Urban Fuel Co-Op System Design and Operational Analysis

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1 Executive Summary.

An Urban Fuel Cooperative (Co-Op) is described and analyzed for feasibility and efficiency. An Urban Fuel Co-Op differs from the more familiar Farm-based co-ops in several key ways:

- Urban dwellers are assumed to have a “day job” that is outside of agricultural production. They are only available for fuel making on weekend days of the week.
- Urban dwellers do not have land to grow feedstock. They must use waste material for feedstock for their fuel.

The concept of the Urban Fuel Co-Op is that Co-Op members collect stale bakery products that have become inedible and are destined to be discarded. Processing of this type of feedstock into ethanol was studied extensively by the author and two colleagues in 2012. We found that this feedstock could be processed into ethanol using one enzyme (gluco-amylase) that requires just one pH adjustment and can operate at low temperature (as low as 115 degrees F).

The stale bakery waste is available year round. A highly resource-efficient model has been developed and analyzed for ethanol fuel production using this feedstock material. A concept model for an Integrated Bio-Refinery is described in this document that can reuse the energy recovered from distillation for processing the next batch of feedstock. The Integrated Bio-Refinery can also reuse stillage from distillation to greatly reduce water consumption. Fuel grade ethanol (near azeotrope) can be continuously produced using this Integrated Bio-Refinery model for an energy cost that is less than 20% of the energy in the ethanol fuel that is produced.

A 20 person Co-Op should be able to collect stale bakery waste from an average population of 107,000 people. The amount of waste collected is enough for the Co-Op to produce 20,000 gallons of fuel ethanol per year (50 week per year operation; 2 week per year preventive maintenance downtime). 20%, or 4,000 gallons, is dedicated to process energy, leaving 16,000 gallons, or 800 gallons per Co-Op member, for distribution. This is enough to fuel every member’s car for the year. In exchange for this fuel, each Co-Op member is required to devote one weekend day every 5 weeks to either feedstock collection or feedstock processing.

The Urban Fuel Co-Op is theoretical at this time and is not without problems and issues. The largest single issue that has been uncovered is the time to collect feedstock from many small sources. Success of the Co-Op may depend upon finding points of concentration for the feedstock, such as food banks and other charities. Transportation and unattended operation are two additional issues, owing to the fact that Co-Op members do not reside and work at the processing facility.

This document presents a complete operational, thermodynamic, and flow analysis for the Urban Fuel Co-Op and the Integrated Bio-Refinery. The tools, concepts and issues presented herein may be useful to other small scale ethanol production models as well.

The next logical step would be development and operation of a pilot facility that would be used to flesh out the issues and validate the theoretical models that are documented herein.

2 Terminology.

The following terminology is used consistently throughout this document:

- **Abv**: Alcohol By Volume. The percent alcohol in an aqueous (water) solution, as measured by the volume.
- **Azeotrope**: A mixture whose boiling point is below the boiling points of all of its constituents. Ethanol and water form an azeotrope at approximately 96% ethanol, 4% water, by volume. Ordinary (simple) distillation cannot further separate the ethanol from the water, leaving "hydrous ethanol" (ethanol mixed with some water) as the product of simple distillation of ethanol and water.
- **Beer**: In this context, a "beer" is a solution of ethanol in water (along with non-fermentable material) that is the result of yeast fermentation of the wort. After fermentation is complete, the beer is distilled to produce high proof alcohol fuel.
- **Co-Op**: An association or organization of people who contribute their labor in exchange for a share of a product. In this case, the labor is collecting and processing feedstock and the product is hydrous ethanol fuel.
- **Feedstock**: For the purposes of this document, the term "feedstock" refers to stale bakery waste, including various types of bread loaves (often moldy), pastries, bagels, and muffins.
- **Integrated Bio-Refinery**. For the purposes of this document, the term "integrated bio-refinery" refers to a set of equipment that produces fuel grade ethanol from feedstock in an integrated manner, such that water and energy are recycled and used to their maximum potential to minimize fuel production costs.
- **Mash**: Starchy feedstock is ground up and mixed with water, forming a "mash". The mash is then pH adjusted and cooked in enzymes to reduce it to "wort".
- **Product**: In this context, the product is fuel grade (azeotropic) hydrous ethanol.
- **Stillage**: The residue of distillation from the bottom of the still column.
- **TTB**: Alcohol and Tobacco Tax and Trade Bureau; the arm of the US Department of the Treasury that is responsible for regulating the production and distribution of alcohol.
- **Wort**: A solution of fermentable sugars in water resulting from the feedstock processing of a mash. The wort may contain other water soluble and insoluble material resulting

from processing the mash. Yeast is pitched into the wort, which then ferments in fermentation vessels to convert the fermentable sugars into ethanol (beer).

3 Overview.

This document presents a conceptual, functional, and operational design for an Urban Fuel Cooperative (Co-Op). The Co-Op members live in an urban area and are only available on weekend days to contribute labor to the Co-Op. The Co-Op produces fuel which, in this instance, is hydrous ethanol distilled to near the azeotrope. In return for their labors, each Co-Op member receives at least 800 gallons of fuel per year. This is approximately enough to operate one vehicle (12,000 miles at 15 mpg on ethanol). In return for the fuel, the co-op members are expected to work no more than one weekend day per month, maximum, and to pay a small nominal cost per gallon for fuel to cover the operating costs of the production facility (consumables, rent, amortization of capital cost, equipment repair, insurance, etc). Detailed cost analysis is beyond the scope of this document; however, the conceptual design for the processing equipment (Integrated Bio-Refinery) is highly efficient and the recurring fuel production cost is very close to zero. The feedstock is assumed to be free, and the water to make the mash is recycled stillage. Almost all of the processing energy is that required by physics to distill the fuel is recovered from the stillage and is used to provide most of the remaining processing energy needs. Less than 20% of the fuel produced is re-cycled back into production. Other consumables include enzymes, yeast and acid/base (for pH adjustment), all of which are nominal in cost per gallon.

The design of the Integrated Bio-Refinery, which is the fuel production facility, is based upon a series of "feedstock processing experiments" that were performed in 2012 (hereafter referred to as "2102 Feedstock Processing Experiments"). These experiments resulted in a reliable recipe for processing stale bakery waste at low temperature and with only one pH adjustment. Stale bakery waste is ubiquitous in the urban environment and is estimated to be discarded in large quantities. See the following document for feedstock processing experimental results:

http://www.liquidsunenergy.com/projects/FeedstockProcessingExperimentsPreliminaryReport.zip

The system and operational concepts described in this document are based upon a number of assumptions. The assumptions are clearly stated as they are used. These assumptions need to be validated by further research, experimentation, and/or pilot production activities. *This design is presently only a "paper" design and it needs to be validated and refined based upon pilot production and actual hands-on experience.*

4 Urban Fuel Co-Op Model.

4.1 Concept.

Small scale ethanol fuel production is usually thought of as a rural (farm-based) activity. Some portion of farm or ranch acreage is allocated to growing or producing some feedstock, which is then processed into ethanol fuel on-site. This leaves out most of the population of the United States, which is based in urban or suburban areas.

The concept described in this document is aimed at urban/suburban dwellers. As such, there are a number of problems that have not been addressed in rural fuel co-op models of the past:

1. Urban dwellers earn their living at occupations that are not tied to the land. Therefore, they do not produce their own feedstock.

2. Urban dwellers are not tied to the land where a fuel processing facility is located. They work weekdays at jobs in the city or suburbs. Therefore, they can only devote weekend days (Saturday and/or Sunday) to fuel production.

This author, along with Lucy Geever and Mark Kent, conducted a year-long series of laboratory experiments to determine an efficient and reliable recipe for processing stale bakery waste into ethanol. Stale bakery waste is available at the retail level (supermarkets, boutique bakeries, doughnut shops, coffee shops, bagel shops, sandwich shops, restaurants, etc.) in urban/suburban areas nationwide (USA). This is a result of intentional overproduction/overstocking of baked goods to satisfy customer demand at any time of the day that the retail establishment is open. Generally speaking, the end-of-day residue is either discarded or is donated to charitable organizations such as food banks, where only a small fraction can be distributed for human consumption before it becomes inedible. Most of this material ends up inedible and is discarded. The 2012 Feedstock Processing Experiments, referenced above, developed a reliable recipe for efficiently processing this inedible material into ethanol.

The model Co-Op described in this document has 20 members. This allows a commitment of less than one day per month per member for collecting and/or processing the feedstock in 2 person teams. It is assumed that Co-Op membership consists mainly of people who are interested in trading time for automobile fuel. 600 gallons of gasoline will provide fuel for 12,000 vehicle miles at 20 mpg. At $3.50 per gallon for retail gasoline, the average annual cost of fuel to Co-Op members is $2,100. At present, gasoline costs more than $3.50 per gallon nationwide, and the price will only go up with time. Co-Op members could expect to purchase fuel from the Co-Op for a very nominal cost (less than $1 per gallon) and a commitment of one weekend day every 5 weeks of labor. Since ethanol has 36% lower energy content than gasoline, the equivalent amount of ethanol for 12,000 vehicle miles is 800 gallons. Hence, each Co-Op member would save at least ($2,100 - $800 =) $1,300 per year in exchange for 11 days of labor or in-kind donation. Most of the $1.00 per gallon cost is assumed to be in facility/land rental and processing equipment capital cost amortization. An urban fuel Co-Op could achieve a much greater saving if they can find a lower cost (even rental-free) place for their processing facility and if they manufacture their own processing equipment out of surplus materials.

The 20 person Co-Op produces 20,000 gallons of hydrous ethanol fuel per year. It is assumed that 4,000 gallons (20%) of this fuel is cycled back into processing energy, leaving 16,000 gallons to be distributed to members. This works out to 800 gallons per member. The 20% figure is conservative, as less than 15% is required for distillation, leaving another 5% for miscellaneous energy needs. A detailed operational description and thermodynamic analysis of the fuel processing facility is presented in sections 5 and 6 of this document.

The Co-Op model can, of course, be scaled upwards or downwards. The production can be scaled based upon the number of members and the membership fuel needs. Having less than 20 people in the Co-Op increases the labor commitment burden on the members, and is probably a difficult sell. Having more than 20 members increases the fuel production requirements, which increases the labor needs, but at less than proportional scaling, which is desirable. However, there are certain labor-intensive activities described in this document that cannot be arbitrarily increased without adding more people to perform the labor. As of this writing, the operational scenario time assumptions described in this document are crude theoretical estimates and need to be refined via experience in a pilot facility. In the interest of a conservative operational concept, we limit this analysis to a 20 person Co-Op producing 20,000 gallons of ethanol fuel per year, of which 16,000 gallons is distributed to members as in-kind payment for their labor.

4.2 <u>Feedstock Description.</u>

The general category of "stale bakery waste" was chosen in early 2012 as a candidate feedstock for an urban fuel Co-Op. This waste material results from intentional overproduction of baked goods in order for retail establishments to have product to sell all day long. This general category contains a broad variety of material including, but not limited to:

- Bread
- Rolls
- Muffins
- Cake
- Pastries
- Cookies
- Bagels
- Doughnuts

In addition to this breath of material, there are two general categories of product:

- *<u>Preserved</u>*: product produced with preservatives that is wrapped (usually in plastic) and has a shelf life of days. This material is usually sold by supermarkets. This material generally stays moist (owing to the plastic wrapping) and is removed from retail shelves after its “go bad” date has expired, and/or if mold begins to appear. Non-moldy but expired product may be donated to charities for human consumption, but generally has very little shelf life left before it becomes inedible. In addition, while edible, it does not have taste and texture that is desirable. The 2012 study revealed that very little (10% or less) of this material actually gets consumed before it becomes inedible and is discarded.

- *Not Preserved*: this includes fresh-baked bakery material of all sorts that does not have preservatives added and is usually not wrapped in plastic (it may be wrapped in paper or other material that does not keep the product moist). This material has only a few hours shelf life – one day at the maximum. After one day, it generally dries out and becomes inedible. This material is found in supermarkets that sell fresh baked products (often from their own bakery) and in most boutique baked goods retail establishments such as doughnut shops, sandwich shops, bagel shops and boutique bakeries. Some of this material is sold as “day old” at a steep discount, but most is simply discarded at the end of each day.

The 2012 Feedstock Processing Experiments[1] established a reliable and repeatable recipe for processing the discarded material in all of these categories. The presence of mold and/or the absence of moisture in the feedstock did not adversely impact our ability to process the material into ethanol. The variability of this material (and of its moisture content, in particular) did impact the ethanol yield when a constant ratio of 26 lbs of feedstock per 10 gallons of water was used to make the mash. The nominal ethanol yield (estimated via sugar hydrometer testing of the wort) for this ratio was 10% alcohol by volume (abv). However, our test batches varied between 7% abv and 13% abv. We attempted to compensate for this variability by adding feedstock or reducing water content when low ethanol yield was anticipated. However, we found that if we created too thick a mash, the processing took longer than our desired 4 hour timeline and the fermentation exceeded our requirement of completion within 7 days. The 4 hour processing and 7 day fermentation were requirements of the Urban Co-Op model, owing to the constraints listed in section 4.1, above. Therefore, the design of a processing facility, and the expected weekly yields, must anticipate this level of variability from weekly batch to weekly batch. A Co-Op that limits the material that it collects to a subset of what we processed in 2012 can anticipate lower variability in the weekly ethanol production.

The 2012 Feedstock Processing Experiments found that all of this wide variety of material can successfully be processed into ethanol fuel using a single, simple recipe:

26 lbs of feedstock per 10 gallons of water to make the mash

- pH adjust the mash to nominally pH = 4.5, with a range from pH = 4.3 to pH = 4.8. Note that all material that we tested was either naturally in the range of this pH (sourdough) or

[1] http://www.liquidsunenergy.com/projects/FeedstockProcessingExperimentsPreliminaryReport.zip

it had a higher initial pH (ph = 5.4 to 6.8) which was adjusted downward by addition of small amounts of dry citric acid (0.0 – 8.0 grams per 1 gallon mash; usually about 5 grams).

- Complete hydrolysis of the starch in the feedstock was always achieved by cooking this mash, pH adjusted, in gluco-amylase (GA) enzyme at 115 degrees F for four hours. We successfully tested both a liquid GA at 0.8 ml per gallon of mash, and 4.8 grams of a solid GA per gallon of mash.

Our lab tests were limited to one gallon batches of mash, but we have every reason to believe that all quantities scale linearly (except for cooking time, which is a constant 4 hours regardless of batch size). Lowering cooking temperatures definitely extended conversion time out beyond a 5 hour time limit. Holding these values was highly repeatable, regardless of the type, mixture and condition of the feedstock. The only exception that we had on cooking and fermentation times was when the mash was too thick, owing to our attempts to increase the estimated alcohol content of the wort. Regardless, we never had a failed batch!

Based upon the 2012 Feedstock Processing experimental results, we can scale our 20 person Co-Op to process weekly batches of feedstock as follows:

- We *assume* that the annual production requirement of 20,000 gallons of ethanol fuel will take place over 50 weeks of processing activity, leaving 2 weeks downtime for bi-annual preventive maintenance (still column cleaning and other PM activities).
- Using a nominal 10% abv, 20,000 gallons per year of ethanol fuel is produced over 50 weeks at a nominal rate of 20,000/50 = 400 gallons of azeotropic ethanol produced per week. Of this, 80% (of 400 gallons = 320 gallons) is stored for distribution to members, and 20% = 80 gallons is retained for the next week's production energy needs.
- Using a nominal 10% abv, a weekly mash exceeding 4,000 gallons is made using (90% of 4,000 =) 3,600 gallons of water/stillage and (26 * 3,600 / 10 =) 9,360 lbs of feedstock.
- pH adjustment of a mash made with tap water would typically require 5 grams of citric acid per gallon of mash = 18 Kg per Co-Op weekly batch. A stronger acid can be used to reduce this quantity. Moreover, the operating principle is to use stillage and the pH of the stillage is expected to be close to the desired pH for the mash.
- Liquid GA enzyme is required at (0.8g * 3,600 gallons =) 2.9 Kg per weekly batch.

4.3 <u>Feedstock Availability.</u>

In order to quantify the availability of feedstock, the following model is used:

- *Assume* that an average person consumes ¼ lb of bakery goods per day. This is equivalent to fewer than 4 slices of bread per day. One sandwich for lunch accounts for two slices of bread and the other two are accounted for by some combination of breakfast muffins, bagels, pastries, doughnuts or toast and bread, rolls cake or cookies with dinner. This assumption would appear to be conservative. Over the course of one week (7 days), this would amount to (7 * ¼ =) 1.75 lbs per person per week.

- *Assume* 10% excess production that is discarded. 10% of 1.75 lbs per person per week = 0.175 lbs of available feedstock per week per person in a community.

- *Assume* that the Co-Op can only collect half of this surplus. Some sources will be uncooperative or produce too little surplus for time and cost-effective collection by Co-Op members. Therefore, the weekly collectable feedstock per person in a community = ½ * 0.175 lbs = 0.0875 lbs per person in a community.

- The Co-Op needs to collect a total of 9,360 lbs of feedstock per week (per section 4.2). Therefore, <u>a community of</u> (9,360 / 0.0875 =) <u>107,000 people is required to provide feedstock for one 20 member Co-Op</u>.

- At 2 houses per acre * 4 people per house = 8 people per acre population density (low suburban density), the Co-Op's feedstock supply area would be (107,000 people / 8 people per acre =) 13,378 acres, or (13,378 acres / 640 acre per sq mile =) 21 sq miles.

This represents substantially more feedstock than would be needed for any reasonable expectation of the number of local people interested in participating in an Urban Fuel Co-Op.

4.4 <u>Feedstock Collection and Transportation.</u>

Collection and transportation of stale bakery waste as feedstock presents a *significant logistical challenge*. The 20 person model Co-Op requires that 9,360 lbs of this material be collected and transported to the processing facility every week. In keeping with the premise that Co-Op members are only available to work on weekend days, this quantity of material must be collected and transported in a single day. In keeping with the notion that each Co-Op member be required to donate no more than one weekend day per month, 2 people must collect and transport this amount of material weekly, and do so in one day, while another two people spend the other weekend day processing the material into alcohol fuel. With 20 Co-Op members and 4 people working a weekend day every weekend, each member will be scheduled to work one weekend day once every 5 weeks.

4.4.1 <u>Feedstock Collection Logistics.</u>

On average, the Co-Op collects material from an area of approximately 21 square miles. This area is not terribly large, however many of the retail sources of feedstock are small shops. <u>Assume</u>, for the moment, that each stop provides 100 lbs of feedstock, and that travel and pickup from one stop to the next takes 10 minutes. That means that a collector is able to collect 600 lbs per hour (6 ten minute slots per hour). If there are two collectors, each must collect approximately (9,360 / 2 =) 4,680 lbs per collector. At 600 lbs per hour, 4,680 / 600 = 7.8 hours! This is continuous collection, without breaks and without the ability to unload between pickups.

The feedstock source for the 2012 Feedstock Processing Experiments was a residential mental health facility whose volunteers collected the surplus material several times a week from two Safeway supermarkets and a Starbucks coffee shop. Initially, they only collected human edible material, of which about 10 – 15 lbs per week was discarded as inedible. When the volunteers found out that we were putting discarded material to use, they collected already spoiled material as well as edible material and we received over 50 lbs per week. This one facility might possibly have been able to scale up to 100 lbs per week, but this would be a stretch.

The fact that material from several retail locations was found to be concentrated in a non-profit facility as charitable donations provides some hope that larger non-profits (e.g. food banks, soup kitchens) might provide a point of concentration for 100 lbs or greater of feedstock for weekly pickup. It is reasonable to expect that there are such points of concentration in major metropolitan areas. However, it is currently unknown what percentage of the overall amount of material might be found in these facilities. Furthermore, it is unknown how many such facilities might be located within a 21 square mile area (probably not many). *The logistics of feedstock collection, therefore, presents a major operational challenge and might be a major obstacle to the Urban Fuel Co-Op concept*.

4.4.2 *<u>Feedstock Transportation Logistics.</u>*

9,360 lbs of stale bakery waste is a lot of weight to haul around. Only the largest non-commercial pickups can handle this amount of weight (e.g. Ford SuperMax, spec-ed at 11,000 lbs). Even ½ of this load is too heavy for the bed of a smaller pickup, e.g. Ford F150. However, most pickups and larger SUVs can tow a trailer that will handle 5,000 lbs or more (the SuperMax can tow in excess of 24,000 lbs). Clearly, an Urban Fuel Co-Op needs several vehicles with high capacity tow hitches and large trailers for material collection and transportation.

It is also clear that some sort of centrally located material depository would be helpful, and perhaps even necessary, if the processing site is far away. This depository would serve as a point of concentration for a week's worth of material, prior to hauling it all to the processing facility. It would certainly help if the Co-Op owned, leased or rented light industrial space for a processing facility centrally within their feedstock collection area. The material would then be concentrated where it was needed. However, if the processing facility is rural, say 1 hour away, then a separate, urban depository would certainly be needed as the place for collectors to drop off loads on collection day (or perhaps multiple collections during the week).

Material volume is also an issue. In its uncompressed state (as collected), bakery products can be expected to take up about 1/10 to 1/20 cubic foot per pound. For example, a loaf of bread weighing 1.5 lbs measures approximately 9" x 5" x 4" = 0.1 cubic feet. The bread, therefore, weighs (0.1 / 1.5 =) 0.07 cubic feet per pound. 9,360 lbs of bread, uncompressed, would take up (9,360 * 0.07 =) 655 cubic feet.

Grinding/shredding the material as it is collected provides only limited volume compression. The 2012 Feedstock Processing Experiments used a kitchen food processor's grating blade to grind (more like shred) the feedstock for introduction into the mash. We always used 2.6 lbs of feedstock to add to 1 gallon of water to make our test batches of mash. The ground up feedstock was placed in large serving bowls and we found that 2.6 lbs took up between 0.75 and 1.25 gallons of serving bowl space. 1 gallon (liquid measure) equates to about 0.13368 cubic feet (http://www.metric-conversions.org/volume/us-liquid-gallons-to-cubic-feet.htm?val=1.0). Consequently, in order to have the proper mixture for 3,600 gallons of water (stillage), the volume of similarly ground up feedstock would (nominally) be (0.13368 * 3,600 =) 481 cubic feet of material. This is still a large volume of material. Hauling this material from an urban depository to a rural processing site would require a 20 foot truck or commercial tractor-trailer!

Based upon this analysis, a centrally located material depository with on-location grinding/shredding machinery would be desirable. Locating the whole feedstock processing facility at this central, urban location seems highly desirable from a transportation logistics standpoint, albeit it requires cost to acquire, lease or rent industrial real estate.

4.4.3 Logistics Summary.

There are significant and undeniable problems with gathering and transporting feedstock. This might be surprising, given the high availability of this feedstock. The very attribute that makes this feedstock so ubiquitous – that it is retail overage – also makes it a logistical challenge to collect and transport. Obviously, some Co-Ops might have easy access to a large commercial bakery or other such places where a week's supply of feedstock might be available at a single stop. However, *the more general application of this model requires further study of the chain of custody of this material*, from small retail location to the dump site, in order to identify points of concentration that make sense from a logistical standpoint. The logistics of feedstock collection and transportation definitively require further study and are identified as ***significant issues*** with the Urban Co-Op model described in this document.

4.5 Processing Facility Operational Concepts.

The Urban Fuel Co-Op model limits the availability of labor to convert feedstock into fuel to one day per week. Several parts of the conversion process, specifically fermentation and distillation, cannot be accomplished within a single day. Fortunately, these parts of the process do not require manual labor, albeit they do require monitoring and control[2]. An overview of the operational concept for the fuel production process is depicted in figure 4.5-1, below. Sections 5 and 6 of this document analyze this process in detail.

[2] The distinction between on-site "labor" and off-site "monitoring" is discussed further in section 7 of this document.

Referring to figure 4.5-1, the three major steps in making fuel from feedstock are as follows:

1. Mash Cooking: The feedstock is added to 3,600 gallons of fresh water or stillage (residue from distillation) and cooked in an enzyme for four hours in order to reduce the starches in the feedstock to fermentable sugars (wort).

2. Fermentation: Yeast is added to the wort and left to ferment. The fermentation process converts the sugars in the wort into CO2 gas and liquid ethanol. The 2012 Feedstock Processing Experiments always completed fermentation in 5 to 6 days, as long as the mash was properly prepared and cooked. The result of fermentation is called a "beer" and contains approximately 10% alcohol by volume (abv). The 2012 Feedstock Processing Experiments showed a significant variability in the alcohol concentration, largely due to the varying nature of the feedstock from batch to batch. The variation was from a low of 7% abv to a high of 13% abv.

3. Distillation: The beer is far too weak for use as a fuel. In order to make an acceptable fuel, the ethanol must be separated from the water and other material in the beer. The process to do this is called distillation and the apparatus to perform distillation is commonly called a "still". The Still requires heat energy to vaporize the beer into a "still column", where the separation activity takes place. This makes distillation a relatively slow process and it takes a reasonably sized Still to distill a week's batch of beer into 400 gallons of ethanol and 3,600 gallons of "stillage" (water and other material removed by distillation) over the course of one week.

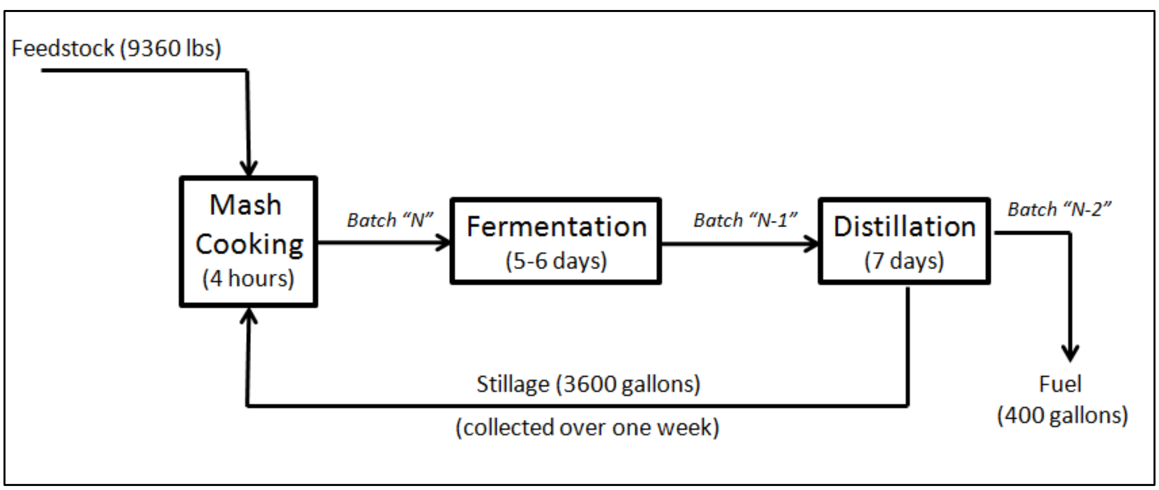

Figure 4.5-1. Overview of Fuel Making Process.

In order to fulfill the Urban Co-Op requirement for weekly batches of fuel production, a "pipeline" operation is envisioned. If the current batch of feedstock brought to the fuel processing facility is designated as batch "N", then batch "N-1" that was cooked into wort the previous week, was left to ferment all week, and is now in the state of a beer. At the same time, batch "N-2" that was fermented the week before has been distilling over this past week and is now fuel (collected in a Fuel Tank) and stillage (collected in a mash cooking tank, ready to serve as "water" for the new batch "N" of feedstock).

4.6 Fuel Distribution.

The fuel is collected, continuously, in a holding tank. The fuel is quite flammable and the holding tank must meet all relevant fire and safety standards for this type of chemical substance. Approximately 400 gallons of fuel grade ethanol is processed per week, 50 weeks per year. Of this, 20%, or 80 gallons, is retained on-site to provide energy for distillation and other processing facility needs. The remaining 320 gallons is distributed to the Co-Op members as in-kind payment for their labor and investment in the Co-Op. Each member receives (320 / 20 =) 16 gallons of fuel per week, using this model.

A centrally located processing facility makes the distribution of fuel to Co-Op members relatively easy. The members can simply pick it up at this central location, either once per week or "as needed" by pumping it directly into their vehicle. However, a remotely located processing facility requires that members' fuel be transported back to an urban central location. It would not make sense for members to drive 50 – 100 miles out to some rural processing facility every time a member needed to top off their fuel tank! In this scenario, there would be a proper fuel storage tank located centrally, probably at the central feedstock depository described in section 4.4.2, above. If the processing facility is remote, the Co-Op would have to own or lease a suitable fuel transport tanker truck with a capacity of about 320 gallons. This would be in addition to the feedstock transport truck or trailer, and both vehicles would need to make at least one round trip to and from the processing facility per week. Once again, this argues for a centralized processing facility at an urban industrial location that can serve as a feedstock depository, processing facility and fuel storage and distribution point, all at one central and easily accessible location.

5 Feedstock Processing Facility – Integrated Bio-Refinery.

This section describes a conceptual and functional model for a system to process feedstock into fuel. Most of this analysis assumes the nominal conditions of 3,600 gallons of water/stillage per week, 9,360 lbs of feedstock per week, processed (in the pipelined fashion described above in section 4.5) into 400 gallons of fuel and 3,600 gallons of stillage. Note that there is an assumption here of achieving 10% abv in the beer. As previously noted, the 2012 Feedstock Processing Experiments resulted in variability in alcohol concentration between a low of 7% abv and a high of 13% abv, with 10% abv being the "average" value. The design of a realistic feedstock processing facility (or "integrated bio-refinery") must account for these extremes in order to maintain efficient, continuous, pipelined operation.

5.1 Integrated Bio-Refinery Overview.

We introduce the term "Integrated Bio-Refinery" to describe the equipment necessary to process the feedstock, using the process summarized in section 4.5, above. The Integrated Bio-Refinery equipment is part of a feedstock processing facility in that the latter is the name given to the entire facility (including land, buildings, security fencing, and storage) and the former refers, specifically, to the equipment needed to actually perform the conversion of feedstock into fuel.

The bio-refinery is "integrated" because stillage is recycled for use as "water" to make the mash and energy, in form of heat in the stillage (as well as the 20% of fuel produced that is retained for on-site use) is recycled to virtually eliminate external energy needs for feedstock processing. This integrated operation is possible due to the findings of the 2012 Feedstock Processing Experiments; specifically that the mash can be successfully cooked (in 4 hours) at a temperature as low as 115 degrees F. The integrated process is called a "bio-refinery" because it utilizes a biological process (fermentation) to create the ethanol.

5.2 Integrated Bio-Refinery Assumptions.

In order to provide a system-level operational and functional design for an Integrated Bio-Refinery for an Urban Fuel Co-Op, certain assumptions must be made about the overall environment under which the Integrated Bio-Refinery is to be operated.

The concept model for an Urban Fuel Co-Op described in this document requires year round processing. This means that the Integrated Bio-Refinery must operate under a wide range of ambient temperature extremes and other weather conditions (e.g. high wind, rain, snow), or else the processing must be done inside a climate controlled facility. From a cost standpoint, housing the Integrated Bio-Refinery equipment in an open shed or similar, inexpensive, structure is most desirable. However, this may require the Integrated Bio-Refinery equipment to operate under extreme conditions, such a freezing in winter and too hot for fermentation in summer. On the other hand, providing a fully enclosed, fully climate controlled facility is likely to be prohibitively expensive and require external energy sources such as electricity for air conditioning. One additional consideration is government requirements for security – specifically, securing the Still from access by unauthorized people.

This document takes an intermediate approach to the problem. We assume that the Integrated Bio-Refinery is housed in some suitable, enclosed building (e.g. cinder block "shed") with provision for blocking out weather while providing natural ventilation. The Still Column is very tall and would likely protrude through the roof of the "shed", necessitating that it be well insulated from weather effects and weatherproofed against the elements. Otherwise, the Integrated Bio-Refinery equipment described herein <u>assumes operation in dry conditions between ambient temperatures of 40 degrees F and 90 degrees F</u>. Operation over more extreme temperature ranges requires either powered climate control in the "shed" or else design of equipment to operate properly over more extreme weather conditions than are assumed here.

The Urban Fuel Co-Op model requires labor only one (weekend) day per week. The activities that this labor performs are described, in detail, in section 5.4, below, and are largely associated with preparing and processing the mash. Under well controlled conditions, the processes of fermentation and distillation proceed without manual attendance, albeit some form of monitoring during the week must be provided to ensure that everything is operating properly. Unfortunately, the assumption that the Integrated Bio-Refinery equipment is required to run over ambient temperature ranges of 40 – 90 degrees F violates the definition of "well controlled conditions". If the equipment is designed to run at 90 degrees F, certain pieces of equipment must be insulated and/or fitted with heat exchangers to add in heat when the ambient temperature is lower. This also necessitates some sort of automatic control to maintain temperature within these pieces of equipment within a reasonable range. Automatic temperature control of equipment with integral heat exchangers is easy to provide with simple thermostatic or PID temperature controllers. This topic is addressed further in section 6.5, below.

The Integrated Bio-Refinery described herein produces hydrous ethanol at near azeotrope. This means that the "fuel" is a liquid containing about 96% ethanol and about 4% water. This is the end product of the process as far as this document is concerned. Government regulations may require that the ethanol fuel be "denatured" before being removed from the premises on which it is produced. The usual denaturant is gasoline; generally speaking, 2% - 3% gasoline added to the hydrous ethanol will suffice. Additionally, it may be desirable to mix the ethanol fuel with larger percentages of gasoline; e.g. to top off with conventional gasoline in an emergency. In this event, it may be necessary to dry to fuel ("anhydrous ethanol") as an additional step after distillation. Denaturing and Drying the fuel is discussed, briefly, in section 8.1, below. Lastly, some sort of quality assurance should be provided for each batch of fuel produced to ensure its quality and suitability for use as automotive fuel, or other uses to which the fuel may be put (e.g. cooking, heating). This topic briefly discussed in section 8.2, below.

5.3 Integrated Bio-Refinery Equipment Overview.

An overview of the process for converting feedstock into fuel grade ethanol is presented in section 4.5, above. The reader should be fully familiar with this process before proceeding to read through this section.

Figure 5.3-1 contains a functional concept model for the Integrated Bio-Refinery equipment that fulfils the operational requirements for the Urban Fuel Co-Op, per section 4 of this document.

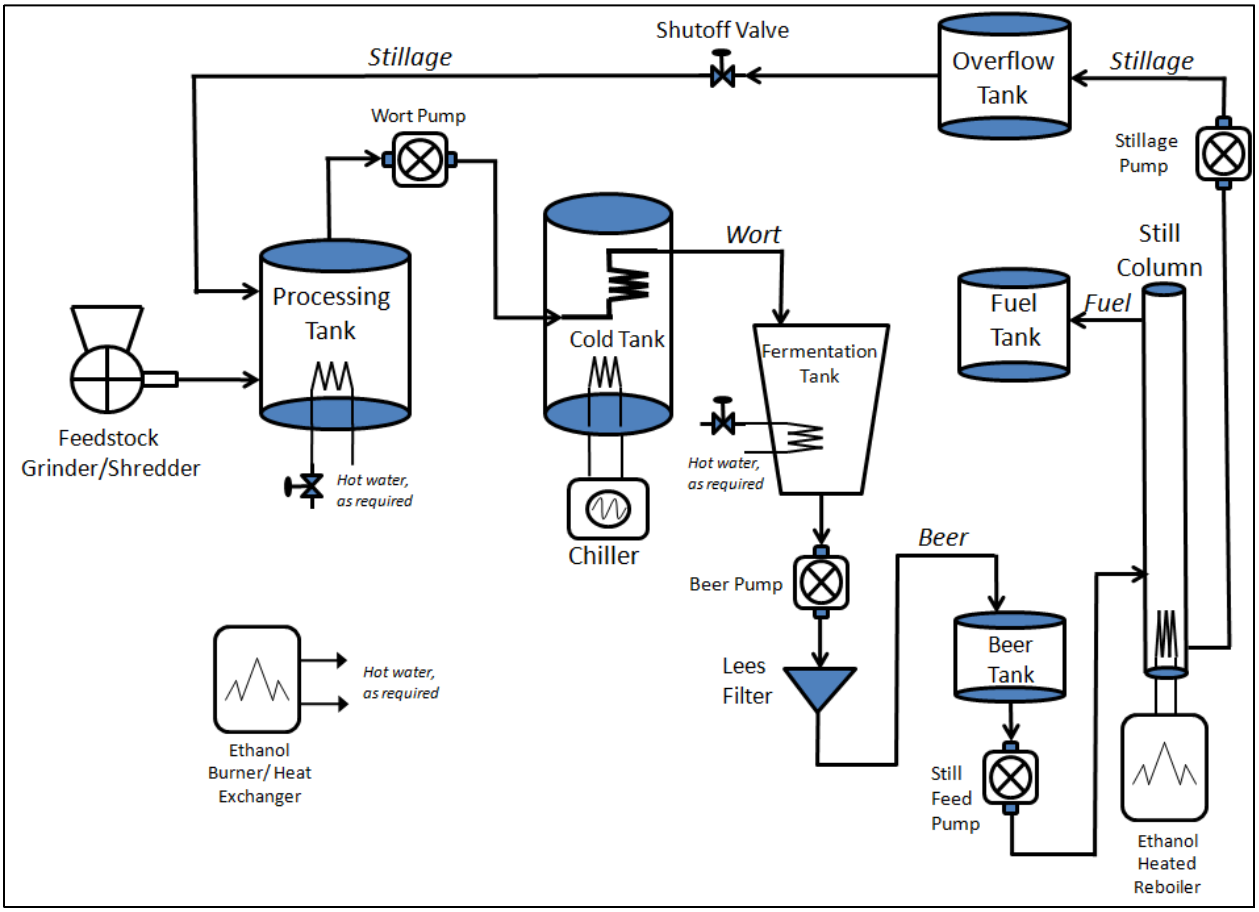

Figure 5.3-1. Integrated Bio-Refinery Concept Model.

We call this a "concept model" because each item depicted in figure 5.3-1 represents a specific function in the feedstock processing flow. This document does not intend to break each function down into its actual physical parts; e.g. in a physical Integrated Bio-Refinery system, there may be multiple, small tanks that together provide the function of the "Processing Tank" described herein.

Referring to figure 5.3-1, the process generally flows from left to right, as follows:

- Feedstock Grinder/Shredder: The function of this unit is to grind up new feedstock to be added to the stillage in the Processing Tank to form the mash.

- <u>Processing Tank</u>: This is a well insulated storage tank that collects stillage throughout the week and has an access port into which ground up feedstock is introduced. The Processing Tank has a motorized agitator that runs continuously while the feedstock is being mixed into the mash and while it is being processed into wort. The Processing Tank has a heat exchanger and electronically controlled valve which allows hot fluid from the Ethanol Burner/Heat Exchanger to provide additional heat to the tank so that the stillage in the Processing Tank is maintained at the proper cooking temperature (115 deg F – 135 deg F) even in cold ambient conditions. The access port on the Processing Tank is also used to measure/adjust pH and to introduce enzymes into the mash for processing. The Processing Tank has an output port and manually controlled motorized "Wort Pump" that pumps the resulting wort though the Cold Tank and into the Fermentation Tank. Lastly, the Processing Tank can be opened to provide easy access for personnel to clean it weekly, after each batch of feedstock is processed.

- <u>Cold Tank</u>: This is a very well insulated tank that contains a reservoir of cold fluid; nominally water or brine. The Cold Tank contains a large heat exchanger through which the wort is pumped, in order to rapidly cool the wort down to below 90 deg F for fermentation[3]. The Cold Tank has a proportional value that controls the percentage of wort that is cooled through the Cold Tank and the percentage that bypasses the Cold Tank. This bypass feature provides a means to adjust the amount of heat removed from the wort, overall, so that the final temperature for fermentation is close to 90 deg F, regardless of the initial wort temperature from the Processing Tank. The Cold Tank has a small refrigerator/chiller and heat exchanger that is electronically controlled to slowly cool down the brine during the week, so that it is ready to absorb the large heat load from the wort. Ideally, the Chiller is able to run off of the ethanol produced on-site. Alternatively, it is electrically driven off of the electric grid and an equivalent amount of energy in fuel ethanol produced at the site is sold to pay for the electricity for the Chiller.

- <u>Fermentation Tank</u>: This is a well insulated tank in which cooled wort ferments over the course of a week. The Fermentation Tank has an access port into which yeast/starter and nutrients can be manually introduced to start the fermentation process. The Fermentation Tank has a manually controlled motorized "Beer Pump" (or gravity feed) to drain out the fermented beer after fermentation is complete. The Fermentation Tank has a small heat exchanger which, under electronic control, adds heat to the fermenting wort to keep the fermentation temperature within the range of 75 deg F – 90 deg F during the fermentation

[3] Wort, as basically a sugar-water solution, is highly susceptible to infection by both wild bacteria and wild yeast. If either takes hold before the distiller's yeast is added and takes over fermentation, the resulting beer batch can be ruined. The longer that the wort stands around before distiller's yeast is added, the higher the probability of infection and a ruined batch. The 2012 Feedstock Processing Experiments always cooled the wort in an ice-water bath to reduce the time between completing of feedstock processing to inoculation with distiller's yeast. The Cold Tank is used to perform a similar, rapid cool-down, function in a scaled up manner.

process[4]. The Fermentation Tank is sealed to keep out air during fermentation, but is provided with an airlock device to let CO2 gas escape. The Fermentation Tank can be opened up to provide easy access for personnel to clean and sterilize it weekly, after each weekly batch of feedstock is processed.

- Lees Filter: When fermentation is complete, the Fermentation Tank contains a significant amount of solid material called "lees". Lees are mostly dead yeast, but also contains insoluble material from the original mash. This material is filtered from the beer via the Lees Filter, so that it does not enter the still column where it can clog up the Still and interrupt the process flow. The Lees Filter contains disposable or reusable filtering material that is manually replaced or cleaned weekly, as fermented beer is transferred from the Fermentation Tank to the Beer tank.

- Beer Tank: The Beer Tank is a large, insulated tank that holds the finished beer and feeds it into the Still, via a "Still Feed Pump", at a calibrated rate for distillation over the course of a full week. Depending upon the effectiveness of the Lees Filter in removing fine particles from the beer, the Beer Tank may also be provided with a sediment trap at the bottom of the tank. This trap allows fine particles that are not removed by the Lees Filter to settle down to the bottom of the Beer Tank, below the beer takeoff for the Still, and be manually cleaned out weekly while the tank still has beer in it. The Beer Tank itself needs to be cleaned during preventive maintenance activities, but need not be cleaned weekly if the Lees Filter and sediment trap operate properly. The Beer Tank does not need its own heat exchanger, as the Still provides the necessary heat over the full ambient temperature range of the Integrated Bio-Refinery. The Beer Tank should be at least 25% larger than the intended weekly batch to ensure continuous operation of the Still, uninterrupted by the weekly feedstock processing activities and variability of the beer yield from batch to batch.

- Still: The Still consists of the Still Feed Pump, the still column, a re-boiler that is powered by ethanol produced on-site, various heat exchangers (condensers -- not shown), a Fuel Tank to collect and hold the condensed ethanol fuel, and a "Stillage Pump" to remove the stillage into the Overflow Tank. The Still is envisioned as a continuous still design, having a rectifier section and a stripping section of the still column. The still column may be either a stacked design (rectifier section on top of the stripper section, with the beer feed being in the middle) or a split design (rectifier section and stripper

[4] The 2012 Feedstock Processing Experiments demonstrated that fermentation completes in less than one week in a temperature controlled room kept between 64 and 75 deg F. Fermentation is an exothermic process and temperatures above about 95 deg F can kill the yeast and cause fermentation to fail. Conversely, low temperatures lengthen the fermentation time significantly. A "reasonable" range for assured fermentation is between 75 and 90 deg F. Wort is cooled when entering the Fermentation Tank to around 90 deg F via the Cold Tank process. The Fermentation Tank is insulated to help contain heat loss over the week of fermentation; however, the heat exchanger can add additional heat in the event of abnormally cold ambient conditions.

section side-by-side, with pipes and pumps in between). Beer from the Beer Tank is pumped through the condenser(s) to remove heat from the still column and condense the ethanol product back to liquid. This process adds heat to the beer. The hot beer is then passed through a heat exchanger with the stillage coming out of the bottom of the stripper section to further heat the beer (and cool the stillage down somewhat in the process). Fuel grade ethanol is removed from the top of the rectifier section, condensed to liquid and collected in the Fuel Tank.

A well designed and sited continuous still, once calibrated and brought into equilibrium, remains in equilibrium and operates without the need for external control as long as it is undisturbed and as long as the beer concentration remains the same. Since the beer concentration can be expected to change from batch to batch, manual or automatic recalibration of the Still is required on a weekly basis.

The still column needs to be disassembled and the packing/plates cleaned periodically. This operational model assumes that the Still is designed so that two, one - week semi-annual preventive maintenance periods can suffice. Otherwise, the Still runs continuously, 50 weeks per year.

- Overflow Tank and Shutoff Valve: The Overflow Tank receives stillage continuously from the Still and forwards it, via the Shutoff Valve, to the Processing Tank for accumulation over the course of a full week. The reason for needing an Overflow Tank and Shutoff Valve is that the Processing Tank should be isolated from new stillage flow during mash making and processing, and must be isolated from new stillage flow during the necessary weekly cleaning. During these time periods, the Shutoff Valve is used to manually shut the flow of stillage off from the Processing Tank. The stillage accumulates in the Overflow Tank, which is a well insulated tank, like the Processing Tank, albeit a lot smaller. After cleaning, the Processing Tank is again available to receive stillage, and the Shutoff Valve is manually opened to release the stored stillage, plus new stillage, to flow into the Processing Tank.

- Ethanol Burner/Heat Exchanger: The Ethanol Burner/Heat Exchanger burns some of the ethanol produced on-site for use, via the Heat Exchanger, to provide heat to stillage accumulating in the Processing Tank and to wort fermenting in the Fermentation Tank. Ideally, the latter components are designed to hold in enough heat to maintain their processes without the need to add extra heat energy to them during the week. However, the wide range of ambient temperatures expected over the course of a year for Integrated Bio-Refinery operations means that no reasonable amount of passive insulation can keep the internal process temperatures of these components uniform. The design presented in this document assumes that passive insulation is selected based upon the highest specified ambient temperature (90 deg F) and that supplemental insulation is added seasonally to accommodate lower ambient temperatures. As such, supplemental heating is not needed, in theory, down to ambient temperatures of 40 deg F. Supplemental heating capability is added to the Integrated Bio-Refinery concept model to prevent unanticipated unusually low temperatures from ruining a weekly process batch.

Alternatively, the system could be designed based upon a middle value of ambient temperature, and a combination of heating and cooling (the latter via the Cold Tank) be used to maintain ideal process temperature.

It is assumed here that ethanol produced on-site is burned to provide this extra heat. This design approach is chosen because of its simplicity and assumed low cost, even if it uses a little more energy than a more complex arrangement.

An electronic controller is used to fire up the Ethanol Burner whenever one of the aforementioned processes requires some heat input via their internal heat exchangers. The Ethanol Burner heats up water (or alternative fluidic heat transfer medium) and then electronically open valves to direct hot fluid flow through the necessary heat exchanger(s). When no on-site process requires additional heat, the valves are closed and the Ethanol Burner is shut off.

5.4 Integrated Bio-Refinery Operational Timeline.

The following is a model timeline for the one-day-per-week on-site operation of the Integrated Bio-Refinery. It is assumed that a two person team comes on-site with 9,360 lbs of feedstock at the beginning of the day, and leaves after the new batch of feedstock is processed to wort and all equipment has been checked and calibrated for proper operation over the ensuing week.

1. *Arrival:* a two person team arrives with 9,360 lbs of fresh feedstock for processing.

2. *Site Check:* the team checks that everything on-site is OK and that the previous week's processing has completed as expected. This means: (a) approximately 400 gallons of fuel grade ethanol has been added to the Fuel Tank, (b) approximately 3,600 gallons of (approximately 145 - 150 degree F) stillage has been accumulated in the Processing Tank, (c) fermentation has completed, as evidenced by lack of activity in the airlocks and visual appearance of the beer, and (d) that the Still is operating normally and that there remains beer in the Beer Tank. (*estimated time: 15 minutes*).

3. *Mash Making*: the team closes the Shutoff Valve and verifies that the flow of stillage has been shut off from the Processing Tank and that stillage is accumulating in the Overflow Tank. The team starts the agitator on the Processing Tank, then opens the access port on the Processing Tank and uses the Feedstock Grinder/Shredder to grind up the feedstock (if not previously ground up) and add it to the Processing Tank to make the mash. During the feedstock grinding process, the team checks the mash thickness to ensure that the mash does not get too thick to ferment in one week (refer to the 2012 Feedstock Processing Experiments report for details on the "thick mash" situation). After the mash

is prepared, the team checks the pH and uses acid, as needed, to adjust the pH to within the proper processing range (pH 4.2 – pH 4.8, nominally pH 4.5). The addition of the cool feedstock mass reduces the temperature of the mash from to within the nominal processing range of 115 deg F to 135 deg F. The mash thickness, pH adjustment, and mash temperature is recorded. Then the team adds in the GA enzyme, closes the access port, and sets a 4 hour timer. (*estimated time: 2 hours*).

4. *Mash Cooking*: the mash takes 4 hours to cook into wort. During this time, the team: (a) pumps the previous week's batch of beer from the Fermentation Tank, through the Lees Filter, and into the Beer Tank, (b) cleans and sterilizes the Fermentation Tank and air lock, (c) cleans and replaces the filter material in the Less Filter and drains the Beer Tank sediment trap (if one exists), and (d) recalibrates the Still (the Still Feed Pump rate) for the new batch of beer. (*estimated time: 4 hours*).

5. *Wort Transfer*: When 4 hours cooking has elapsed, the team: (a) verifies complete reduction of starch to sugar (iodine test), estimates concentration of ethanol in the wort after conversion to beer (sugar hydrometer test), re-verifies pH of the wort, and records the results, (b) pumps the beer through the Cold Tank/bypass and into the Fermentation Tank and verifies and records the temperature of the wort in the Fermentation Tank, (c) adds yeast/starter solution and yeast nutrient (as required), and (d) closes and checks the airlock on the Fermentation Tank. (*estimated time: 2 hours – mostly pumping/cooling time*).

6. *Processing Tank Cleaning:* the team cleans out and sterilizes the Processing Tank. After this, the team opens the Shutoff Valve and verifies that hot stillage is flowing into the Processing Tank. (*estimated time: 30 minutes*).

7. *Site Cleanup and Final Checks:* the team performs any remaining cleanup or minor maintenance items and double checks and records that all site operation is normal prior to leaving the site. The team ensures that all government documentation regulations have been met and that the site is properly secured prior to leaving (*estimated time: 15 minutes*).

Total time on site = 9 hours.

5.5 Design Alternatives.

This section describes various alternatives to some design decisions inherent in the Integrated Bio-Refinery described above.

5.5.1 Off-Site Feedstock Preparation.

The operational timeline presented in section 5.4 of this document assumes that grinding/shredding of the feedstock is performed on-site, as part of the feedstock processing one-day-per-week activity. The possibility of grinding/shredding the feedstock as it is collected is discussed in section 4.4.2, above. This alternative transfers this activity from feedstock processing to feedstock collection. It has the advantage of somewhat reducing the volume of the feedstock as it is collected and transported. On the other hand, this alternative adds some time to the collection activity (which is already time-constrained) and does not materially reduce the processing timeline. One way or the other, 9,360 lbs of ground feedstock must be loaded into the Processing Tank.

5.5.2 Cold Tank.

Wort (sugar-water solution) is highly vulnerable to microbial infection. Such infection can result in a spoiled batch run which would not only waste one week's activity, but would interrupt the entire pipelined workflow of the Integrated Bio-Refinery. Cooking the mash into wort at 115 deg F and pH of 4.5 does not inhibit microbial infection and the wort does not become "sterilized" to any significant degree until the alcohol content raises to at least 2% or 3% during fermentation. Consequently, the wort is already vulnerable to microbial infection for 6 – 8 hours, exclusive of any time spent cooling the wort down to under 90 degrees F for inoculation with yeast. A volume of wort in excess of 4,000 gallons requires a huge amount of heat to be removed. Assuming that "wort" gains and looses sensible heat at the same rate as pure water:

- 1 BTU raises or lowers the temperature of 1 lb of water by 1 deg F
- A gallon of water weighs 8.34 lbs. Therefore, it takes 8.34 BTUs to raise/lower one gallon of water 1 deg F.
- It therefore takes (8.34 BTU/gal * 4,000 gal =) 33,360 BTU to raise/lower the temperature of the wort 1 deg F
- If processing is at 115 deg F and we want to lower the temperature to 90 deg F (115 – 90 = 25 deg F), we have to remove (33,360 BTU/deg F * 25 deg F =) 834,000 BTU.

Our operational timeline (section 5.4, item 5) allocates 2 hours to this process. Therefore, we must remove 834,000 BTU in 2 hours or 417,000 BTU per hour. Removing this much heat in this short a time period is the reason for the Cold Tank.

An alternative to the Cold Tank would be to allow the wort to cool over a full week. A full week is 168 hours, therefore 834,000 / 168 is approximately equal to 4,964 BTU per hour. This method would add a stage into the pipeline, but would allow cooling with little or no need for an energy consuming refrigerator/chiller. However, leaving the wort vulnerable to infection for an entire week would likely result in a significant number of batch failures due to infection.

It may be possible to keep the wort sterile while cooling. Adding sulfites (as in winemaking) is one possibility. The cost of doing so is not very high. However, standard sulfating procedures require adding chemicals daily (or at least several times over a week) as the SO2 gas, which performs the sterilization, dissipates rapidly. The necessity for doing this is incompatible with the one day per week processing labor assumption of the Urban Fuel Co-Op model. It is possible that this process could be automated, or that some other sterilization process that requires only one step per week could be used. This alternative is certainly worth exploring.

5.5.3 Batch Still.

A continuous still has been selected for the functional design of the integrated bio-refinery for several reasons:

1. Distillation takes time and a still, once in equilibrium, needs to be kept in equilibrium; otherwise, it may take a long time (several hours) to restore the equilibrium in the still column. A continuous still stays in equilibrium and does not require any recalibration or alteration of its operation, as long as everything else stays the same. A well designed, well sited and well insulated continuous still should only require recalibration when the beer concentration changes (even then, may not upset the column equilibrium very much as it changes to a new temperature gradient profile). Therefore, a continuous still is most suitable for unattended operation. In contrast to this, a batch still's boiler changes concentration of the beer continuously during distillation and requires constant readjustment of the reflux ratio in order to maintain high proof of the fuel product. This can be automated (as in the C803 design), but it is less energy efficient and more prone to problems during unattended periods.

2. A continuous still uses heat removed from the still column to heat up the beer on the way into the column. This heat is below the boiling point of the beer, but it saves energy in sensible heat and makes the overall distillation process more energy efficient.

3. A batch still requires more total energy input to boil the beer than does a continuous still. A continuous still only has to boil beer that is always at a fixed ethanol concentration. The beer in the boiler of a batch still is continually being stripped of ethanol and the boiling point continuously rises, requiring more and more energy to distill as the batch run proceeds.

4. It takes a large amount of energy to boil 4,000 gallons of beer in a batch still. The latent heat of vaporization of a 10% beer is around 9,316 BTU per gallon of azeotropic ethanol produced by the still[5]. Since a weekly batch run produces 400 gallons of fuel, (9,316 * 400 =) over 3.7 million BTUs are required to boil the beer. Any reasonable bulk boiler would take a very long time to add in this much heat! A continuous still, by contrast, boils the beer gradually; only as it enters the column. The total heat required for distillation does not change, but the rate of heat input required in the boiler (re-boiler in a continuous still) is much lower for the continuous still, as it is spread evenly over an entire week of distillation.

[5] Still math courtesy of Curbie.

Nothing in this analysis says that a batch sill would not work to distill the fuel ethanol out from the beer. However, a batch still would seem to violate many of the operational assumptions behind the Urban Fuel Co-Op model.

6 Integrated Bio-Refinery Equipment Detailed Requirements and Supporting Analysis.

This section presents the detailed requirements and technical analysis for the concept model of the Integrated Bio-Refinery system presented in section 5, above. The purpose of this section is three-fold:

a) To validate the concept model; specifically, to validate that the energy content of 20% of the production is sufficient to provide all of the energy needed to process each batch of feedstock.

b) To provide a starting point for the detailed design and fabrication of an Integrated Bio-Refinery equipment.

c) To provide a set of tools for analyzing and optimizing the detailed design and operation of an Integrated Bio-Refinery, of any size or scale, that processes stale bakery product waste into ethanol.

The technical analysis is based upon an Excel Workbook. The Workbook can be downloaded, along with this document, in a zip archive at:

http://www.liquidsunenergy.com/projects/UrbanFuelCoop.zip

No attempt has been made to optimize the design of the concept model from a technical standpoint. Overall system cost is dependent upon the material and construction costs as well as the operational costs. Material and construction costs are highly dependent upon the materials and components that may be obtained by any given Co-Op, as well as upon the construction skills and abilities of the Co-Op members. It is not possible to tradeoff operational and thermal efficiency against these unknown and variable costs.

Throughout this analysis, we use English Engineering units common in the United States, vs. the international SI units. The units used in this paper are:

Length: foot (ft)
Area: square foot (sq-ft)
Volume: cubic foot (cu-ft), and U.S. gallons (gal)
Mass: pound (lb)
Heat energy: British Thermal Unit (BTU)
Temperature: degrees Fahrenheit (deg F)
Time: hour (hr)

6.1 Thermal Analysis – Mathematical Principles.

6.1.1 Heat, Temperature, and Mass.

Heat is a form of energy. Heat is radiated through space in electromagnetic form. When heat is absorbed by matter (*mass*), the heat energy manifests itself by increasing molecular motion in the matter. The average amount of molecular motion in a given mass is measured as the *temperature* of the mass. Therefore, the amount of heat energy added to or removed from some mass is proportional to the mass and to the change in temperature of that mass. The proportionality constant is known as the *specific heat* of the mass and is a characteristic of the particular type of matter that comprises the mass[6]. Stated mathematically:

$$\Delta Q = c * m * \Delta T \qquad \textit{equation 6-1}$$

Where:

ΔQ = Heat energy added/removed (BTU)
c = Specific heat (BTU/(lb * deg F))
m = mass (lb)
ΔT = change in temperature (deg F)

Technically speaking, equation 6-1 assumes conditions of one atmosphere of pressure, as this is the condition under which specific heat (c) is usually measured and documented. The specific heat (c) of water (at one atmosphere of pressure) is 1.0, meaning that one BTU raises one pound of water one degree F. This is not a coincidence – it is the definition of the BTU.

We will assume that all mass is water for the purposes of the analysis in this section. This assumption is very close for stillage, as stillage is beer stripped of ethanol and is therefore mainly water. This assumption is a little bit poorer for beer, as our beer ranges from 7% to 13% ethanol (by volume). This assumption is of unknown validity for mash and wort, as the material and water content of the feedstock varies greatly. Nevertheless, the mass of the feedstock is treated as water for thermal analysis under the belief that it is better to include something than to ignore it. During the 2012 Feedstock Processing Experiments, we noted a temperature drop in our pre-heated water as we added in the ground up feedstock (as evidenced by the Controller turning the heat on almost immediately as we added in feedstock).

[6] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html

6.1.2 Mixing Liquids of Differing Temperatures.

Consider mixing two liquids, each having a different mass and different temperature prior to mixing. When mixed, the total mass is the sum of the masses of the two liquids, but what is the temperature of the mixture? Equation 6-1 is used to provide the answer.

The heat energy transferred to/from liquid 1 is:

$$Q1 = c1 * m1 * \Delta T = c1 * m1 * (Tf - T1)$$

The heat energy transferred from/to liquid 2 is:

$$Q2 = c2 * m2 * \Delta T = c2 * m2 * (Tf - T2)$$

Where:

Q1 = energy added to liquid 1
Q2 = energy added to liquid 2
c1 = specific heat of liquid 1
c2 = specific heat of liquid 2
m1 = mass of liquid 1
m2 = mass of liquid 2
Tf = final temperature of the mixture
T1 = initial temperature of liquid 1
T2 = initial temperature of liquid 2

The principle of conservation of energy says that Q1 + Q2 = 0 because there is no other heat source or sink. Whatever heat flows out of liquid 1 must flow into liquid 2, and vice versa.

Therefore:
Q1 + Q2 = 0 = $c1 * m1 * (Tf - T1) + c2 * m2 * (Tf - T2)$

Therefore:
*0 = $c1 * m1$ * Tf - c1 * m1 * T1 + c2 * m2 * Tf – c2 * m2 * T2*

If both liquid 1 and liquid 2 have the same specific heat (if they are both the same substance, e.g. water), then c1 = c2 = c. *Therefore:*

*0 = c * (m1 + m2) * Tf – c * (m1 * T1 + m1 * T2)*

Therefore:
*c * (m1 * T1 + m1 * T2) = c * (m1 + m2) * Tf*

Therefore:

$$Tf = \frac{(m1 * T1) + (m2 * T2)}{m1 + m2} \qquad \textit{equation 6-2}$$

If the masses of the two liquids are equal, then the final temperature is simply the midpoint between the two starting temperatures.

By definition: Density = Mass / Volume; therefore: Mass (m) = Density (d) * Volume (V). If liquid 1 and liquid 2 are the same substance (e.g. water), then the density is the same for both masses (d1 = d2 = d); thus equation 6-2 may be rewritten in terms of volume as:

$$Tf = \frac{(V1{*}d * T1) + (V2{*}d * T2)}{V1{*}d + V2{*}d} = \frac{d{*}(V1{*}T1) + d{*}(V2{*}T2)}{d{*}(V1{+}V2)} = \frac{(V1{*}T1) + (V2{*}T2)}{(V1{+}V2)}$$

Therefore:

$$Tf = \frac{(V1 * T1) + (V2 * T2)}{V1 + V2} \qquad \textit{equation 6-2a}$$

6.1.3 Dynamic Heat Transfer.

Heat energy transfers by three means: *convection* (mixing masses), *conduction* (transferring heat between masses through a conducting or insulating medium) and *radiation* (electromagnetic radiation through space). Here we are concerned with convection and conduction of heat from one mass (e.g. a tank of wort to be fermented) to another medium (e.g. to the outside, through the insulated walls of the Fermentation Tank).

Newton's law of cooling states that *the rate of heat loss (gain) of a body is proportional to the difference in temperatures between the body and its surroundings*. For a tank of liquid, the proportionality constant is the conductivity of the material separating the liquid from the environment, which is a function of the material, its thickness and the surface area, but is independent of temperature. With these facts in mind, we can write Newton's law of cooling as a first order, linear differential equation, as follows:

$$\frac{dQ}{dt} = h * A * (T - T_{env})$$

Where:

h = heat transfer coefficient (conductivity) between the fluid and the tank wall
A = surface area of the tank
T = current temperature of mass inside the tank
T_{env} *= temperature of the outside environment*

From the calculus, the first order time derivative is the limit, as the time increment approaches zero, of the difference of the variable over time, or:

$$\lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = h * A * (T - T_{env})$$

The solution to the aforementioned differential equation is:

$$\Delta Q = (T_0 - T_{env}) * e^{-h*A*t}$$

By equation 6-1: $\Delta Q = c * m * \Delta T$. If we assume that we are transferring heat into or out of water (c = 1.0), *therefore:*

$$\lim_{\Delta t \to 0} \frac{\Delta T}{\Delta t} = \frac{h*A}{m} * (T - T_{env}) \quad \textit{equation 6-3}$$

We will use the formulation of equation 6-3 for certain complex problems by computing ΔQ and/or ΔT at small time increments on a spreadsheet. Otherwise, we will use the formal solution to the aforementioned differential equation, which is (in terms of temperature):

$$T = T_{env} + (T_0 - T_{env}) * e^{-kt} \quad \textit{equation 6-4}$$

Where:

$$k = \frac{h*A}{m} = \frac{A}{R*m} \quad \textit{equation 6-5}$$

Where:

A = surface area of the tank (sq-ft)
m = mass of the contents of the tank (lbs), which for water, is volume (gallons) * 8.34 lb/gal
R = 1/h = thermal resistance per unit area of the tank insulation (deg F * hr * sq-ft / BTU)

The value of R for various insulating materials can be found in tables in the literature, e.g. http://en.wikipedia.org/wiki/R-value_(insulation)

The R-value listed in tables such as referenced above are usually in units of one inch thickness, e.g. the R-value for a "typical" high density fiberglass bat is 4.0 per inch thickness.

6.1.4 *Area and Volume of Cylindrical Tanks.*

Computation of "k" for dynamic heat transfer analysis requires that we calculate the volume and area of various tanks used in the Integrated Bio-Refinery. Our concept model uses cylindrical tanks, since these are most easy to find and to fabricate.

A cylindrical tank has a volume:

$$V = \pi * R^2 * h \qquad \textit{equation 6-6}$$

Where:

V = volume (cu-ft)
R = radius of top/bottom of the tank (ft)
H = height of the tank (ft)

Note that for water, one gallon comprises 0.13368 cu-ft (http://wiki.answers.com/Q/How_many_cubic_feet_are_in_a_gallon)

To compute the surface area of the tank, we note that the surface area comprises the top, the bottom and the side, where the top and bottom areas are equal. The top and bottom areas are the area of a circle:

$$A_{circle} = \pi * R^2 = \pi * (\frac{D}{2})^2 = \pi * \frac{D^2}{4}$$

Where:
A = area (sq-ft)
D = diameter of a circle (ft)
R = radius of a circle = half the diameter (ft)

The area of the side of a cylinder is the circumference of the cylinder times the height of the cylinder, i.e.

$$A_{side} = \pi * D * \mathrm{h}$$

Combining these:

$$A_{cylinder} = \left(2 * \pi * \frac{D^2}{4}\right) + \pi * D * h$$

Combining terms:

$$\boxed{A_{cylinder} = \pi * D * (\frac{D}{2} + h) \qquad \textit{equation 6-7}}$$

6.2 Use of the Excel Workbook.

Most of the calculations presented in the next section of this document are made on an Excel (2007) Workbook. The Workbook is in the zip file from which this document was obtained. It can be downloaded from:

http://www.liquidsunenergy.com/projects/UrbanFuelCoop.zip

The Excel Workbook is intended as a tool to support the detailed design and development of equipment for an Integrated Bio-Refinery based upon the concept model presented and analyzed in this document. This section describes the Workbook format and use.

Readers who want to use the Workbook should download it from the website to their computer, unzip it and store it in a handy location on their computer. The Workbook is in Excel 2007 format.

General use of the Workbook is indicated by the color of the cells on the worksheets, as follows:

- Light Gray: These are constants used in the calculations and should not be changed.
- Yellow: These cells are user inputs and the user must set the value of these cells accordingly.
- Red: These cells carry forward data from other tabs in the Workbook and should not be changed. Where these cells contain user input, the user input should be changed on the tab where the cell is yellow. A Dark Red color indicates that the value comes from the OVERVIEW tab. A Light Red color indicates that the value comes from the calculated result of another worksheet in the Workbook.
- White: cells colored white contain Workbook calculations and should not be changed by the user.

- Green: cells colored Green contain calculated results of significance in the design and should not be changed by the user.

As an Excel Workbook, there are a number of tabs along the bottom. Each tab is a worksheet in the Workbook and relates to the thermodynamic analysis of a specific component of the Integrated Bio-Refinery. The tabs are as follows:

- OVERVIEW: this tab contains the constants used in the calculations within the Workbook. The cells where constants are used within the Workbook are colored Light Gray. The notes (little red triangles in the upper right hand corner of a cell on the worksheet) provide Internet references for these values. In addition, this tab contains the basic user input values that are used throughout the workbook, indicated by cells colored in Yellow. The values that the user must enter are: (1) ambient temperature, and (2) temperature of stillage exiting from the Still. The intent is to use the Workbook to calculate thermodynamic performance of the Integrated Bio-Refinery are various different ambient temperatures between the specific range of 40 deg F and 90 deg F. The stillage temperature is also needed as this is dependent upon the design specifics of the Still, as well as upon the atmospheric pressure.

- FERMENTATION TANK: this tab calculates heat loss in the Fermentation Tank due to the temperature difference between the fermenting wort and the ambient temperature surrounding the tank. User input is required on the Yellow tabs: R-value of the tank insulation, height and diameter of the tank, initial temperature of the wort in the tank, and volume of wort in the tank. Outside ambient temperature and constants are carried forward from the OVERVIEW tab.

- PROCESSING TANK: this tab calculates the temperature of the stillage in the Processing Tank, as new stillage is added and heat is simultaneously lost to the environment. It also estimates additional heat loss due to the introduction of cold feedstock into the stillage for cooking. User input is required on the Yellow tabs: R-value of the tank insulation, height and diameter of the tank, and final volume of stillage in the tank. Initial stillage temperature, outside ambient temperature, and constants are carried forward from the OVERVIEW tab.

- COLD TANK XCHANGE: this tab calculates the dynamic heat exchange between the wort flowing through the Cold Tank and the cold medium in the Cold Tank. User input is required on the Yellow tabs: height and diameter of the tank, volume of wort that is transferred, time to transfer the wort, volume (mass) of the cooling medium, initial temperature of the cooling medium, and the percentage of wort that flows through the Cold Tank (the rest bypasses the Cold Tank). Constant value of a Ton of refrigeration and other constants are carried forward from the OVERVIEW tab. Input temperature of the wort is carried forward from the PROCESSING tab.

- COLD TANK COOL: this tab calculates the energy needed to cool down the Cold Tank cold medium over the course of a week. User input is required on the Yellow tabs: R-value of the tank, desired final temperature of the medium in the tank, COP (coefficient of performance) of the refrigeration unit and Tons of refrigeration. The ambient temperature and constants are carried forward from the OVERVIEW tab. The height and diameter of the Cold Tank, as well as the initial temperature of the medium in the tank is carried forward from the PROCESSING tab.

6.3 Thermodynamic Analysis of the Integrated Bio-Refinery

6.3.1 Fermentation Tank.

- Problem Statement: The Fermentation Tank is where yeast fermentation of sugar into ethanol takes place. Temperatures nominally above 95 deg F may kill the yeast. Fermentation is a mildly exothermic process. Therefore, we choose to begin fermentation at around 90 deg F in order to provide a little margin for error. On the other extreme, low temperatures slow or stop fermentation. Our pipelined operation requires that fermentation be complete in one week or less. Consequently, we need to keep the temperature in the Fermentation Tank between 90 deg F on the high side and 75 deg F on the low side.

  We can control the temperature of the wort as it is introduced into the Fermentation Tank via the Cold Tank process. We thus design the system to introduce wort into the Fermentation Tank at approximately 90 deg F. If the ambient temperature is below 90 deg F, the wort in the Fermentation Tank loses heat to the environment over the course of the week. Ideally, the Fermentation Tank is well insulated, such that the temperature of the wort never falls below 75 deg F. Under adverse conditions, there may be times where the wort cools to below 75 deg F. In order to account for such a circumstance, a small heat exchanger is added to the Fermentation Tank and is intended to make up for heat loss where the wort temperature falls to around 75 deg F. The problem is to determine the R-value of the insulation on the Fermentation Tank to keep the contents above 75 deg F over the full ambient temperature range (90 deg F down to 40 deg F) and, should the low temperature fall below the specified limit or the R-value be too low, to calculate how much heat must be added, and at what rate, to the Fermentation Tank in order to keep the temperature of the wort from falling below 75 deg F.

- Solution: Equations 6-4 and 6-5 are used to compute the passive heat loss from the wort, through the insulated Fermentation Tank, and out into the environment, as a function of time. Equation 6-4 could be solved algebraically to determine the time (t) at which the wort temperature (T) reaches 75 deg F at the lowest specified environmental temperature (40 deg F). However, we choose to solve equation 6-4 numerically on the Excel Worksheet; i.e. to simply compute the wort temperature at each hour of the 168 hour week in a table on the worksheet. In parallel, we use equation 6-1 to compute the heat loss over each hourly period, using the temperature loss at each hour (temperature at the previous hour minus temperature at the current hour) for the value of delta T.

The solution to the problem then involves setting the ambient temperature to its lowest value (40 deg F) on the Overview tab and looking down through the Fermentation Tank worksheet table listing temperature vs. time to see what the calculated wort temperature is at the end of the week (168 hours). If the wort temperature never falls below 75 deg F, we have sufficient R-value in the tank insulation and no heat needs to be added via the internal heat exchanger. If the temperature drops below 75 deg F before the last hour of the week, then the R-value is too little and must either be increased or heat must be added. In order to find how much heat must be added to maintain a wort temperature of 75 deg F for the rest of the week, we find an hour where the wort temperature is at, or just slightly above, 75 deg F. We then look across the table to the calculation of heat loss at that time interval, and this is the amount of heat that we need to add, per hour, to maintain the temperature at that value. We also note the hour at which sustaining heat must be added and subtract it from a full week (168 hours) in order to determine the number of hours that this heat must be added for. The total added heat over the week is then the heat value per hour times the number of heating hours.

- <u>Worksheet Details</u>: The Fermentation Tank tab of the Excel Workbook contains the implementation of this solution. The table computing temperature and heat loss as a function of time (hours of the week) is contained in columns F, G and H. Cells B2 and B3 contain constants carried forward from the Overview tab of the Workbook. Cell B10 contains the temperature of the environment, also carried forward from the Overview tab of the Workbook (this is a user input). User data must be input on the Fermentation Tank tab, as follows:
  - The R value of the insulation on the Fermentation Tank is entered in cell B6.
  - The height and diameter of the Fermentation Tank is entered in cells B7 and B8 respectively, and cell B11 computes the volume of the tank using equation 6-6, and cell B12 converts this into gallons, using the conversion constant in cell B3.
  - The tank must hold all of the wort, with at least 20% extra volume to account for foaming during active fermentation. The actual volume of the wort is a user input into cell B11.
  - The total surface area of the Fermentation Tank is computed in cells B14, B15 and B16, using equation 6-7.
- <u>Assumptions</u>: The analysis performed on the Fermentation Tank worksheet assumes that the wort/beer under fermentation is water. This is a reasonable assumption, as the beer will contain 87% water in the worst case (13% beer). We therefore use the specific heat value of water (1.0). We assume 4,000 gallons of wort (user input value, consistent with a 10% beer producing 400 gallons of ethanol after distillation) and use this value for the

mass in the temperature and heat loss calculations. This assumption ignores mass (and heat) lost as CO2 gas out of the airlock during fermentation.

The analysis assumes that the ambient temperature value carried forward from the Overview tab is a constant. In reality, it will vary from hour to hour and day to day, but what we are seeking here is the performance at any specific temperature(s) that we choose to enter on the Overview tab.

The analysis also assumes that heat is conducted out of the Fermentation Tank equally though all of its surfaces – top, bottom and side – and that all such surfaces are insulated with the same R-value material. The tank is assumed to cylindrical in shape. The tank is larger than the volume of liquid within it (to allow for foaming during fermentation). We assume that the extra volume (air above the liquid) is at the same temperature as the liquid and conducts heat equally as does the liquid.

- Results: Assume that the Fermentation Tank measures 12 feet in diameter and is 7 feet tall. This gives a tank capacity of almost 6,000 gallons, which is 1/3 greater than the 4,000 gallons of liquid in the tank. The initial temperature of the wort will be 90 deg F, based upon the conceptual design of the system. The Cold Tank must remove sufficient heat to deliver wort to the Fermentation Tank at this temperature.

  For illustrative purposes, we assume that the Fermentation Tank is insulated on all surfaces to R-6. We note that a value of R-8 would remove the need for any added heat to maintain temperatures above 75 deg F, even at ambient environmental temperatures of 40 deg F (the worst case per our specifications). With R-8, the worksheet shows that the temperature of the wort after 168 hours at 40 deg F ambient is 76.73 degrees.

  With a value of R-6 in cell B6, we find that the wort temperature is reduced to 75.06 deg F at hour 145. This is the lowest temperature that we want for the wort, as the next hour temperature is below 75.00 deg F. At hour 145, the heat loss is 2,867.06 BTU per hour, so we would need to add in heat at this rate in order to maintain a temperature of 75.06 deg F for the rest of the week. The week contains 168 hours, so that this heat must be added for (168 – 145 =) 23 hours, for a total of (23 * 2867.06 =) 65,942.38 BTU. This requires less than one gallon of ethanol to produce this heat (76,000 BTU per gallon), if it is needed.

  For completeness, we run the same design parameters at ambient environmental temperatures of 65 deg F and 90 deg F on cell B11 of the Overview worksheet. At 65 deg F, the minimum temperature of the wort (hour 168) is 81.57 deg F and at 90 deg F, the temperature of the wort always remains at the initial 90 deg F, since no heat is lost where the temperature difference is zero.

  The main result is that with R-8 insulation (2 inches of fiberglass bat) we do not need to add any heat to the Fermentation Tank, even under the coldest specified conditions. It would be wise to provide the Fermentation Tank with a heat exchanger “just in case” some very extreme condition were to occur, but we need not plan to actually use any of our product to keep the wort warm during fermentation.

6.3.2 <u>Processing Tank.</u>

- <u>Problem Statement</u>. The Processing Tank receives hot stillage from the Still, via the Overflow Tank and Shutoff Valve. The flow of stillage is continuous over the week. At the end of one week (168 hours) the Processing Tank contains 3,600 gallons of hot stillage. The temperature of this hot stillage must be high enough so that after the feedstock is added to make a mash, the cooking temperature must be between 115 deg F and 135 deg F. Temperatures nominally higher than 135 deg F may destroy the GA enzyme needed for converting the starches into sugar. Temperatures below 115 deg F are too low for starch conversion to complete within the operational specification of 4 hours of cooking.

- <u>Solution</u>. The Processing Tank problem is difficult because the mass of the stillage is changing continuously throughout the week. Each hour, nominally 21.43 gallons of hot stillage is added to the Processing Tank. In the meantime, though, the accumulated mass of stillage since the beginning of the week has been losing heat through the insulated tank into the environment. Some heat loss is desirable, because the stillage coming out of the Still is too hot for our purposes. However, too much heat loss results in too low a temperature for 4 hour completion of feedstock processing. The solution involves finding the "best" value for insulating the Processing Tank such that the final temperature of the stillage, when making a batch of mash, is at the high end of the acceptable range when the ambient environment is hot (90 deg F) and then adding insulation or extra heat (via the internal heat exchanger) to the Processing Tank in order to achieve the minimum mash temperature (115 deg F) needed for cooking the mash at the coldest specified ambient temperature (40 deg F).

  Since the Processing Tank contains a mixture of new and old stillage, the mixing equation (equation 6-2 or 6-2a) is used to compute the temperature of the stillage at each hour of the week. In doing so, we assume that the new 21.43 gallons of stillage per hour arrives all at once during the hour period and that mixing is instantaneous. Then, we use equations 6-4 and 6-5 to compute the heat loss to the environment over the course of one hour, and we repeat this process for every hour of the 168 hour week. Using this iterative process, we arrive at an estimate of the temperature of the stillage just prior to adding in the feedstock. We then add in the feedstock, which we assume to be at the ambient temperature of the environment, and use the mixing equation 6-2 again, to compute the final temperature at which the mash cooks.

- <u>Worksheet Details</u>: The Processing Tank tab of the Excel Workbook contains the implementation of this solution. The table computing temperature and heat loss as a function of time (hours of the week) is contained in columns F through L. Cells B2, B3, and B4 contain constants carried forward from the Overview tab of the Workbook. Cells B10 and B11 contain the temperature of the environment and the temperature of the stillage, both carried forward from the Overview tab of the Workbook (this is user input). User data must be input on the Processing Tank tab, as follows:

- The R value of the insulation on the Processing Tank is entered in cell B7.
- The height and diameter of the Processing Tank is entered in cells B8 and B9, respectively, cell B13 computes the volume of the tank using equation 6-6, and cell B21 converts this into gallons, using the conversion constant in cell B2.
- The tank must hold all of the stillage plus the feedstock, which is initially mostly insoluble in water. Therefore, we oversize the tank by about 35%. The final volume of the stillage is a user input into cell B12, and the rate of arrival of new stillage per hour is computed in cell B20 using this value and the number of hours in a week (cell B4).
- The total surface area of the Processing Tank is computed in cells B15, B16 and B17, using equation 6-7.
- The mass of the stillage is computed in cell B21 and the mass of the feedstock is computed in cell B22, based upon the ratio of 26 lbs of feedstock per gallon of ethanol and assuming a 10% beer (thus 26 lbs of feedstock for 10 gallons of stillage).
- Cell B23 copies the computed final temperature of the feedstock from cell J173 and cell B24 copies the temperature of the feedstock from the environment temperature of cell B11. Cell B25 then uses the mixing equation (equation 6-2) to compute the temperature of the mash. Cell B26 computes the amount of energy (BTU) needed to heat up the mash to above 115 deg F, if the temperature is below this value (using equation 6-1 on the combined mass of stillage plus feedstock). Cell B27 again uses the mixing formula to compute the target final temperature of the feedstock needed to achieve exactly 115 deg F temperature of the mash after mixing.
- Cells F5 through L173 use the methodology of the solution to compute the temperature of the stillage in the Processing Tank as a function of time (hour of the week). Column G contains the volume of stillage at the beginning of the hour and column H contains the volume of stillage at the end of the hour (after adding in 21.43 gallons). Column I uses equation 6-5 to compute the value of “k” based upon the volume of stillage at the beginning of the hour, and column J uses equation 6-4 and the corresponding value of “k” to compute the temperature of the initial stillage volume through one hour of heat loss to the environment. Column K uses the mixing equation based upon volume (equation 6-2a) to compute the new temperature assuming that one hour’s worth of hot stillage is

added all at once at the end of the hour. Column L uses equation 6-1 to compute the heat loss, from hour to hour, based upon the current mass of the stillage and the temperature loss over the hour.

- Assumptions. Our solution involves an assumption that we can compute the temperature of the stillage in the Processing Tank by assuming that the whole hour's worth of stillage arrives all at once and mixes instantaneously. Since one hour is a small fraction of a week's time, this approximation is good enough for our purposes here. There is also an assumption that the stillage in the Processing Tank at any given time loses heat through the entire surface of the tank. This assumption to close to reality at the end of the week when the tank is pretty full, but is bad at the beginning of the week when there is only a little stillage in the Processing Tank. At the beginning of the week, the liquid stillage is in contact with only a small portion of the tank and is also in contact with the cool air above it in the tank. Loss of stillage heat into the air may be greater than or less than conduction loss of stillage through the tank, so the validity of this assumption is unknown.

  One further assumption is that we can treat the stillage and the feedstock mass as having the specific heat of water (1.0). Since the stillage is stripped beer, it is mostly water and this assumption is good. However, the assumption that the feedstock has the same specific heat as water is probably far from true. The problem is that the feedstock varies so widely in its composition and moisture content that no specific single value is likely to be valid. We use the value for water because we know (from the 2012 Feedstock Processing Experiments) that the temperature of the stillage drops when we add in the feedstock, so we feel that it is better to account for this with an inaccurate assumption rather than not account for it at all.

  Our solution does not account for temperature loss during the 4 hours of cooking the feedstock, nor does it account for any heat loss differences between the Overflow Tank (where stillage accumulates during feedstock processing) and the Processing Tank. All in all, we need an electronically controlled heat exchanger in the Processing Tank to ensure that the feedstock is processed within the correct temperature range. This analysis (with all of these assumptions) is sufficient to estimate the heat exchanger capacity needed and to estimate the amount of product that might be needed to be recycled back to provide the computed amount of heat under worst case conditions.

- Results. The requirement for feedstock processing is that the temperature of the mash be between 115 deg F and 135 deg F. The stillage comes out of the Still Column at 190 deg F and therefore we rely on heat loss to the environment in order to cool the stillage sufficiently, over the course of the week, so that we end up in the correct temperature range. We opt for the final temperature to be too low under worst case conditions, rather than too high, so that we can compensate by adding in heat or insulation, rather than removing heat. However, it should be noted that the Cold Tank requires heat removal, so the latter option is available as a detailed design choice.

Based upon this approach to the problem, we first size the Processing Tank to be about 35% larger than needed to hold 3,600 gallons of stillage. This requires a 7 foot high by 12 foot diameter tank. We next set the ambient temperature to the highest specified value (90 deg F), which gives us the hottest stillage over our specified temperature range. We then set various values of R for Processing Tank insulation in order to provide us with the stillage temperature needed for a mash to be the highest allowed temperature (135 deg F). For these values, R-4 insulation (one inch fiberglass bat) gives us a stillage temperature of 149.21 deg F at the end of a week (cell B23), resulting in a mash temperature of 135.14 deg F after mixing in feedstock at 90 deg F (cell B25). Obviously, no heat needs to be added at an ambient environment temperature of 90 deg F.

Next, we use the same values but change the ambient to the other extreme – 40 deg F (cell B11 of the Overview tab). We now find that the final stillage temperature is 128.81 deg F, resulting in an estimated mash temperature of 107.7 deg F after adding in feedstock at 40 deg F temperature. This temperature is too low and cell B26 computes that *we need to add in 287,255.8 BTU of heat* to bring the mash up to 115 deg F. This is the equivalent to the heat energy contained in (287,255.8 / 76,000 =) *3.8 gallons of ethanol* (at 76,000 BTU per gallon). Of course, we don't add in this large amount of heat all at once. Cell B27 tells us that we need to keep the stillage temperature up above 138.38 degrees F in order to achieve 115 deg F mash after mixing in feedstock. Looking at column L for a temperature above this value shows that *we need about 2,100 BTU per hour to maintain this temperature* (cell L9), albeit this is not constant since the mass of the stillage is always changing. This occurs at hour 4, so we could have to add this amount of heat in for 164 hours for *a total of 344,400 BTU*, which is equivalent to the energy in (344,400 / 76,000 =) *4.5 gallons of ethanol*.

Changing the ambient temperature to 65 deg F with these same values shows that we process the feedstock at a comfortable 121.4 deg F and do not need to add in any heat. If we then go back to an ambient temperature of 40 deg F and change the R-value to 6, we find that we do not have to add any heat to process the feedstock under worst case cold conditions. HOWEVER, at an ambient temperature of 90 deg F, our stillage is too hot. *These results suggest that by simply adding ½ inch of fiberglass batting during the fall and removing it during the spring would save us 4.5 gallons of ethanol per week over the winter months.*

6.3.3 Cold Tank and Refrigeration Unit (Chiller).

- Problem Statement. The wort out of the Processing Tank must be cooled down to below 90 deg F for fermentation. If the wort is too hot, the yeast dies and fermentation does not take place. Additionally, the cooling must take place rapidly in order to reduce the possibility of bacterial infection and wild yeast contamination of the wort. The operational timeline of section 5.4 specifies that the wort must be transferred from the Processing Tank to the Fermentation tank, while simultaneously cooling it, in 2 hours or less. Since the specification for the Integrated Bio-Refinery is that it must operate at ambient temperatures as high as 90 deg F, cooling of the wort by heat conduction to the environment would require a truly massive heat exchanger and would, in all likelihood, take far more time than can be allotted. Forced heat removal (refrigeration) is required.

A large amount of heat must be removed from the wort via refrigeration in a relatively short period of time. It is possible to meet this requirement with a suitably large, industrial- sized refrigeration unit. However, such a unit would be very expensive and would only be required to run 2 hours per week – not a very cost effective approach. The Cold Tank contains a large reservoir of cold liquid which is used to cool down the wort by pumping some of the wort through a heat exchanger in the Cold Tank while bypassing the Cold Tank heat exchanger with the rest of the wort (via a variable bypass valve). The "bypass ratio" is controlled via the bypass valve such that the final temperature of the wort in the Fermentation Tank ends up at approximately 90 deg F. Using this approach, the rest of the week, (168 – 2 =) 166 hours, may be used to cool the Cold Tank liquid back down, resulting in the need for a much smaller (and much more cost effective) refrigeration unit; albeit one that runs for most of the week.

The problem is to size the Cold Tank, specify its insulation needs, size the refrigeration unit, and determine the energy required to cool down the Cold Tank under the full required range of ambient temperature.

- <u>Solution</u>. The design of the heat exchanger in the Cold Tank is beyond the scope of this document. However, this heat exchanger is assumed to be large enough (have a large enough surface area and a very low R-value) so that heat exchange between the wort and the Cold Tank liquid is very rapid. If we assume that the heat is fully exchanged in the time that it takes for the wort to flow through the Cold Tank heat exchanger, then over a small interval of time (e.g. 1 minute out of a 2 hour total flow time), the temperature of the wort exiting the Cold Tank is close to that of mixing the two liquids – wort and Cold Tank liquid. We make this assumption and use the mixing formula (equation 6-2 or 6-2a) to determine the temperature of the wort after passing through the Cold Tank at each minute of the transfer. Since some of the wort bypasses the Cold Tank, we use the mixing formula again to determine the temperature of the liquid accumulating in the Fermentation Tank for each minute of the two hour (120 minute) transfer of wort from the Processing Tank to the Fermentation Tank. We manually adjust the ratio of wort passing through the Cold tank to wort bypassing the Cold Tank (the "bypass ratio") until we achieve the desired 90 deg F Fermentation Tank temperature at the end of the transfer. Knowing the bypass ratio allows us to then calculate the mass of wort that was transferred through the Cold Tank and thus calculate the final temperature of the liquid in the Cold Tank. Assuming that the Cold Tank liquid is water, we can use equation 6-1, with specific heat of 1.0, to determine how many BTUs of heat we must remove from the Cold Tank over the next 166 hours in order to prepare the Cold Tank to receive the next week's batch of wort to cool. This value can then be converted to tons of refrigeration and, using the Coefficient of Performance (COP)[7] for the refrigeration unit, we can calculate the energy required to run the refrigeration unit, per weekly batch of ethanol production.

The worst case scenario for the Cold Tank is, clearly, the highest possible environmental temperature (90 deg F), since this is the temperature that the wort exiting the Processing Tank is the highest. In addition, this is also the worst case for heat removal from the Cold Tank after wort transfer, because the environment wants to transfer heat into the Cold Tank rather than help to remove heat from it. Obviously, we need to provide a lot of insulation (high R-value) on the Cold Tank in order to minimize environmental effects. We use an approximation to the differential equation of section 6.1.3 to compute the heat loss/gain each hour due to the environment[8] and add to this the heat removed by the refrigeration unit in order to obtain the net heat flow out of the Cold Tank while it is cooling down.

We assume that the Cold Tank liquid is water or brine at 40 deg F. The reason for this choice is discussed in "Assumptions", below.

- <u>Worksheet details</u>. This complex problem is divided between two worksheets. The "Cold Tank – XChange" tab of the Excel Workbook is used to manually determine the Cold Tank bypass ratio (user setting in cell B20) such that the final Fermentation Tank temperature is very close to 90 deg F. This tab computes the final Cold Tank temperature based upon the bypass ratio and computes how much heat must be removed from the Cold Tank over the intervening 166 hours in order to restore the Cold Tank temperature back to its nominal value of 40 deg F. The "Cold Tank – Cool" tab is used to determine the refrigeration and cooling energy requirements for the Cold Tank Chiller in order to return the Cold Tank to the initial temperature required at the beginning of a new weekly batch, as set by the user in cell B14.

  Looking first at the "Cold Tank – XChange" tab:

  - The table for computing the heat exchange resulting in the temperature of liquid in the Fermentation Tank is in cells E5 through O124. Column E contains the time interval, in one minute increments, over the two hour (120 minute) total transfer time allowed by the operational analysis (section 5.4 of this document). Cell F5 begins the

[7] http://en.wikipedia.org/wiki/Coefficient_of_performance

[8] This approximation makes the assumption that the heat loss due to conduction to/from the environment is very small for each one hour period of the week. Thus, the differential reduces to a difference (heat gain or loss) where the time interval is one hour and the temperature difference is constant.

calculations using the user input target initial Cold Tank temperature from cell B15. Cell G5 computes the temperature of the Cold Tank one minute later using the mixing formula based upon mass (equation 6-2). Cell F6 then uses this as the starting Cold Tank temperature for the next minute interval and cell G6 re-computes the Cold Tank temperature one minute later, again using the mixing formula (equation 6-2). These calculations proceed down columns F and G to the bottom (minute 120) of the table.

- Columns H, I, J, and K accumulate the mass and volume in the Fermentation Tank as time proceeds, using calculated values in cells B22 and B23 which are based upon the mixing ratio that the user enters in cell B20, and the mass to volume constant in cell B2 (carried forward from the Overview worksheet).
- Column L computes the total volume in the Fermentation Tank by adding the accumulated volume through the Cold Tank (column I) with the accumulated volume bypassing the Cold Tank (column K). Column M computes the accumulated temperature of the liquid in the Fermentation Tank that came through the Cold Tank, and column N picks up the temperature of the Fermentation Tank liquid that bypassed the Cold Tank (from cell B11, which is carried over from the Processing Tank final wort temperature calculation). The mixing formula is applied, once more, to the mixing of Cold Tank and bypassed liquid in the Fermentation Tank to arrive at the overall temperature of the wort in the Fermentation Tank, in column O.
- Cells B2, B3, B4 and B7 contain constants carried over from the Workbook Overview tab. Cell B11 contains the wort temperature into or bypassing the Cold Tank, as carried over from the Processing Tank worksheet.
- The user enters the height and diameter of the Cold Tank in cells B8 and B9, and the total volume of wort to be transferred from processing Tank to fermentation tank in cell B10.
- Cells B12 and B13 accept user input for the desired ending temperature of the wort in the Fermentation Tank (nominally 90 deg F) and the total transfer time allowed (2 hours). Cell B14 contains the user entry for the number of gallons of cooling liquid in the Cooling Tank. We have assumed 4,000 gallons is used in a tank that can hold almost 6,000 gallons (computed in cells B17 and B18), leaving room for a large heat exchanger in the tank. Cell B15 contains the user-specified starting temperature of the Cold Tank liquid, nominally 40 deg F.
- Cell B16 contains the user provided value for the coefficient of performance (COP) of the refrigeration system. The COP specifies how much heat energy is moved given a certain amount of mechanical energy to the refrigeration unit. A typical COP value for a refrigeration system is 2 (two units of heat moved for every one unit of energy input). The actual value would be provided by the manufacturer of the chosen system.

- Cell B19 computes the flow rate of wort out of the Processing Tank and into the Fermentation Tank based upon the total volume of wort and the 2 hour time period. Cell B21 computes the mass of the Cold Tank liquid, based upon its volume and unit weight (assuming water). Cells B22 and B23 compute the mass flow rate of wort through and bypassing the Cold Tank, using the bypass ratio that the user specifies in cell B20.
- Cells B24 and B25 capture the final Fermentation Tank wort temperature and the final Cold Tank liquid temperature after the 2 hour transfer period, based upon the calculations in the table E5 – O124. The mass of the Cold Tank liquid (water) is computed in cell B26 and cell B27 uses equation 6-1 to compute the total heat that must be removed from this mass over the next week (166 hours) in order to restore the Cold Tank liquid back from its final value to the desired original value (cell B15).
- Cell B30 is a check on the calculation in B27. B30 computes the heat lost in the wort (using equation 6-1) for comparison with the heat that was gained (must be removed) in the Cold Tank. These two values should be close (heat in must equal heat out), but are not exact owing to the discrete steps used in the table calculation.

Looking now at the “Cold Tank – Cool” tab:

- The table in cells E4 through J 170 computes the temperature drop in the Cold Tank over a 166 hour period. Column B is an hour by hour listing. Column F starts off (in cell F5) with the temperature in cell B12 which is carried over from the “Cold Tank – XChange” worksheet as the final temperature of the Cold Tank liquid. It then uses the hourly temperature drop computed in column J to accumulate the hourly temperature of the Cold Tank over the week (166 hour) period. Column G uses equation 6-3 (approximation to the differential using a one hour period) to compute the approximate heat loss/gain from the Cold Tank due to the environment, and column H lists the constant heat removal due to refrigeration using the fact that one ton of refrigeration removes 12,000 BTU per hour[9]. Column I totals columns G and H to determine total heat loss over each hour of the week. Finally, column J uses equation 6-1 to compute the temperature drop due to this total heat removal, at each hour period of the week.
- Cells B2 through B6 are constants, carried forward from the Overview tab. Cell B13 is the ambient temperature, also carried forward from the Overview tab.
- Cells B10, B11, B12, and B15 are carried forward from the “Cold Tank – XChange” tab.

[9] http://en.wikipedia.org/wiki/Ton_of_refrigeration

- Cell B9 contains the user specified R-value of the insulated Cold Tank. We assume a very well insulated tank for this analysis (R = 20). This is equivalent to 5 inches of fiberglass bat.
- The user enters desired values into cells B14 and B16, the same as for the “Cold Tank – XChange” tab.
- Cells B17 through B24 are calculated values, as explained for other worksheets in this workbook.
- The user enters the tons of refrigeration in cell B25. This value is iterated until the final Cold Tank liquid temperature, cell F170, gets close to the desired Cold Tank initial value.
- Cell B26 computes the BTU per hour removed based upon the tonnage of the refrigeration unit and cell B27 uses the COP to determine the power required to run this size refrigeration unit (in Kw). Cell B28 then multiplies B27 by the total number of hours (166) to compute the energy (in KwH) required to run the refrigeration unit. Cell B29 converts this energy to equivalent gallons of ethanol, at 76,000 BTU per gallon. *Note, however, that this is a grossly unfair calculation, as the conversion of heat energy to mechanical energy involves thermodynamic losses (entropy losses) which are not accounted for here. This is discussed further in the Results section*.
- Cell B30 simply copies the final temperature value of the Cold Tank from cell F170.

▪ <u>Assumptions</u>. We assume that the Cold Tank liquid is water or brine at 40 deg F. Clearly, the colder the liquid in the Cold Tank, the faster and more efficiently heat is removed from the wort. The choice of 40 deg F is a compromise that allows us to use water without freezing. Freezing could improve the Cold Tank efficiency due to the fact that latent heat of fusion (melting) is higher than sensible heat. However, phase changes (freezing) incur other complexities, such as large density changes and mechanical stress on the components. The Cold Tank base temperature could be colder without a phase change using brine or another liquid with a lower freezing temperature than water. However, brine is corrosive and use of other liquids might incur logistical and cost issues.

This analysis relies on the mixing equations (equations 6-2 and 6-2a) to compute heat exchange. Actual mixing exchanges heat through convection. The Cold Tank heat exchange process does not involve mixing liquids but rather heat exchange through a heat exchanger (conduction). The rate of heat exchange differs significantly between these two methods. However, the result, <u>given enough time for complete heat exchange</u> by either convection or conduction, is the same. The final temperature is always determined by the mass ratios (given the same specific heat for both fluids). In this analysis, we assume that the Cold Tank contains a heat exchanger that is very large; i.e. it has a very low R-vale (e.g. copper or aluminum pipe) and a very high surface area (e.g. a radiator design with large fins to vastly increase the surface area for rapid heat exchange). The design of the heat exchanger is beyond the scope of this analysis, but it is assumed here that the heat exchanger is large enough to achieve the final temperature (based upon the mixing formula) in the time that the wort passes through the Cold Tank.

The "Cold Tank – Cool" calculations in column G assume that the temperature of the Cold Tank liquid is constant over each hour that it loses or gains heat to/from the environment (so that we don't have to solve a differential equation for conductive heat loss). In point of fact, with a well insulated tank, the heat loss/gain due to the environment is very small, given a reasonably large R-value. It is much smaller than the heat removal by the refrigeration unit (Chiller) – compare columns G and H. In any event, the temperature change of the liquid in the Cold Tank due to both heat conduction to the environment and heat removal via refrigeration is less than 0.3 degrees in any given hour, so the assumption of constant temperature difference between the Cold Tank liquid and the environment in any given hour is very close to reality.

- Results. The worst case for the Cold Tank is the highest ambient temperature which is 90 deg F. This is because the heat loss of the stillage into the Processing Tank is the lowest and thus the wort temperature after processing is the highest. The higher the wort temperature, the more heat must be removed from the wort in order to bring the wort temperature in the Fermentation Tank down to the target of 90 deg F. Setting the ambient temperature to 90 deg F on the Overview tab, we go to the "Cold Tank – XChange" tab and determine that we need to enter a bypass ratio of 65% (cell B20) in order for the final wort temperature (cell B24) to be close to 90 deg F. This means that 65% of the wort will follow through the Cold Tank and 35% will bypass the Cold Tank. The "Cold Tank – XChange" tab also tells us that the final Cold Tank liquid temperature will be 85.66 deg F (cell B25) and that the heat that must be removed to restore this fluid to 40 deg F is approximately 1.5 million BTUs (cell B27), or 9,175 BTU/hour (cell B28). Now that we know our refrigeration requirement, we go to the "Cold Tank – Cool" tab and find that we need 0.83 tons of refrigeration (9,960 BTU/hour) to get the Cold Tank liquid temperature back under 40 deg F in 166 hours. We compute this to require 242 KwH of electricity (cell B28), or the equivalent energy to 10.88 gallons of ethanol.

  As mentioned in the Worksheet details discussion, the conversion of KwH (electrical energy, which is approximately the amount of mechanical energy needed for cooling) to BTUs and then to gallons of ethanol is unfair because entropy losses are not accounted for. Entropy losses are significant: a typical gasoline car engine is only about 25% efficient at converting heat from burning fuel into mechanical energy. If we ran our refrigeration unit off of a highly efficient gas turbine engine optimized for ethanol burning, we might achieve a thermodynamic efficiency of 60% or possibly 70%, but this type of engine could be very pricey. It probably makes more sense to use electricity to run the refrigerator (that is what most are designed for), assuming that electricity is available. If electricity costs $0.10/KwH and we calculate that we need 242 KwH (cell

B29), then the electricity needed for the Cold Tank process will cost us $24.20 per week. If retail gasoline costs $3.60/gallon and ethanol returns 2/3 of the heat energy, then a gallon of ethanol is worth ($3.60 * 2/3 =) $2.40. Thus, we "invest" about 10 gallons of ethanol by returning it to the Co-Op members and use this extra ethanol value to buy the electricity needed for the worst case of the Cold Tank process. It is on this basis that we feel comfortable is saying that the Cold Tank process requires an equivalent of 10.88 gallons of ethanol.

Another way of looking at the refrigeration energy costs is that we are nominally producing 400 gallons of ethanol per week, and we are investing $24.20 per week for the necessary cooling. Therefore, the cost per gallon of ethanol produced for the Cool Tank process is, in the worst case situation, (400 / $24.20 =) 16.5 cents per gallon.

For completeness, we run our analysis at ambient temperatures of 40 deg F and 65 deg F. At 40 deg F ambient, the temperature of the wort is 115 deg F and we iterate on the bypass ratio (cell B20 of "Cold Tank – XChange") and find that a bypass ratio of 41% gives us a final wort temperature in the Fermentation Tank of 89.89 deg F (cell B24) and that we must remove only 846,154 BTUs in the next week (cell B27), or 5,097 BTU per hour. Going to the "Cold Tank – Cool" tab with this in mind, find that 0.4 tons of refrigeration (cell B25) cools the Cold Tank down to 39.96 deg F in 166 hours (cell F170) and this is the equivalent to 5.24 gallons of ethanol (cell B29), on the same basis as discussed above. Of course, we won't actually put in a smaller refrigeration unit; rather, we will run it for fewer hours per week. The energy calculation is the same.

At 65 deg F ambient, the temperature of the wort is 121.42 deg F (cell B11) and we iterate on the bypass ratio (cell B20 of "Cold Tank – XChange") and find that a bypass ratio of 50% gives us a final wort temperature in the Fermentation Tank of 89.56 deg F (cell B24) and that we must remove 1,074,014 BTUs in the next week (cell B27), or 6,470 BTU per hour. Going to the Cool tab with this in mind, find that 0.56 tons of refrigeration (cell B25) cools the Cold Tank down to 39.88 deg F in 166 hours (cell F170) and this is the equivalent to 7.34 gallons of ethanol (cell B29), on the same basis as discussed above.

This Cold Tank analysis assumes the same size tank as used for Fermentation and Processing and about 4,000 gallons of water is used as the cold storage medium. In the worst case (ambient 90 deg F), this Cold Tank fluid heats up to 85.66 deg F and in the best case (ambient 40 deg F), this Cold Tank fluid heats up to 65.36 deg F. Since the rate of heat exchange is proportional to temperature difference, and we desire a final wort temperature of 90 deg F, the worst case is going to have a very low rate of heat exchange at the end of the transfer from Processing Tank to Fermentation Tank. Although we are assuming that the heat exchanger in the Cold Tank is large enough to accommodate this, it could certainly be smaller if the Cold Tank was larger and had more liquid in it. Additionally, a smaller heat exchanger would be needed if the initial Cold Tank temperature was lower than 40 deg F, i.e. if we chilled brine down to say 10 deg F. The cost of the Cold Tank size vs. Cold Tank heat exchanger cost is beyond the scope of this document but should be considered in the detailed design of an actual Integrated Bio-Refinery based upon the conceptual design analyzed in this document.

6.3.4 *Still.*

- Problem Statement. Distillation requires energy. The beer is vaporized so that the vapors can ascend the distillation column and mix (on plates or packing) with liquid descending the column, due to gravity. Each mixing (each plate or each unit of packing) results in further separation of the substances in the beer. The energy needed to vaporize the beer consists of "sensible heat" to raise the beer to its boiling point and then "latent heat" to effect the phase change from liquid to vapor. The distillation process relies on the fact that the substances to be separated (ethanol and water, in this case) have different latent heat of vaporization per unit (mole, mass, or volume). In the case of alcohol distillation, the ethanol has a much lower latent heat of vaporization than does water, so each time a mixture of ethanol and water is vaporized, the ethanol content of the vapor is higher than the ethanol content of the liquid mixture prior to vaporization.

  Vaporization energy is supplied by a boiler, or "re-boiler". Commonly used energy sources are electricity and natural gas. However, we assume that the Still in the Integrated Bio-Refinery has an ethanol burner that uses ethanol distilled and collected on previous weekly batches. The problem is to calculate the energy needed for distillation based upon the Integrated Bio-Refinery concept model described in this document.

- Solution. The Still design chosen is a continuous still, based upon designs and analysis by Curbie. Curbie has generously supplied his time and analytical tools to the specific parameters of the Integrated Bio-Refinery being analyzed in this document. The results, below, are thanks to him.

  A continuous still has two column sections (usually stacked vertically), and a re-boiler supplying the heat energy at the very bottom. The beer is introduced at the level between the two column sections. The lower section is called the stripping section and consists of a series or plates or packing that progressively (down the column) strips ethanol from the beer. The liquid that falls to the bottom of the stripping section is re-boiled to send vapor up the column, including vapor that mixes with the liquid beer introduced above the stripping section.

  The rectifying section is above the point of beer entry into the distillation column. Vapors ascending the stripping section and boiling the beer further ascend the column to the top. At the very top of the column, a condenser cools the vapor back to its boiling point (dew point) so that it liquefies and sends liquid (mostly ethanol at this point) back down the column. At each plate (real or theoretical) in the column, liquid flowing down the column mixes with vapor flowing up the column and heat is exchanged between them due to mixing. When the still column is in equilibrium, a stable temperature gradient exists going up the column where the temperature at each plate is the boiling point of the mixture of ethanol and water at that point in the column. The lowest point in the column is essentially at the boiling point of water (212 deg F at 1 atm pressure), and the column design is such that the temperature gradient would have the top of the stripping section be at the boiling point of the beer. This is why the new beer flowing into the column boils. The ethanol content further improves going up the rectifying section until it is at or very near the azeotrope (boiling point approximately 173 deg F at 1 atm pressure) at the condenser at the top of the column. It is at this point that the vapor is condensed back to liquid and most of the liquid is returned back down the column as "reflux" while a small percentage may be taken off as the fuel ethanol product.

The still column must be very well insulated, so that the only place where heat is removed is in the condenser[10]. After the column is in equilibrium, it cannot store any more heat (else it would not be in equilibrium) and all of the heat (all of the latent heat, at any rate) must be removed by the condenser, owing to conservation of energy. The condenser is usually a coil of pipe or tubing with a very low R-value (e.g. copper tubing). Curbie's continuous still design pumps cold beer through the condenser to absorb the latent heat, heating up the beer in the process. By equation 6-1, the maximum temperature that the liquid beer in the condenser can attain is the boiling point of the vapor. At that point, delta T is zero, thus the heat removed is zero. The condenser is designed so that the tubing length and flow rate can condense all of the vapor back to liquid, thus removing all of the latent heat. The temperature of the beer exiting the condenser, therefore, is near the boiling point of the product – near 173 deg F for azeotropic distillation. The process of using cold beer (beer in the beer tank at ambient temperature) in the condenser recycles some of the energy input to the still column back into sensible heat, but the temperature is too low to boil the beer.

Ethanol distilled to near azeotrope exits the top of the still column. Therefore, everything else (mostly water, but also any sediment, dissolved solids and liquids with boiling points higher than the azeotrope) falls back down the column and exits the bottom of the still column as "stillage". This is a consequence of conversation of mass, because there are no other exit points from the column but the top and the bottom, and the full mass of the original beer input to the column must exit somewhere (except the finite volume retained in the column). At equilibrium, the column is saturated and can retain no more mass. The stillage is at or very near the boiling point of water (212 deg F at 1 atm pressure),

[10] Depending upon still head design, there may be two condensers, one for the product and the other for the reflux, or a single condenser for both. As used here, the term "condenser" is the sum of all condensers in the actual still design.

carrying with it the latent heat that was input to the still column minus the latent heat that was carried away in the condenser (once more, owing to conservation of energy).

Curbie's still design takes the hot beer exiting the condenser and uses a high efficiency heat exchanger to transfer some of the heat in the stillage to the already hot beer. This additional heat can be exchanged because the temperature of the stillage is higher than the temperature of the beer exiting the condenser. The volume of the stillage is approximately 87% to 93% of the beer flowing through the heat exchanger at any given time, because the beer (which then feeds the column) is between 7 % (100% - 7% = 93%) and 13% (100% - 13% = 87%) alcohol by volume. As a consequence of the mixing equation 6-2a, the stillage can be expected to exit this heat exchanger at approximately 190 deg F, and the beer exiting the same heat exchanger is also at this temperature (approximately 190 deg F). There are two consequences to this fact:

- The beer entering the still column is close to its boiling point, so that the re-boiler energy requirement is mostly the energy needed to vaporize it (latent heat requirement) and only a little extra energy needs to be supplied to actually raise it to its boiling point (sensible heat). Curbie uses these facts to compute the heat requirement for the re-boiler.
- The stillage exiting the column carries with it most of the energy that was supplied by the re-boiler, which is substantial. However, this energy is at a temperature of approximately 190 deg F and is therefore limited in what it can be used for. It cannot, for example, be used to boil a mash, as the boiling point of a starch and water mash is at or above the boiling point of water (which is higher than the temperature of the stillage). However, the 2012 Feedstock Processing Experiments result that stale bakery waste can be successfully cooked at only 115 deg F allows us to reuse this energy to cook the mash. The fact that the stillage must be further cooled (see Processing Tank thermodynamic analysis, section 6.3.2 above) means that there is more than enough energy in the stillage to perform the feedstock cooking. This is the very basis for the Integrated Bio-Refinery concept – that the energy necessary to distill the beer may be recycled so that no further energy input (in theory) is required to process the feedstock to produce ethanol.

The actual calculations have been performed by Curbie as a contribution to this design. The results are presented below.

- <u>Assumptions</u>. The major assumption in Curbie's still design (in fact all still designs) is that the still column is very well insulated. A still column that is insufficiently well insulated will lose measurable heat to the environment and thus be unable to maintain equilibrium. Given this assumption, there is no impact on the thermodynamics of the Still from the large ambient temperature range that has been specified for the Integrated

Bio-Refinery (40 deg F to 90 deg F). There is, however, an impact on the Still performance due to the variation in the beer. This is discussed in the Results section, below.

There is an additional assumption that the beer contains only ethanol and water. In reality, there are other volatile substances (e.g. methanol, aldehydes, fusil oils) in a beer resulting from fermentation. The relative quantities of the substances are small, however, and experience says that they can be ignored, at least as far as thermodynamic calculations are concerned.

The beer inevitably contains some solids, both soluble and non-soluble (sediment). The Lees Filter is responsible for removing most of the sediment. It is assumed that the remaining sediment, as well as any soluble solids (that cannot be removed by the Lees Filter), do not interfere with the operation of the distillation column. Real world experience says that this is true, for a well designed column with the right packing material, and under the assumption that the column is cleaned according to a periodic preventive maintenance schedule. The operational analysis for the Integrated Bio-Refinery assumes 2 downtime periods per year for periodic maintenance activities, including taking apart the still column for cleaning of the packing. It is assumed, but has not been verified, that this semi-annual cleaning is sufficient. This assumption needs to be accounted for in the detailed design and fabrication of the Still.

- <u>Results</u>. The thermodynamic and functional analysis of the Still has been performed by Curbie, using the flow rate specifications and beer concentration range for the Integrated Bio-Refinery presented in document. The worst case for distillation rate and energy is the lowest specified beer concentration – 7% for this concept model. The lower the ethanol content of the beer, the more energy required to distill it. Curbie has calculated that a continuous still to meet the specifications for the Integrated Bio-Refinery must use 6.75 Kw of heating, or 23,047 BTU per hour. This requires a 7% abv beer flow rate into the still of 27.09 gallons per hour and a fuel ethanol production rate of 1.8 gallons per hour – both slightly above what is needed for continuous Integrated Bio-Refinery operation. The still column diameter needs to be 4.8 inches, supporting a vapor velocity of 17 inches per second up the column.

  Higher ethanol concentrations can either reduce the re-boiler power or can decrease the flow rate at the same (6.75 Kw) power. It is usually simpler to change the flow rate than to change the re-boiler power. At 13% abv and the same 6.75 Kw re-boiler power, the beer flow rate needs to be reduced to 23.25 gallons per hour, but the product production rate raises to 2.87 gallons per hour, owing to the higher ethanol concentration of the beer. At the nominal 10% abv and the same 6.75 Kw re-boiler power, the beer flow rate into the column needs to be 25.24 gallons per hour and the resulting fuel production rate is 2.4 gallons per hour. These settings always produce a 17 inches per second vapor velocity rate inside the still column, needed for efficient distillation. The following table summarizes the results of this analysis (using 168 hours per week):

% abv of beer	Beer flow rate (gal/hr)	Total beer flow per week (gal)	Product production rate (gal/hr)	Product produced in a week (gal)
7%	27.09	4551	1.8	302
10%	25.24	4240	2.4	403
13%	23.25	3906	2.87	482

The amount of stillage produced (used for the next batch) is the difference between the beer flow in and the product out, as follows:

% abv of beer	Stillage Flow Rate (gal/hr)	Total Stillage (gal)
7%	(27.09 – 1.8 =) 25.29	(25.29 * 168 =) 4249
10%	(25.25 – 2.4 =) 22.80	(22.80 * 168 =) 3830
13%	(23.25 – 2.87 =) 20.38	(20.38 * 168 =) 3424

There are 3,414 BTU per hour per Kw. 6.75 Kw * 168 hours per week = 1,134 KwH per week, or (1,134 * 3,414 =) 3,871,476 BTU required per week to run the still. At 76,000 BTU per gallon of ethanol, we need (3,871,476 / 76,000 =) *51 gallons of ethanol per week to run the Still*. At a nominal fuel production rate of 403 gallons per week (10% abv), this represents (51 / 403 =) 12.7% of the fuel produced is needed to distill it.

6.3.5 Summary of Energy Requirements of the Integrated Bio-Refinery.

As stated at the beginning of section 6, the purpose of the thermodynamic analysis is three-fold:

a) To validate the concept model; specifically, to validate that the energy content of 20% of the production is sufficient to provide all of the energy needed to process each batch of feedstock.

b) To provide a starting point for the detailed design and fabrication of an Integrated Bio-Refinery system.

c) To provide a set of tools for analyzing and optimizing the detailed design and operation of an Integrated Bio-Refinery system to process stale bakery product waste into ethanol.

The analysis of section 6.3 can be summarized as follows:

1) Distillation requires 3,871,476 BTU per week which can be supplied by 51 gallons of ethanol. At a nominal weekly production of 403 gallons of fuel ethanol (nominal 10% abv beer), 12.7% of the previous week's production is used for fuel distillation of the next week's production.

2) With just a little attention to adding/removing wrapped insulation in the spring and fall, no further heat is required to process the feedstock. Heat from distillation can be recycled, via the stillage, to cook the feedstock.

3) Extra energy input is needed owing to the need for rapid cooling of the wort. There is plenty of excess energy available from heat removal from the still column, however this temperature (nominally 190 deg F) is too low to be used for cooling. Cooling requires forced heat transfer against the natural tendency of heat to flow from high to low temperature. Methods for doing this require either thermo-mechanical or thermo-electrical action, and both of these require much higher temperatures (than 190 deg F) to have any reasonable thermodynamic efficiency. The Cold Tank process therefore invests another 10.8 gallons of fuel ethanol per week, or (10.8 / 403 =) 2.7% of the nominal fuel ethanol weekly production. Thus, the total weekly investment of fuel ethanol is 62 gallons or (62 / 403 =) 15.3% of production. *This is significantly less than the assumed 20% (80 gallons) and therefore validates the thermodynamics of the operational concept model for the Integrated Bio-Refinery*. Another (80 – 62 =) 18 gallons of ethanol per week, which equals (18 * 76,000 =) 1.37 million BTUs of heat energy per week, is available for other uses, such as facility electricity, pumping energy, or transportation uses and still meet the 20% re-investment assumption.

4) Sizing parameters and insulation needs of various tanks and the still column have been used in this analysis and provide a starting point for the detailed design of an actual Integrated Bio-Refinery based upon the operational concept model presented earlier in this document. The actual sizes and shapes and other attributes of these components will largely be driven by what can be purchased off-the-shelf to help reduce fabrication needs and costs. These parameters can be adjusted as needed on the Excel Workbook in order to keep the entire Integrated Bio-Refinery consistent with this design and with the fuel re-cycle assumption of < 20% per week.

5) The Excel Workbook can also be used to scale the Integrated Bio-Refinery to larger or smaller sizes, depending upon the particular needs of an Urban Fuel Co-Op.

6.4 Throughput Analysis of the Integrated Bio-Refinery.

Section 6.3, above, analyzed and validated the thermodynamics of the Integrated Bio-Refinery concept model that was presented in section 5 of this document. The thermodynamic analysis also provides a starting point for the specification of the individual components of the Integrated Bio-Refinery; specifically those components where heat exchange takes place (intentionally or otherwise). This section analyses the throughput needs for the same Integrated Bio-Refinery concept model as a starting point for the specification, design and selection of the various other components, such as pumps and filters.

6.4.1 Stillage Pump and Overflow Tank.

The Still contains a "Stillage Pump" to move the stillage from the bottom of the distillation column out to the Processing Tank through the Overflow Tank. Still design data from Curbie (section 6.3.4) computes the maximum stillage flow rate out of the Still at 25.29 gallons per hour, or (25.29 / 60 =) 0.42 gallons per minute. Since one gallon is equivalent to 0.13368 cubic feet, the flow rate can be expressed as (0.42 * 0.13368 =) 0.056 cu-ft per minute. Note that the Stillage Pump must handle liquid at approximately 190 deg F.

The Stillage Pump needs to pump the stillage uphill; at least above the height of the Processing Tank in order to fill the latter. The Overflow Tank location is not specified in the Integrated Bio-Refinery concept model. One possibility is that the Overflow Tank is located higher than the Processing tank so that the Stillage Pump pumps stillage into the top of the Overflow Tank, which then drains into the Processing Tank by gravity. The Overflow Tank is not very large – it only has to buffer the stillage while the Processing Tank is in use making and cooking the mash (and cleaning after cooking is complete). If the Overflow Tank is sized for 6 hours flow at the maximum rate (25.29 gallons per hour), it needs to hold only (25.29 * 6 =) 152 gallons, or (152 * 0.13368 =) 20.3 cubic feet. A 2 foot diameter tank would need to be less than 2 feet tall to handle this volume. Given a 7 foot tall Processing Tank and allowing for 1 foot between the two tanks (for the Shutoff Valve), we can assume that the Stillage Pump needs to pump the stillage uphill 10 feet.

A 10 foot high column of water is (10 * 12 =) 120 inches high. 120 cubic inches of water weighs 4.34 lbs (http://www.onlineconversion.com/waterweight.htm); therefore it exerts a pressure of 4.34 psi. Add atmospheric pressure (14.7 psi at 1 atm) and pump has to be rated for (4.34 + 14.7 =) 19 psi.

6.4.2 Wort Pump.

The Wort Pump pumps wort from the Processing Tank through the Cold Tank and bypass and into the Fermentation Tank. The largest volume of stillage is 4,249 gallons (per section 6.3.4). The volume increases with the mass of the feedstock. Adding 35% for feedstock (an assumption) gives us a total liquid volume to pump of (4249 * 1.35 =) 5,736 gallons. The allocated transfer time is 2 hours; hence the Wort Pump must be capable of transferring (5,736 / 2 =) 2,868 gallons per hour or (2,868 / 60 =) 48 gallons per minute, or (48 * 0.13368 =) 6.4 cubic feet per minute. This is a rather large pump!

The Wort Pump must pump the wort up a total distance that is the height of the Fermentation Tank, or at least 7 feet. Allowing an extra foot (total height of 8 feet = 96 inches), we compute the pressure of the wort at 3.5 psi, assuming that the wort weighs the same as water. In fact, the wort probably weighs more than water, so we should make an allowance for this and assume 5 psi. Adding to this atmospheric pressure at 14.7 psi gives us a requirement that the pump pressure specification be at least (14.7 + 5 =) 19.7 psi.

6.4.3 Beer Pump and Lees Filter.

The Beer Pump pumps fermented beer from the Fermentation Tank through the Lees Filter and into the Beer Tank. The operational timeline (section 5.4) allows a total of 4 hours to this transfer, including time for cleaning and sterilizing the Fermentation Tank. Since the Wort Pump is required to pump a similar amount of liquid a similar vertical height in two hours, the Beer Pump would likely be the same as the Wort Pump.

The one wildcard in this analysis is the Lees Filter. The 2012 Feedstock Processing Experiments encountered a lot of difficulty in removing insoluble sediment (lees) from the wort. This material should be well filtered out before the beer is sent into the still column in order to prevent clogging the Still. Several approaches to the Lees Filter have been considered, but no particular one has been selected at this time:

a) The most effective approach would appear to be a centrifuge decanter. These devices operate continuously to remove solids via centrifugal force that is thousands of times higher than the force of Earth's gravity. Centrifuge decanters appear to be highly effective at this task and don't require filter material; however, they are very expensive. A centrifuge decanter would impose no further requirements on the Beer Pump.

b) A less expensive approach to using centrifugal force would be a centrifugal filter. Such a filter uses centrifugal force to push liquid through a paper or cloth mesh filter (much in the way that washing machines spin water out of clothing). Such a filter could operate in either continuous or batch mode. Possible clogging of the filter material is an issue to be investigated further. A centrifugal filter would likely impose no further requirements on the Beer Pump.

c) Another approach to the Lees Filter is to use a drum filter. A drum filter uses a large rotating drum to agitate the beer as it passes through a paper or cloth mesh filter, hopefully avoiding clogging the filter material. The 2012 Feedstock Processing Experiments taught us that the filter material clogs up easily with the silt of the lees. Since the drum filter relies on gravity to separate the solids from the liquid through a filter, and the force of gravity is much weaker then centrifugal force of the previous approaches, it is unknown how much valuable beer would be left behind the filter mixed with the sold material. A drum filter might require that the Beer Pump raise the beer up a few feet higher so that gravity can be used to pull the beer through the filter and into the Beer Tank.

d) The last approach considered is a simple gravity filter. This notion was proposed by Curbie based upon the observation (from the 2012 Feedstock Processing Experiments) that the lees settle to the bottom of the Fermentation Tank during fermentation, leaving the top half (or more) of the beer relatively clean and clear. The idea here is to siphon or pump (decant) the clear beer directly from the Fermentation Tank into the Beer Tank and then pump the bottom part, which is heavy with sediment, into a gravity driven filter and let gravity supply the force to slowly filter the clear beer out of the sediment without any agitation. The force of gravity is weak (compared to centrifuges) and this process will take a significant amount of time. However, the clear beer that was decanted off the top of the Fermentation Tank is good for at least half of the week, allowing 3.5 days for the rest of the beer to be filtered. This filtration approach is the least expensive but it is unknown how well it works nor how much valuable liquid is left behind in the process. The gravity filter would require that the Beer Pump raise the beer up a few feet higher so that gravity could be used to pull the beer through the filter and into the Beer Tank.

6.4.4 Still Feed Pump.

The Still Feed Pump pumps beer from the Beer Tank into the Still Column. The feed rate must be calibrated to the Still based upon the alcohol concentration of the beer. Section 6.3.4 lists the required feed rates for Curbie's continuous still for 7%, 10% and 13% beer. The highest beer flow rate is 27.09 gallons per hour (7% abv), or (27.09 / 60 =) 0.45 gallons per minute, or (0.45 * 0.13368 =) 0.06 cubic feet per minute.

Since the Beer Tank is large, we assume that it is not elevated. Thus the Still Feed Pump must lift the beer from ground level up to the level of the beer feed into the still column. This level is typically half way up the column and the column is approximately 21 feet tall. Thus the beer feed pump must lift the beer 11 feet at the maximum feed rate. Beer weighs a little less than water – we will use the weight of water to compute the pressure. 11 feet is (11 * 12 =) 132 inches and 132 cubic inches of water weighs 4.8 lbs (http://www.onlineconversion.com/waterweight.htm); thus the pressure of the beer is 4.8 psi. Adding atmospheric pressure (14.7 psi), the Still Feed Pump must exert a pressure greater than (4.8 + 14.7 =) 19.5 psi.

6.4.5 Feedstock Grinder/Shredder.

The Feedstock Grinder/Shredder must grind up 9,360 lbs of feedstock in less than 2 hours. Therefore, it must process at least (9,360 / 2 =) 4,680 lbs per hour. An estimate of the feedstock volume was given in section 4.4.2 at 655 cubic feet. Therefore, the Feedstock Grinder/Shredder must process at least (655 / 2 =) 328 cubic feet per hour of stale bakery waste.

6.5 Control, Monitoring and Automation.

6.5.1 Introduction.

The operational concept for the Urban Fuel Co-op has limited human participation in the fuel production process as an essential element. The concept model requires that human operators be present at the Integrated Bio-Refinery only one day per week (9 hours during that day). The rest of the week the system must run unattended. It should be noted here that "unattended" does not imply "unmonitored". Monitoring is important and is discussed further below. "Unattended" does imply that the Integrated Bio-Refinery must operate itself, under normal operating circumstances, without human intervention. "Normal operating conditions" means that the ambient temperature remains within the specified range (40 – 90 deg F) and that the system is not subjected to abnormal conditions such as clogging, leaks, ruptures, breakdowns, power outages, and other factors that can (and will) arise due to extreme weather conditions, mechanical wear and tear, and other factors beyond the Co-Op's control. It is assumed that the Integrated Bio-Refinery equipment will be designed with such factors in mind and that preventive maintenance is adequate to mitigate wear and tear issues, albeit failures and process interruptions cannot be totally eliminated.

The consequences of a failure or other anomalous deviation from normal operating conditions are generally an interruption in the pipelined flow. Such an interruption may result in a ruined batch and in a week or more delay in new production after the problem is resolved, owing to the need to re-establish the pipeline. Establishing the pipeline is discussed further in section 6.6, below.

Certain types of failures can result in explosion, fire and other extremely hazardous situations. This is because ethanol vapors in the Still are explosive in nature and liquid ethanol fuel stored on-site is extremely flammable. A certain degree of automation and control is a necessary as an adjunct to monitoring in order to react immediately to shut down ("scram") the system, sound an alarm for personnel that may be close-by, and sent alerts to Co-Op members for intervention (albeit not necessarily in real-time).

6.5.2 Control.

The Integrated Bio-Refinery concept model described in section 5 of this document has been specifically developed to limit real-time control and most active processes to the 9 hour per week period when human operators are in attendance. This human attendance period also provides for a limited amount of human inspection and preventive maintenance, per section 5.4. When humans leave the site, the following are the only processes that are left operating:

a) *The wort is fermenting in the Fermentation Tank*. Fermentation will proceed on its own as long as the temperature within the Fermentation Tank stays within the operational limits of 75 – 90 deg F. The thermodynamic analysis of section 6.3.1 demonstrates that this can be achieved passively. However, it is prudent to fit the Fermentation Tank with a burner and heat exchanger that can thermostatically operate to provide a little extra heat when needed to avoid a fermentation failure in the event of an anomalous ambient temperature condition. A simple and inexpensive electronic controller, such as the Feedstock

Processing Controller[11] that was developed and used as part of the 2012 Feedstock Processing Experiments, can be used to automate this process.

b) *Distillation of beer is taking place*. A continuous still design has been specifically chosen because once the Still is calibrated to the beer concentration and brought into equilibrium (all done during the 9 hour per week human attendance period), it (theoretically) needs no further adjustments as long as no outside factors disturb it. The Still contains explosive ethanol vapors and produces highly flammable liquid ethanol fuel and, as such, needs to be monitored and have automated emergency shutdown ("scram") facilities in the event of a problem. A low cost automated controller was developed for the Curbie continuous still design specifically for this purpose[12]. It is also possible to use this same Controller to automatically make small adjustments to the beer feed rate and the reflux ratio in the event of minor fluctuations in beer concentration (e.g. due to gravity filtering in the Lees Filter) and/or minor environmental aberrations (e.g. wind gust on the still column).

c) *The Processing Tank is filling with hot stillage.* The thermodynamic analysis of section 6.3.2 demonstrates that that can be achieved passively. However, it is prudent to fit the Processing Tank with a burner and heat exchanger that can thermostatically operate to provide a little extra heat when needed to avoid too low a stillage temperature for feedstock processing within the 4 hour operational time limit. The same Controller that was mentioned for the Fermentation Tank can be used for Processing Tank temperature control and a single burner can be used for both. The Controller can be programmed to turn on the burner whenever either tank needs added heat, and to open a solenoid valve to allow hot liquid to flow through the relevant heat exchanger when the heat transfer liquid is hot enough. When no added heat is needed for either the Fermentation Tank or the Processing Tank, the burner is turned off and both values are open to stop heat exchange circulation.

d) *The Cold Tank is cooling down*. The thermodynamic analysis of section 6.3.3 shows that the Chiller is only running for part of the week. After the Cold Tank cools down to its target temperature (nominally 40 deg F), the Chiller is turned off, and need only be turned on again if the Cold Tank temperature raises due to heat conduction in from the ambient environment. A simple thermostatic control can automate this cycling of the Chiller. The same Controller that was mentioned for the Fermentation Tank and for the Processing Tank can be used to cycle the Chiller on and off.

The Feedstock Grinder/Shredder, the Cold Tank heat exchange and bypass, the Overflow Tank, the Wort Pump, the Beer Pump, and the Lees Filter (under most options) are not being used when the site is unattended.

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[11] See "Feedstock Processing Controller" at: http://www.liquidsunenergy.com/projects/projects_home.html

[12] See "Open Source Controller" at: http://www.liquidsunenergy.com/projects/projects_home.html

6.5.3 *Monitoring.*

The Still Controller and the Heat Exchange Controller discussed above perform extensive monitoring of the Still, the Fermentation Tank, the Processing Tank and the Cold Tank; i.e. all of the processes that are active when the site is unattended. The critical parameters that must be monitored in order for these Controllers to perform their limited control functions are also those parameters that need to be limit tested to generate alerts to Co-Op members and to be collected, logged and tracked for local and/or remote long term monitoring of the Integrated Bio-Refinery operations.

It would be useful, but not mandatory, to monitor additional parameters such as possible flow obstructions in the beer feed to the Still and stillage feed to the Processing Tank. Obstructions to these flows ultimately result in anomalous temperature readings that are already being monitored, but flow rate monitoring might provide some advanced notification that could be helpful in the event that a Co-Op member could be alerted and get to the site in time to prevent a spoiled run or interruption to the pipelined process flow. The Heat Exchange Controller can easily handle some additional digital and analog sensors and could be programmed to monitor flow obstruction sensors if the system were so outfitted.

In addition to control and monitoring of the Integrated Bio-Refinery, the site environment itself might need monitoring and even some limited control. Certainly, it is desirable to have heat and fire sensors present at the facility, even if passive sprinklers are used for fire suppression. Monitoring and logging ambient temperature over the course of each week of site operation is also useful. Thermostatically controlled indoor ventilation can help keep the facility cooler in summer and motorized greenhouse panels in the roof can help keep the facility warmer in winter while not adding heat in the summer. The same Open Source Controller hardware as used for the Still Controller and the Heat Exchange Controller can be employed for these additional purposes.

6.5.4 *Alerts, Logging and Reporting.*

The Controller devices described in the previous section all have USB-serial ports and can be programmed to send short messages over these ports to a desktop or laptop computer with multiple USB ports and Internet access (wired, WiFi, or via cell phone carrier). This computer, in turn, can be used to log the data to an internal disk drive or database management software, send out e-mail, IM, or SMS text alerts, log data to the cloud, and/or provide web access to real-time and long term logged data. A computer capable of running these tasks does not have to be very sophisticated or expensive. Any computer capable of running Windows (even XP), the Mac OS or any version of Linux will suffice, even Raspberry PI. Open source software exists, particularly for Linux devices, to host a web server (e.g. Apache Tomcat), host a database management system (e.g. MySQL), script dynamic web pages based upon data in the DBMS (e.g. OpenPHP), and forward data to mobile devices via e-mail, IM and SMS texting. Some software development is needed to tie these together, but the resources are low cost or even free.

- *Alerts*. Anomalous conditions should alert Co-Op members as soon as they are detected. The Co-Op members may or may not be able to respond to these alerts immediately; however, they need to be notified so that they can make informed decisions. SMS text messages may be formatted and sent via any computer that has a cellular modem attached. Moreover, any computer that is on the Internet can send an e-mail or IM to mobile users. If the Co-Op members do not have e-mail and IM clients open to receive timely alerts, all major cell phone carriers have e-mail to SMS text services and SMS texting is ubiquitous for cell phone users. There are also commercial e-mail to SMS text sites that are not carrier dependent, albeit using these sites incurs additional cost. In any event, a simple script to an open source e-mail client such as Eudora can turn alerts from the Controllers into e-mails that result in SMS text messages to a designed list of Co-Op member cell phones.

- *Web access to site status*. The on-site computer that receives monitoring information from the on-site Controllers has several options for providing real-time access to site/system information via the world wide web. One such option is to host a web server on-site and use PHP or other scripting language to produce dynamic web pages based upon monitoring data supplied to the computer and/or recorded in an on-site database. The only real restriction in on-site web hosting is the need for a static ip address. The alternative is to use a web hosting service (e.g. Network Solutions, 1 and 1, GoDaddy) and FTP monitoring data to it. Web hosting services that fulfill this need are pretty inexpensive -- $5 - $10 per month -- and include a large amount of storage space, DBMS and scripting software, and FTP access, at a minimum. Many also provide a large number of e-mail boxes and Internet security services. Using a web hosting service obviates the need to have a static ip address for the processing site. If the web hosting service also hosts a database that collects monitoring data for long term tracking and reporting, reliability and protection of the data is also enhanced, as these services are hosted in monitored, attended, secured and environmentally controlled data centers. Yet another option is to log data to a cloud-based "Internet of Things" site, such as CoSM[13].

- *Reporting*. Long term accumulation of site monitoring data is very helpful in retrospectively assessing maintenance needs and making adjustments to site operations and equipment to improve reliability and production. If additional information is logged, particularly fuel production and disposition, the reporting function may also serve to satisfy government regulations for documentation. A relational database management system (RDBMS) is an ideal way to log and accumulate such information over time and can use SQL or commercial software tools (e.g. Crystal Reports) to query the database and format useful and easy to interpret reports. The DBMS can be hosted on-site in the same computer that receives the monitoring data, and the reporting function can be

[13] http://www.mithral.com/cosm/

hosted on the same computer as well. The DBMS and reporting function can also be hosted using a commercial web hosting service, as described above, and the reports made available via the web.

7 Maintenance, Safety and Hazard Prevention.

7.1 Introduction.

The topic of maintenance includes both preventive maintenance (PM) and corrective maintenance (CM). Proper and timely PM can often prevent (but not completely eliminate) unanticipated downtime due to CM. The operational concept for the Urban Fuel Co-Op assumes that personnel are only on-site one weekend day per week. The lack of timely response to unanticipated failures of the Integrated Bio-Refinery make PM all the more important. Automatic system shutdown and passive hazard mitigation features are also necessary to protect life and property in the event of a system failure, prior to someone coming on-site to perform CM.

7.2 Preventive Maintenance (PM).

The operational concept model for the Urban Fuel Co-Op allows for 2 weeks of system downtime per year. Given that people are assumed to be available for on-site work only on weekend days, there can be only one or two PMs performed per year. PM activities break the "pipeline" of ethanol fuel production. In order to meet a 50 week per year production schedule, the "pipeline" must be re-established as quickly as possible.

As with "Control, Monitoring and Automation" discussed in the prior section of this document, the fact that the Integrated Bio-Refinery is designed to have minimal parts involved in production during periods when nobody is on-site is an asset for a successful PM strategy. Another asset to the PM strategy is that some parts of the Integrated Bio-Refinery are cleaned (and even sterilized) on a routine, weekly basis. This includes the Processing Tank, the Lees Filter, and most importantly, the Fermentation Tank. This means that PM activities may skip cleaning of these components, albeit they must be inspected for leaks, cracks, rust, and have any moving parts lubricated and repaired/replaced as necessary. The PM strategy further assumes that the stillage, which is recycled every week, should be drained and replaced with fresh, heated water during one or both annual PM periods. The PM operation described in this section makes this assumption, although refreshment of the stillage is not essential to the overall PM operational concept.

In order to understand the PM operational concept, it is very important to recall that, at the end of a week's normal processing, the Integrated Bio-Refinery is always in the following state:

- *Fermentation Tank*: fermentation is complete and the Fermentation Tank contains one week's worth (nominally 4,000 gallons) of beer (nominally 10% abv).
- *Beer Tank*: the Beer Tank is mostly empty but is assumed to have up to 25% reserve in order to keep the Still going continuously. The Still must normally be fed during the processing of new feedstock and must have enough beer in the Beer Tank to account for weekly differences in the Still feed rate, owing to the fact a weekly batch of beer may

vary in alcohol content from 7% to 13% abv. Per section 6.3.4, above, this variation requires feed to the Still of between 3,906 gallons of beer per week (13%) and 4,551 gallons per week (7%).

- *Still*: the Still is distilling continuously, supplying fuel to the Fuel Tank and stillage to the Processing Tank (via the Overflow tank, which is just a pass-through unless feedstock processing is taking place).

- *Processing Tank*: the Processing Tank contains nominally 3,600 gallons of hot stillage that has accumulated over the prior week. It is receiving new stillage continuously from the Still, unless the Shutoff Valve is closed forcing stillage to accumulate in the Overflow Tank.

It is also important to recall that the Fermentation Tank was oversized to allow expansion space for foaming during active fermentation. However, fermentation is no longer active at the end of a week of processing.

The system component that is driving the material flow is the Still. In order to perform PM, the Still is shut down and hence the routine flow stops. The Still is shut down by first increasing the reflux ratio to 100%, so that product is not coming off the top of the still column. The re-boiler heat source is then cut off so that boiling of beer stops within a relatively short period of time, and the still column begins to cool down. The beer feed may be shut off and a water feed substituted to help cool down the column quickly while not wasting beer.

Once the beer feed to the Still is stopped, the beer remaining in the Beer Tank is pumped into the Fermentation Tank, to “top it off” over the week’s production that is already there. The high capacity pump that normally pumps beer out of the Fermentation Tank through the Lees Filter and into the Beer Tank may be reconfigured, via manual valves and pipes, to pump the residual beer from the Beer Tank back into the Fermentation Tank in a short period of time (fraction of an hour).

If the stillage is to be refreshed, a stopcock at the bottom of the Processing Tank is opened and the old stillage is drained out and discarded. Once these operations are complete, the following is the state of the Integrated Bio-Refinery:

- All pumps are off.
- The Fermentation Tank is full of beer.
- The Lees Filter is offline.
- The Beer Tank is empty.
- The Still Column is cooled down and empty.
- The Fuel Tank has fuel and is isolated from change.
- The Overflow Tank is empty.
- The Processing Tank is drained and empty.

- The Cold Tank is isolated (nothing flowing through it) and contains cold liquid from the prior week's cooling (however, this could be disabled the previous week to save energy, as the Cold Tank is not used this PM week).
- The Feedstock Grinder/Shredder is not used this PM week.

This means that every component of the Integrated Bio-Refinery is empty and shut down, except for the full Fermentation Tank. The entire Integrated Bio-Refinery may now be taken apart, every part cleaned and inspected (and repaired or replaced as necessary), parts lubricated as necessary, and reassembled. The Fermentation Tank contains beer which does not spoil if it sits for an extra week. The Fermentation Tank, having been cleaned and sterilized weekly during normal operation, and having no new fermentation planned for the upcoming week (because no feedstock processing happens the PM week), does not need cleaning and inspection during the PM week.

Once the Integrated Bio-Refinery has had every part cleaned, inspected, restored, reassembled and visually double checked, the following operational scenario may be used to restore the system to "pipeline ready" over the following week:

- *Still*: Heat is restored to the now reassembled still column, but water feeds it and not beer. The water flow rate is adjusted (lower than for beer) to ensure vaporization the water feed. The reflux ratio is set to 100% so that no water vapor exits the top of the still column. With only water in the column, the Still does not fractionate (nothing to fractionate, just plain water); thus the still column heats up uniformly to the boiling point of water. The water exits the column as stillage (i.e. from the bottom). The stillage pump is turned on and pumps this "stillage" (plain, hot water) though the Overflow Tank and into the Processing Tank, whose stopcock is now closed. Over the next week, this hot water accumulates in the Processing Tank in preparation for mashing making the next weekend.

- *Processing Tank*: The water accumulating in the Processing Tank is at or near the boiling point of water, which is a little hotter than the usual stillage (212 deg F vs. 190 deg F, at 1 atm pressure). If this PM operation takes place in hot summer, some insulation may need to be removed from the Processing Tank in order to ensure that the water is not too hot for new feedstock processing at the end of the week. The Excel Workbook, "Processing Tank" worksheet can be used to determine this temperature given any specific ambient temperature and insulation R-value. In winter, this most likely won't be an issue, but perhaps the extra winter insulation may be removed for this one week.

- *Cold Tank*: chilling of the liquid in the Cold Tank is resumed in preparation for the following weekend processing.

- *Fermentation Tank*: the beer may be left in the Fermentation Tank this week or it may be pumped back into the Beer Tank during the PM weekend. The latter provides the opportunity to clean and inspect the Fermentation Tank, albeit this would not appear to be necessary if proper cleaning and sterilization (and inspection) happens weekly.

- *Beer Tank*: the Beer Tank may be left empty for the week, or the Beer Tank filled from the Fermentation Tank, through the Lees Filter during the PM weekend activity. In either event, beer is not pumped into the Still this week. Fresh water is pumped into the Still all week long which keeps the Still Column hot and provides hot water to the Processing Tank for the next weekend's resumption of feedstock processing operation.

The weekend following a PM activity sees resumption of normal feedstock processing. The following is the status the weekend after PM:

- *Site, Overall*: The intra-week operation has been almost the same as any normal processing week. The Still Column is hot and hot stillage (water) is pumped through the Overflow Tank and into the Processing Tank. The only part of the intra-week operation that has been different is that beer is not being pumped out of the Beer Tank and into the Still Column – rather, fresh water has been used. This is an excellent opportunity for the crew arriving on-site (with new feedstock to process) to inspect this part of the system for proper operation and to detect and repair any leaks.

- *Still*: The Still Column is hot – actually, a little too hot. It is in equilibrium at the boiling point of water, with no temperature gradient existing across the packing.

- *Beer*: A full week's worth of beer (plus a reserve) is either in the Fermentation Tank or in the Beer Tank, depending upon the option chosen. The beer is an extra week old, but this is not a problem (it keeps).

- *Processing Tank*: the Processing Tank is full of hot water, ready for feedstock processing. If insulation was removed the previous weekend (to help with the extra environmental cooling), it is restored at this time. If the water temperature is too hot, some water may be drained via the stopcock at the bottom of the tank and replaced with fresh cold water until the temperature is within the requisite range, per the Excel Workbook worksheet.

- *Cold Tank*: the Ciller has been run over the intervening week and the Cold Tank contains cold liquid at approximately 40 deg F.

Once inspection of the site is complete, a new batch of feedstock is processed, according to the normal operational scenario presented in section 5.4 of this document, with one small exception. Once beer flow is restored to the still column, the column temperature must be reduced and the temperature gradient up the column restored to a new equilibrium with the beer. Since the column has been kept hot (heating new water for feedstock processing), a long heating up period is not needed. The following steps are followed to get distillation of beer going again:

- The reflux ratio remains at 100%; no product is taken off of the top of the still column.
- Beer flow is restored at a rate suitable for the beer concentration (per section 6.3.4, above).
- Fractionation begins as the beer is vaporized into the column. The column starts cooling down and a temperature gradient starts to form vertically up and down the column.
- When the temperature gradient stabilizes (equilibrium is reached), the top if the column is at the boiling point of the azeotrope (approximately 173 deg F at 1 atm pressure).
- The reflux ratio is slowly reduced, keeping the column in equilibrium[14]. Product (at the azeotrope, or other desired proof) starts being removed from the column into the Fuel Tank.
- Once the reflux ratio is the lowest that it can be and still produce the desired proof of the product, distillation may continue unattended, just as in any normal week.

The PM procedure described in this section eliminates fuel production for a total of one week. Therefore, two PM periods per year are allowed under the operational concept of 50 week per year production. The detailed design and selection of components of the Integrated Bio-Refinery must provide that they operate, reliably, for a minimum of 6 months between PM periods.

The main component needing PM (that is not cleaned and serviced weekly) is the Still. The column plates and/or packing will foul with any silt that passes through the Lees Filter, and any soluble material that distills out of the beer. This is of particular concern for the stripping section of the column. Packing material such as marbles, which resist fouling and clogging, should be used in lieu of mesh or other such material that clogs easily. Marbles have a much lower HETP than does mesh packing and their use dictates a taller column. However, the consequences of clogging the column are severe: bad batches of fuel at a minimum, and possibly increased pressure in the column leading to rupture and perhaps even an explosion. <u>The Still is not the place to cut corners</u>!

7.3 <u>Cold Start.</u>

"Cold start" is necessary when the Integrated Bio-Refinery is first brought up on-site, or whenever it is relocated, completely disassembled, or otherwise placed into its initial state. In

[14] The column will not actually remain in equilibrium, as the temperature gradient must migrate to accommodate the product takeoff. This procedure is done <u>slowly</u> so as not to disturb the boiling point at the top of the column (thus maintain product proof). Though technically untrue, we consider this to be "keeping the column in equilibrium" because changes happen slowly, in the middle of the column and do not impact the proof of the product.

this sense, “cold start” is the same process as PM, except that there is no beer in the Fermentation Tank or in the Beer Tank and no ethanol fuel on-site.

The process for starting up the system from a cold start is very similar to the PM startup process. Since there is no beer, it takes two week’s distillation with water before beer can be distilled. The first week brings the cold Still Column up to operating temperature, distilling water that provides a hot cooking medium in the Processing Tank at the end of the week. Over the intervening weekend, feedstock is processed on site and left to ferment, with distillation of water continuing and refilling the Processing Tank over the next week. At the end of the second week, there is beer in the Fermentation Tank and the “pipeline” has been established, allowing normal operation thereafter.

It is wise to begin normal operation with a quantity of beer that is in excess of the normal week’s production. This excess (suggested: 25%) is to ensure that the Still always has beer to distill, even after a few weeks worth of low ethanol content due to the variability of the feedstock. This can be accomplished by making a larger than normal batch for the first few weeks after cold start (the system components are unlikely to have 25% over capacity to achieve this in one week’s time). This can be achieved simply by using feedstock that produces a known, higher than normal, ethanol concentration, either by judicious selection of feedstock or by investing in adding some sugar to the wort.

The other “cold start” issue is the lack of fuel on-site for powering the Still and the ethanol Burner/Heat Exchanger. Given that these components are designed to run on ethanol, it is probably simplest to invest in some commercial fuel ethanol to get the pipeline going. An alternative is to provide an optional power source for these components; e.g. electricity or natural gas. Purchasing ethanol is probably easier and cheaper in the long run, however.

7.4 Corrective Maintenance (CM).

Corrective maintenance (CM) is performed whenever there is an actual or imminent failure of some component of the Integrated Bio-Refinery. The failed part must be repaired or replaced. While the repair is occurring, the failed part may be bypassed temporarily (if possible), may be switched out and a redundant pathway used, or the Integrated Bio-Refinery simply taken down and brought back up, as with the PM or “cold start” process.

Many components of the Integrated Bio-Refinery are only used when people are working on-site. Given a supply of spare parts, tools, and supplies on-site, the routine work can be interrupted briefly and the failed component repaired or replaced. Failures occurring during the week and those that ruin the ability to process a new batch of feedstock require that the system be taken down or restarted (PM or cold start process) anyway. Therefore, we deem it unnecessary to go to the expense of building in automatic bypasses and redundancy, as these are unlikely to be cost effective.

7.5 Safety and Hazard Prevention.

Due to the fact that the Integrated Bio-Refinery does not have Co-Op personnel on-site most of the time, it is essential that hazards be anticipated and that various means be provided to mitigate them, at least to the extent of site and system safety.

Leaks and spills can be anticipated, regardless of how well designed and maintained the equipment is. Most of the liquid used in the Integrated Bio-Refinery is relatively harmless to humans and to the environment; albeit some can be messy. Stillage is mostly water with a little ethanol and some silt. It can be very hot, but is otherwise harmless. Passive collection and removal of spilled stillage should be designed into the processing facility, perhaps with a slightly sloped concrete floor and suitable drainage. This same system can mitigate spills of wort and beer. Runoff to the outside environment is not a problem, as these liquids are relatively benign.

Fire is always a danger and the processing facility must be provided with a passive sprinkler system. Local fire codes would require this anyway. Ethanol fires, in particular, are very effectively fought with water since ethanol and water mix in all proportions.

The still column contains ethanol vapor which is explosive if ignited. Curbie's still column is 21 feet tall and likely protrudes up through the roof of a processing facility. In one sense this is good, as ethanol vapors escaping from the column are vented to the environment (where they won't do any significant damage), vs. collecting inside the facility where an explosion could take place. However, lightning strikes are a significant hazard and must be mitigated via passive means such as lightning rods.

Another possible issue with the still column is pressure building within the column due to a blockage of some sort. The still column is designed to run at atmospheric pressure. However, clogging of the packing or material falling onto the column and blocking venting to the atmosphere can cause pressure to build up within the column resulting in a breach. In most cases, the Still Controller would detect a problem and "scram" the Still by shutting off the heat to the re-boiler and shutting down the beer feed (possibly substituting a water feed to cool down the column faster). However, passive overpressure relief valves should be part of the Still design. In addition, the Still should have an extra, high capacity, condenser at the very top of the column for emergency use. This condenser would be gravity fed with cold water upon automatic actuation of a valve by the Still Controller and/or other emergency signal. The emergency condenser would ensure that all vapor was condensed (100% reflux), thus preventing release of flammable vapor out of the still column.

On-site collection and storage of liquid ethanol fuel is also a fire hazard. All such storage must be in approved containers for this type of material, with suitable passive sprinkler available to rapidly quench any ethanol fire.

TTB regulations, as well as common sense, dictate that the access to the processing site, the Integrated Bio-Refinery equipment and its facility, and the Still in particular, be physically controlled so that only authorized persons are allowed entry. Gates and locks must be used for physical access control, but must allow access to emergency personnel even when an authorized Co-Op member is not physically present.

The ability of electronic controllers and computerized monitors to take emergency action and to notify off-site Co-Op members of operational problems depends upon these components being powered. Electrical power outages must not compromise the site or the ability to automatically control and monitor Integrated Bio-Refinery equipment, issue alerts, and log issues.

The controllers described in section 6.5, above, are Arduino-based microcontrollers and run off of low voltage DC power, which can be supplied externally (e.g. battery or "wall wart") or via USB connection to a host computer. The sensors are powered by the Arduinos. Actuators, such as solenoid valves, electrical contactors, and motors for small pumps (beer feed pump and stillage pump) may be DC or AC powered. If DC powered, a small power supply should suffice to power them off of the AC mains.

These devices, as well as the on-site host computer that issues alerts and status over the Internet, must have uninterruptable power, as should any router, cable, phone or wireless modem, and any other components that are needed for Internet access from the site. An inexpensive uninterruptable power source (UPS)[15] can power all of these devices for at least one or two hours for under $200. The UPS also conditions power when the grid is operating to eliminate power line fluctuations and momentary outages that could reset computers and controllers, or cause electrical damage to them. These small UPS devices have USB monitoring capability that can be used by the on-site host computer to maintain site operations for 45 minutes or more of grid power outage, and then signal the Controllers to shut down operation in an orderly fashion if the outage persists.

The only large, AC powered device that is contemplated for the Integrated Bio-Refinery is the Chiller that cools down the Cold Tank. It would probably not be worth the cost of a UPS sufficient to keep the Chiller running. If the AC power fails, the Cold Tank may not be ready for a new batch the next weekend. Monitoring (per section 6.5, above) will alert Co-Op members of this condition and they will be prepared accordingly.

The discussion above is only an overview of sensible safety and hazard prevention measures that must be considered in the siting and design of the Integrated Bio-Refinery feedstock processing equipment and facility. The design and selection of actual components and the facility itself must be subjected to a detailed Safety and Hazard Analysis that is specific to the individual system and to its staffing and operation. The Safety and Hazard Analysis must list all

[15] E.g.: http://www.amazon.com/Tripp-Lite-SMART1500LCDT-1500VA-Battery/dp/B009TZTGWK/ref=lp_764572_1_12?ie=UTF8&qid=1381299396&sr=1-12

foreseeable hazards and contain a plan to mitigate them for safety first and for protection of the Co-Op investment second.

8 Other "Real-World" Considerations.

This chapter discusses important considerations for the Urban Fuel Co-Op model that have not been previously discussed and analyzed. Detailed analysis of these considerations is beyond the scope of this document but is important enough to bear some mention.

8.1 Denaturing and Drying.

The Integrated Bio-Refinery described in detail in this document produces hydrous, or "wet" ethanol. Ethanol and water form an "azeotrope" at approximately 96% ethanol and 4% water. Further separation of ethanol and water beyond the azeotrope cannot be achieved by simple distillation.

Azeotropic ethanol is quite flammable and makes an excellent automotive fuel. In fact, ethanol at 90% (180 proof) has reportedly been used in automobiles with excellent results, and there are reports of 80% ethanol, 20% water (160 proof ethanol) actually working in automobile engines. The addition of a little bit of water to engine fuel can actually raise the horsepower of an engine. Water has a very high latent heat of vaporization, meaning that water absorbs and carries away a lot of heat energy when it changes state from liquid to vapor. This factor, combined with the fact that water does not burn (the molecule is fully oxygenated) makes water very good at putting out fires. Too much water in the ethanol prevents an engine from running, for these reasons. However, a little water in the ethanol can absorb heat from the engine during the compression stroke, but not enough heat to prevent the ethanol from burning during the power stroke. The compression stroke of an automobile engine is a power robber because as the vaporous fuel is compressed, it heats up, and as a gas heats up, it increases pressure and resists further compression. When heat is removed from the compression stroke (by vaporizing water droplets), the pressure resisting further compression is reduced and less power is robbed from the engine. More detail about this can be found in the paper at:
http://www.liquidsunenergy.com/learning/ppt/ice.pdf

The quality and usefulness of hydrous ethanol notwithstanding, gasoline and water do not mix and the presence of water in the ethanol fuel can prevent gasoline from being mixed into the fuel. The ability of ethanol, water and gasoline to stay in mixture (in a single phase) is a complex function of the relative concentrations of each component as well as of the ambient temperature. Thus, if the ethanol fuel is intended to be mixed with gasoline, e.g. for flexible fueling of the automobile, then the ethanol must be dried; made "anhydrous". Note that if the Co-Op desires to sell some of its ethanol product on the open market, the fuel must be dehydrated (and denatured) per the ASTM[16] D4806 standard.

[16] American Society of Testing and Materials

Various means exist to dry ethanol at or near the azeotrope. Most of these techniques involve passing hydrous ethanol liquid or vapor through materials that absorb or adsorb (not the same thing) the water. Commercial fuel ethanol processors generally use zeolites that adsorb water from the azeotrope as a vapor, albeit there are zeolites that work in the liquid phase. Whatever means is used to dry the ethanol fuel, the drying agent has a limited ability to retain water and must itself be dried prior to being reused. This adds cost and complexity to the Integrated Bio-Refinery.

TTB[17] regulations (in the United States) require that ethanol used for fuel be "denatured" before leaving the processing site. Otherwise, the ethanol is considered a beverage, and as such would be taxed and regulated well beyond its economic value as a fuel. Denaturing technically means "bittering" to make the ethanol non-consumable. In a practical sense, this usually means poisoning it. One way to denature ethanol that is inexpensive, simple, and virtually guaranteed to meet TTB muster is to add 2% - 5% gasoline to the fuel. There are alternatives to gasoline, but gasoline is easy to obtain and cheap in these low concentrations. Denaturing with gasoline usually involves concentrations of gasoline that are too low to cause phase separation when mixed with hydrous ethanol near azeotrope; however phase separation can occur if the ambient temperature is very low. Denaturing is one more reason why it may be desirable to dehydrate the ethanol fuel.

8.2 <u>Quality Control.</u>

Proof of the ethanol produced by the Co-Op must be monitored and tested if it is to be useful as a fuel. In addition to proof (water content), the presence of small amounts of solids, acids and other material in the fuel can quickly ruin an engine or burner. Fermentation produces more than ethanol; methanol, fusil oils, acids and other substances are also produced, albeit in small quantities. While most of these substances simply burn up in an engine, some produce regulated air pollutants whose quantities in the exhaust must be kept low. The relevant standard for fuel ethanol is ASTM D4806. Any fuel that the Co-Op intends to sell commercially must be tested to meet this standard. Prudence would dictate that the fuel be certified to meet D4806 even if it is not sold commercially. It makes no sense to join a fuel Co-Op to save money if the Co-Op's fuel ruins your car's engine!

Testing to ASTM D4806 requires a certified laboratory, such as Midwest Laboratories[18]. Samples should be mailed in for analysis at least annually, and preferably after a PM activity or other change to the Integrated Bio-Refinery that might alter the quality of fuel.

In addition to full laboratory testing, each batch of fuel should be tested for proof and for the presence of harmful contaminants, specifically solids. Proof testing is done by the Still

[17] The Alcohol and Tobacco Tax and Trade Bureau ("TTB", formally "ATF") is the branch of the United States Treasury Department that taxes and regulates alcohol, as well as tobacco and other substances.

[18] https://www.midwestlabs.com/ethanol-denaturant-packages/

Controller monitoring and logging the vapor temperature at the condenser. Additional batch testing using an alcohol hydrometer is recommended. Clarity of the fuel should be observed for any presence of cloudiness that might indicate the presence of particulates in the fuel.

One recommendation for future work is the development of a standard test kit that can be used by a fuel Co-Op for low cost, easy to use, batch testing of the fuel. This test kit would augment, but not replace, actual laboratory testing at intervals discussed above.

8.3 Equipment Modularity.

The concept model for the Integrated Bio-Refinery that is described and analyzed in sections 5 and 6 of this document contains a single "thread" of equipment. This means that each piece of equipment is singular (quantity of one) and sized to the needs of the 20 person Urban Fuel Co-Op. It has been stated previously that the Integrated Bio-Refinery can be scaled, upward or downward in size, to accommodate a larger or smaller Co-Op. This suggests an alternative approach to equipment design – scaling down the equipment to a smaller size, but having multiple quantities of each running in parallel (multiple threads). For example, in lieu of 5,000 – 6,000 gallon tanks for feedstock processing, fermentation, beer storage, Cold Tank, etc., a scaled down system could be built using only 1,000 gallon tanks, and the still column diameter, pumps, etc. scaled down accordingly. A 1/5 scale system would produce 1/5 of the weekly needs of the Co-Op, so five such scaled down systems would be run in parallel at the processing site. There are pros and cons to this approach.

On the "pro" size, smaller prices of equipment are easier to purchase or fabricate, easier to transport, easier to clean and maintain, and may further reduce cost by existing for other (higher volume) industries such as microbrewing and dairy processing. Mass production reduces cost. In addition, the cost of spare parts may be reduced by having only one or two spares for each small piece of equipment on-site, vs. one spare for each large piece of equipment. If the cost of a spare part is proportional to its size (not always true), the costs of spares can be reduced. Furthermore, large equipment necessitates having to have additional large equipment on-site just for access (e.g. ladders).

The biggest "pro" for multiple threads of equipment, however, is scalability. The Co-Op can start off small, with a few members and one thread of equipment, and scale up by adding other threads as the membership grows. Furthermore, running multiple threads of production means that a problem with one thread most likely would not impact the others threads, so failure of a weekly batch in one thread out of five running in parallel would result in loss of only 1/5 of a week's production vs. a full week's production. This is particularly important for the Urban Fuel Co-Op because the site is unstaffed most of the time. As discussed in section 7.4, a problem occurring on-site when unattended would, most likely, shut down production pending corrective action, losing perhaps two or even three week's production in the process. It is much better to lose several week's production of one thread in five then to lost a few week's production of the entire facility.

The "con" side of multiple threads of equipment is most likely higher cost. Unless economy of scale overcomes this, larger is not usually proportionally more expensive. In most cases, a smaller device is less costly than a larger device, but not proportionally so. Five small pumps probably cost (in aggregate) more than one large pump. Five small tanks probably cost (in aggregate) more than one large tank. Multiple threads of processing also means more controllers, more monitoring and more record keeping and regulatory filing. Multiple threads also means more maintenance; both PM and CM. It generally takes less overall effort to clean one large tank or filter than to clean five smaller tanks and filters.

There does not seem to be an obvious conclusion to one large thread vs. multiple small threads. There are pros and cons to both. A Co-Op that starts small would, in all likelihood, add threads as its membership grows, not because it is more efficient or less costly to do this, but because of the need to be "right sized" at any given point in time. Conversely, a Co-Op that begins with a membership that saturates the feedstock availability in its territory (section 4.3, above) may very likely opt for one large single thread of equipment.

One potential "game-changer" for single vs. multiple threads would be commercial offering of equipment specifically designed and mass produced for this purpose. Such a manufacturer would be forced to offer equipment in one or just a few sizes and purchasers would elect one or more threads based upon the availability of low cost, mass produced equipment specifically designed for this application.

8.4 Economic and Legal Considerations.

It has already been mentioned that a still permit is required from the TTB (in the United States). There are also state and local codes and regulations that need to be considered. Discussion and analysis of these topics is beyond the scope of this document. A good overview discussion of this topic can be found in the book "Alcohol Can Be A Gas[19]" by David Blume, chapter 26.

8.5 Cost.

The notion of an Urban Fuel Co-Op has been driven by the results of the 2012 Feedstock Processing Experiments. These experiments demonstrated that a readily available supply of feedstock can be obtained, for free, in urban areas. The experiments further demonstrated that this feedstock can be processed to wort at low temperatures and with reduced enzymes, suggesting reuse of stillage to eliminate the cost of cooking energy and greatly reduce the cost of water. This gave rise to the notion of the Integrated Bio-Refinery. The work documented herein has demonstrated the feasibility of the Integrated Bio-Refinery concept and the promise of low cost ethanol fuel production in exchange for a limited amount of labor.

There remain a great many costs that have not been analyzed as part of this effort. These include:

[19] ISBN 9780979043789, 9780979043772; http://www.permaculture.com/

- Transportation costs associated with the collection of feedstock and the distribution of fuel to Co-Op members.
- Facility costs associated with the Integrated Bio-Refinery equipment as well as site and building leasing.
- Cost of Insurance for the Co-Op.
- Utility costs for power, water, Internet access and web site hosting.
- Storage costs for the fuel.
- Costs associated with dehydrating, denaturing, quality control, and testing.
- Costs associated with consumables: enzymes, yeast, yeast nutrient, cleaning and sanitizing agents.

Cost is key and the next logical step is the detailed design and analysis of at least a pilot version of the system described in this document. A pilot system would help to flush out most of the costs and would also provide a test system for validation of the design and analysis presented in this document. A lot of work has been done to provide the information in this document. A lot more remains to be learned!

9 Issues and Alternatives.

9.1 Alternative Business Models.

The Urban Fuel Co-Op described in this document has been envisioned as a non-profit entity that supplies its members with low cost fuel in exchange for their labor. In the analysis of the Cold Tank (section 6.3.3), it was suggested that the Chiller would likely run off of AC electrical power and that the Co-Op could potentially sell the equivalent energy content of the ethanol fuel that it produced to pay for the electricity. The sale might be to other Co-Op members, or the fuel sold on the wholesale commercial market[20].

Ethanol made from discarded bakery waste arguably has an extremely low carbon footprint. All of the carbon emissions associated with cultivation and harvest of the gain, transportation, preparation and baking, are borne regardless of whether the stale residue is made into fuel or is simply discarded into a landfill. In point of fact, processing this waste material into ethanol means that it won't decay in a landfill into methane – a powerful greenhouse gas. A credible argument can therefore be made that the carbon footprint of fuel produced efficiently from this waste material is zero or even negative. This means that the fuel should be classified as meeting the second generation bio-fuel requirements of the US Federal Renewable Fuel Standard (RFS2) and be eligible for the special RINs associated with this fuel category. Additionally, the fuel should qualify as a low carbon fuel under California's LCFS and be marketed under California's cap-and-trade system for such fuels. In other words, this fuel might have a wholesale commercial value that is far in excess of its energy content.

A small scale commercial ethanol fuel bio-refinery can use the same principles described in this document. As such, the Co-Op would be structured as a commercial for-profit entity in which Co-Op members would work for pay. Another interesting possibility is for the Co-Op to partner with a non-profit food bank that is already collecting and concentrating large quantities of stale bakery waste (and likely discarding 90% of what they collect). The Integrated Bio-Refinery could be sited right on the food bank's property and operated either by food bank employees/volunteers or by Co-Op members. The fuel would be sold by the non-profit and the food bank and Co-Op would share in the revenues. The feedstock collection problem is eliminated, or at least greatly reduced, while the non-profit structure possibly remains.

[20] If sold commercially, the fuel must be dehydrated, denatured and quality tested to ASTM D4806.

9.2 Summary of Issues.

The section summarizes the known issues with the Urban Fuel Co-Op model described in this document. A well designed pilot project would flush out most of these issues and provide a solid basis for deciding whether or not it is feasible to scale up to the full Co-Op production.

9.2.1 Feedstock Collection and Transportation.

Perhaps the largest of the known issues is collecting the feedstock and transporting it to the processing site. The operational concept is discussed in detail in section 4.4 of this document. It is very clear that points of concentration of feedstock must be identified. At a minimum, the average weekly pickup from any routine pickup site must be at least 100 lbs. Otherwise, it is theoretically impossible to complete the collection task within the time and manpower constraints of the Urban Fuel Co-Op. Furthermore, the sheer weekly volume of feedstock for a 20 person Co-Op requires large trucks and/or trailers pulled by vehicles with significant towing capacity. Even though the feedstock is free (it is waste), its collection and transportation might incur significant cost.

The most obvious solution to these issues is to leverage off of the existing infrastructure. As waste material, the feedstock is already collected and is ultimately transported to a dump site. Unfortunately, the stale bakery products are normally mixed with other non-recyclable waste in trash cans or dumpsters and collected in bulk as part of routine trash collection. Stationing the Co-Op pickup at the dump site requires that the Co-Op have some means to separate the desirable feedstock from the other trash. Otherwise, the businesses or the private or municipal trash collection would have to segregate this material at pickup, much as recyclables and lawn waste are separated in many communities today. The Co-Op would have to work with local officials and trash haulers to institute such a trash segregation program. This is more likely to happen in a small town than in a large city. In any event, public officials would very likely need to see a functioning Urban Fuel Co-Op with at least a pilot processing facility up and running before they would commit to mandating feedstock segregation in trash.

The other possible solution to this issue is for the Co-Op to partner with a large food bank that has its own donation stream (where segregation of feedstock can occur) and its own transportation infrastructure. This possibility was raised in section 9.1, above.

9.2.2 Cost.

The analysis presented in this document is focused on processing costs. The result of the analyses is that the processing operational cost component of ethanol fuel made from stale bakery waste is extremely low (at most, a few cents per gallon). However, this cost does not include transportation, facilities, equipment, permitting and insurance. Unlike a farm fuel Co-Op, an Urban Fuel Co-Op would likely incur significant costs in these areas; cost that must be amortized over the production of fuel. Estimation of these costs is beyond the scope of this document and is likely to be highly variable based upon location and membership assets. One area of costs that can and must be addressed is equipment cost, and a well designed pilot project can be highly useful in flushing this out.

9.2.3 Ambient Environment.

Highly energy efficient production of ethanol fuel can be achieved by the equipment, methods and techniques described in chapters 5 and 6 of this document. A key factor in achieving this efficiency is the continuous processing of feedstock in a “pipelined” operation. Continuous, year round processing is also necessary to achieve the Co-Op objective of returning enough fuel to members to power their automobiles. However, year round processing mandates accommodation of a very wide ambient temperature range.

Much of the work documented in chapters 5 and 6 of this document has focused on design and analysis of equipment that can successfully process fuel from stale bakery waste under the wide ambient temperature range of 40 deg F to 90 deg F. As challenging as this is, most places in the United States experience periods of ambient temperatures beyond these range limits. The specification of 40 to 90 degrees operating range has a little margin on the high and low side. Beyond this margin is the problem of freezing on the low end and of being too hot for fermentation on the high end.

Freezing temperatures are a problem for any equipment than handles mostly water, not to mention the people who must work in this environment. It is best to simply avoid freezing. The most obvious way to do this is to enclose the integrated Bio-Refinery inside an insulated building. The Still requires almost 3.9 million BTUs of heat energy per week, and this heat has to be removed to the environment. It is not very hard to keep an insulated shed or cinderblock building warm, given this amount of inside heating. The flip side of this coin, however, is dissipating this heat out of the facility in summer, least the inside temperature get too high. Ventilation, even passive, should suffice in all but the hottest of summer days. The large amount of unattended operation, however, indicates that some sort of powered ventilation needs to be provided; e.g. a large, thermostatically controlled fan and louvered, normally closed vents.

Summer heat would appear to be the largest issue here. Adding heat is easy. There is the Still and plenty of ethanol that can be burned. Removing heat is more problematical, as the Cold Tank analysis demonstrates. Air conditioning must be used where passive ventilation does not work, but the combination of ambient heat and process heat that must be removed from the facility is large and this can make the fuel production (as well as equipment costs) high. It can be argued that the air conditioning needs to be run only on hot summer days. This might not impose a big cost burden in normally cool climates, but might be very costly in normally hot climates. In the latter case, fermenting with yeast that can tolerate higher ambient temperatures might be a feasible solution. Strains of “turbo yeast” have been bred specifically for fast fermentation of sugar washes and these strains can ferment at 105 or even 110 degrees F. The 2012 Feedstock Processing Experiments used only regular distillers yeast, with a recommended fermentation temperature of below 95 deg F; however, there is no known reason why a higher temperature yeast could not be used.

9.2.4 Unattended Operation.

The notion of an Urban Fuel Co-Op mandates that the Integrated Bio-Refinery operate in an unattended mode most of the time. The operational concepts described in this document limit unattended operation to fermentation, distillation and collection of stillage. Fermentation is passive and inherently safe to leave unattended. The worst consequence of a fermentation failure is a spoiled batch of wort. There are no safety or environmental consequences to mitigate (only a possible mess to clean up). Stillage collection requires active pumping and the possibility of overflow or leaks spilling the stillage. Since stillage is mostly water and a little ethanol, the consequences of problems while unattended are easily mitigated by passive drainage.

Unattended distillation is the major issue here. We have attempted to mitigate this with electronic control that can sense problems and shut down ("scram") the Still if necessary. We have augmented this active Still control and monitoring with passive fire suppression equipment. These measures would seem to be sufficient; however, the concept has not been tested with local, state and federal regulators, nor with insurance carriers. A small scale pilot project would serve as a vehicle to further flush out these issues. It is possible that no suitable solution can be found. It is also possible that permitting, regulation and insurance will not be a problem. This is simply an unknown area at this point in time.

9.2.5 Fuel Storage and Distribution.

The design and analysis work presented in this document has not given much attention to the issues surrounding fuel storage and distribution. It has been assumed that storage containers and containment standards exist for the safe and legal storage of large amounts of fuel ethanol. Since ethanol is widely produced and stored in very large quantities, this is a safe assumption. However, the costs, regulations, standards, and permitting issues have not been explored to date. They would have to be explored and resolved as part of a well designed pilot production follow-on project.

If the fuel processing facility is far from the urban area where the Co-Op members live, there is the additional issue of getting the fuel to the Co-Op members. It makes no sense for Co-Op members to drive more than a few miles to fill up their tanks. If the on-site storage at the fuel processing facility is not within this range, the fuel must be transported back to the urban area where the Co-Op members live, stored somewhere, and made accessible to Co-Op members (and not to anyone else). Significant additional per-gallon costs, as well as permitting, siting and insurance issues, can be anticipated in this event.

9.2.6 Automobiles and Ethanol.

There isn't any question that automobiles can run well on ethanol, even azeotropic hydrous ethanol. The behavior of automobile engines and the modifications necessary to run them on ethanol, and/or make them flexibly fueled, are well known and well documented. A "layman's" summary of these issues can be found at: http://www.liquidsunenergy.com/learning/ppt/ice.pdf.

While there are no unknown or unresolvable technical issues with using the fuel produced by the Integrated Bio-Refinery in automobiles, there are legal and regulatory issues. Government regulations currently permit fueling non-FFVs only with E10 (10% anhydrous ethanol, 90% gasoline), with some states now allowing E15 (15% anhydrous ethanol, 85% gasoline) in unmodified vehicles model year 2001 and newer (EPA "E15" standard). FFVs can be fueled with ethanol content up to E85 (85% anhydrous ethanol, 15% gasoline). It is technically illegal to fuel a vehicle that is driven on public streets with a fuel that is not certified for it, per the above standards. It is not clear what the consequences are for fueling with a non-approved fuel. It seems that enforcement of these standards is via labeling at the pump for consumer awareness. It is illegal to intentionally sell fuel for an unapproved use in automobiles but it is unclear if there are any legal penalties for individuals using an unapproved fuel in their personal vehicles.

Vehicle engine modification for alternative fuels is another issue. There are no technical barriers to modifying an automobile to run on hydrous ethanol, and it is entirely legal for people to do so for personally owned vehicles that operate off-road (e.g. racing, farm use). However, it is illegal to modify an automobile engine without obtaining EPA (and CARB, in some states) approval of the engine modification. These approvals are very expensive to obtain. They require extensive engine testing for lifetime emissions; basically the same tests that automobile manufacturers must perform on the cars and light trucks that they sell. The cost of such testing is prohibitive for any individual. The test protocols are not designed to be time or cost effective on a per vehicle basis. State smog checks may have engine compartment inspections that are designed to catch such modifications (California's smog check protocol is one example). Unapproved engine modifications result in failure of the smog check and, thus the inability to register the vehicle for on-street use.

The Urban Fuel Co-Op model is that Co-Op members exchange their labor for low cost fuel for their automobiles. The ethanol fuel may be used elsewhere, of course: e.g. heating, cooking, off road vehicular use. However, the main appeal of the Urban Fuel Co-Op is on-street vehicular use. The alternative model of selling the ethanol commercially avoids this problem, as the commercial ethanol will ultimately be blended with gasoline in legally approved on-road mixtures. The question of what it takes (legally) for an Urban Fuel Co-Op to perform their own blending (e.g. make their own E10 or E85) has not been studied to date.

9.3 Pilot Production Facility.

Many of the issues listed above can best be flushed out in a well designed pilot project. The pilot project goal is to limit up-front cost and labor while developing, manufacturing, siting and operating a scaled down but fully functional Urban Fuel Co-Op. A 1/20 scale pilot (1,000 gallon per year production) would serve these purposes well. Any paper analysis, no matter how complete and thorough, cannot substitute for real world "hands-on" experience. A pilot production facility that is built and operated along the principles described in this document is an essential next step in the development of a fully functional Urban Fuel Co-Op.

While a 1/20 scale pilot system would be manageable and cost effective, there is some argument to be made for a 1/5 scale pilot. The equipment that is designed, manufactured, built and operated in a 1/5 scale pilot would be quite reasonable for parallel, multi-threaded operation (see section 8.3, above). Thus a 1/5 scale pilot, while more costly and requiring more labor than a 1/20 scale pilot, would itself be able to be used as the first thread in a multi-threaded production facility after the pilot project was complete. There is more risk at 1/5 scale than there is at 1/20 scale, but there is also more long term re-use potential.

10 Conclusions and Recommendations.

The analysis presented in this document clearly demonstrates that it is very cost effective to convert stale bakery waste into ethanol fuel. The energy required to process the ethanol represents less than 20% of the energy content of the ethanol so produced. Distillation requires energy, but the energy can be recycled to process the feedstock into wort, owing to the low temperature required to do so. Furthermore, the stillage can recycle water for making the mash. Energy and water are significant cost drivers in the small scale production of ethanol.

The analysis presented in this document also demonstrates that stale bakery waste is ubiquitous and available in quantity to urban dwellers. A Co-Op of 20 people should be able to obtain sufficient feedstock to run their cars on the ethanol produced from that feedstock out of a population of 107,000 residents.

An Urban Fuel Co-Op imposes special limitations that are not usually considered for farm production of ethanol. The main limitation is the time that Co-Op members can spend on-site for ethanol fuel processing and monitoring activities. A concept model for an Integrated Bio-Refinery is described that efficiently processes stale bakery waste into ethanol fuel with a limited requirement for on-site time by Co-Op members. The remainder of the time, the system can process feedstock unattended, albeit with electronic control and monitoring, augmented by passive fire and safety hazard mitigation methods.

The system and operational concepts presented in this document are not without issues. While feedstock is deemed to be available, the logistics of feedstock collection and transportation are significant. Likewise, the fixed costs involved are presently unknown, involving issues such as facility and land lease costs. Furthermore, legal and regulatory precedents that have been set for farm production of ethanol have not been tested in the urban arena and present further, unknown issues. Lastly, the concepts and analysis presented herein are theoretical, except for the actual processing requirements of the feedstock (which were exhaustively lab tested in 2012).

The next logical step is a well thought out pilot program that would provide a vehicle to further explore the unknowns and to validate the theoretical analysis presented herein. The pilot system can be designed using the mathematical tools developed for this analysis and described in detail in this document.

Regardless of the path forward for an Urban Fuel Co-Op, we hope that the concepts, analysis and discussion of issues presented in this document are useful and helpful to small scale ethanol producers, regardless of the setting or business model contemplated.

11 Author's Endnote.

A diligent reader will have noted that the volume and flow numbers presented in this document do not exactly line up. I started out with round numbers from a Co-Op point of view (e.g. 20,000 gallons per year). The flow analysis gave me beer rate and stillage rate volumes, which I passed on to Curbie as the Still design requirement. Curbie graciously worked through the Still design and gave me back the results. In so doing, Curbie rounded up the Still numbers to make sense for a real Still. At that point, I should have gone back and made the necessary adjustments to the Co-Op volumes and Integrated Bio-Refinery flow descriptions. This task would require a lot of editing and my excuse for not doing so was time pressure to get drafts of this document out for review. In truth, the differences are numerically small and certain not to change any of the conclusions or issues. The next step in development, which hopefully is a pilot system, must use consistent numbers across all operational components. Please accept my apologies if you have noticed a discrepancy that caused you confusion or anxiety.

Bob Glicksman, 2013