Food Product Environmental Footprint Literature Summary:

Beer

State of Oregon
DEQ Department of Environmental Quality

with support from

The Oregon Sustainability Board

A report by: Center for Sustainable Systems, University of Michigan

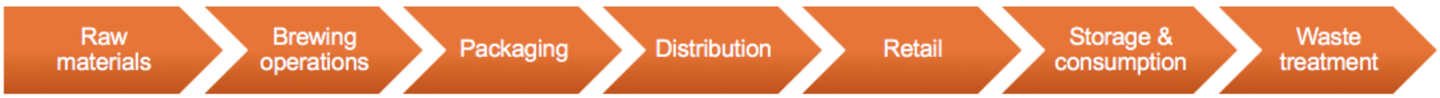
Martin Heller
September 2017

This page is intentionally left blank.

Executive Summary:

Beer

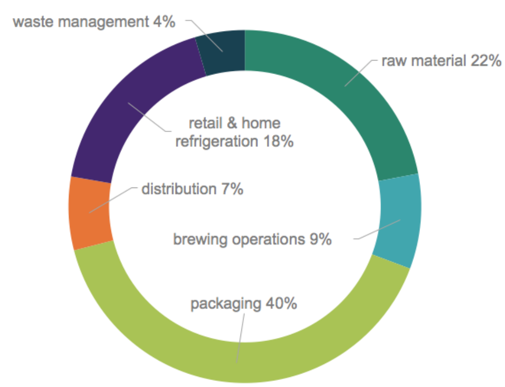
Oregon's booming craft beer industry had the 6th most permitted breweries (281) in the nation in 2015. Oregonians consume 36% of the craft beer production in-state, the highest level in the country. But all of that beer drinking adds up; according to the Oregon Consumption Based Greenhouse Gas Emissions Inventory, the upstream (i.e., raw materials through retail) emissions of beer consumption in Oregon (in-state beers plus imports) amount to 202,700 metric tons of CO_2 equivalents annually. That's about the same as 42,800 average passenger vehicles operated for a year.



The life cycle of beer is depicted above. Understanding the life cycle of beer can help focus attention on areas with the greatest potential for reducing environmental burdens. This summary highlights results from life cycle assessment (LCA) studies of beer. Such studies, while not specific to breweries in the Pacific Northwest, can help guide improvement efforts to those parts of the beer value chain where they are likely to have the most bearing, while also identifying potential trade-offs or unintended consequences.

Key Findings

Barley-based beers are the main type of beer represented in the LCA literature. Greenhouse gas emissions (GHGE), also known as carbon footprint, are the dominant environmental impact examined in these studies, although energy and water use are also considered, and a handful of studies evaluate a full suite of environmental impacts spanning environmental and human health indicators.



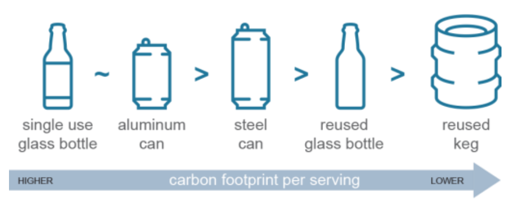
Carbon footprint by life cycle phase of beer

An overview of the reviewed beer LCA studies reveals that the packaging format typically contributes the most to environmental impacts. The chart to the right shows an average contribution to the carbon footprint of beer for each life cycle phase, based on studies in the literature. In general, production of raw materials (dominated by malted barley), packaging, and refrigerated storage emerge as the most important life cycle stages for a variety of environmental impact categories.

Conclusions

The LCA literature on beer production and consumption offers the following conclusions:

- Raw material production, specifically malted barley, is consistently an important contributor to most environmental impact categories considered.
- Opportunities may exist to reduce the carbon footprint of raw material production by brewing with un-malted barley and industrial enzyme.
- The GHGE from brewery operations are largely driven by energy use, and account for 2 – 28% of the impact. Efficiency efforts can lead to reduced impacts.
- Distribution transport was not a standout contributor in the LCA studies reviewed.
- Retail and home refrigeration of beer can be a notable contributor to the carbon footprint, and is dependent on how long the beer is kept cold.
- Producers can reduce the carbon footprint of beer by changing to packaging formats with a lower carbon footprint as shown below.



State of Oregon
DEQ Department of Environmental Quality

This page is intentionally left blank.

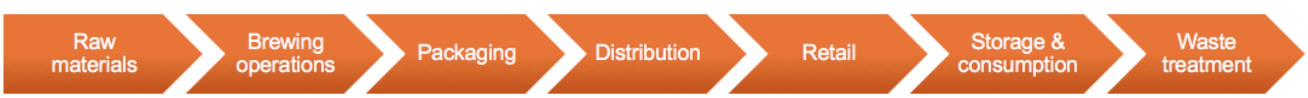
Overview

Beer, an ancient beverage that has been alluring and intoxicating humans throughout our history, is presently the most produced food commodity in the world on a weight basis. One hundred and eighty-nine million metric tons of beer (from barley) were produced globally in 2013. The U.S. is the second largest global producer at 22.4 million metric tons. U.S. beer production steadily increased from the 1960s, plateaued in the late 80s and early 90s and actually has been slowly decreasing since a peak in 1991[1]. If total production volume has decreased slightly, you certainly wouldn't know it by looking around the U.S. In 1983 there were 49 breweries in the U.S. and by 2015 the U.S. Alcohol and Tobacco Tax and Trade Bureau permitted more than 6,000 breweries. Between 2009 and 2015, 7% of the total beer market shifted from larger brewers and importers to smaller brewers, although the top five brewery companies still control 82.5% of the total market share. Beer remains the alcoholic beverage of choice for Americans, according to a 2015 Gallup poll[2].

Oregon has a booming craft beer industry. In 2015, Oregon had 281 permitted breweries, the 6th highest in the nation. Thirty-six percent of Oregon craft beer production is consumed by Oregonians themselves, the highest level in the country. At present, Oregon's craft beer brewing industry contributes $1.8 billion to the state's economy annually[3]. But all of that beer drinking adds up; according to the Oregon Consumption Based Greenhouse Gas Emissions Inventory[4], the upstream (i.e., beer brewing plus supply chain) emissions of beer consumption in Oregon (in-state beers plus imports) amount to 202,700 metric tons CO_2 eq. annually, equivalent to 42,817 average passenger vehicles operated for a year[5].

Diversification of the U.S. beer market creates ample opportunity for innovation. What can your favorite brewery do to reduce the environmental impact of your beer of choice? In this summary, we highlight results from life cycle assessment (LCA) studies of beer. Such studies, while not specific to breweries in the Pacific Northwest, can help guide improvement efforts to those parts of the beer value chain where they are likely to have the most bearing, while also identifying potential trade-offs or unintended consequences.

FIGURE 1. Generic life cycle of beer production.



This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the Food Product Environmental Footprint Foreword.

1 Food and Agriculture Organization of the United Nations: faostat.fao.org

2 https://www.nbwa.org/resources/industry-fast-facts

3 http://www.worldatlas.com/articles/top-us-craft-beer-producing-states.html

4 http://www.oregon.gov/deq/mm/Pages/Consumption-based-GHG.aspx

5 https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Available LCA Research

We have identified 15 LCA studies dating back to 2005 that consider the environmental impacts of the beer life cycle (see Figure 1). Three of these studies evaluate U.S. breweries or consider North American formats. Others consider beer production in the UK, Denmark, Greece, Italy, Spain, Thailand and West Australia. The available studies consider beers that are predominantly barley based. Greenhouse gas emissions (GHGE), also known as carbon footprint, is the dominant environmental impact examined in these studies, although energy and water use are also considered, and a handful of studies evaluate a full suite of environmental impacts including eutrophication potential, acidification potential, ozone depletion potential, and human and ecotoxicity.

Key Findings

An overview of the reviewed beer LCA studies reveals inconsistencies about which life cycle stage makes the greatest contribution to environmental impacts. This variability appears to be largely dependent on what packaging/delivery format is being used. In general, production of raw materials (dominated by malted barley) and packaging emerge as the two most important life cycle stages for a variety of environmental impact categories. One U.S. study shows that if beer is refrigerated by the retailer and then kept in refrigeration by the consumer for a long period, retail and home refrigeration can also be an important contributor to the carbon footprint of beer; however, not all studies include these stages in their assessment. Figure 2 shows the average contribution of each life cycle phase to the overall carbon footprint (CF) of beer production found in literature.

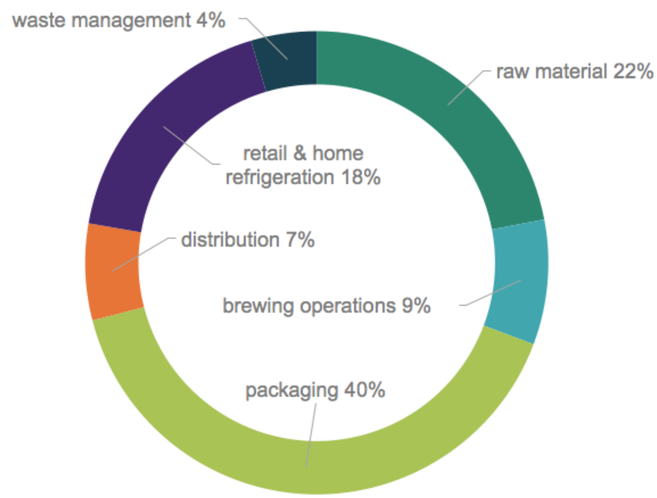
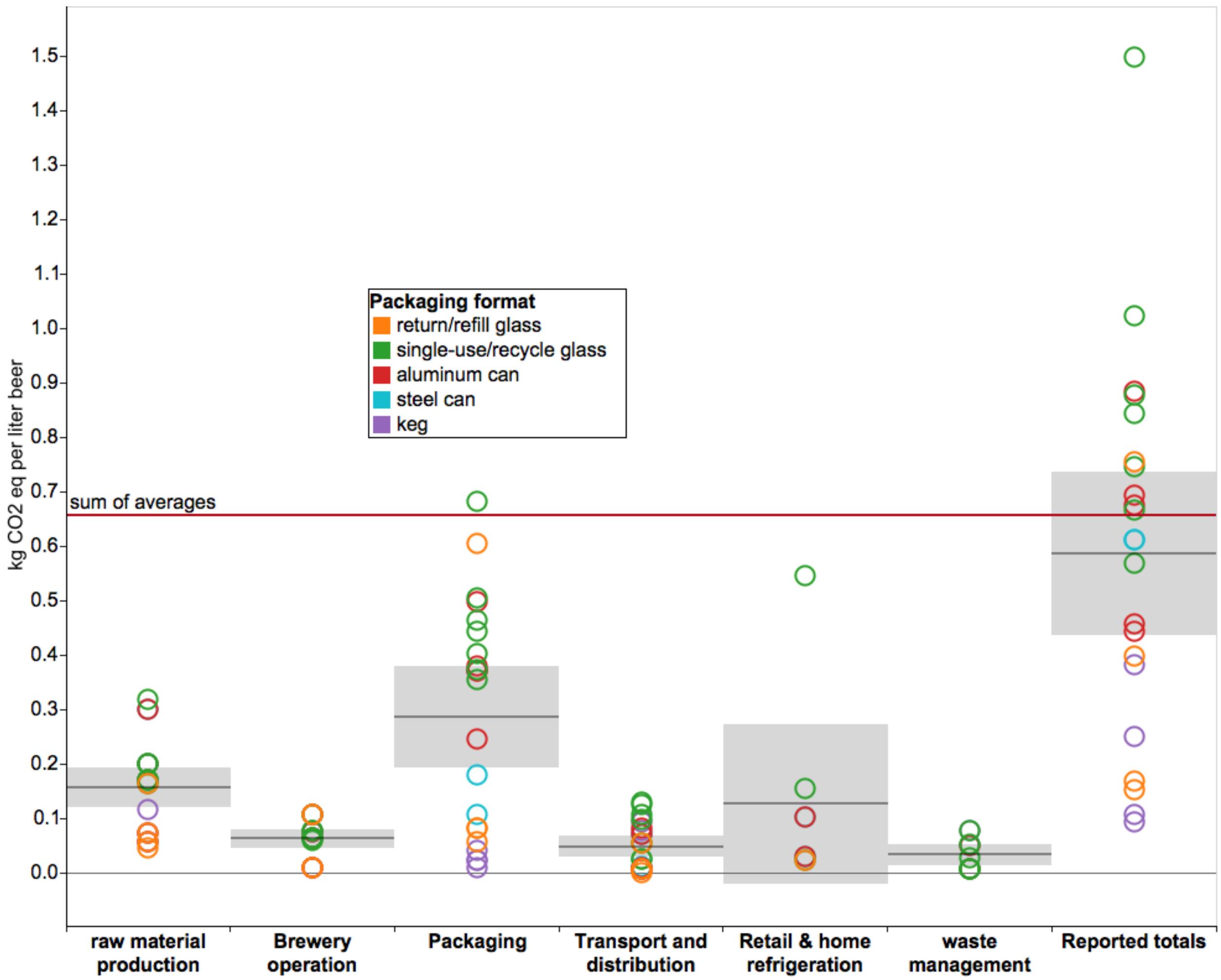


FIGURE 2. Average contribution of each life cycle phase to the overall CF of beer production.

Figure 3 provides an aggregated look at the distribution of greenhouse gas emissions across major life cycle stages for the production and consumption of one liter of beer. Color-coding of the packaging format in Figure 3 demonstrates a distinguishing trend in the packaging stage. Most single-use glass and aluminum can scenarios have larger carbon footprints than average for the stage, whereas steel can and keg delivery scenarios are below the average. The glass bottle scenarios below the average are return/refill glass scenarios; the one high return/refill scenario assumes only a 51% return, meaning every other filled bottle is newly made glass. In the following sections, we provide more information on the environmentally important stages in the beer life cycle.

FIGURE 3. Life cycle greenhouse gas emission results from seven reviewed beer LCA studies, some with multiple scenarios, displayed across life cycle stages.



Circles represent individual scenario results, offering a sense of the data spread or cluster. Horizontal grey bars represent averages for each stage, and grey blocks are 95% confidence intervals around the averages. The "Reported totals" column shows totals for a given scenario, although it is important to recognize that not all studies include the full life cycle stages represented here. The red bar indicates the sum of the averages from each life cycle stage.

Raw Material Production

The dominant ingredient in most beer recipes is malted barley. Agricultural production of barley is a significant contributor to the carbon footprint of beer, and also the dominant source of eutrophying emissions. Barley yields can vary significantly with growing region and production practices, with corresponding variability in environmental impact. A study of the Italian lager, *Peroni*, estimated that use of Italian-grown organic barley in place of conventionally grown Italian barley would reduce the beer carbon footprint by 11%, whereas importing conventional barley from 1500 kilometers away (with transport via truck) would increase the beer GHGE by 9%. Importing organic barley, also from 1500 kilometers, decreases the beer GHGE 6% (note that in these cases, differences are due to regional production differences *and* transport) (Cimini and Moresi, 2016). Malting of barley requires additional energy. In one detailed study, the malting process represented 28% of the GHGEs associated with the malted barley ingredient, whereas agricultural production was 66%, and the remainder was due to transport of barley and malt (The Climate Conservancy, 2008). Hops are also an important ingredient in beer, but typically used in small quantities relative to malt, and do not contribute significantly to the beer environmental footprint. For New Belgium Brewery's Fat Tire ale, hops production represents only 0.2% of the total beer carbon footprint (The Climate Conservancy, 2008).

One interesting study compares conventional brewing using malted barley vs. the use of a novel enzyme that allows brewing directly from 100% un-malted barley (Kløverpris et al., 2009). Avoiding the malting process saves energy, and somewhat less barley is needed to brew in this way, but the addition of the industrial enzyme adds an environmental burden. While the study was conducted in a Danish context, a conservative estimate thought to be more widely applicable was also given. This estimate found that brewing with 100% barley (no malting) reduced GHGE by 162 kilograms CO_2 eq. per ton of malt replaced, or 2.4 kilograms CO_2 eq. per 100 liters of beer produced, which amounted to about an 8% reduction in the carbon footprint of a can of beer. The study also included a sensory analysis conducted by a professional tasting panel at the Technical University of Berlin that found no significant differences between the beers when brewed at full scale by the Danish brewery, Harboes Bryggeri.

Brewing

Operations at the brewery – the actual brewing process – represent between 2 and 28% of the total life cycle GHGE of beer in the scenarios in Figure 3. The primary GHGE contribution from the beer brewing stage comes in the form of energy use[6] – electricity, natural gas, etc. It should come as no surprise, therefore, that improving the energy efficiency of the brewery process can lead to reductions in carbon footprint. While not a LCA, Sturm et al. (2013) identify opportunities and barriers for efficient energy use in medium-sized breweries and estimates that easily applicable efficiency measures such as improving insulation and implementing basic heat recovery could potentially reduce energy demand at the brewery by 20% with payback periods of around 1.3 years. The BIER LCA study gathered brewery energy efficiency data from their members and found that the range resulted in the brewery stage representing 12 to 38% of the total beer LCA in the European format and 5 to 20% of the total in the North American format. A study presented at the 2016 LCA Food conference found that the total carbon footprint per liter of beer was more than double from craft breweries compared to industrial production in an Italian context (Gavinelli et al., 2016). This was attributed to more grains used in the brewing recipe but also lower energy efficiencies of the craft breweries.

Beer Packaging

The beer delivery system – how beer is packaged – was the most differentiating feature across the environmental assessments reviewed. In general, the environmental impact of common beer packaging decreases in this order: glass bottles, aluminum cans, steel cans, kegs. There are, of course, caveats and exceptions.

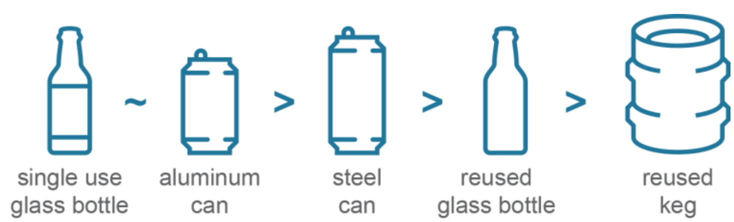


FIGURE 4. Relative environmental impact of different beer packaging.

The Beverage Industry Environmental Roundtable (2012) conducted a carbon footprint analysis of two "typical" beers in common packaging formats: European – in 0.33 liter returnable/re-filled glass bottles, distributed in a 24-pack plastic (HDPE) crate, and North American – in 0.355 liter aluminum cans, distributed in a 24-pack fiberboard carton. The full life cycle GHGE associated with the European format was less than half of the North American format, and while there were other differences in the two scenarios, sensitivity analysis points to packaging being the primary driver of this difference (see Table 1). The returnable bottles were modeled as being re-used 30 times; if non-returnable glass were used instead, the carbon footprint (packaging only) per European bottle increased by a factor of 12.5, making the bottle go from 13% of the total carbon footprint to 65%, and resulting in a full life cycle carbon footprint greater than the North

[6] While beer brewing emits carbon dioxide during fermentation, this CO_2 results from the digestion by yeast of sugars that were built up in the grains through photosynthesis, which draws CO_2 out of the atmosphere. In other words, this "carbon cycle," similar to the digestion of foods by humans, is considered short-term and a net-zero emission from a global warming perspective, and therefore is not accounted for in carbon footprint calculations.

American aluminum can format. Increasing the recycled glass content from the assumed 65% to a hypothetical maximum of 100% did not have a big impact on the overall beer carbon footprint. The emissions associated with production of aluminum cans (0.131 kilograms CO_2 eq per can) are significantly greater than those of steel cans (0.034 kilograms CO_2 eq per can), primarily due to the large energy demand necessary for aluminum production. If the North American format switched from aluminum to steel cans, the overall carbon footprint of the beer would be reduced by 29%.

Study	Scenario	GHGE (kilograms CO_2 eq. per liter beer)	
		Primary packaging contribution	Total life cycle
BIER, 2012	Europe, 0.33 liter returnable glass	0.055	0.42
BIER, 2012	Europe, 0.33 liter single-use glass	0.68	1.05
BIER, 2012	N. America, 0.355 liter Al. cans[7]	0.37	0.9
BIER, 2012	N. America, 0.355 liter steel cans	0.096	0.64
Cimini and Moresi, 2016	0.33 liter single-use glass bottle, 24 per carton[8]	0.44	0.67
Cimini and Moresi, 2016	0.33 liter single-use glass bottle, 8 per cluster pack, 3 packs per carton[9]	0.51	0.74
Cimini and Moresi, 2016	0.66 liter single-use glass bottle, 15 per carton[10]	0.36	0.57
Cimini and Moresi, 2016	0.33 liter Al. can, 24 per tray[11]	0.50	0.69
Cimini and Moresi, 2016	30 liter steel keg, re-used 72 times[12]	0.040	0.25

TABLE 1. Absolute GHGE values for varying packaging scenarios.

Note that comparisons within studies are more valid than between studies because modeling approaches and scope can differ between studies.

A thorough examination of the environmental impacts of beer production and consumption in the UK compares different packaging options across a wide array of impact categories (Amienyo and Azapagic, 2016). Results summarized in Table 2 show that beer in steel cans has the lowest impact in seven of the twelve impact categories, per liter of beer delivered. The study also showed that if glass bottles are re-used three times, the GHGE would be comparable to aluminum cans, and that for every 10% increase in recycled glass content in single-use bottles, the GHGE for the beer life cycle decreases by about 3%. Decreasing glass weight by 10%

[7] Reported baseline, typical values

[8] 12.5% of Peroni beer

[9] 9.8% of Peroni beer

[10] Most common format for Birra Peroni Srl brewery (Italy), representing 66.6% of Peroni beer

[11] 6.9% of Peroni beer

[12] 4.2% of Peroni beer

results in a GHGE savings of 5% across the beer life cycle. Such bottle lightweighting efforts have been implemented in the UK[13].

Another study of a pale lager in Italy found that the carbon footprint of beer delivered in a 30 liter keg was 2.7 times smaller than in a 0.33 liter glass bottle (Cimini and Moresi, 2016). This same study showed that bottling in larger 0.66 liter bottles decreased the carbon footprint by 15%, but 0.33 liter aluminum cans increased the carbon footprint slightly (relative to the 0.33 liter glass bottle). Absolute values from this study can be found in Table 1.

Environmental impact category	% change relative to glass bottle w/o secondary packaging		
	aluminum can	steel can	glass bottle w/ secondary packaging
GHGE	-20%	-29%	17%
primary energy demand	-28%	-34%	11%
water demand	-2%	-1%	0%
abiotic depletion potential	-33%	-45%	1%
acidification potential	-16%	-39%	5%
eutrophication potential	-9%	-10%	2%
human toxicity potential	800%	82%	5%
marine aquatic ecotoxicity potential	95%	-43%	2%
freshwater aquatic ecotoxicity potential	-41%	-49%	11%
terrestrial ecotoxicity potential	-17%	-15%	11%
ozone depletion potential	-52%	-46%	5%
photochemical oxidants creation potential	-37%	-5%	8%

Table 2. Percent change in life cycle impacts of beer (not including retail and home refrigeration) in different packaging options relative to a base case of glass bottles without secondary packaging.

The aluminum and steel can scenarios also do not include secondary packaging. Negative percentages represent a decrease in impact from the base case. The best option in each category is highlighted in light green. Adapted from Amienyo and Azapagic, 2016.

[13] http://www.wrap.org.uk/sites/files/wrap/Case%20Study%-20%20GlassRite_16%2010%2008_1230.pdf

Refrigeration

A very thorough carbon footprint assessment of Fat Tire Amber Ale brewed by New Belgium Brewing Company found retail refrigeration (energy use and fugitive refrigerant emissions) to contribute 28% of the full life cycle GHGE. Refrigeration in the home contributed an additional 8.2% (The Climate Conservancy, 2008). This study assumed that all Fat Tire was sold refrigerated, a one week retail turnover time for each 6-pack, and a two week storage in the refrigerator at home. These assumptions are all more conservative than other studies that consider downstream refrigeration and may explain the rather high contribution. The BIER study considered the sensitivity of product cooling by varying parameters as in Table 3. In this study, retail and home refrigeration represented between 2 and 15% of the total beer carbon footprint (2-10% in North American format). It appears that the high value in the Fat Tire study is largely driven by the assumed fraction of product that is refrigerated at retail.

	Baseline	High	Low	Fat Tire assumption
Temperature at retail	6.7˚C	10˚C	3.3˚C	not specified
Fraction of production cooled at retail	3%	5%	0%	100%
Retail storage duration	6 days	13 days	2 days	1 week
Domestic storage duration	2 days	10 days	1 day	2 weeks
Resulting GHGE emissions (kilograms CO_2 eq/ liter beer)	0.0214 (EU) 0.0297 (NA)	0.0697 (EU) 0.0958 (NA)	0.0121 (EU) 0.0169 (NA)	0.544

TABLE 3. Range of product cooling parameters and the resulting effect on retail and home refrigeration GHGE from the BIER LCA study (Beverage Industry Environmental Roundtable, 2012). Values from the study of Fat Tire Amber Ale are included for comparison. GHGE emission results are shown both for the Europe format scenario (EU) and the North American format (NA).

Research Gaps

The available beer LCA studies provide a fairly good overview of the environmental impacts involved. Consumers or brewers may be interested in differences between beer styles (IPAs, porters, stouts, lagers) but such an assessment would need to be conducted for a particular brewery and specific recipes. A number of other alternatives available to the consumer, such as organic beers, gluten free beers, or beers based largely on other grains, have not received coverage in the existing LCA studies. While not a question for LCA, one area of inquiry raised in this summary, given the potential environmental benefit, would be the reasons for the lack of steel-canned beer in the U.S. marketplace.

Conclusions

The LCA literature on beer production and consumption offers the following conclusions:

- Raw material production, specifically malted barley, is consistently an important contributor to most environmental impact categories considered.

- Opportunities may exist to reduce the carbon footprint of raw material production by brewing with un-malted barley and industrial enzyme.
- Beer packaging is also an important contributor, but this varies depending on the packaging format. With one exception, the carbon footprint of beer packaging options in the studies reviewed decrease in this order: single-use glass bottles ≈ aluminum cans > steel cans > re-used bottles > re-used kegs.
- The GHGE associated with brewery operations are largely driven by energy use, and contribute 2 – 28% of life cycle GHGE for the studies in Figure 3. Efficiency efforts can lead to reduced impacts.
- Retail and home refrigeration of beer can be a notable contributor to the carbon footprint, but this is dependent on how long the beer is cooled in the product chain.
- While certainly important, distribution transport was not a standout contributor in the LCA studies reviewed, averaging 9% of life cycle GHGE for the studies in Figure 3 (standard deviation =±9%, median=5%). This may be partly dependent on the modeling assumptions made. In general, shorter distance, maximizing shipment loading, and, when possible, utilizing rail over truck, will reduce the carbon footprint of beer distribution.

References

Amienyo, D. and A. Azapagic. 2016. Life cycle environmental impacts and costs of beer production and consumption in the UK. The International Journal of Life Cycle Assessment 21(4): 492-509.

Beverage Industry Environmental Roundtable. 2012. Research on the carbon footprint of beer. Available from http://media.wix.com/ugd/49d7a0_70726e8dc94c456caf8a10771fc31625.pdf.

Cimini, A. and M. Moresi. 2016. Carbon footprint of a pale lager packed in different formats: assessment and sensitivity analysis based on transparent data. Journal of Cleaner Production 112: 4196-4213.

Gavinelli, C., G. Dotelli and F. Recanati. 2016. Comparing the environmental performances of craft and industrial beer: strengths and weaknesses of Life Cycle Assessment. 10th International Conference on LCA in the Food and Argiculture Sector, Dublin, Ireland.

Kløverpris, J. H., N. Elvig, P. H. Nielsen and A. M. Nielsen. 2009. Comparative Life Cycle Assessment of Malt-based Beer and 100% Barley Beer. Available from https://www.novozymes.com/en/-/media/Novozymes/en/sustainability/customer-benefits/improve-and-document-performance/Documents/Comparative-LCA-of-malt-based-and-barley-based-beer---Full-report.pdf?la=en.

Melon, R. P., V. Wergifosse, R. Renzoni and A. Léonard. 2012. LIFE CYCLE ASSESSMENT OF AN ARTISANAL BELGIAN BLOND BEER. [avniR] 2nd LCA Conference, Lille, France.

Sturm, B., S. Hugenschmidt, S. Joyce, W. Hofacker and A. P. Roskilly. 2013. Opportunities and barriers for efficient energy use in a medium-sized brewery. Applied Thermal Engineering 53(2): 397-404.

The Climate Conservancy. 2008. The Carbon Footprint of Fat Tire® Amber Ale. Available from http://www.newbelgium.com/files/shared/tinkerer/the-carbon-footprint-of-fat-tire-amber-ale-2008-public-dist-rfs.pdf.