IPRO 340: Business Study of Alternative Uses for Brewers' Spent Grain

Final Project Report

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<Insert brief description of IPRO>

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Abstract

The Chicago Metropolitan area has over 50 small micro-breweries and brew-pubs producing a range of traditionally crafted beer styles. Almost all of them are producing some quantity of brewers spent grain (BSG). For the larger micro brewer with multiple locations, they are generating in excess of a quarter of a million pounds per year. Small, local brewers are generating 300-500 lbs per batch several times per week. Much of this winds up in a landfill. At best, a farmer is willing to haul it away if it is convenient for the farmer.

The City of Chicago poses unique challenges for the micro brewer opting to set-up shop in an urban environment. Narrow, car filled streets and tight back alleys are a daunting task for a delivery driver or waste hauler. The aggravation of picking up several thousand pounds of wet, spent grain to haul it 70 miles into the country is not an economically viable choice for most farmers. With limited options, the brewers usually resort to filling the dumpster in the alley and paying up to $30 per yard to have it hauled away. As a comparison, quality topsoil sells to the general public for about $40 per yard– the two products aren't all that different! The smell of spoiling spent grain wafting into the Friendly Confines from the local brew pub, on a hot summer day doesn't produce much neighborly goodwill.

So, what to do with all that spent grain? The mega-brewers have been pondering this question for decades and much of the current practice is a direct result of externalities affecting the brewer. When commodity prices are high, farmers look for alternatives to offset the per bushel cost of feed stocks and are willing to pay the brewer for quality BSG. When energy prices or waste disposal costs rise the brewers look to by-product waste streams to recapture the value that is being disposed of. Large brewers have large budgets to deal with large waste streams however the small brewer is rarely afforded this luxury. For the micro-brewers and brew-pubs of the world an alternative use of BSG waste must factor in location, BSG output, disposal costs and ethical considerations.

Background Information

Our sponsor, Rock Bottom Brewery, is a local microbrewery that has several brewpubs throughout the Chicagoland area. The types of beer available at each of the locations are different and are up to the discretion of the Brewmasters. The types of beers can depend on the time of year or the resources that are available at that location. Each of the Brewmasters develops their own recipes for each batch of beer they make and each batch has of beer has their own signatures in them.

At each of the locations, the Brewmasters all use a similar brewing process to create their concoction. The brewing process takes the grain through seven different stages before it becomes beer and is ready to serve. They are: the Mill, the Grist Hopper, the Mash Tun, the Brew kettle, the Plate heat exchanger, the Fermentation vessel, and the Serving vessel. Throughout these seven stages, two major products are formed, spent grain and beer. Our IPRO is set with the task of working with the former.

Spent grain is the product that comes from the Mash Tun; it is primarily a mixture of grain and grain husks that has had the majority of its sugars extracted. In the past, the majority of spent grain produced was disposed of in a dumpster but recently there have been more alternatives for brewers to get rid of their spent grain. Currently, the majority of the spent grain from brewers are being trucked away and used as cattle feed. Much smaller portions of it are being used for composting, growing mushrooms, cooking, bio-ethanol production, and production of biodegradable plastics. The idea of using spent grain for cooking has become quite popular; there is a patent for a method of separating the husks from the bran in the spent grain through a continuous process so that large amounts of the grain can be processed. There is some research being done currently to find better alternatives, if any, to dispose of the tons of spent grain produced daily. But of the research being done, there are some promising results. There is an instance where the spent grain is being used to purify water contaminated with lead or cadmium. Results are showing removal of up to 90 percent of the heavy metals. All these alternatives may be areas of interest for our IPRO as the project progresses.

Rock bottom currently produces 3000 to 5000 pounds of this spent grain per week from its Chicagoland breweries. The spent grain is contained in 40 gallon garbage pails or deposited in a dumpster to be removed by a waste removal contractor. We estimate that the spent grain is 5 to 7 pounds per gallon depending on its saturation level and each facility produces about 2 yards of waste per week. The average disposal cost of a 2 yard dumpster is $40 to $50 per week. Loose agreements have been established with local farmers/agriculturists for feed or compost, however the farmer has the final say if he feels the product has “turned” and is not able to use for feed, which is more valuable than feed. If the pails are stored outside of the building, depending on the weather conditions, the spent grain will become unfit for any purpose as soon as 24 hours. In colder environs the life of the product can be extended.

Currently our sponsor, specifically at the Lombard, Illinois location does not have any problems with its methods of disposing spent grain; but they would like to find out if there is a better alternative than giving it to a farmer to use as animal feed or throwing it in a landfill.

Objectives and Goals

IPRO 340 will work with the sponsor company, Rock Bottom Brewery, to identify uses for spent grain, a valuable by-product of the beer brewing process. The team will identify the barriers prohibiting microbreweries in the Chicagoland, specifically the sponsor brewery, from participating in the spent grain business market. The team will work to determine ways to overcome those barriers, as well as work to find additional uses for spent grain. One of the alternatives that will be evaluated is the practicality of implementing a Butanol solution similar to Scottlands recent discovery. Other alternative applications for spent grain that will be studied include making tofu, granola bars, and other food products. The team will also look into developing storage methods for spent grain that prolong its viability. During the IPRO project, members of our IPRO will evaluate the business practices, logistics, costs, storage, partnering, environmental impact, and practicality of each use option in order to find a solution that best suits the needs of our project sponsor.

- Learn and understand the various applications of spent grain
- Determine which application will best serve our sponsor's needs
- Work together to deliver Rock Bottom in Lombard a solution and use of their spent grain
- Work together to complete deliverables on time, as put forth by the IPRO Office

Organization and Approach

To be able to fully understand what spent grain is and where it comes from, the IPRO visited the Rock Bottom Brewery in Lombard, Illinois to learn about the brewing process from our sponsor, Timothy Marshall. At this visit, the IPRO was able to experience firsthand how beer is made and which part of the process produces the spent grain byproduct. This was also a chance for the IPRO to address whatever questions they had about the tasks and figure out what the team was to achieve by the end of the semester.

At this point the IPRO was divided into three primary research groups; logistics, food alternatives, and innovative applications. While divided into teams, the IPRO as a whole conducted a survey of all Chicagoland breweries to see what is currently being done with spent grain. These primary research teams were together until mid-semester where most the preliminary research was done and presented to Timothy in a preliminary report. At this mid-semester visit, the IPRO was able to update our sponsor on our progress and gauge his interest in the topics that were researched. The IPRO came out of this meeting with a better understanding of what is feasible for Rock Bottom and what is left to be done before the end of the semester.

The remaining of the semester was spent on individuals or teams of two doing more comprehensive research into specific alternatives. The research consisted of performing experiments, contacting industry specialists, and numerous other resources; this lead to the compilation of a catalog of alternatives that will be presented to our sponsor as a final deliverable.

Research and Analysis

Throughout the entire semester, a copious amount of research was done. All this research has been compiles into a catalog that has been presented to our sponsor, Timothy Marshall of Rock Bottom in Lombard, Illinois. This catalog contains a detailed description of all the alternatives that our IPRO researched. It also rates each of the alternatives based on applicability for different types of breweries. This rating shows the recommended brewer size, amount of capital investment, ease of implication, brewers' spent grain condition, and amount of brewers' spent grain required. A simplified version of this catalog has been added in this report in the appendix.

Our IPRO concluded that there is not a single best alternative; the best alternative depends on many factors. The size and location of the brewery being the biggest of the constraints, the criteria that our IPRO have looked at is only a few of those that need to be considered. Each of the alternatives has many pros and cons and it may in the end be up to the decision of the brewer to decide which is best. A major hindrance in many of the alternatives is that it requires a lot of spent grain, a lot more than a single brewery can provide. But this can be worked around by forming a co-op with other breweries in the area to combine the amount of spent grain. Larger breweries in Chicagoland, e.g. Goose Island, may be able to implement some of these alternatives but then it comes down to the capital costs. Capital costs are another big hindrance in many of the alternatives.

One of the more favorable alternatives that our IPRO looked at is biogas. Spent grain can produce biogas through an anaerobic digester. This technology is currently in use and will be available in Chicago within two years at the Vertical Farm project. Our IPRO was able to put our sponsor in contact with Professor Blake Davis from the Vertical Farm project.

In many of the alternatives, a co-op between many breweries is the easiest solution, the capital costs can be split and the spent grain produced from each brewery can be combined. This is why a portion of our research was done for the logistics of transporting the spent grain to a central location. We ran an economic analysis to see how much it would cost to drive a truck around Chicago and pick up spent grain two or three times a week. We also drew theoretical maps of the truck routes that could be used; this can be found in the appendix. Using these routes and the cost of a truck and gas today, the cost is approximately $0.05 a pound.

With transportation taken care of, the issue of spent grain spoiling after two days needs to be addressed. Our IPRO looked into four different ways of preserving the spent grain. We looked at freezing, vacuuming, salting, and drying. For freezing, one would extrude the spent grain in a package similar to a sausage and hang to freeze in a large chest freezer. The reasoning for the sausage is because it is easier to freeze this way. Brewers would generally fill spent grain in a large 50 gallon container and throw it out back in the winter. The center of the container doesn't freeze until about 2 days outside, in this time, the spent grain has already degraded. The idea behind vacuuming is that food is generally vacuumed to take out the air in the package to slow down the spoilage. Our IPRO did an experiment to test this theory with spent grain and the results show that vacuuming the spent grain does extend its shelf life. The only limitation with vacuuming is the packaging size; even a small Chicago brewery produces enough spent grain to fill a Toyota Prius in a week's time. With salting, it would require the spent grain to be salted to about 8% salt by weight. This amount of salt is over two times more salty than ocean water. This would make any downstream process of the spent grain unfeasible.

Our IPRO decided that drying would be the best option to preserve the spent grain. The only drawback of drying is that a commercial drying process is very expensive and very large. Breweries in Chicago are already limited in space and cost. A future project could be to develop a less expensive and small but efficient dryer. We have investigated smaller machinery that reduces that amount of water to about 45% but the spent grain still degrades at this moisture level. The spent grain needs to be at approximately 14% moisture to be stable enough to store long term.

On a different note, our IPRO have been able to create many recipes that uses spent grain. We were able to show that spent grain is delicious. We were able to make cookies, granola, crackers, and many other foods. The idea behind this is that brew pubs can serve these foods in their restaurant. The only down fall of this alternative is that spent grain foods use a very small portion of the spent grain that they produce. We were able to dry to the spent grain and create a spent grain flour so that more of the spent grain can be used in the recipes. Without turning the spent grain into a flour, the spent grain is only used a filler.

Throughout this semester, our IPRO has run into many problems that needed to be solved in order to make these alternatives viable. But there is still much research and testing to be done to fully be able to say that these alternatives will be viable in Chicago.

Conclusion

IPRO 340 have addressed the spent grain that breweries inevitably produced, is being discarded by small breweries, while there lies within it a potential of being a source of income and benefit to the brewery and the customer respectively. The process to attaining our end goal included embarking on extensive research (both scientific and business based) collecting information from the Chicagoland breweries, experimenting hypotheses, getting advice from professors, and sharing the information with the sponsor, Rock Bottom. In fact, we created a catalogue describing the business alternatives of spent grain for their sponsor, which impressed them to a level that they wish to share it with the Chicago Brewers Association.

Thus, we have surpassed the level of our initial goals of the semester:

- Determine the plausible uses of spent grain for our sponsor
- Determine the best use of the spent grain for our sponsor
- Evaluate business practices, logistics, costs, storage, composition, packaging, partnering, etc. in order to find the best solution.
- Stay in touch with our sponsor, so to find out if there has been any new developments

After extensive research and analysis of the numerous applications of spent grain, we have reached the conclusion that there is not one best alternative. Although some alternatives are more superior to the other, the *best* alternative varies with the type of brewer. The size, storage space, amount of spent grain produced, location, and other features of the brewery, all contribute to judging what alternative suits them the most.

Recommendations

The future of this study involves outreaching to farms, experimentation labs, and large-scale brewers to strengthen the results of what the team has found. In addition, since we have initiated a relationship with Rock Bottom and the vertical farm, we will stay in touch with the outcome of their shared benefits. The findings of IPRO 340 will be shared with the Brewers Association of Chicago via a catalogue. Our sponsor Rock Bottom's master brewer, Timothy Marshall, was highly impressed with our results and has given encouraging remarks regarding the potential of our work.

Appendix

Nutritional Content

Table 1: Comparison of BSG nutritional value

Component (%Dry Weight)	BSG[1]	GBF[2]
Cellulose	25.4	8.9
Arabinoxylan	21.8	17.0
Lignin	11.9	8.2
Protein	24.0	46.0
Lipids	10.6	10.2
Ash	2.4	2.0

1. Brewers Spent Grain

2. Germinated barley food stuff (before mashing process)

Alternatives

Biogas

Biogas generation from microbial conversion of biogenic organic wastes under anaerobic conditions has a global attraction because of its importance as a method of waste treatment and resource recovery. Tests done in the Nnamdi Azikiwe University, Nigeria, indicated that brewers spent grains can be utilized for biogas production when digested anaerobically. They produced 58-65% methane. The sludge generated thereafter can provide high quality manure since nitrogen content of the stabilized bio-wastes increased at the end of the digestion as revealed by the proximate analysis. Spent grain can also be added to other components to produce biogas. For instance in a paper "Biogas Production from Blends of Powdered Rice Husk, with some Agro-Industrial wastes" by Uzodinma, E.O.U from the University of Nigeria, it was discovered that Rice Husk produced a biogas yield of 5.5L, but when blended with SG the flammable biogas production increased to 18.8L. There was also a 95% confidence level increase. Also amongst all the other wastes, RH + BSG exhibited the shortest lag time of 2 days as opposed to the 16 days of RH alone. The gas analysis from SG:RH showed methane (70.6%), CO2(23.3%), CO(6.3%) and H2S (2.1%). G. Bochmann et al in the paper "Application of enzymes in anaerobic digestion" goes further to talk of the best enzyme for obtaining biogas from. Using a cheap raw multi-enzyme produced by a solid state fermentation, the hydrolysis of ligno-cellulose is promoted and biogas production is also increased and the quality of the gases produced is also enhanced.

The usage of brewers spent grain (BSG) to create biogas is typically seen with larger brewers. However, with advances in technology and fermentation techniques, smaller brewers are now able to take advantage of biogas. However, even with advances in technology, the startup costs are high (possibly prohibitive) and the payoff does not justify the effort.

Current techniques to convert BSG into methane are similar to that in converting livestock manure to biogas. This process is detailed in the paper *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities* [USDA:NRCS 2007]. A basic overview is that the BSG is put into a lagoon or plug flow digester wherein which the grain is first processed by bacteria to break down the carbohydrates and allow for other bacteria to further process. The bacteria then convert the sugars from the carbohydrates into hydrogen, ammonia, and organic acids. These are then converted in acetic acids, which are then converted by methanogens into methane and carbon dioxide. The produced methane is then separated then used where needed.

According to studies conducted by Engler, et.al from Texas A & M, the average investment into a biogas conversion facility averages $149,700. Amortized with repairs and maintenance, risk, and annual costs, the expected annual cost is $23,911.

Table 2: Overall Investment Costs (Engler 1997)

Table 2. Investment costs for Carrell Dairy anaerobic digester.

Item	Life (yr)	Investment	Annual Cost[1]	Repairs & Maintenance[2]	Risk[3]
Tank	15	$ 40,000	$ 4,215	$ 211	$ 126
Cover	15	47,800	5,037	252	151
Solids Separator	15	22,000	2,318	116	70
Engine	5	5,000	1,150	57	34
Generator	15	5,600	590	30	18
Other Equipment	15	18,000	1,897	95	57
Materials/Supplies	15	5,600	590	30	18
Contractor	15	5,700	601	30	18
TOTAL		$ 149,700	$ 16,398	$ 821	$ 492

[1] Investment amortized at 7.5% for life of investment with no salvage value.
[2] Estimated at 5% of annual investment cost.
[3] Estimated at 3% of annual investment cost.

Table 3: Expected Average Cost (Engler 1997)

Table 3. Expected annual costs.

Item	Annual Cost
Investment	$ 16,398
Repair & Maintenance	821
Risk	492
Variable (labor[1], supplies[2])	6,200
TOTAL	$ 23,911

[1] Labor estimated at 10 hr/wk at $10/hr.
[2] Supplies estimated at $1,000.

Assuming an average cost of electricity at $0.067/kWh, the expected average benefit is $14,300/year. Comparing this to the expected annual cost of $23,911 resulting from investment and repair/maintenance costs, there is a net average loss of $9,600. This means that it is not economically feasible using typical anaerobic digesters in breweries. This is also true in 2007 [USDA:NRCS 2007].

However, advances in anaerobic digester technology may provide a hope for breweries willing to invest in the technology. Magic Hat brewery in Vermont is collaborating with Eric Fitch and PurposeEnergy, Inc., an Arlington, MA company in order to convert their spent grain into biogas. Their process is patented, detailed in USP 7727395. However, the basic concepts remain the same with the exception being that PurposeEnergy's process is more efficient than usual biogas conversion. The only limiting factor is that it is not economically feasible unless the brewer(s) are producing over 150,000 barrels of beer per year (the typical output of Magic Hat in a year). If the brewery is not producing up to this level, the savings in electrical costs are either minimal or non-existent.

Biogas production from BSG is usually associated with larger brewers such as Anheuser Busch due to the economic constraints of smaller brewers. Usually, only large brewers have the capital and production capability in order to benefit from biogas production. However, with advances by Purpose Energy, smaller brewers are able to take advantage of this opportunity. Hopefully, in the future, technology will advance to the point where it is economically beneficial for them to produce biogas. However, biogas is currently limited to breweries that produce over 150,000 barrels a year.

Bricks

One possibility for the disposal of spent grains is to use them to increase the porosity in brick. During the firing process in the kiln, the spent grains burn away, leaving pores in the brick. In laboratory experiments involving materials added to bricks to increase porosity, have shown that the origin and therefore the composition of the clay as well as that of the added materials significantly influences the properties of the bricks as building materials. The low amount of ash coupled with the high amount of fibrous material (lignin, hemicellulose and cellulose) makes BSG suitable for use in building materials. Russ et al. (2005) found that fired finished bricks produced with BSG have a characteristic higher strength, higher porosity (higher water absorption capacity) and a lower density, which give them better properties of thermal insulation than those produced from a similar production clay. However this alternative is not realistic for on-site operations. It would be suitable on a larger scale where microbrewers would need to join forces and work together or a cooperative of breweries send their waste stream to the local brick manufacturer.

Charcoal

Okamoto Hiroyuki et al wrote in the journal Kagaku Kogaku Ronbunshu, a Japanese publication, of a process for the production of charcoal bricks from spent grain. In their publication, the physical and chemical properties of the charcoal bricks were deduced and evaluated. To make the charcoal bricks, the beer spent grain was first dried from its 67% wt water content, and then pressed at high temperature and pressure to make bricks without any binder. The spent grain bricks were finally carbonized in a low oxygen atmosphere through the heat recycling carbonization process, to produce charcoal bricks. This method yielded charcoal bricks with a constant quality and high yield. The charcoal bricks were recorded to have a high calorific value of about 27MJ/Kg, which was equivalent in power to that of "Bincho-tan" and was roughly 13% lower than that of “Oga-tan”. Both Bincho-tan and Oga-tan is traditional wood charcoal common to the Japanese culture. Given the nutritional values of BSG, the contents of nitrogen and phosphorus in the charcoal bricks were 9-20 times and 40 times greater than those of Bincho-tan and Oga-tan, respectively. As the spent grain charcoal bricks contained various minerals such as calcium, magnesium and phosphorus, they had the possibility to be used as a source of natural minerals.

Composting

According to the International Soil Conservation Organization, 65% of the world’s soil is degraded. Directly staunching the causes of topsoil loss (poor agriculture and forestry practices) may be difficult for brewers, but compost is an effective and accessible way they can help revive soil health and a great source of nitrogen and organic matter for the compost pile. Spent grains are a great source of carbon to balance the nitrogen from green compost materials, and it is also a good way to recycle one of the largest waste products from the beer-making process.

Layering the Compost

Spent grain needs to be mixed with high carbon materials to compost efficiently and these are the items that are needed:

- 4-foot by 4-foot compost bin
- Pitchfork or shovel
- Spent grains from beer making
- Grass clippings, plant trimmings, and other "green" compost materials
- Hose and water source
- 6-foot by 6-foot tarp
- 4 large stones or bricks

1. Choose a convenient place near your garden to compost. Look for an area with firm, flat ground. Build or set up the compost bin in your chosen location.
2. Shovel 3 to 6 inches of green material into the bottom of the compost bin. Top this with an equal amount of spent grain. Repeat these layers until you run out of materials.
3. Sprinkle the compost bin with water until it has the moisture level of a damp sponge.
4. If the weather is either hot and dry or very wet, cover the bin with the tarp and weigh it down with stones or bricks. This will keep the compost from drying out or becoming too wet. If the weather is dry, check the moisture level often and add water as necessary. Remove the tarp at night to allow air into the compost.
5. Use the pitchfork or shovel to turn the compost weekly, or any time you add additional materials. Check the moisture level when you turn the compost and add water if necessary.
6. When the compost is evenly colored and feels like potting soil, it is ready to be worked into the garden.

Tips and Warning

1. If you need to cover the bin to prevent over- or under-watering, remove it as soon as possible to allow air to enter the compost.
2. If you notice foul odors coming from the compost pile, turn it more frequently. Odors result from a lack of oxygen in the decomposition process, which prevents compost from forming properly.

Drying

Several methods have been proposed to prolong brewer's spent grain (BSG) storage time as a result of its high moisture content. Factory drying has been the most effective method of preserving BSG. However, owing to the growing global concern over high energy cost, many breweries, especially those can no longer afford this practice. Drying as a preservation method has the advantage of reducing the product volume, and decreases transport and storage costs. From all current research done by the Richards Engineering Group Ltd, it was discovered that marketing spent grain instead of wet spent grain, provides a higher margin of return. Drying and milling spent grain into flour is also necessary if we want to bake it into favorite cookies, or dog biscuits. It is also better to dry the spent grain if one wants to feed animals with it.

The types of Grain Dryers

- Steam-Tube Dryer: this has lower operating costs, but has higher initial cost than direct fired-types. These do not require the recycling of previously dried spent grain as in the Direct-Fired Dryer. It takes in an input rate of 20,597 pounds per hour of 5% moisture spent grains. It produces 7922 pounds per hour of dried grains at 9% moisture content. It takes 1.54 pounds of steam to evaporate a pound of water. The first costs of the dryer is $295,000
- Direct Fired Dryer: This has being hailed by most brewers for effective performance. It was first used in 1941, in the Miller Brewery Company of Milwaukee, WL. Since then it has been used all over the world. It has a three pass unit. It is powered by natural gas or fuel. If an hourly load of 22,365 pound with 65 percent moisture content is mixed with about 1265 pounds per hour of previously dried grains, making a total of 23, 630 of spent grain and 62 percent moisture, water will be evaporated at 13,763 pounds per hour. This reduces the moisture to roughly about 9 percent moisture, which is sufficient enough for preserving the spent grain, and making ease of transport. After considering projected annual costs, it is discovered that it will require $338,436 annually to run this equipment.
- Flash-Type Dryer: This is accepts an input of 36,000 pounds per hour at 65% moisture content. It outputs 13,846 pounds per hour at 9%. After considering projected annual costs, it is discovered that it will require $342,720 annually to run this equipment. They also demand more installation space than the rotary types and require rigid control of incoming grain moisture levels to prevent malfunction.
- Rotary Drum Dryer Method: The mostly used process for drying brewer's spent grain is performed by means of rotary ovens requiring a high initial investment. Drying by rotary ovens does not alter the final product features as long as the process is not performed under high temperatures during prolonged periods. To prolong the storage time of spent grains and to reduce their mass (consequently to lower the transportation cost), spent grains need to be dried

to about 10% moisture content. The traditional drying operation (heated-air drying in rotary-drum dryers) is energy-intensive. To save energy, superheated steam (SS) could be used for drying spent grains. The circulation of SS in the closed-loop drying system can reduce the energy wastage that occurs with hot-air drying. Also, the exhaust steam produced from the evaporation of moisture from the wet product can be used in other operations in the distilleries, such as cooking raw materials, stripping and rectifying distillation of ethanol, and concentrating residual stillage. In addition to the reduced energy consumption, drying in SS has numerous other merits compared with traditional hot-air drying. These include: a reduction in the environmental impact, an improvement in drying efficiency, the elimination of fire or explosion risk, and a recovery of valuable volatile organic compounds. However, the application of this drying technique needs more complex drying equipment compared with hot air drying, and high-temperature of the product in SS drying creates a problem.

- Freeze-drying & Oven-drying: Their findings showed that preservation by oven drying or freeze-drying reduces the volume of the product and does not alter its composition, while freezing is inappropriate as it affects the composition of some sugars such as arabinose. But overall, freeze-drying is economically not feasible at the large scale; making the oven-drying to be the preferred method. Although the costs of these drying systems seem high, it must be considered that the price is economically justifiable when compared with the benefits of drying spent grain.

There are other patented methods on how to dry Spent Grain.

Examples: WIPO Patent Application WO/2010/053493 by LOPEZ, Benito; (AR).

PONTIGGIA, Rodrigo Martin; (AR) and FERNANDEZ, Hector, which contends to be a process for drying brewer's spent grains, so as to obtain a product with moisture lower than or equal to 15% by weight, biologically stable in time, high nutritional value, commercially profitable, and environmentally safe.

Dye Absorbent

Textile and dye industries use enormous volumes of water for wet processing. This leaves significant amounts of pollutants in the water. Spent grain has been shown to be effective in waste water removal of these organic dyes. The absorption properties of spent grain are due to the presence of functional groups such as hydroxyl, carboxyl and amine groups, which have a high affinity for metal ions. Spent grain has great potential in the sense that it is easily available and it is made in abundant amounts. In numerous experiments, the spent grain was repeatedly washed with boiling water and then air dried. Then the dried spent grain was sieved and only particles less than 1 mm were combined with perchloric acid magnetic fluid. Contact between the magnetic fluid and the spent grain caused adsorption of iron oxide nanoparticles onto the surface of the spent grain. Although the magnetically modified spent grain has shown to be potentially useful in the removal of organic dyes, the adsorption properties are strongly dependent on the type of dye. Other studies have been done regarding the case of dye; brewer's spent grain was tested as an adsorbent on acid orange 7 dye (AO7), a monoazo acid dye used in paper and textile industries. The maximum adsorption capacity was 30.5 mg AO7/g BSG, at 30°C. This led to a conclusion that high levels of color removal (>90%) can be achieved with low contact and that BSG can be successfully used as adsorbent of AO7 dye in aqueous. Certain dyes have higher adsorption capacities than others. Moreover, solution pH greatly affects the adsorption properties of the brewers spent grain. Currently physical and chemical methods for dye removal are used in the industry. Research shows that the bio-based alternatives e.g. spent grain, are highly efficient; however the research is in its initial stages and detailed economic analysis is not available. It can be noted that micro-brewers would have to work together with the textile industry and waste water management to determine if this alternative is economically feasible.

Food Alternatives

Because of BSG's high nutritional content of protein, fibre, along with trace amounts of vitamins and minerals it makes an ideal supplement to recipes using whole wheat flour. The wet spent grain can be added directly into the recipe (accounting for the inherent water) or it can be dried and incorporated or dried and milled into flour. Yeast risen breads can use up to 15% substitution with little affect on taste or palatability. Higher amounts result in the sharp fibrous husks beginning to make a increasingly dense loaf of bread.

For small brew-pubs, care must be taken to assure the freshness of the product. Drying in a commercial oven at 170°F or above is an effective way to prepare BSG for long term storage, eliminate dangerous pathogens and reduce the weight of the grain. Spent grain has a slightly nutty flavor and rarely imparts any "beer-like" flavors. Most recipes will benefit from the spent grain being pulsed in a food processor to reduce the needle like characteristics of the grain hulls. Some studies have been conduct to remove a large portion of the hull from the spent grain to allow for increased amounts of BSG in common food stuffs.

After drying, standard rotary grain mills can turn the BSG into a fine flour. Mixing the BSG with whole grains in a predetermined ration prior to milling will result in a uniform consistency and a lighter color (some people are put off by the slightly
grey tint of the milled grain).

Growing Mushrooms

Spent grain compost can also be used as a growing medium for mushrooms. Not only is it a simple process, but it also eliminates the problem of drying or freezing spent grain for maintenance purposes. While setting up the mushroom habitat itself is time consuming, the process over all yields a high quantity of valuable products for a minimal effort. The spent grain does not require treatment prior to setting up the mushroom micro-environment; a process that would be simple for either a micro brewer or farmer providing they have no space constraints. The cultivation of mushrooms requires a substantial amount of spent grain plus an additional growing medium to be mixed at 1:1 ratio with the BSG; hay is a common pairing with BSG that produces a microhabitat suitable to establish mushroom beds. A person only needs to wait for the mushrooms to spawn (approximately 3 weeks), and then harvest the mushrooms for that crop cycle (approximately 12 weeks).

Oyster mushrooms sell at the market for approximately $2.75 per pound, while an oyster mushroom growing kit can be purchased for approximately $40. Mushrooms have a long and abundant "fruit cycle," so the initial investment in the mushroom kit will certainly be regained. Another benefit of cultivating oyster mushrooms is their high nutritional value. A 3.5oz serving of oyster mushrooms has only 38 calories, are 15-25% protein, and are rich in phosphorus with 140mg. It has also been noted in recent studies that regular consumption of oyster mushrooms can reduce blood glucose and cholesterol levels in diabetes patients.

The growing medium used for mushroom cultivation can be used for compost material or can be used as supplemental fish feed in a farm. Spawning mushrooms is a particularly good option for microbreweries that have a restaurant on site or have a relationship with a farmer.
It requires the following items:

- A propane burner
- A 55 gallon metal drum (stainless steel will last longer but plain steel drums also work and are much more affordable)
- A metal basket slightly smaller than the inside of the 55 gallon drum with mesh that won't let excess straw fall out of the basket
- A hunting broad head or ideally a row of hunting broad heads screwed into a 2 x 4
- Plastic bags
- Healthy mushroom spawn
- Alcohol or bleach to sterilize surfaces that contact mushroom substrate or spawn
- A stainless steel table to lay out the pasteurized straw
- Powdered gypsum
- Straw
- Spent brewery grain or other nitrogen supplement (optional)

The steps begin with gathering all the required materials and heating a 55 gallon drum with three-fourths of water to a temperature of 160 degrees Fahrenheit. The straw can be shred by hand or a bale chopper, to make it an optimal length of 4-6 inches in length. Next, the basket must be filled with the optimal amount of straw and spent grain, alternating the layers; the ratio of straw to spent grain should be 1:1. After heating the materials to 160 F, it should be placed in a drum and submerged in the water (using blocks or other weights to keep it submerged). It should be kept in that position for 45 minutes to one hour. Next, the basket of straw should be removed and the straw must cool, possibly on a stainless steel table. This is the part where the specific gypsum and mushroom spawn is added, depending on the type of mushroom that is desired. It must be mixed thoroughly and put into plastic bags with the substrate. The bags must be punctured with arrow heads and placed at room temperature, approximately 75oF; the holes must be at least four inches apart. After the bags are colonized, they must be placed in a humid environment, or a microhabitat, making the environment for mushroom growth ideal them. For oyster mushrooms specifically, for every 10-12 lbs of both straw and spent grain, 1 lb of fresh oyster mushroom can grow.

Paper

According to Introduction to Green chemistry by Alfred S. Matlack, BSG has been fractionated, and it's been observed. 1-2% protein, 30% cellulose and 60% hemicellulose and several percent silica that can be use in the production of paper at a level of 10%. Now to make paper, the BSG has to be bleached. BSG is high in hemicellulose (28.4% w/w) and extractives (5.8% w/w) contents. This affects the pulping and breaching process. Research has shown that Soda pulping of acid pretreated BSG gave a cellulose rich pulp (90.4% w/w) with low hemicellulose and extractives contents (7.9% w/w and <3.4% w/w, respectively), which was easily bleached achieving a kappa number of 11.21, viscosity of 3.12 cp, brightness of 71.3%, cellulose content of 95.7% w/w, and residual lignin of 3.4% w/w; all great qualities for paper.

Xylitol

Xylitol a sugar alcohol, it is a unique sweetener because it synthesized from sugars and has about 1/3 fewer calories for the equivalent sweetness. It causes less gastrointestinal distress that its main competitor, Sorbitol, and can be used to fight dental problems, control illnesses such as diabetes, reduce problems in lipid metabolism and parenteral and renal lesions. It is also thought to aid in the prevention of lung infections, otitis and osteoporosis.

When Xylitol is compared with other sweeteners, an obvious advantage is the fact that it can be produced by a biotechnological process, which has economic benefits because it is very specific and requires less energy than a chemical fractionation process. Xylitol production by fermentation also has minimal environmental impact owing to the use of low-cost ligno-cellulosic wastes that can be found in large quantities at
any large brewery.

Xylitol is in the polyol family of sugar alcohols including manitol, sorbitol, and maltitol. Sorbitol makes up more than half of the $1.3 billion global market for polyols. The Xylitol market is approximately $125 million and growing. Xylitol retails for approximately $3.50/lb in bulk form.

The most abundant monosaccharides present in BSG are xylose, glucose and arabinose (Mussatto, 2009) BSG contains sugars polymerised into cellulose and hemicellulose. So if the BSG is subjected to a fractionation process under proper conditions, a liquor rich in xylose will be produced. Xylose is a sugar that can be used as a carbon source for xylitol or ethanol production. Brewer's spent grain has been reported to be easily and readily utilized by the yeasts Debaryomyces hansenii (Carvalheiro et al., 2006, 2007) and Candida guilliermondii where they grow and produce xylitol (Mussatto and Roberto, 2008) due to its high initial xylose concentrations, oxygen limitation, high inoculum density and appropriate medium supplementation.

Experiments

Flour

Brewers spent grain has plenty of starch, fiber and nutrients to produce a coarse flour. There are also trace mineral, vitamins and other nutrients that make it ideal as an additive to white bread. Unlike dried barley grains used to produce barley flour, spent grain must be dried to a moisture level below 10%. This heating will also kill bacteria or pathogens that maybe found naturally on the grain or picked up during cooling in the mash tun. Depending on the milling equipment, a combination of another millable grain may be required to ensure the mill performs properly.

Equipment

- 500g Brewers Spent Grain (Wet)
- 300g Red Wheat
- Residential Oven
- Digital Thermometer
- Drying Rack
- Nutrigrain Heavy Duty Mill

1. Spread the Brewers Spent grain on the drying pan approximately ¼" Deep
2. Preheat oven to 170^{o}F and monitor with digital thermometer until stabilized
3. Place rack in oven and check weight of product every 3 hours until mass no longer changes
4. Remove from oven and cool to touch
5. Blend the red wheat with the dry BSG (this will allow proper feeding of the equipment)
6. Remove ground BSG and Red wheat flour and store in an airtight container

Results

Original BSG Weight	500g
Post Drying Weight	108g
Reduction in Weight	392g
Wt Reduction	78.4%

Preparation Time: 5-10 minutes

Drying Time: 19.5hours

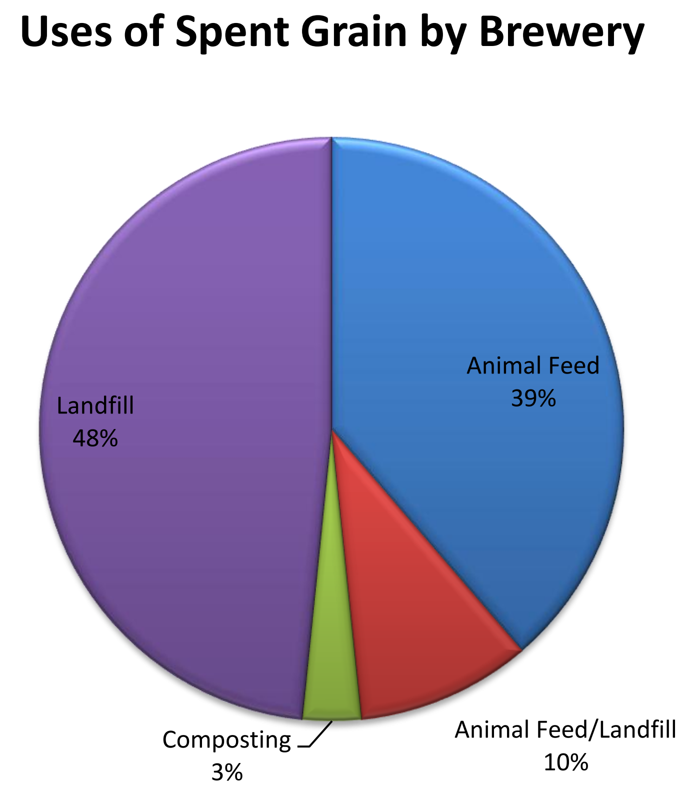
Energy Used: 0.9kWh x 19.5 hrs x $0.13/kWh = 2.28/~100g

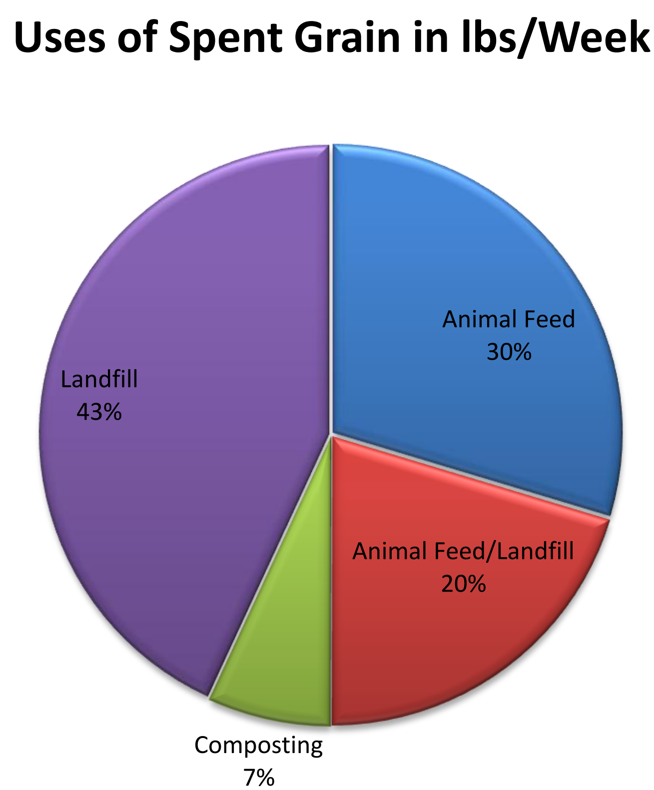
Milling Time: ~1 minute

Vacuuming and Salting

The idea of vacuuming spent grain was thought of later in the semester however it seemed ideal to pursue the concept further. The very first experiment was to place spent grain in a jar and burn the oxygen in the jar using an alcohol soaked cotton ball. This experiment was a fair success since there was little to no change in the spent grain during the first week. However this experiment was done with spent grain that was frozen for a while. After this experiment the team thought it was ideal to seek advice from experts that is when we contacted the National Center for Food Safety and Technology. The first expert contacted was Dr. Larkin who the Chief of the FDA Process Engineering Branch, Dr. Larkin confirmed that under the right conditions vacuum packing the spent grain it will increase the spent grain's self life. Dr. Larkin also gave advice on other ways to preserve spent grain such as controlling the levels of Water activity, PH balance, and adding salt to the spent grain. Taking Dr. Larkin's advice the IPRO team conducted a simple experiment we hand vacuum packed regular spent grain and vacuum packed with salted spent grain with 8% of salt which is between the recommended 5% of salt that makes the product safe from spoilage and 10% that guarantees the preservation of the product. The there were also samples without vacuum packing as a control. These samples were then checked after 3 days and 5 days the result of this experiment proved that vacuum packed salted grain was preserved best. We also planned a meeting with the Dr. Larkin and Dr. Koontz, a research chemist, and other researchers at National Center for Food Safety and Technology. At the meeting the researcher were optimistic about vacuum packing and can be done at a brewery as long as there is the right equipment and packaging.

Chicagoland Brewery Survey Results





Chicago Land Breweries

Brewpubs				BSG Alternatives									
Brewery Name	Location	Annual BSG Waste	Logistics Rating	Available Kitchen	On-Site Drying	On-Site Baking	Animal Feed	On Site Composting	Truck Toute Candidate	On-Site Vertical Farming	On-Site Mushroom Growing	On-Site Biogas Medium	On-Site Fermentation Medium
America's Brewing Company	Aurora	32,000	5	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Emmetts Tavern & Brewing	Palatine	50,000	3	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Emmetts Tavern & Brewing	West Dundee	50,000	3	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Emmets Alehouse #2	Downers Grove	50,000	3	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Flatlanders Restaurant & Brewery	Lincolnshire	52,000	4	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Flossmoor Station Brew Pub	Flossmoor	30,000	2	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Gordon Biersch Brewery and Restaurant	Bolingbrook	20,000	5	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Granite City Food and Brewery	Orland Park	25,000	5	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Hamburger Marys	Chicago	30,000	1	Yes	Possible	Possible	Yes(TR)	No	High	No	No	No	No
Harrisons Restaurant and Brewery	Orland Park	40,000	4	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Haymarket Pub and Brewery	Chicago	36,000	1	Yes	Possible	Possible	Yes(TR)	No	High	No	No	No	No
Limestone Brewing	Plainfield	50,000	5	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
The Lucky Monk	South Barrington	52,000	5	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Mickey Finns Brewery	Libertyville	78,000	4	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Moonshine	Chicago	39,000	1	Yes	Possible	Possible	Yes(TR)	No	High	No	No	No	No
Onion Pub and Brewing Co	Barrington	90,000	5	Yes	Possible	Possible	Yes	Yes	Low	No	No	No	No
Piece Brewery	Chicago	90,000	1	Yes	Possible	Possible	Yes(TR)	No	High	No	No	No	No
Ram/Big Horn Brewing	Schaumburg	72,000	5	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Ram/Big Horn Brewing	Wheeling	72,000	5	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Revolution Brewing	Chicago	50,000	1	Yes	Possible	Possible	Yes	No	High	No	No	No	No
Rock Bottom	Chicago	48,000	1	Yes	Possible	Possible	Yes	No	High	No	No	No	No
Rock Bottom	Lombard	72,000	4	Yes	Possible	Possible	Yes	No	Medium	No	No	No	No
Rock Bottom	Orland Park	72,000	4	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Rock Bottom	Warrenville	72,000	4	Yes	Possible	Possible	Yes	No	Low	No	No	No	No
Stockholms Vardus	Geneva	5,000	2	Yes	Possible	Possible	No	No	Low	No	No	No	No
Three Floyds Brewing Co	Munster	78,000	3	Yes	Possible	Possible	Yes	No	Low	No	No	No	No

Logistics Rating

Easy to Navigate to, Large Vehicle Accessible	5
Easy to Navigate to, Small Vehicles Only	4
Remote Location, Large Vehicle	3
Remote Location, Small Vehicles	2
Urban Jungle, Limited Space, Small Vehicles Only	1

Truck Route Candidate

Urban Location, Difficult to Access	High
Collar County, Low Density of Similar Breweries	Medium
Close to Farming Community	Low

Microbrewers				BSG Alternatives									
Brewery Name	Location	Annual BSG Waste	Logistics Rating	Available Kitchen	On-Site Drying	On-Site Baking	Animal Feed	On Site Composting	Truck Toute Candidate	On-Site Vertical Farming	On-Site Mushroom Growing	On-Site Biogas Medium	On-Site Fermentation Medium
Argus Brewery	Chicago	90,000	2	N/A	N/A	N/A	Yes(TR)	No	High	No	No	No	No
Doubleheart Brewing	Chicago	30,000	2	N/A	N/A	N/A	Yes(TR)	No	High	No	No	No	No
Half Acre Beer Company	Chicago	72,000	2	N/A	N/A	N/A	Yes(TR)	No	High	No	No	No	No
Metropolitan Brewing	Chicago	120,000	3	N/A	N/A	N/A	Yes(TR)	No	Low	No	No	No	No
Two Brothers	Warrenville	192,000	5	N/A	N/A	N/A	Yes(TR)	No	Low	No	No	No	No
		504,000											

Regional Brewers				BSG Alternatives									
Brewery Name	Location	Annual BSG Waste	Logistics Rating	Available Kitchen	On-Site Drying	On-Site Baking	Animal Feed	On Site Composting	Truck Toute Candidate	On-Site Vertical Farming	On-Site Mushroom Growing	On-Site Biogas Medium	On-Site Fermentation Medium
Goose Island Beer Company	Chicago	2,160,000	5	N/A	Possible	N/A	Yes	No	Low	Yes	Yes	Yes	Yes

Logistics Rating

Easy to Navigate to, Large Vehicle Accessible	5
Easy to Navigate to, Small Vehicles Only	4
Remote Location, Large Vehicle	3
Remote Location, Small Vehicles	2
Urban Jungle, Limited Space, Small Vehicles Only	1

Truck Route Candidate

Urban Location, Difficult to Access	High
Collar County, Low Density of Similar Breweries	Medium
Close to Farming Community	Low

Brewer's Classification

Using the Craft Brewers Association Guidelines

Micro-brewery: A brewery that produces less than 15,000 barrels (17,600 hectoliters) of beer per year with 75% or more of its beer sold off site. Micro-breweries 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 tap-room or restaurant sales.

Brew-pub: A restaurant-brewery that sells 25% or more of its beer on site. The beer is brewed primarily for sale in the restaurant and bar. The beer is often dispensed directly from the brewery's storage tanks. Where allowed by law, brew-pubs often sell beer "to go" and /or distribute to offsite accounts. Note: BA re-categorizes a company as a micro-brewery if its off-site (distributed) beer sales exceed 75 percent.

Contract Brewing Company: A business that hires another brewery to produce its beer. It can also be a brewery that hires another brewery to produce additional beer. The contract brewing company handles marketing, sales, and distribution of its beer, while generally leaving the brewing and packaging to its producer-brewery (which, confusingly, is also sometimes referred to as a contract brewery).

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

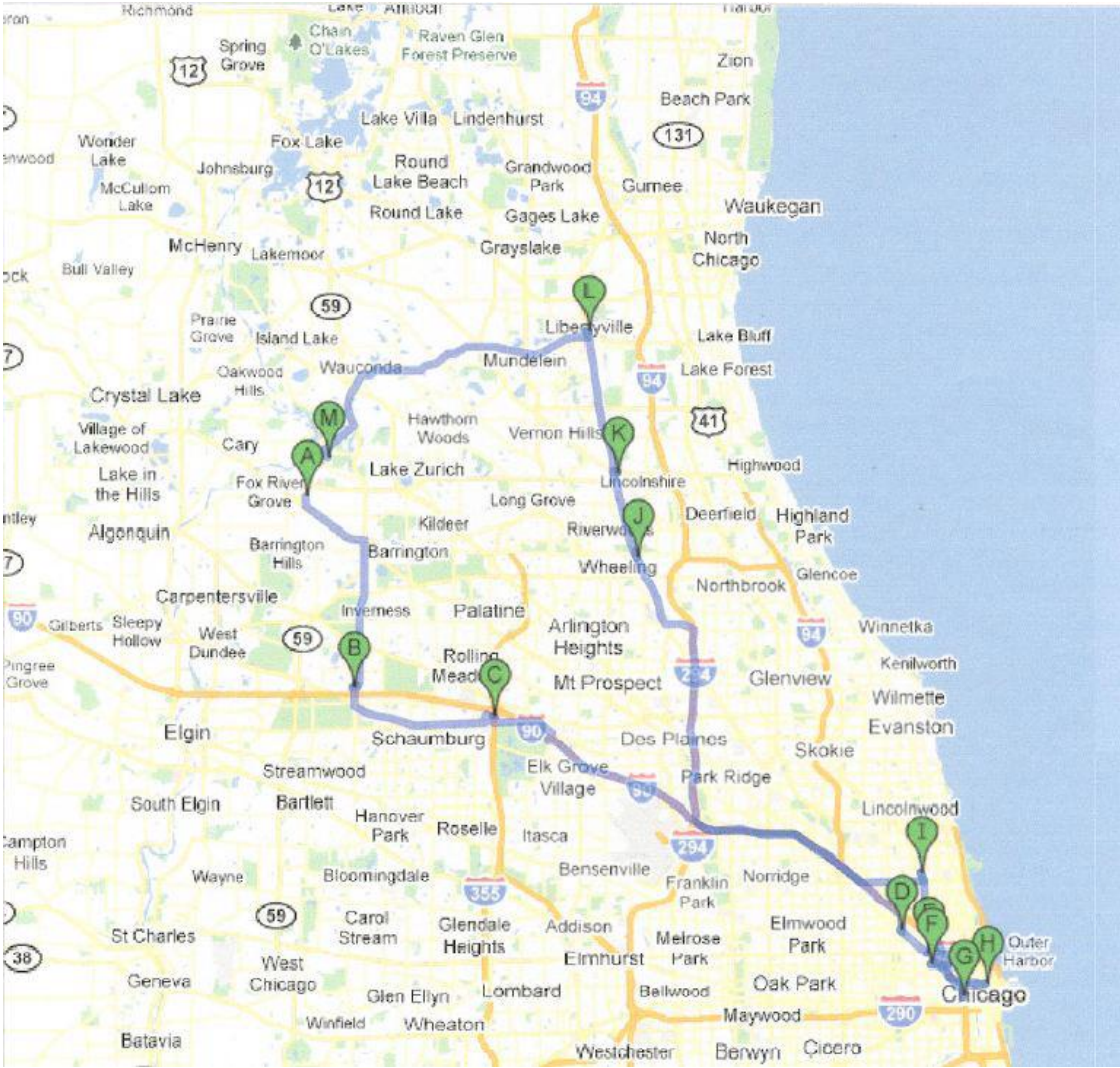
Regional Craft Brewery: An independent regional brewery who has either an all malt flagship or has at least 50% of its volume in either all malt beers or in beers which use adjuncts to enhance rather than lighten flavor.

Large Brewery: A brewery with an annual beer production over 6,000,000 barrels.

Truck Routes

Figure 1: Theoretical truck route 1

Figure 2: Theoretical truck route 2



References

- http://www.inplacemachiningjvic.com/images/industries_papermill.jpg
- http://www.vermontmushrooms.com/indoorcultivationmethods.htm
- http://www.academicjournals.org/AJB/PDF/pdf2011/17Jan/Aliyu%20and%20%20Bala.pdf
- http://jotamac.typepad.com/jotamacs_weblog/files/no_waste_economy__gunter_pauli.pdf
- http://www.freepatentsonline.com/4377601.pdf
- http://www.foodnavigator.com/Science-Nutrition/Scientists-make-cheap-xylitol-from-spent-grain
- http://www.vermontmushrooms.com/indoorcultivationmethods.htm
- http://www.springerlink.com/content/lg71x36160589082/
- http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WHK-4GNTFP5-1&_user=10&_coverDate=01%2F31%2F2006&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1733518575&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=cc41ae425488adef78fcf0f56ef47dbc&searchtype=a