

The Utilization of Brewery By-Products Generated by North Carolina Craft Breweries

By
Jayna Sananikone

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Abstract

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The rise of craft breweries in North Carolina recently developed within the last 40 years; therefore, there is little to no information on the methods of by-product disposal used by these craft breweries. This study was conducted to fill that gap. The study focuses on the utilization of brewery by-products generated by North Carolina craft breweries. An investigation was conducted in which 208 North Carolinian craft brewers were contacted to participate in a simple survey regarding their operations and by-product disposal methods. Forty-two (42) craft brewers responded and participated in the study. The research found regardless of craft brewers' location, size, establishment time frame, metro area, and annual production there was no common disposal method among all the craft brewery by-products; however, most of the craft brewers disposed of brewery by-products either two to three times a week or when required and incurred no costs associated with the disposal of brewery by-products. In addition, the research found that spent hops and spent yeast has a larger variation in disposal methods. Small-craft brewers and urban craft brewers use a wider range of disposal methods for spent hops and spent yeast compared to medium- and large-craft brewers and rural craft brewers. Limitations to this research study could result from the participation rate, i.e., the study participants represent a fifth of North Carolina craft brewers. Further, while the respondents were geographically distributed across North Carolina, population-based survey statistics were not used to guide the participant selection. As a result, the results of this study may not fully represent the utilization of brewery by-products generated by all North Carolina craft breweries. During the research study several craft brewers were contacted regarding clarifying metrics of volume produced annually or to elaborate on unique disposal methods. At the time of this study, some responses were not received; however,

this does not affect the conclusions of the study. The results of this study could be of interest to varied environmental organizations (e.g., the NC Department of Environmental Quality, private engineering/consulting firms) for developing cooperative partnerships and by designing future investigations into how local brewery by-products can be used to remediate contaminated soils.

Biography

Jayna Sananikone is an Associate Environmental Scientist with WSP in Charlotte, North Carolina. At WSP, Ms. Sananikone focuses on due diligence and compliance related work. Prior to employment with WSP, Ms. Sananikone conducted environmental assessment activities, which included remediating and mitigating contaminated groundwater, soil, and air. Ms. Sananikone graduated from North Carolina State University with a Bachelor's in Environmental Technology and Management with minors in Biological Sciences and Environmental Toxicology in May of 2018.

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Introduction

Selling beer directly to a consumer was illegal less than 40 years ago in the state of North Carolina (NC) (NC Museum of History, 2022). Once the law was lifted in 1985, the craft brewing industry expanded tremendously. Now, NC has established the name “State of Southern Beer” because there are over 300 craft breweries across the state (Visit NC, 2022). Craft brewer is defined as a small (annual production of 6 million barrels of beer or less) independent (less than 25% is owned or controlled by a beverage alcohol industry member) brewer (Brewers Association, 2019).

The craft brewery production process inevitably generates brewing by-products. To date, there is no comprehensive information regarding the utilization of brewery by-products among craft breweries in NC. With the increase in breweries in NC and the modern day brewing technological advancements, this is important because brewery by-products have found to be useful in many ways. In addition, there are economic advantages for the brewing industry in producing valuable by-products. The main brewing by-products includes spent grain, spent hops, and spent yeast, whose post-brewing uses are discussed below.

Spent Grain

Spent grain is the most abundant by-product of the brewery process (Mussatto et al., 2006). It has a high protein content and is generated during the mashing process (Kerby and Vriesekoop, 2017). Spent grain has many applications as it can be readily recycled and reused (Mussatto et al., 2006). Applications of spent grain includes food for animals and humans, composting into fertilizer, the production of biogas, the production of building materials such as bricks, raw material for paper production, an adsorbent for Volatile Organic Compounds (VOCs), a substrate in biological processes, enzyme production, and cultivation of

microorganisms, and an additive or carrier in the brewing process (Mussatto et al., 2006). The most common application of spent grain is animal feed.

Spent Hops

During the brewing process, spent hops are commonly removed from the wort production process before fermentation occurs (Kerby and Vriesekoop, 2017). Some craft brewery production processes do not generate spent hops as a by-product. Applications of spent hops includes composting into fertilizer and an essential oils source which can act as an insect repellent (Kerby and Vriesekoop, 2017). Due to the bitterness, spent hops is not usually used as animal feed (Kerby and Vriesekoop, 2017). Spent hops has the smallest number of applications out of the three brewery by-products.

Spent Yeast

Spent yeast cells are removed at the end of the bulk fermentation process (Kerby and Vriesekoop, 2017). They are also high in nutrients such as proteins, minerals, and vitamins (Jaeger et al., 2020). Applications of spent yeast includes food for animals and humans, an enzyme source for biological processes, a fermentation substrate, production of biofuels, and a biosorption agent of heavy metals (Jaeger et al., 2020). Spent yeast can be utilized for meat substitution and bakery products (Jaeger et al., 2020).

Methods

While working for an environmental engineering consulting firm, I was exposed to the idea of using craft brewery waste to aid with contaminated-soil remediation by degrading contaminants and reducing contaminant concentrations. There were little to no studies conducted in the United States; however, pilot studies were in planning stages and possibly upcoming. This idea was fascinating, and my initial intention was to further explore how the process worked and

what was the magnitude of the impact to pollutant reductions. I sought out active or recent studies in the United States, hoping to find available raw data to use for my project. I utilized the NC State University Library and Google Scholar databases to search for such studies. I used the following key search terms: “spent grain,” “spent hops,” “spent trub,” “spent yeast,” “brewery waste,” “brewery disposal,” “brewery sludge,” “brewery process,” “brewery waste management”, “distillery waste,” and “distillery spent wash.”

No active or recent studies with available data were found regarding the use of brewery waste in remediating polluted soils. However, after reviewing several studies, one stood out as having the potential to generate novel study data myself, albeit, considering a different brewery-based theme and study purpose. A study was conducted in the United Kingdom (UK) that examined craft brewery waste utilization (Kerby and Vriesekoop, 2017). Dr. Graham thought this was a unique study that could be conducted in North Carolina within a reasonable time frame and considering the available tools and resources (i.e., principally myself, a computer, and the old information highway). The study began by researching all the craft breweries in North Carolina using the *North Carolina Craft Brewers Guild* and *NC Beer Guys* websites, which listed craft brewers and their location. NC craft brewers’ information was then gathered including name, address, phone number, and email and summarized in a Microsoft (MS) Excel spreadsheet. Then, a survey similar to the to the UK study was created using Google Forms (see Appendix A).

The online survey was distributed to 208 craft breweries across North Carolina with an overall goal to geographically span the entire state and based on where complete contact information was readily obtained. The craft breweries identified varied in size and location. In the survey, the responding breweries were asked to indicate their location by city and region (see

Figure 1), the year in which the craft brewery was established, the typical batch size that could be brewed, and an estimate of annual production in volume. All responding craft breweries were then asked to indicate how spent grain, spent yeast, and spent hops was disposed of, how often they were disposed of, and if there were any costs associated to dispose of them. At the end of the survey, craft breweries were asked if they were aware craft brewery by-products could be utilized to remediate contaminated soils and if they could be contacted for follow up questions.

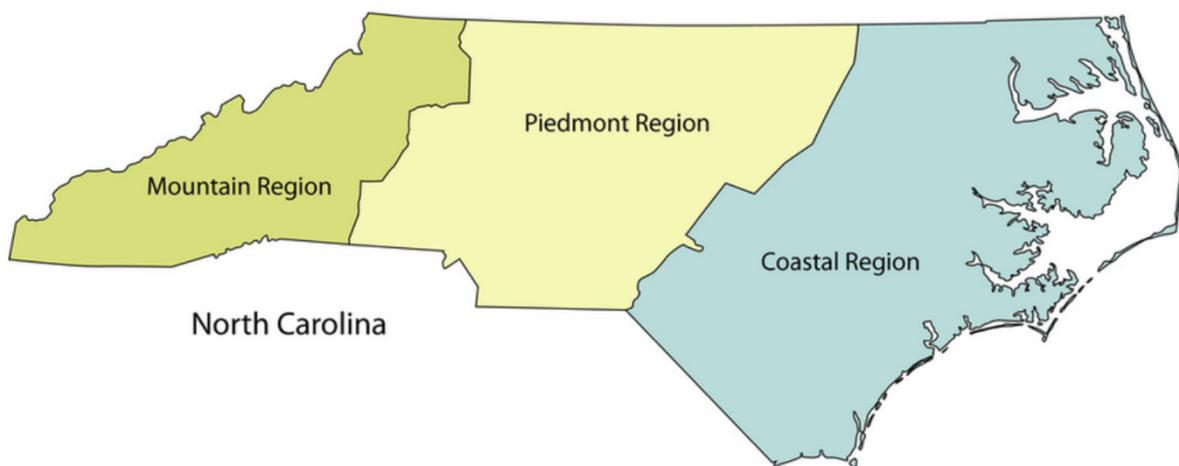


Figure 1. North Carolina divided into three regions: mountain, piedmont, and coast.

Once the data was collected, the responses were analyzed for any data gaps or unique responses. Eight brewers did not specify the units for the estimate of annual production in volume. These craft brewers were contacted again to verify the units and six out of eight craft brewers responded. The two craft brewers who were unable to specify the units for the estimate of annual production in volume were then categorized as an “unknown” volume. Examples of unique responses included a mixture of disposal methods or a disposal method that was not listed in the survey. These responses were then altered during the data preparation step and was listed as “other” or “mix”. Three craft brewers had unique “other” disposal methods, in which they

were contacted for additional information. At the time of this paper, there has been one out of three responses to this request.

Brewery responses for batch size were categorized in the survey as small (<1,000 L), medium (1000 – 2000 L), and large (>2000 L). The county location of each craft brewer as being within or outside of a metropolitan statistical area (MSA) was then categorized based off the United States Office of Management and Budget (OMB) 2020 Standards for Delineating Core Based Statistical Areas data (Office of Management and Budget, 2021). Latitude and longitude data were obtained by entering brewery addresses into Google Earth. These geographic data were then used to create a map of the brewery locations via the free trial version of Tableau[®] (Tableau, 2022).

Pivot tables were created in each of three MS Excel spreadsheet tabs, considering the three types of brewery waste and the brewery response counts and accounting for the potential influential attributes. Quality of the data generated using the pivot tables was assessed by hand by comparing calculated values to those filtered in the raw data sheet. Where variable responses were consolidated for brevity, original information was retained within the raw data sheet (e.g., an establishment year of 2020 was originally entered as 2/29/2020 by the brewery), highlighted/used colored font, and followed by changes made in the pivot table tabs (i.e., 2020). The response count data was converted to percentages and by using a conditional formatting option in MS Excel, illustrative heatmaps were generated. A single color coding schema was used for each table and increased color deepness corresponded with an increased value.

Results and Discussion

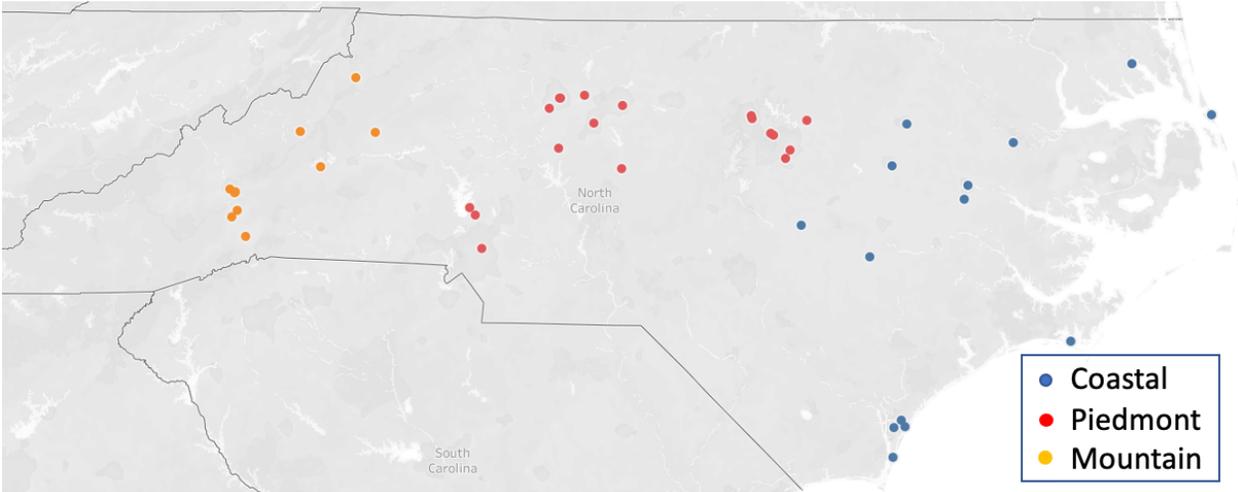


Figure 2: Craft Breweries Location Map

Of the 208 Breweries contacted, a total of forty-two (42) craft breweries across North Carolina participated in the survey, resulting in a 20% overall response rate. Out of the forty-two craft breweries, eighteen are in the piedmont region; fourteen are in the coastal region; and ten are in the mountain region (see Figure 2). The coastal region includes 9 small-, 3 medium-, and 2 large-sized craft brewers. The mountain region includes 5 small-, 4 medium-, and 1 large-sized craft brewers. The piedmont region includes 4 small-, 10 medium-, and 4 large-sized craft brewers. There is a relatively greater number of small-craft breweries in the coastal region and more medium and large-craft breweries in the piedmont region.

Spent grain

Table 1: How spent grain is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Grain Disposal Method		
		Animal Feed	Compost	Mix
Location	Coastal	93%	0%	7%
	Piedmont	89%	0%	11%
	Mountain	90%	10%	0%
Batch Size	<1000 L (small)	89%	6%	6%
	1000 - 2000 L (medium)	100%	0%	0%
	>2000 L (large)	71%	0%	29%
Year	≤ 2016	80%	5%	15%
	> 2016	100%	0%	0%
Metro Area	In MSA (urban)	88%	3%	9%
	Out MSA (rural)	100%	0%	0%
Annual Production	<25000 Gal	95%	5%	0%
	25000-50000 Gal	91%	0%	9%
	>50000 Gal	75%	0%	25%
	Unknown	100%	0%	0%

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production the main method of spent grain disposal is animal feed (see Table 1). Close to a tenth of coastal and piedmont craft brewers disposed of spent grain by a mixture of multiple disposal methods and exactly a tenth of mountain craft brewers disposed of spent grain by composting.

Less than a tenth of small-craft brewers disposed of spent grain by either composting or a mixture of multiple disposal methods. One hundred percent of the medium-sized craft breweries disposed of their spent grain as animal feed. Close to three-tenths of large-craft brewers disposed of their spent grain by a mixture of multiple disposal methods.

A fifth of craft brewers established before or in 2016 disposed of spent grain by either composting or a mixture of multiple disposal methods. One hundred percent of crafter brewers established after 2016 disposed of their spent grain as animal feed.

Close to a tenth of urban craft brewers disposed of spent grain by either composting or a mixture of multiple disposal methods. One hundred percent of the rural craft breweries disposed of their spent grain as animal feed.

Less than a tenth of craft brewers that annually produce less than 25,000-gallons disposed of spent grain by composting. Almost a tenth of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent grain by a mixture of multiple disposal methods. A quarter of craft brewers that annually produce greater than 50,000-gallons disposed of spent grain by a mixture of multiple disposal methods. One hundred percent of the craft brewers with an unknown annual production disposed of spent grain as animal feed.

Most craft brewers that disposed of spent grain by a mixture of multiple disposal methods, disposed of spent grain by composting in addition to animal feed. One craft brewer disposed of spent grain in a third way, which included distribution to a local regenerative micro farm. This craft brewer was contacted to gain additional information, however at the time of this report no response has been received.

Table 2: How frequent spent grain is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Grain Disposal Frequency			
		Daily	2-3/Week	Weekly	When Required
Location	Coastal	0%	43%	29%	29%
	Piedmont	6%	39%	39%	17%
	Mountain	10%	50%	30%	10%
Batch Size	<1000 L (small)	0%	33%	39%	28%
	1000 - 2000 L (medium)	0%	65%	29%	6%
	>2000 L (large)	29%	14%	29%	29%
Year	≤ 2016	10%	40%	35%	15%
	> 2016	0%	45%	32%	23%
Metro Area	In MSA (urban)	6%	45%	39%	9%
	Out MSA (rural)	0%	33%	11%	56%
Annual Production	<25000 Gal	0%	29%	43%	29%
	25000-50000 Gal	0%	73%	18%	9%
	>50000 Gal	25%	38%	25%	13%
	Unknown	0%	50%	50%	0%

Regardless of craft brewers' location, size, establishment time frame, MSA, and annual production, there was not a common frequency in which spent grain was disposed of (see Table 2). Over two-fifths of the coastal craft brewers disposed of spent grain two to three times a week; and almost three-fifths disposed of spent grain either weekly or when required. Close to two-fifths of piedmont craft brewers disposed of spent grain weekly; a third disposed of spent grain two to three times a week; and a little less than three tenths disposed of spent grain when required or daily. Half of mountain craft brewers disposed of spent grain two to three times a week; three-tenths disposed of spent grain weekly; and a fifth of disposed of spent grain either daily or when required.

Almost two-fifths of small-craft brewers disposed of spent grain weekly; a third disposed of spent grain two to three times a week; and almost three-tenths disposed of spent grain when required. A little over three-fifths of medium-craft brewers disposed of spent grain two to three times a week; almost three-tenths disposed of spent grain weekly and less than a tenth disposed of spent grain when required. Almost three-fifths of large-craft brewers disposed of spent grain either daily, weekly or when required and a little more than a tenth disposed of spent grain two to three times a week.

Three-quarters of brewers established before or in 2016 disposed of spent grain either two to three times a week or weekly; and a quarter disposed of spent grain either daily or when required. Almost half of craft brewers established after 2016 disposed of spent grain two to three times a week; over three-tenths disposed of spent grain weekly; and almost a quarter disposed of spent grain when required.

Almost half of urban craft brewers disposed of spent two to three times a week; almost two fifths disposed of spent hops weekly; and a little over a tenth disposed of spent grain either daily or when required. Almost three fifths of rural craft breweries disposed of spent when required; a third disposed of spent grain two to three times a week; and a little over a tenth disposed of spent grain weekly.

A little over two-fifths of brewers that annually produce less than 25,000-gallons disposed of spent grain weekly; and almost three-fifths disposed of spent grain either two to three times a week or when required. Almost three quarters of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent grain two to three times a week and a little over a quarter disposed of spent grain either weekly or when required. Almost two-fifths of craft brewers that annually produce greater than 50,000-gallons disposed of spent grain two to three times a week; half disposed of spent grains either daily or weekly; and a little over a tenth disposed of spent grain when required. Half of craft brewers with an unknown annual production disposed of spent grain two to three times a week and the other half disposed of spent grain weekly.

Table 3: The costs associated with removing spent grain based on craft brewery location, size, establishment time frame, metro statistical area, and annual production.

		Grain Disposal Cost			
		Get Payment	No Cost	Facilitate Disp.	All Cost
Location	Coastal	0%	86%	14%	0%
	Piedmont	0%	100%	0%	0%
	Mountain	10%	80%	0%	10%
Batch Size	<1000 L (small)	0%	83%	11%	6%
	1000 - 2000 L (medium)	0%	100%	0%	0%
	>2000 L (large)	14%	86%	0%	0%
Year	≤ 2016	5%	90%	0%	5%
	> 2016	0%	91%	9%	0%
Metro Area	In MSA (urban)	3%	91%	3%	3%
	Out MSA (rural)	0%	89%	11%	0%
Annual Production	<25000 Gal	0%	90%	5%	5%
	25000-50000 Gal	0%	91%	9%	0%
	>50000 Gal	13%	88%	0%	0%
	Unknown	0%	100%	0%	0%

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production most craft brewers incurred no costs associated with removing spent grain (See Table 3). A little over a tenth of coastal craft brewers facilitated the disposal of spent grain. One hundred percent of piedmont craft brewers incurred no costs for removing spent grain. A fifth of mountain craft brewers either received payment or incurred all costs for removing spent grain.

A little less than a fifth of small-craft brewers either facilitated the disposal of spent grain or incurred all costs for removing spent grain. One hundred percent of medium-craft brewers incurred no costs associated with removing spent grain. A little less than a fifth of large-craft brewers received payment for removing spent grain.

A tenth of craft brewers established before or in 2016 either received payment or incurred all costs for removing spent grain. A little less than a tenth of craft brewers established after 2016 facilitated the disposal of spent grain.

Just under a tenth of urban craft brewers either received payment, facilitated the disposal, or incurred all costs for removing spent grain. A little over a tenth of rural craft brewers facilitated the disposal for removing spent grain.

A tenth of craft brewers that annually produce less than 25,000-gallons either facilitated the disposal or incurred all costs for removing spent grain. A little under a tenth of craft brewers that annually produce between 25,000- and 50,000-gallons facilitated the disposal of spent grain. A little over a tenth of craft brewers that annually produce greater than 50,000-gallons received payment for removing spent grain. One hundred percent of the craft brewers with an unknown annual production incurred no costs for removing spent grain.

Spent Hops

Table 4: How spent hops is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Hop Disposal Method					Hop Free		Other
		Animal Feed	Compost	Landfill	Sewage	Mix			
Location	Coastal	14%	7%	21%	29%	21%	7%	0%	
	Piedmont	11%	0%	39%	33%	11%	6%	0%	
	Mountain	20%	40%	0%	20%	10%	0%	10%	
Batch Size	<1000 L (small)	6%	28%	22%	22%	17%	6%	0%	
	1000 - 2000 L (medium)	12%	0%	18%	47%	12%	6%	6%	
	>2000 L (large)	43%	0%	43%	0%	14%	0%	0%	
Year	≤ 2016	15%	10%	35%	25%	10%	0%	5%	
	> 2016	14%	14%	14%	32%	18%	9%	0%	
Metro Area	In MSA (urban)	12%	12%	27%	24%	18%	3%	3%	
	Out MSA (rural)	22%	11%	11%	44%	0%	11%	0%	
Annual Production	<25000 Gal	5%	24%	24%	29%	14%	5%	0%	
	25000-50000 Gal	27%	0%	18%	36%	18%	0%	0%	
	>50000 Gal	25%	0%	38%	13%	13%	0%	13%	
	Unknown	0%	0%	0%	50%	0%	50%	0%	

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production there was not a common method to dispose of spent hops (see Table 4).

Almost three quarters of coastal craft brewers disposed of spent hops by either landfill, sewage,

or a mixture of multiple disposal methods; around a fifth disposed of hops by either animal feed or composting; and a less than a tenth were spent hops free. Their craft brewery production process does not generate spent hops as a by-product. Almost three-quarters of piedmont craft brewers disposed of spent hops by either landfill or sewage; a little over fifth disposed of spent hops by either animal feed or a mixture of multiple disposal methods; and less than a tenth were spent hops free. Two-fifths of mountain craft brewers disposed of spent hops by composting; two-fifths disposed of spent hops by either animal feed or sewage; and a fifth disposed of spent hops by either a mixture of multiple disposal methods or other.

Almost three-tenths of small-crafter brewers disposed of spent hops by composting; a little over two-fifths disposed of spent hops by either landfill or sewage; a little under three-tenths disposed of disposed of spent hops by either animal feed, a mixture of multiple disposal methods, or they were hop free. Almost half of medium-craft brewers disposed of spent hops by sewage; close to a fifth disposed of spent hops by landfill; close to a quarter disposed of spent hops by animal feed or a mixture of multiple disposal methods; and less than a tenth was hop free. More than four fifths of large-craft brewers disposed of spent hops by either animal feed or landfill and over a tenth disposed of spent hops by a mixture of multiple disposal methods.

Over three-tenths of craft brewers established before or in 2016 disposed of spent hops by landfill; a quarter disposed of spent hops by sewage; a fifth disposed of spent hops by either composting or a mixture of multiple disposal methods; and over a tenth disposed of spent hops by animal feed. Close to a third of craft brewers established after 2016 disposed of spent hops by sewage; close to two fifths disposed of spent hops by either animal feed, composting, or landfill; close to a fifth disposed of spent hops by a mixture of multiple disposal methods; and less than a tenth was spent hops free.

A little under a third of urban craft brewers disposed of spent hops by landfill; almost a quarter disposed of spent hops by sewage; almost a fifth disposed of spent hops by a mixture of multiple disposal methods; almost a quarter disposed of spent hops by either animal feed or composting; and less than a tenth disposed of spent hops by either other or was spent hops free. Almost two-fifths of rural craft brewers disposed of spent hops by sewage; almost a fifth disposed of spent hops by animal feed; and a third disposed of spent hops by either composting, landfill, or was spent hops free.

Almost three-tenths of craft brewers that annually produce less than 25,000-gallons disposed of spent hops by sewage; almost half disposed of spent hops by either composting or landfill; and almost a quarter disposed of spent hops by either animal feed, a mixture of multiple disposal methods, or were spent hops free. Almost two-fifths of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent hops by sewage; a little over a quarter disposed of spent hops by animal feed; and almost two-fifths disposed of spent hops by either landfill or a mixture of multiple disposal methods. Almost two fifths of craft brewers that annually produce greater than 50,000-gallons disposed of spent hops by landfill; a quarter disposed of spent hops by animal feed; and a little over a third disposed of spent hops by sewage, a mixture of multiple disposal methods or were free of spent hops. Half of the craft brewers with an unknown annual production disposed of spent hops by sewage and the other half was free spent hops.

Most craft brewers that disposed of spent hops by a mixture of multiple disposal methods, disposed of spent hops by a combination of animal feed, composting, or sewage. One craft brewer disposed of spent hops in a third way, which included to a local regenerative micro farm. Two craft brewers disposed of spent hops in another way, which was listed as “other.”

They disposed of spent hops by using their on-site wastewater treatment plant to generate biogas. These craft brewer was contacted to gain additional information, however only one craft brewer responded. The craft brewer stated the biogas is produced by an anaerobic digester that is part of their process water treatment plant. Because their system is new, they are still determining how much biogas is being generated, at what frequency, and what quality is coming out of the system. The craft brewer hopes to utilize the biogas to fuel a combined heat and power engine to help power the brewery during peak demand on the grid, however there are storage space constraints at their facility.

Table 5: How frequent spent hops is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Hop Disposal Frequency				
		Daily	2-3/Week	Weekly	When Required	Hop Free
Location	Coastal	0%	36%	21%	36%	7%
	Piedmont	17%	22%	22%	33%	6%
	Mountain	10%	40%	30%	20%	0%
Batch Size	<1000 L (small)	0%	33%	28%	33%	6%
	1000 - 2000 L (medium)	6%	41%	24%	24%	6%
	>2000 L (large)	43%	0%	14%	43%	0%
Year	≤ 2016	15%	40%	20%	25%	0%
	> 2016	5%	23%	27%	36%	9%
Metro Area	In MSA (urban)	12%	33%	24%	27%	3%
	Out MSA (rural)	0%	22%	22%	44%	11%
Annual Production	<25000 Gal	0%	24%	38%	33%	5%
	25000-50000 Gal	9%	45%	9%	36%	0%
	>50000 Gal	38%	38%	13%	13%	0%
	Unknown	0%	0%	0%	50%	50%

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production there was not a common frequency in which spent hops was disposed of (see table 5). Almost three-quarters of coastal craft brewers disposed of spent hops either two to three times a week or when required; close to a fifth disposed of spent hops weekly; and less than a tenth were hop free. A third of piedmont craft brewers disposed of spent hops when required;

over two-fifths disposed of spent hops either two to three times a week or weekly; less than a fifth disposed of spent hops daily; and less than a tenth were hop free. Two-fifths of mountain craft brewers disposed of spent hops two to three times a week; three-tenths disposed of spent hops weekly; a fifth disposed of spent hops when required; and a tenth disposed of spent hops daily.

Two-thirds of small-crafter brewers disposed of spent hops by either two to three times a week or when required; a little under three-tenths disposed of spent hops weekly; and less than a tenth was spent hops free. Over two-fifths of medium-craft brewers disposed of spent hops two to three times a week; almost half disposed of spent hops either weekly or when required; and a little over a tenth disposed of spent hops daily or were spent hops free. A little over four fifths of large-craft brewers disposed of spent hops either daily or when required and a little a tenth disposed of spent hops weekly.

Two-fifths of craft brewers established before or in 2016 disposed of spent hops two to three times a week; a quarter disposed of spent hops when required; a fifth disposed of spent hops weekly and over a tenth disposed of spent hops daily. Almost two-fifths of craft brewers established after 2016 disposed of spent hops when required; a little under three tenths disposed of spent hops weekly; a little under a quarter disposed of spent hops two to three times a week; and over a tenth disposed of spent hops daily or were spent hops free.

A third of urban craft brewers disposed of spent hops two to three times a week; a little less than three-tenths disposed of spent hops when required; almost a quarter disposed of spent hops weekly; and a little over a tenth disposed daily or were spent hops free. A little over two fifths of rural craft brewers disposed of spent hops when required; a little over two-fifths

disposed of spent hops either two to three times a week or weekly; and a little over a tenth were spent hops free.

Almost two-fifths of craft brewers that annually produce less than 25,000-gallons disposed of spent hops weekly; a third disposed of spent hops when required; almost a quarter disposed of spent hops two to three times a week; and less than a tenth were spent hops free.

Almost half of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent hops two to three times a week; almost two-fifths disposed of spent hops when required; and less than a fifth disposed of spent hops either daily or weekly. A little under four-fifths of craft brewers that annually produce greater than 50,000-gallons disposed of spent hops either daily or two to three times a week and almost a quarter disposed of spent hops either weekly or when required. Half of the craft brewers with an unknown annual production disposed of spent hops when required and the other half was free spent hops.

Table 6: The costs associated with removing spent hops based on craft brewery location, size, establishment time frame, metro statistical area, and annual production.

		Hop Disposal Cost			
		Get Payment	No Cost	Facilitate Disp.	All Cost
Location	Coastal	0%	79%	21%	0%
	Piedmont	0%	67%	17%	17%
	Mountain	0%	70%	0%	30%
Batch Size	<1000 L (small)	0%	78%	11%	11%
	1000 - 2000 L (medium)	0%	71%	18%	12%
	>2000 L (large)	0%	57%	14%	29%
Year	≤ 2016	0%	70%	10%	20%
	> 2016	0%	73%	18%	9%
Metro Area	In MSA (urban)	0%	67%	15%	18%
	Out MSA (rural)	0%	89%	11%	0%
Annual Production	<25000 Gal	0%	71%	14%	14%
	25000-50000 Gal	0%	91%	9%	0%
	>50000 Gal	0%	50%	13%	38%
	Unknown	0%	50%	50%	0%

Regardless of the location, size, establishment time frame, metro area, and annual production most craft brewers incurred no costs associated with removing spent grain (See Table

6). Almost a fifth of coastal craft brewers either facilitated the disposal of spent hops or incurred all costs for removing spent hops. Almost a third of piedmont craft brewers either facilitated the disposal of spent hops or incurred all costs for removing spent hops. Three-tenths of mountain craft brewers incurred all costs for removing spent hops.

Almost a fifth of small-craft brewers either facilitated the disposal of spent hops or incurred all costs for removing spent hops. Three-tenths of medium-craft brewers either facilitated the disposal of spent hops or incurred all costs for removing spent hops. A little less than three-tenths of large-craft brewers incurred all costs for removing spent hops and a little over a tenth facilitated the disposal of spent hops.

A fifth of craft brewers established before or in 2016 incurred all costs for removing spent hops and a tenth facilitated the disposal of spent hops. A little under a fifth of craft brewers established after 2016 facilitated the disposal of spent hops and a little under a tenth incurred all costs for removing spent hops.

A little under a fifth of urban craft brewers incurred all costs for removing spent hop and a little over a tenth facilitated the disposal of spent hops. A little over a tenth of rural craft brewers facilitated the disposal for removing spent hops.

A little under three-tenths of craft brewers that annually produce less than 25,000-gallons either facilitated the disposal or incurred all costs for removing spent hops. A little under a tenth of craft brewers that annually produce between 25,000- and 50,000-gallons facilitated the disposal of spent hops. Almost two-fifths of craft brewers that annually produce greater than 50,000-gallons incurred all costs for removing spent hops and a little over a tenth facilitated the disposal of spent hops. Half of the craft brewers with an unknown annual production incurred no costs for removing spent hops and the other half facilitated the disposal of spent hops.

Spent Yeast

Table 7: How spent yeast is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Yeast Disposal Method					
		Animal Feed	Compost	Sewage	Propagation	Mix	Other
Location	Coastal	7%	0%	64%	7%	21%	0%
	Piedmont	0%	6%	83%	0%	11%	0%
	Mountain	20%	0%	40%	0%	20%	20%
Batch Size	<1000 L (small)	11%	0%	56%	6%	28%	0%
	1000 - 2000 L (medium)	6%	6%	76%	0%	6%	6%
	>2000 L (large)	0%	0%	71%	0%	14%	14%
Year	≤ 2016	5%	0%	55%	5%	25%	10%
	> 2016	9%	5%	77%	0%	9%	0%
Metro Area	In MSA (urban)	3%	3%	64%	3%	21%	6%
	Out MSA (rural)	22%	0%	78%	0%	0%	0%
Annual Production	<25000 Gal	10%	0%	67%	5%	19%	0%
	25000-50000 Gal	0%	0%	82%	0%	18%	0%
	>50000 Gal	13%	0%	50%	0%	13%	25%
	Unknown	0%	50%	50%	0%	0%	0%

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production the main method of spent yeast disposal is sewage (see Table 7). Around a fifth of coastal craft brewers disposed of spent yeast by a mixture of multiple disposal methods and less than a fifth disposed of spent yeast by either animal feed or propagation. A little over a tenth of piedmont craft brewers disposed of spent yeast by a mixture of multiple disposal methods and a less than a tenth disposed of spent yeast by composting. Three-fifths of mountain craft brewers disposed of spent yeast by either animal feed, a mixture of multiple disposal methods, or other.

Less than three tenths of small-craft brewers disposed of spent yeast by a mixture of multiple disposal methods and less than a fifth disposed of spent yeast by either animal feed or propagation. Almost a quarter of the medium-sized craft breweries disposed of their spent yeast as either animal feed, composting, a mixture of multiple disposal methods, or other. Almost

three-tenths of large-craft brewers disposed of their spent yeasts by either a mixture of multiple disposal methods or other.

A quarter of craft brewers established before or in 2016 disposed of spent yeast by a mixture of multiple disposal methods; a tenth disposed of spent yeast by other; and a tenth disposed of spent yeast by either animal feed or propagation. Less than a fifth of crafter brewers established after 2016 disposed of their spent yeast by either animal feed or a mixture of multiple disposal methods and less than a tenth disposed of spent yeast by composting.

Almost a fifth of craft brewers that annually produce less than 25,000-gallons disposed of spent yeast by a mixture of multiple disposal methods; a tenth disposed of spent yeast by animal feed; and less than a tenth disposed of spent yeast by propagation. Almost a fifth of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent yeast by a mixture of multiple disposal methods. A quarter of craft brewers that annually produce greater than 50,000-gallons disposed of spent grain by other and a little over a quarter disposed of spent yeast by either animal feed or a mixture of multiple disposal methods. Half of the craft brewers with an unknown annual production disposed of spent yeast as composting and the other half disposed of spent yeast by sewage.

Most craft brewers that disposed of spent yeast by a mixture of multiple disposal methods, disposed of spent yeast by a mix the following methods: animal feed, composting, sewage, or propagation. One craft brewer disposed of spent grain in a third way, which included to a local regenerative micro farm.

Table 8: How frequent spent yeast is disposed of based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Yeast Disposal Frequency			
		Daily	2-3/Week	Weekly	When Required
Location	Coastal	0%	29%	7%	64%
	Piedmont	11%	28%	17%	44%
	Mountain	20%	40%	10%	30%
Batch Size	<1000 L (small)	6%	22%	11%	61%
	1000 - 2000 L (medium)	6%	41%	18%	35%
	>2000 L (large)	29%	29%	0%	43%
Year	≤ 2016	15%	40%	10%	35%
	> 2016	5%	23%	14%	59%
Metro Area	In MSA (urban)	12%	33%	15%	39%
	Out MSA (rural)	0%	22%	0%	78%
Annual Production	<25000 Gal	5%	19%	19%	57%
	25000-50000 Gal	9%	36%	9%	45%
	>50000 Gal	25%	63%	0%	13%
	Unknown	0%	0%	0%	100%

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production there was not a common frequency in which spent yeast was disposed of (see Table 8). Over three-fifths of coastal craft brewers disposed of spent yeast when required; almost three-tenths disposed of spent yeast two to three times a week; and less than a tenth disposed of spent yeast weekly. Over three-fifths of piedmont craft brewers disposed of spent yeast when required; less than three-tenths disposed of spent yeast either two to three times a week; less than a fifth disposed of spent yeast weekly; and over a tenth disposed spent yeast daily. Two-fifths of mountain craft brewers disposed of spent yeast two to three times a week; three-tenths disposed of spent yeast either when required; a fifth disposed of spent yeast daily; and a tenth disposed of spent yeast weekly.

Over three fifths of small-crafter brewers disposed of spent yeast when required; a little over a fifth disposed of spent yeast two to three times a week; and less than a fifth disposed of spent yeast either daily or weekly. Over two fifths of medium-craft brewers disposed of spent yeast two to three times a week; a little less than two-fifths disposed of spent when required; and

less than a quarter disposed of spent yeast either daily or weekly. A little over two-fifths of large-craft brewers disposed of spent yeast when required and almost three-fifths disposed of spent yeast either daily or weekly.

Two-fifths of craft brewers established before or in 2016 disposed of spent yeast two to three times a week; a little less than two-fifths disposed of spent yeast when required; a quarter disposed of spent yeast either daily or weekly. Almost three-fifths of craft brewers established after 2016 disposed of spent yeast when required; a little under a quarter disposed of spent yeast two to three times a week; a little under a fifth disposed of spent yeast either daily or weekly.

A little under two-fifths of urban craft brewers disposed of spent yeast when required; a third disposed of spent yeast two to three times a week; and a little over a quarter disposed of spent yeast either daily or weekly. A little over three quarters of rural craft brewers disposed of spent hops when required; a little under a quarter disposed of spent yeast two to three times a week.

Almost three-fifths of craft brewers that annually produce less than 25,000-gallons disposed of spent yeast when required; a little under two-fifths disposed of spent yeast either two to three times a week or weekly; and less than a tenth disposed of daily. Almost half of craft brewers that annually produce between 25,000- and 50,000-gallons disposed of spent yeast when required; almost two-fifths disposed of spent yeast two to three times a week; and less than a fifth disposed of spent yeast either daily or weekly. A little over three-fifths of craft brewers that annually produce greater than 50,000-gallons disposed of spent yeast two to three times a week; a quarter disposed of spent yeast daily; and a little over a tenth disposed of spent yeast when required. 100% of the craft brewers with an unknown annual production disposed of spent yeast when required.

Table 9: The costs associated with removing spent yeast based on craft brewery location, size, establishment time frame, metro area, and annual production.

		Yeast Disposal Cost			
		Get Payment	No Cost	Facilitate Disp.	All Cost
Location	Coastal	0%	71%	14%	14%
	Piedmont	0%	39%	28%	33%
	Mountain	0%	70%	0%	30%
Batch Size	<1000 L (small)	0%	67%	6%	28%
	1000 - 2000 L (medium)	0%	53%	24%	24%
	>2000 L (large)	0%	43%	29%	29%
Year	≤ 2016	0%	55%	20%	25%
	> 2016	0%	59%	14%	27%
Metro Area	In MSA (urban)	0%	52%	18%	30%
	Out MSA (rural)	0%	78%	11%	11%
Annual Production	<25000 Gal	0%	62%	14%	24%
	25000-50000 Gal	0%	73%	0%	27%
	>50000 Gal	0%	25%	38%	38%
	Unknown	0%	50%	50%	0%

Regardless of craft brewers' location, size, establishment time frame, and metro area, most craft brewers incurred no costs associated with removing spent yeast (See Table 9). Less than a third of coastal craft brewers either facilitated the disposal of spent yeast or incurred all costs for removing spent yeast. A third of piedmont craft brewers incurred all costs for removing spent yeast and a little under three-tenths facilitated the disposal of removing spent yeast. Three-tenths of mountain craft brewers incurred all costs for removing spent yeast.

A little less than three-tenths of small-craft brewers incurred all costs for removing spent yeast and less than a tenth facilitated the disposal of spent yeast. A little under half of medium-craft brewers either facilitated the disposal of spent yeast or incurred all costs for removing spent yeast. Close to three fifths of large-craft brewers either facilitated the disposal of spent yeast or incurred all costs for removing spent yeast.

A quarter of craft brewers established before or in 2016 incurred all costs for removing spent yeast and a fifth facilitated the disposal of spent yeast. A little over a quarter of craft

brewers established after 2016 incurred all costs for removing spent yeast and a little over a tenth facilitated the disposal of spent yeast.

Three-tenths of urban craft brewers incurred all costs for removing spent yeast and a little under a fifth facilitated the disposal of spent yeast. A little over a fifth of rural craft brewers either facilitated the disposal of spent yeast or incurred all costs for removing spent yeast.

Almost a quarter of craft brewers that annually produce less than 25,000-gallons incurred all costs for removing spent yeast and a little over a tenth facilitated the disposal of spent yeast. A little over a quarter of craft brewers that annually produce between 25,000- and 50,000-gallons incurred all costs for removing spent yeast. Almost four-fifths of craft brewers that annually produce greater than 50,000-gallons either facilitated the disposal of spent yeast or incurred all costs for removing spent yeast and a quarter incurred no costs for removing spent yeast. Half of the craft brewers with an unknown annual production incurred no costs for removing spent yeast and the other half facilitated the disposal of spent yeast.

Conclusion

The UK study indicates craft brewers with different locations and sizes vary in disposal methods, frequency, and costs associated within each brewery by-product. This study indicates regardless of the craft brewers' location and size, there are similar means of disposal methods, frequency, and costs associated for spent grains and spent yeast, individually. However, the disposal methods, frequency, and costs associated with spent hops varies based on location and size, which is similar to the UK study findings.

Over 200 craft brewers across North Carolina were contacted to participate in the survey. Forty-two craft brewers responded and provided information on how they utilize their brewery by-products. Based on the study, regardless of craft brewers' location, size, establishment time

frame, metro area, and annual production there was no common disposal method among all the craft brewery by-products; however, most of the craft brewers disposed of brewery by-products either two to three times a week or when required and incurred no costs associated with the disposal of brewery by-products.

Regardless of craft brewers' location, size, establishment time frame, metro area, and annual production the main method of spent grain disposal is animal feed. The research found that spent hops and spent yeast has a larger variation in disposal methods. Small-craft brewers and urban craft brewers use a wider range of disposal methods for spent hops and spent yeast compared to medium- and large-craft brewers and rural craft brewers.

In conclusion, craft breweries across North Carolina demonstrated various unique and sustainable methods of brewery by-product disposal to benefit both the environment and their economic advantage. However, this study found that only five out of the forty-two surveyed craft brewers (12%) were aware brewery by-products could be used to remediate contaminated soil. The results of this study could be of interest to varied environmental organizations (e.g., the NC Department of Environmental Quality, private engineering/consulting firms) for developing cooperative partnerships and designing future investigations into how local brewery by-products can be used to remediate contaminated soils.

Data Gaps/Limitations

There are over three hundred craft breweries located in North Carolina. This research study represents responses from less than one-fifth of North Carolina craft brewers. As such, this study may not fully represent the utilization of brewery by-products generated by all North Carolina craft breweries.

During the research study several craft brewers were contacted regarding clarifying units of volume produced annually or to elaborate on unique disposal methods. At the time of this study, some responses were not received; however, this does not affect the conclusion of the study.

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Appendix
Brewery Waste Management Survey Google Form

Brewery Waste Management Survey

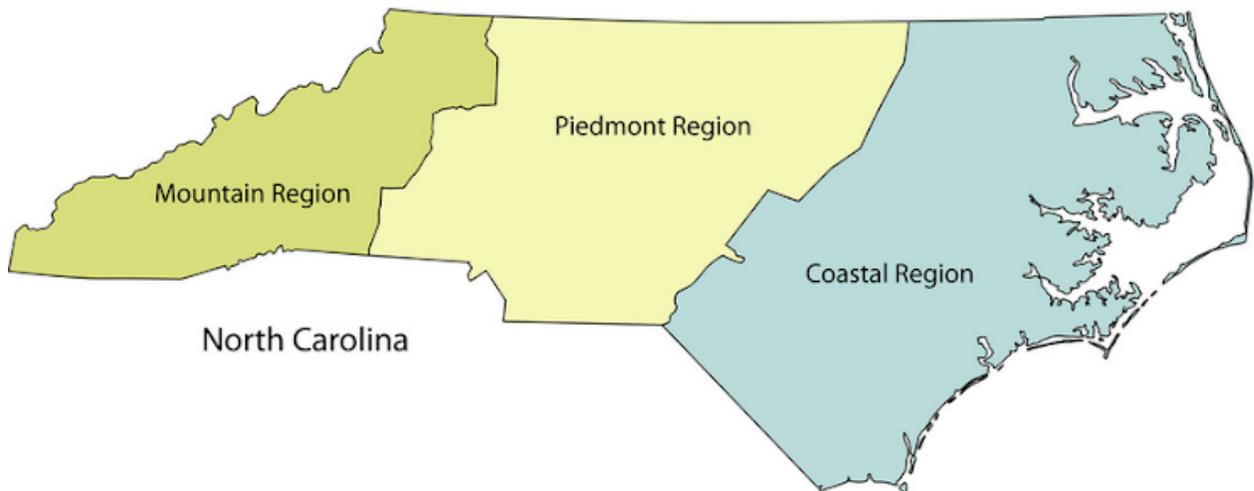
* Required

1. Email *

2. What is the name of your brewery? *

3. What city is your brewery located in? *

4. What region is your brewery located in? *



Mark only one oval.

- Mountain
- Piedmont
- Coastal

5. When was your brewery established? *

6. What is the size of a typical batch that can be brewed? *

Mark only one oval.

- Less than 1,000 Liters (~265 gallons)
- Greater than 1,000 Liters (~265 gallons), but less than 2,000 Liters (~530 gallons)
- Greater than 2,000 Liters (~530 gallons)

7. Please provide an estimate of annual production in volume.

8. How is spent grain disposed of? *

Check all that apply.

- Animal Feed
- Compost
- Fertilizer
- Landfill

Other: _____

9. How often is spent grain disposed of? *

Mark only one oval.

- Daily
- 2-3/Week
- Weekly
- When Required
- Other: _____

10. What costs are involved in the removal of spent grain? *

Mark only one oval.

- Brewery Incurs No Cost
- Brewery Facilitates Disposal
- Brewery Incurs All Costs
- Brewery Receives Payment

11. How is spent yeast disposed of? *

Check all that apply.

- Animal Feed
- Compost
- Fertilizer
- Sewage
- Other: _____

12. How often is spent yeast disposed of? *

Mark only one oval.

- Daily
- 2-3/Week
- Weekly
- When Required
- Other: _____

13. What costs are involved in the removal of spent yeast? *

Mark only one oval.

- Brewery Incurs No Cost
- Brewery Facilitates Disposal
- Brewery Incurs All Costs
- Brewery Receives Payment

14. How is spent hops disposed of? *

Check all that apply.

- Animal Feed
- Compost
- Fertilizer
- Landfill
- Other: _____

15. How often is spent hops disposed of? *

Mark only one oval.

- Daily
- 2-3/Week
- Weekly
- When Required
- Other: _____

16. What costs are involved in the removal of spent hops? *

Mark only one oval.

- Brewery Incurs No Cost
- Brewery Facilitates Disposal
- Brewery Incurs All Costs
- Brewery Receives Payment

17. Did you know beer waste could be used to clean up polluted soils?

Mark only one oval.

- Yes
- No

18. Can I contact you if I have any follow up questions? *

Mark only one oval.

- Yes
- No

19. If yes, please leave contact information here (name, email address, and phone number).

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