longer COVID Recovery	1,183.16	1,276.65	5,738.86	11,269.61	15,756.11	18,907.34
Aggressive Growth	1,183.16	1,276.65	7,263.24	14,637.92	26,371.82	42,956.67
Aggressive Growth with Gilde	1,183.16	1,276.65	12,046.59	19,420.74	31,154.64	47,739.49

Food Donation 30% Spoilage - Low Estimate

Year	2020	2021	2035	2045	2055	2065
Base Case	1,183.16	1,276.65	6,304.03	12,379.35	17,307.43	20,769.23
Longer COVID Recovery	1,183.16	1,276.65	5,738.86	11,269.61	15,756.11	18,907.34
Aggressive Growth	1,183.16	1,276.65	7,263.24	14,637.92	26,371.82	42,956.67
Aggressive Growth with Gilde	1,183.16	1,276.65	12,046.59	19,420.74	31,154.64	47,739.49

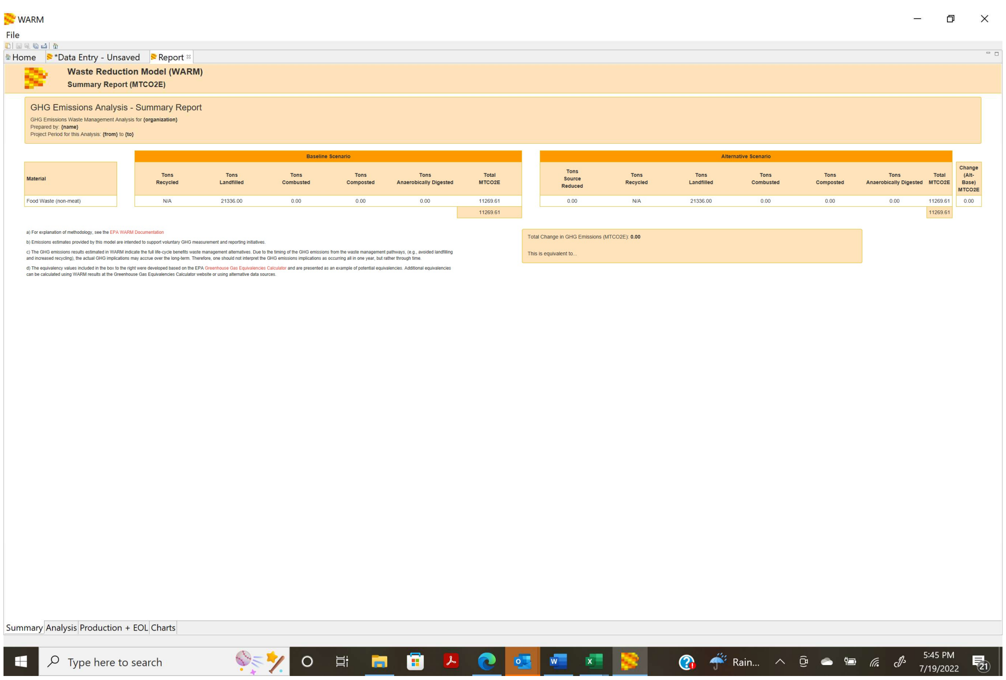

Figure J.1 – WARM Data Inputs

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APPENDIX K
Select WARM Data for Food Donation 30% Spoilage High End Estimate

Table K.1 – Select WARM Data for Food Donation 30% Spoilage High End Estimate

Landfill - NC

Year	2020	2021	2035	2045	2055	2065
Base Case	1,690.23	1,823.86	9,005.76	17,685.09	24,725.43	29,670.41
Longer COVID Recovery	1,690.23	1,823.86	8,198.67	16,099.44	22,509.11	27,010.41
Aggressive Growth	1,690.23	1,823.86	10,376.43	20,911.84	37,673.65	61,366.45
Aggressive Growth with Gilde	1,690.23	1,823.86	17,209.18	27,744.07	44,506.40	68,199.20

Food Donation 30% Spoilage - High Estimate - Source Reduction (70%) & Landfill (30%)

Year	2020	2021	2035	2045	2055	2065
Base Case	(1,197.57)	(1,292.12)	(6,380.78)	(12,529.76)	(17,517.61)	(21,022.01)
Longer COVID Recovery	(1,197.57)	(1,292.12)	(5,808.42)	(11,406.81)	(15,947.56)	(19,137.60)
Aggressive Growth	(1,197.57)	(1,292.12)	(7,352.57)	(14,815.60)	(26,693.25)	(43,479.87)
Aggressive Growth with Gilde	(1,197.57)	(1,292.12)	(12,193.47)	(19,657.03)	(31,534.15)	(48,320.77)

Difference

Year	2,020.00	2,021.00	2,035.00	2,045.00	2,055.00	2,065.00
Base Case	(2,887.80)	(3,115.98)	(15,386.54)	(30,214.85)	(42,243.04)	(50,692.42)
Longer COVID Recovery	(2,887.80)	(3,115.98)	(14,007.09)	(27,506.25)	(38,456.67)	(46,148.01)
Aggressive Growth	(2,887.80)	(3,115.98)	(17,729.00)	(35,727.44)	(64,366.90)	(104,846.32)
Aggressive Growth with Gilde	(2,887.80)	(3,115.98)	(29,402.65)	(47,401.10)	(76,040.55)	(116,519.97)

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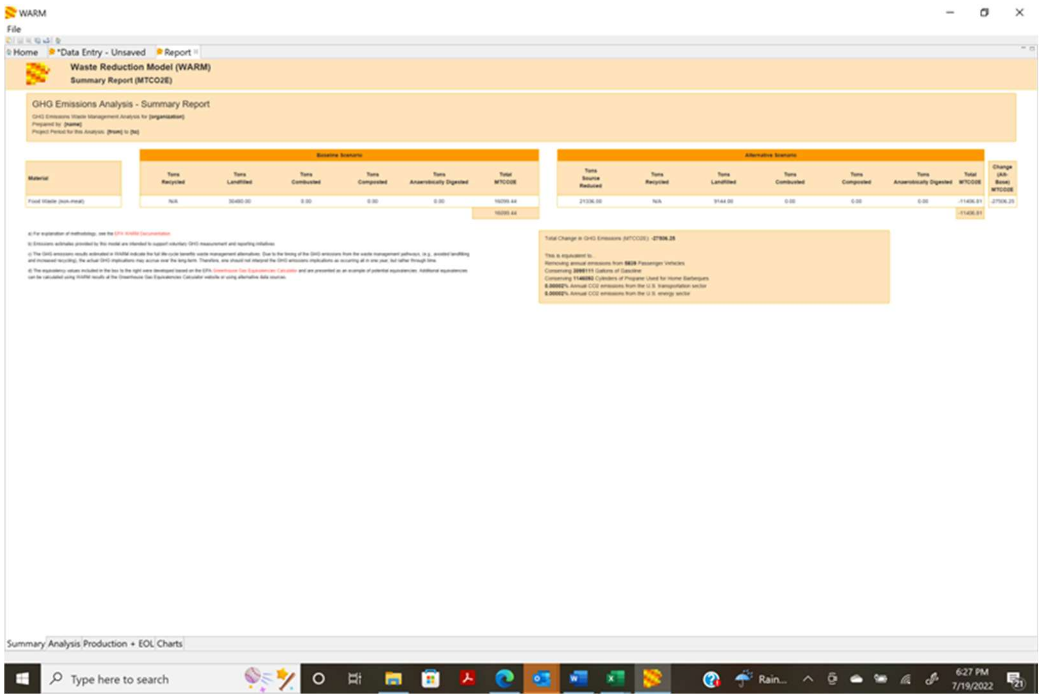
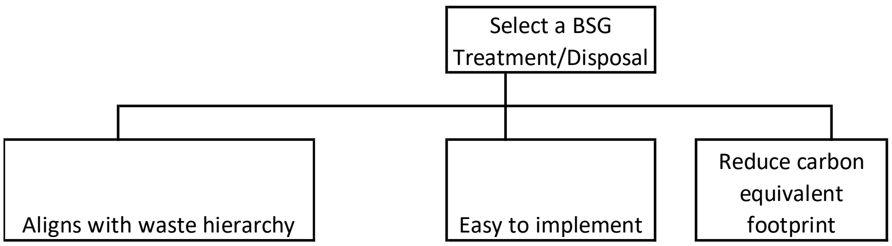


Figure K.1 – WARM Data Inputs

APPENDIX L
Analytical Hierarchy Process Analysis

AHP Analysis

Step 1: Hierarchical Structuring



Step 2: Priority Setting

1. Align with Waste Heirarchy
2. Reduce Carbon Equivalent Footprint per Circular Economy Strategy goal
3. Easy to Implement

Pairwise Comparison

	Waste Heirarchy	Carbon Footprint	Easy to Implement		Geometric Mean
Waste Heirarchy	1/1	1/1	3/1	=	1.44224957
Carbon Footprint	1/1	1/1	3/1	=	1.44224957
Easy to Implement	1/3	1/3	1/1	=	0.480749857
					3.365248997

Normalize Weights

Waste Heirarchy	0.4285714
Carbon Footprint	0.4285714
Easy to Implement	0.1428571
	1

1 - Equal   3 - Moderate   5 - Strong   7 - Very Strong   9 - Extreme

Apprendix L – Continued

Waste Heirarchy

	Combustion	Composting	Anerobic Digestion	Animal Feed	Human Food		Geometric Mean
Combustion	1/1	3/1	1/1	1/5	1/7	=	0.611802
Composting	1/3	1/1	1/3	1/7	1/7	=	0.295878
Anerobic Digestion	1/1	3/1	1/1	1/5	1/7	=	0.611802
Animal Feed	5/1	7/1	5/1	1/1	1/3	=	2.255191
Human Food	7/1	7/1	7/1	3/1	1/1	=	4.003899
							7.778571

Combustion	0.0786522
Composting	0.0380375
Anerobic Digestion	0.0786522
Animal Feed	0.2899236
Human Food	0.5147345
	1 <---Check

Carbon Footprint - Environmental

	Combustion	Composting	Anerobic Digestion	Animal Feed	Human Food		Geometric Mean
Combustion	1/1	1/1	3/1	1/3	1/5	=	0.72478
Composting	1/1	1/1	3/1	1/3	1/3	=	0.802742
Anerobic Digestion	1/3	1/3	1/1	1/3	1/5	=	0.374915
Animal Feed	3/1	3/1	3/1	1/1	1/3	=	1.551846
Human Food	5/1	3/1	5/1	3/1	1/1	=	2.954177

Combustion	0.1130973	6.408459
Composting	0.1252628	
Anerobic Digestion	0.0585032	
Animal Feed	0.2421558	
Human Food	0.4609809	
	1 <---Check	

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Appendix L - Continued

Easy to Implement

	Combustion	Composting	Anerobic Digestion	Animal Feed	Human Food		Geometric Mean
Combustion	1/1	1/9	1/3	1/9	1/5	=	0.241593
Composting	9/1	1/1	3/1	1/3	1/5	=	1.124746
Anerobic Digestion	3/1	1/3	1/1	1/7	1/5	=	0.491119
Animal Feed	9/1	3/1	7/1	1/1	5/1	=	3.936283
Human Food	5/1	5/1	5/1	1/5	1/1	=	1.903654
							7.697395

Combustion	0.0313864
Composting	0.1461204
Anerobic Digestion	0.0638032
Animal Feed	0.5113786
Human Food	0.2473114
	1 <---Check

	Waste Heirarchy	Carbon Footprint	Easy to Implement		
Combustion	0.0786522	0.113097338	0.03138636		0.429
Composting	0.0380375	0.125262805	0.14612035	*	0.429
Anerobic Digestion	0.0786522	0.058503201	0.06380322		0.143
Animal Feed	0.2899236	0.242155805	0.51137862		
Human Food	0.5147345	0.460980852	0.24731144		

		PLACE
Combustion	0.086662136	**4**
Composting	0.0908602	**3**
Anerobic Digestion	0.067895629	**5**
Animal Feed	0.301088114	**2**
Human Food	0.453493922	**1**
	1	

Step 3 - Logical Consistency

Waste Heirarchy > Carbon Footprint > Easy to Implement

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APPENDIX M

Table M.1 Compost Production (Coker, 2022a)

	1	2	3	4	5	6	7	8	9	10
	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
BSG LBS										
Base Production	8,719,626	9,798,032	11,009,811	12,371,458	13,901,507	15,620,786	17,552,699	19,723,542	22,162,865	24,157,523
Longer CoVid Recovery	7,469,345	8,393,122	9,431,147	10,597,552	11,908,212	13,380,969	15,035,870	16,895,442	18,984,999	21,332,983
Aggressive Growth	9,263,745	10,729,314	12,426,743	14,392,714	16,669,710	19,306,939	22,361,390	25,899,070	29,996,427	31,660,038
Aggressive Growth with Gilde	9,263,745	10,729,314	38,298,522	40,264,493	42,541,490	45,178,718	48,233,169	51,770,849	55,868,207	57,531,818
BSG LBS to Tons										
Base Production	4,360	4,899	5,505	6,186	6,951	7,810	8,776	9,862	11,081	12,079
Longer CoVid Recovery	3,735	4,197	4,716	5,299	5,954	6,690	7,518	8,448	9,492	10,666
Aggressive Growth	4,632	5,365	6,213	7,196	8,335	9,653	11,181	12,950	14,998	15,830
Aggressive Growth with Gilde	4,632	5,365	19,149	20,132	21,271	22,589	24,117	25,885	27,934	28,766
Feedstock										
Base Production	23,979	26,945	30,277	34,022	38,229	42,957	48,270	54,240	60,948	66,433
Longer CoVid Recovery	20,541	23,081	25,936	29,143	32,748	36,798	41,349	46,462	52,209	58,666
Aggressive Growth	25,475	29,506	34,174	39,580	45,842	53,094	61,494	71,222	82,490	87,065
Aggressive Growth with Gilde	25,475	29,506	105,321	110,727	116,989	124,241	132,641	142,370	153,638	158,212
Total Feedstock										
Base Production	28,339	31,844	35,782	40,207	45,180	50,768	57,046	64,102	72,029	78,512
Longer CoVid Recovery	24,275	27,278	30,651	34,442	38,702	43,488	48,867	54,910	61,701	69,332
Aggressive Growth	30,107	34,870	40,387	46,776	54,177	62,748	72,675	84,172	97,488	102,895
Aggressive Growth with Gilde	30,107	34,870	124,470	130,860	138,260	146,831	156,758	168,255	181,572	186,978
Volume Shrink 30% Primary Composting										
Base Production	19,837	22,291	25,047	28,145	31,626	35,537	39,932	44,871	50,421	54,958
Longer CoVid Recovery	16,993	19,094	21,456	24,109	27,091	30,442	34,207	38,437	43,191	48,533
Aggressive Growth	21,075	24,409	28,271	32,743	37,924	43,923	50,872	58,920	68,242	72,027
Aggressive Growth with Gilde	21,075	24,409	87,129	91,602	96,782	102,782	109,730	117,779	127,100	130,885
Volume Shrink 10% Curing										
Base Production	17,853	20,061	22,543	25,331	28,463	31,984	35,939	40,384	45,378	49,463
Longer CoVid Recovery	15,293	17,185	19,310	21,698	24,382	27,398	30,786	34,593	38,872	43,679
Aggressive Growth	18,968	21,968	25,444	29,469	34,131	39,531	45,785	53,028	61,418	64,824
Aggressive Growth with Gilde	18,968	21,968	78,416	82,442	87,104	92,503	98,757	106,001	114,390	117,796
Tons/Year Finished Compost 80% - 20% Overs										
Base Production	14,283	16,049	18,034	20,264	22,771	25,587	28,751	32,307	36,303	39,570
Longer CoVid Recovery	12,235	13,748	15,448	17,359	19,506	21,918	24,629	27,675	31,097	34,943
Aggressive Growth	15,174	17,575	20,355	23,575	27,305	31,625	36,628	42,423	49,134	51,859
Aggressive Growth with Gilde	15,174	17,575	62,733	65,953	69,683	74,003	79,006	84,801	91,512	94,237

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APPENDIX N
Select Net Present Value Results

Inflation - 10 Year	**2.30%**
10-Year Treasury Note	**3.80%**

		Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Base Production			14,283	16,049	18,034	20,264	22,771	25,587	28,751	32,307	36,303	39,570
Capital Expense		(3,156,000)										
Cash Flows												
	Revenue		953,067	1,070,939	1,203,388	1,352,218	1,519,454	1,707,374	1,918,535	2,155,811	2,422,432	2,640,451
	Expenses		592,353	665,612	747,932	840,433	944,375	1,061,171	1,192,412	1,339,884	1,505,595	1,641,099
Net Cash			360,715	405,326	455,456	511,784	575,080	646,203	726,123	815,926	916,837	999,352
NPV		1,918,066										

		Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Longer CoVid Recovery			12,235	13,748	15,448	17,359	19,506	21,918	24,629	27,675	31,097	34,943
Capital Expense		(3,156,000)										
Cash Flows												
	Revenue		816,410	917,380	1,030,838	1,158,327	1,301,584	1,462,559	1,643,442	1,846,696	2,075,087	2,331,725
	Expenses		507,417	570,172	640,688	719,926	808,964	909,013	1,021,435	1,147,762	1,289,713	1,449,219
Net Cash			308,993	347,208	390,149	438,401	492,621	553,546	622,006	698,933	785,374	882,506
NPV		1,208,726										

APPENDIX N – Continued

	Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aggressive Growth		17,853	20,061	22,543	25,331	28,463	31,984	35,939	40,384	45,378	49,463
Capital Expense	(3,406,000)										
Cash Flows											
Revenue		1,191,334	1,338,673	1,504,235	1,690,272	1,899,318	2,134,217	2,398,168	2,694,763	3,028,040	3,300,564
Expenses		740,441	832,015	934,915	1,050,542	1,180,468	1,326,463	1,490,515	1,674,855	1,881,994	2,051,374
Net Cash		450,894	506,658	569,319	639,730	718,850	807,754	907,653	1,019,908	1,146,046	1,249,190
NPV	2,936,583										

	Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
	0	1	2	3	4	5	6	7	8	9	10
Aggressive Growth with Gilde		15,174	17,575	62,733	65,953	69,683	74,003	79,006	84,801	91,512	94,237
Capital Expense	(3,406,000)										
Cash Flows											
Revenue		1,012,540	1,172,729	4,186,082	4,400,965	4,649,844	4,938,097	5,271,953	5,658,626	6,106,473	6,288,308
Expenses		629,316	728,877	2,601,743	2,735,298	2,889,982	3,069,137	3,276,636	3,516,962	3,795,309	3,908,323
Net Cash		383,224	443,852	1,584,339	1,665,668	1,759,863	1,868,960	1,995,317	2,141,664	2,311,164	2,379,985
NPV	9,598,566										

Note: Capital Expense is a negative representing amounts subtracted from the balance sheet

Source Notes: Data used in the analysis was obtained from the following sources:

Inflation and Discount Rate (CBO, 2022); Capital Expense (Coker, 2022b); Compost Production Volume (Coker, 2022a); Expenses (Coker, 2022; US BLS, 2021); Compost Sale Pricing (Home Depot, 2022 and Nauta, 2022)

APPENDIX O
General Cost Information

Table O.1 General Cost Information on AHP Options

AHP Ranking	1	2	3	4	5
Option	**Human Food**	**Animal Feed**	**Composting**	**Combustion**	**Anaerobic Digestion**
Capital Investment Required?	Yes	No	Existing Facility in NC	Yes	Existing Facility in NC
Drying Required	Yes and No	No	No	Yes	No
Additional treatment	Milling for flour	No	Mixed with carbon material	No	Yes
Product	Flour for Baked Goods or Ingrediant in Bake Goods	Animal Feed	Compost Material	Methane Gas	Gas
Benefit	Fight food insecurity	Reduce crop, water needs upstream	Increase soil nutirents	Volume reduced 80-85%; power	Gas
Concerns	Cost of flour	Number of farms close by is declining	Number of farms close by is declining	Toxic chemcials and fumes	High moisture content is a significant obstacle (Jackowski et al., 2020)

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APPENDIX O – Table O.1 Continued

Analysis of End Product										
AHP Ranking	1		2		3		4		5	
Option	Human Food		Animal Feed		Composting		Combustion		Anaerobic Digestion	
BSG 2021 Short Tons	3,453		3,453		3,453		3,453		3453	
	3,132,431,473	BSG Equivalent grams	$406.53	Cost of Commerical feed $/ton (2021$) (US BLS, 2022; Scully, 2014)	4,316	cubic yards of compost (Atlas, 2018)	550	kwh/ton of waste (USEPA, 2022d)	273-436	L CH_4/kg of waste (Gladchenko et al., 2017)
	48,191,253	Loaves (65 g/loaf) - (Spent Grains Company, 2022)	$116.15	Brewery Retail $/ton (2021$) (US BLS 2022; Scully, 2014)	$96,788	Mecklenburg County $28.03/ton (2021$) tipping fee for organic waste (Mecklenburg County Government, 2022b; US BLS, 2022a)	1,899,150	kwh generated by combusting BSG	855,174,932 - 1,365,773,884	L CH_4
	42	Loaves per person (US Census Bureau)	$309.74	Adjusted cost for incorporating grains	$18.02	Mecklenburg County Retail Price/cubic yard (Mecklenburg County Government, 2022a; US BLS 2022a)	$0.1159	NC $/kwh (Hope, 2022)	$17.50	2021 Avg $/1000 ft^3 of Natural Gas in NC (US EIA, 2022)
	$7	Retail/loaf (Hewn, 2022)	$96.79	Savings for incorporating grains ($/ton)	$77,778.83	Value of Compost	$220,111	Value of BSG	$528,627 - $844,245	Value of BSG

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APPENDIX O – Table O.1 Continued

AHP Ranking	1		2	3	4	5
Option	Human Food		Animal Feed	Composting	Combustion	Anaerobic Digestion
	$1.50	Average price retail bread 2021 (In2013dollars.com; US BLS 2022)				
	367%	Price Increase (Difference) per loaf				
	6,905,829	pounds				
	$8.77	Value $8/lb BSG Flour in 2018 ($8.77 $2021) (Zimberoff, 2018; US BLS, 2022)				
	$60,564,123	Value $8/lb BSG Flour in 2018 ($8.77 $2021)				
	$0.48	Average price retail flour 2021 (US BLS 2022b)				
	1727%	Price Increase (Difference per pound of flour)				