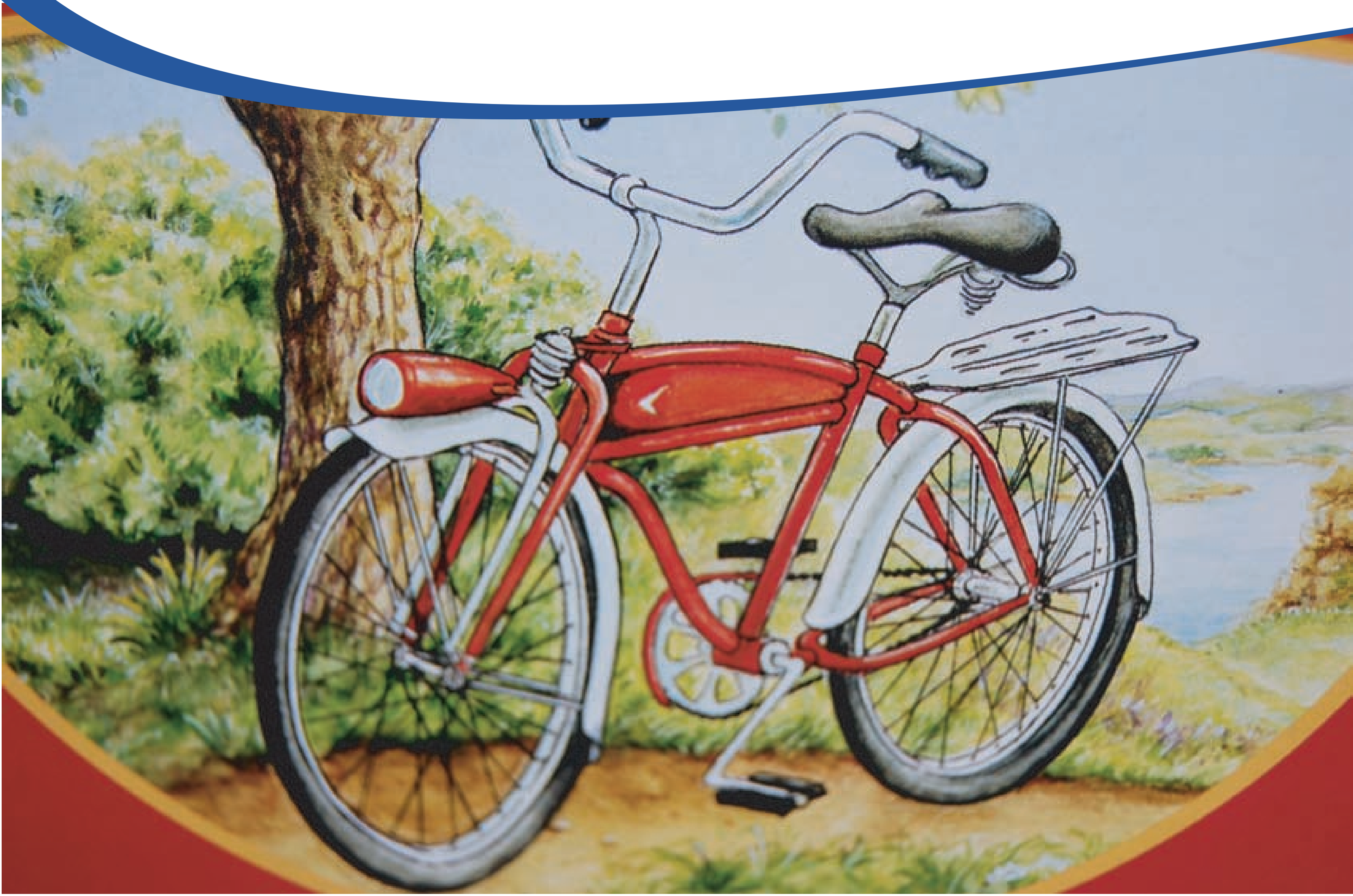
THE CLIMATE CONSERVANCY

The Carbon Footprint of Fat Tire® Amber Ale

Some proprietary content (i.e. trade secrets) has been withheld from this version.



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Executive Summary

3,188.8 g CO_2e

This report contains the results of work performed by The Climate Conservancy in cooperation with New Belgium Brewing Company to assess greenhouse gases emitted across the full life cycle of Fat Tire® Amber Ale.

System boundaries of the assessed life cycle encompass acquisition and transport of raw materials, brewing operations, business travel, employee communting, transport and storage during distribution and retail, use and disposal of waste.

The carbon footprint of a 6-pack of Fat Tire® Amber Ale (FT), or the total greenhouse gas (GHG) emissions during its life cycle, is 3,188.8 grams of CO_2 equivalents (g CO_2e).

Of this total, emissions from New Belgium Brewing Company's own operations and the disposal of waste produced therefrom account for only 173.0 g CO_2e, or 5.4%. Upstream emissions during production and transportation of packaging materials and beer ingredients add up to 1,531.3 g CO_2e, or 48.0% of total emissions. Downstream emissions from distribution, retail, storage and disposal of waste account for the remaining 1,484.6 g CO_2e, or 46.6% of the total.

The largest line item in the tally of GHG emissions is electricity used for refrigeration at retail: 829.8 g CO_2e. The next largest sources are production and transportation of glass and malt (including barley): 690.0 and 593.1 g CO_2e, respectively. These three sources alone account for 68.4% of all emissions embodied in a 6-pack of FT. The bulk of remaining emissions are accounted for by production and transportation of paper and CO_2 for carbonation, refrigeration in consumer's homes, distribution transport, and natural gas consumed during brewing operations. These six sources account for another 25.1% of total emissions per 6-pack of FT.

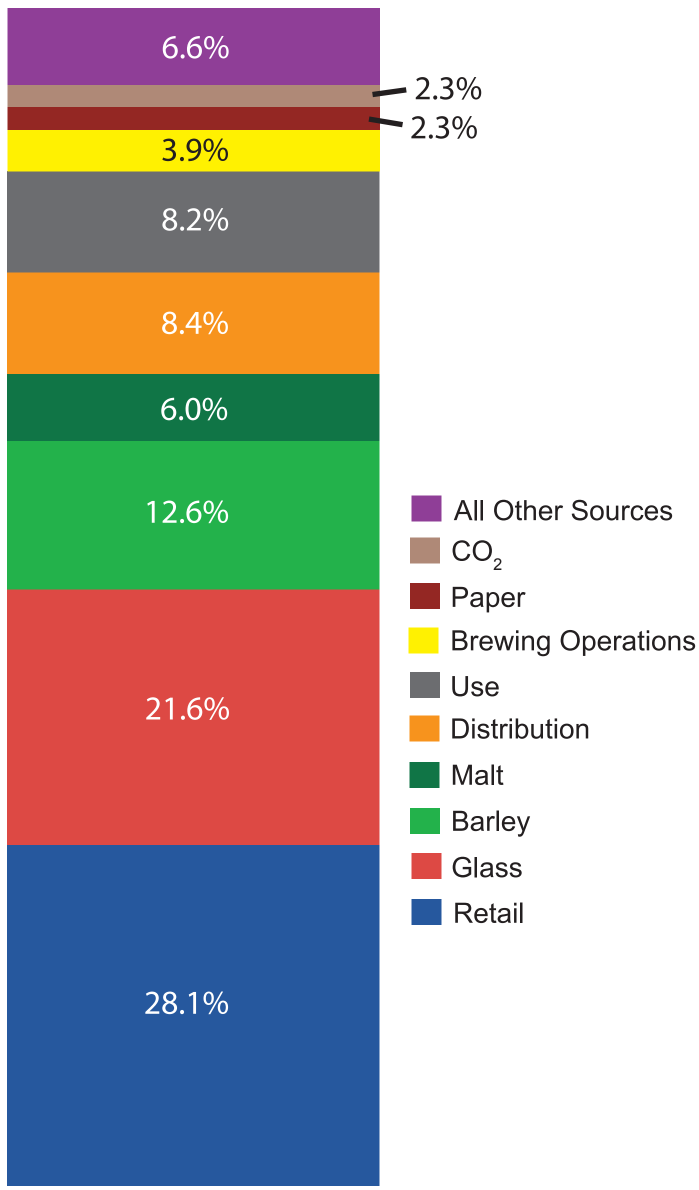


Figure 1. *Carbon Footprint of Fat Tire® Amber Ale showing major sources of GHG emissions by percentage of total emissions.*

Definition of Terms

While we have tried to keep this report as free of jargon as possible, following are some abbreviations, terms and units that may not be familiar to all readers.

6-pack Six glass bottles of 12 fluid ounce capacity each, packaged together in a paperboard carrier.

Carbon Credits See "Offsets"

Carbon Footprint The carbon footprint, or embodied carbon, of a product or service is the total amount of GHGs emitted across the life cycle of a product. Though there are non-CO_2 GHGs that are included in the carbon footprint, the term arises from the most significant GHG: CO_2 (carbon dioxide).

Carbon Emission Factor see "Emission Coefficient"

CO_2e Carbon dioxide equivalent. A unit of GHG emissions including non-CO_2 gases that have been converted to an equivalent mass of CO_2 according to their global warming potentials (see GWP below).

Direct/Indirect These terms are used to refer to greenhouse gas emissions that are immediately related to an operation or process, such as by combustion of fuel or leakage of refrigerant hydrofluorocarbon (direct), or released during the prior production of material or generation of electricity (indirect). In the context of the GHG Protocol of the World Resources Institute and World Business Council for Sustainable Development (WRI/WBCSD), these terms are interchangeable with "Scope 1" "Scope 2/3" emissions, respectively.

Emission Coefficient Fossil sources of energy entail GHG emissions. The mass of GHGs emitted during combustion of fuel or consumption of electricity that is derived from combustion of fossil fuels elsewhere can be calculated using an Emission Coefficient or "carbon emission factor." The US Energy Information Administration (EIA), the UK's Department of Environment, Food and Rural Affaris (DEFRA), and the World Resources Institute (WRI), all provide databases of Emission Coefficients. But note that the Emission Coefficients provided by these sources relate only to GHGs produced during combustion of fuel or consumption of electricity, and NOT the GHGs emitted during the production and delivery of that fuel or electricity.

Entity The business operation responsible for manufacture of the product being assessed

FT Fat Tire® Amber Ale, a product and registered trademark of New Belgium Brewing Company

g or gram 0.035 ounces or 0.0022 pounds

GHGs Greenhouse Gases. TCC's assessment tracks the six "Kyoto" gases regarded as most significant in terms of their climate impact: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

GWP Global Warming Potential. A number that is a nondimensional measure of the warming caused by non-CO_2 greenhouse gases relative to an equivalent mass of CO_2, defined over a specific period of time. For instance, methane has a 100-year global warming potential of 25, meaning that over 100 years, a given mass of methane has the equivalent warming effect of 25 times as much CO_2. Herein, we apply the 100-year global warming potentials prescribed in the Fourth Assessment Report of the International Programme on Climate Change (IPCC) in 2002.

Hectare 2.47 acres

Kg or kilogram 1,000 grams or 2.2 pounds

LCA Life Cycle Assessment. An academic field concerned with the accounting of material and energy flows involved in the life cycle of a product or service, and the assessment of associated environmental impacts. TCC's Climate Conscious Assessment is an LCA of GHGs.

Mt or Metric Ton 1,000 kilograms or 2,204.6 pounds

NBB New Belgium Brewing Company of Fort Collins, Colorado

Offsets GHGs removed from the atmosphere (e.g. by growing trees) or prevented from escaping to the atmosphere (e.g. by capturing exhaust from power plants or gases released from landfills) have been commoditized by companies and organizations which market them as a means of "offsetting" comparable masses of greenhouse gases emitted elsewhere. Purchasers of offsets often seek to obtain amounts sufficient to compensate for all their direct emissions, thus making their product/service/activity "carbon neutral." TCC's assessment does not consider offsets, since we are seeking to quantify the GHGs emissions immediately related to the production system.

RECs Renewable Energy Credits/Certificates. Electricity generated from renewable resources (e.g. wind, solar, geothermal) and fed into one of the national power grids is assumed to reduce demand for electricity generated from fossil fuels (e.g. coal, natural gas, oil) on a 1:1 basis. As such, there is a market for certificates representing electricity generated from renewable resources that effectively allows renewable sourcing of electricity at any location.

TCC The Climate Conservancy, a non-profit located in Palo Alto, California

Ton Where not specified Metric Ton or abbreviated Mt, "ton" refers to a short ton of 2,000 lbs.

Introduction

This report was prepared for New Belgium Brewing Company to help the company manage greenhouse gas emissions throughout the supply chain of Fat Tire® Amber Ale.

The Climate Conservancy

The Climate Conservancy (TCC) is a California nonprofit corporation founded by concerned members of elite academic and business communities. Our mission is to reduce greenhouse gas (GHG) emissions by informing consumers of the relative climate impacts of products and services that they purchase on a daily basis. We achieve this by working in partnership with members of private industry to quantify the GHGs emitted during the life cycle of their companys' product(s) using our Climate Conscious™ assessment methodology and by offering assessed companies the licensed use of our Climate Conscious™ label in connection with their product, provided certain criteria are met.

Our objective in coupling life cycle assessments with an associated labeling program is to create a consumer driven and market-based mechanism that promotes the consumption of products with low GHG intensity and that provides companies with the ability to further differentiate their products in the market. Moreover, as GHG emissions become increasingly commoditized and regulated, our Climate Conscious™ assessment tool will provide increasing value to companies that wish to better manage their GHG assets and liabilities. In concert, we believe our services to industry will play a significant role in, and provide an efficient means for the inevitable transition to a low carbon economy.

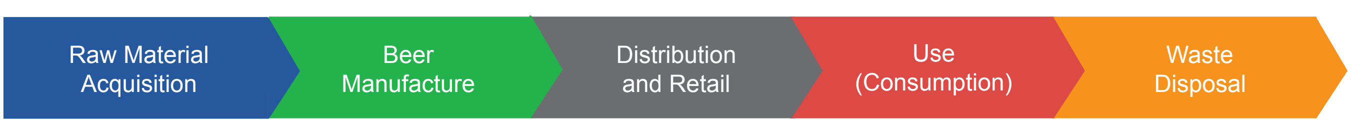
Life Cycle Assessment

The Climate Conscious™ Assessment is a product-level GHG inventory based on the principles of process life cycle assessment (LCA). TCC works with the companies whose products we assess to tally the GHGs emitted during the complete life cycle of their product. The life cycle of a product, as defined by the system boundaries of our LCA methodology, include the production of all raw and manufactured materials, conversion of those materials into finished products and co-products, processing of waste, product packaging, storage and transportation of products during distribution and retail, in-use emissions, disposal or recycling of the product, as well as immediate offset projects and any other innovative solutions of the company whose products are under assessment.

Background of Beer LCA

To our knowledge, there have been only a few attempts at performing an LCA of beer. Those that we were able to find are largely academic in nature and none attempted to quantify the GHG emissions associated with a particular brand of beer (Talve, 2001; Narayanaswamy et al., 2004; Garnett, 2007). Previous efforts have generally used either a more consequential approach in quantifying the GHG emissions associated with decisions made in the brewing process or have focused on the overall contribution of the GHG emissions from the beer industry to the total emissions of all industries. Though the LCA methodologies and system boundaries of previous assessments are quite similar to those defined and used by TCC, the influence of qualitative data and/or the incompleteness of certain other data make it difficult to compare previous results to the results of this assessment.

Figure 2. *Life cycle of a 6-pack of Fat Tire® Amber Ale*



Upstream 1,531.3 g CO_2e

Emissions assessed in this section are those associated with the acquisition of raw materials and any pre-processing of those materials prior to their delivery to NBB.

Packaging & Non-consumable Materials 853.3 g CO_2e

Production of packaging materials using virgin inputs results in GHG emissions due to the extraction and transportation of raw materials, as well as the manufacture of the packaging material. Emissions from both the transportation of virgin inputs as well as the manufacturing process are included as part of the production of packaging materials.

Production of packaging materials using recycled inputs generally requires less energy and is therefore preferable to the use of virgin materials. Though the transportation of material recovered for recycling also results in GHG emissions, these emissions are accounted for in the disposal phase (page 30). In this section, we consider GHGs emitted during the manufacture of packaging materials from recycled inputs based on analyses of the US Environmental Protection Agency (EPA, 2006).[1]

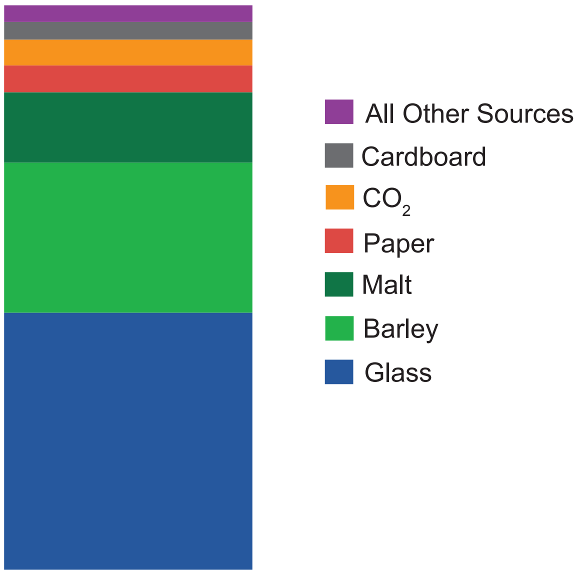


Figure 3. *Major sources of upstream GHG emissions by percentage of total upstream emissions.*

Glass 690.0 g CO_2e

Production 688.2 g CO_2e

Virgin Inputs

The raw materials used in glass production are: wet sand, soda, Chempure sand, limestone, dolomite, Calumite brand slag, nephylene syenite, feldspar, sodium sulphate, iron chromite and water. They are typically melted at 1400ºC to form glass (Edwards and Schelling, 1999). GHG emissions result from quarrying raw materials, transportation, and fuel consumption in the production process.

The combined process and transportation emissions resulting from glass manufacturing from 100% virgin inputs is 0.66 Mt CO_2e per ton of glass produced (1 metric ton = 1,000 kilograms). The mass of glass in a 6-pack of FT is 1,210 g (2.67 lbs),[2] hence the GHG emission is 724.5 g of CO_2e.

Recycled Inputs

Glass produced using recycled inputs permits substantial energy savings because recycled glass cullet requires a lower melting temperature (1250ºC) in the manufacturing process (Edwards and Schelling, 1999). Emissions resulting from producing glass using 100% recycled cullet is 0.33 Mt CO_2e per ton, yielding 362.2 g of CO_2e for the glass contained per 6-pack.

Mix of inputs

Products can be manufactured using a mix of virgin and recycled inputs. Although the national average percentage of recycled input in the production of glass is 23%, the mix of inputs used by Owens-Illinois, Inc. to manufacture bottles for NBB is 10% recycled.[3] Using this figure for the mix of inputs, the weighted average GHG emission is then 688.2 g of CO_2e for the production of glass contained in one 6-pack of FT.

[1] Environmental Protection Agency, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks 2006 (available online at http://epa.gov/climatechange/wycd/waste/SWMGHGreport.html)
[2] This figure includes a scrap rate of 5%. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)
[3] Information throughout this section regarding mix of inputs used by NBB was provided by NBB during a telephone conversation with Jenn Orgolini on March 11, 2008

Transportation 1.8 g CO_2

Twelve ounce brown glass bottles are delivered to NBB from Windsor, Colorado, a distance of 16 miles. These bottles are shipped by OTR (over the road) truck. Because specific information was not available , it is assumed in the calculations that the truck type is a Class 8 tractor-trailer with an average fuel efficiency of 6.3 mpg (miles per gallon),[4] a maximum cargo weight of 20,000 kg and using standard diesel fuel. For a truck to be defined as a Class 8 truck, the minimum gross vehicle weight must be 15,000 kg. However, for profitability and in light of recent higher fuel costs, it is assumed herein that shippers are shipping at the maximum federal weight limit of 36,363 kg.

The sixteen-mile trip requires 2.54 gallons of diesel fuel. The production and transportation of a gallon diesel fuel contributes 11.8 kg of CO_2 to the environment (West and Marland, 2002). The entire trip then emits 29.96 kg of CO_2. Allocating this CO_2 per 6-pack results in a total amount for the transportation of bottles of 1.8 g of CO_2.

Paper 74.0 g CO_2e

Production 62.5 g CO_2e

Virgin Inputs

Beer bottle labels and 6-pack carriers are composed of paper and paperboard, respectively. When 100% virgin inputs are used for the production of paper, GHG emissions during transportation and manufacture are 1.69 Mt CO_2e per ton.[5] Paperboard production is responsible for 1.17 Mt CO_2e per ton.[6] The weight of 6 labels is approximately 5.7 g (<0.01 lb) and the weight of one 6-pack carrier is approximately 95.3 g (0.21 lb).[7] Production of these quantities using virgin inputs results in emissions of 8.7 g of CO_2e for label paper and 101.4 g of CO_2e per 6-pack carrier.

Recycled Inputs

Manufacture of packaging from recycled inputs generate GHG emissions estimated to be 1.65 Mt CO_2e per ton for paper production and 0.62 Mt CO_2e per ton for paperboard. Material for one 6-pack thus represents 8.5 g of CO_2e (paper) in addition to 53.9 g of CO_2e (paperboard).

Mix of inputs

The national average percentage of recycled input in the production of paper is 4% and that of paperboard is 23%. However, inputs to FT are 0% and 100%, respectively, so that the weighted average GHG emissions for the paper and paperboard content of one 6-pack are 8.7 g of CO_2e (paper) and 53.9 g of CO_2e (paperboard).

Transportation 11.5 g CO_2

Paper bottle labels are shipped 946 miles from LaCrosse, Wisconsin to NBB. Although the labels are shipped less than truck load (LTL) it is assumed that the majority of the travel distances are similar to that of the glass bottle shipment and the same assumptions apply. The entire trip consumes 150.16 gallons of diesel fuel that represents a total CO_2 output of 1,771.67 kg. Allocating for the mass of the labels per 6-pack results in a total amount of 0.5 g of CO_2.

6-pack carriers are shipped from the Sierra Pacific Packaging (SPP) plant in Oroville, California at a distance of 1,112 miles after being transported from Altivity Packaging in Santa Clara, California, a distance of 183 miles. Although SPP provided detailed information concerning their operations and shipping, we were not able to ascertain specific information concerning shipping (make, model, year and fuel economy). Using our standard shipping assumptions, the trips require 205.56 gallons of diesel fuel and correspond to a total of 2,425.27 kg of CO_2 per trip. Each 6-pack carrier contributes 11.0 g of CO_2 to that total.

Cardboard 47.7 g CO_2e

Production 47.4 g CO_2e

Virgin Inputs

The carton box that holds 4 6-packs is composed of corrugated cardboard. Its production from 100% virgin inputs results in a net GHG emission of 0.84 Mt of CO_2e per ton of cardboard. The mass of corrugated cardboard allocated to one 6-pack is 60.1 g (0.13 lb, or ¼ of the total mass of a single carton box),[8] which represents emission of 46.0 g of CO_2e.

[4] This figure is an average from McCallen 2006 (5.2 mpg), Huai et al. 2005 (6.6 mpg), Office of Heavy Vehicle Technologies and Heavy Vehicle Industry Partners, DOE 1998 (7.0 mpg)
[5] Using EPA's estimate for magazine-style paper to allocate emissions to beer labels
[6] Using EPA's "broad paper definition" to estimate emissions resulting from 6-pack carrier production
[7] Scrap rate equals 1% in the case of label paper and 5% for paperboard. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)
[8] Scrap rate equals 5%. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)

Recycled Inputs

Process emissions during the manufacturing of cardboard from 100% recycled inputs correspond to 0.92 Mt CO_2e per ton. In this case, production of 0.13 lb of corrugated cardboard therefore results in 50.0 g of CO_2e.

Mix of inputs

NBB inputs match the national average percentage of recycled input for the production of corrugated cardboard is 35%. The weighted average GHG emission for the production of cardboard from this mix of inputs is 47.4 g of CO_2e per 6-pack of FT.

Transportation 0.4 g CO_2e

The corrugated cardboard coming from Temple Inland travels 65 milles from Wheat Ridge, Colorado to NBB, a journey that consumes 10.32 gallons of diesel fuel per truckload. A full truckload contributes 121.73 kg of CO_2 and allocating this mass over the mass of the cardboard used in the production per 6-pack of FT creates 0.4 g of CO_2.

Steel 17.4 g CO_2e

Production 16.0 g CO_2e

Virgin Inputs

Steel is used in beer bottle crowns.[9] Six of these crowns weigh approximately 5.7 g (<0.01 lb).[10] Manufacturing steel products[11] from 100% virgin inputs results in GHG emissions of 3.70 metric tones CO_2e per ton. Transport and manufacture of the mass of steel associated with one 6-pack of FT thus represents 19.1 g of CO_2e.

Recycled Inputs

Recycling of steel entails significantly less GHG emissions than manufacture from virgin inputs: 1.58 Mt of CO_2e per ton. Producing 5.7 g of steel from recycled material results in 8.1 g of CO_2e emissions.

Mix of inputs

Specific data regarding the mix of inputs used by the Pelliconi Group was not available. In the US, the average percentage of recycled input in steel products is 28%. Assuming a mix of virgin and recycled inputs is used, the weighted average of GHG emissions from the manufacturing of 6 steel crowns is 16.0 g of CO_2e.

Transportation 1.4 g CO_2

Beer bottle crowns are manufactured in Atessa, Italy. Because only limited information regarding the shipping of crowns was provided by the Pelliconi Group, it has been assumed that the crowns are shipped by truck from Atessa to the port in Napoli, a distance of 111 miles via Class 8 truck (or named EU equivalent). Truck fleets in the EU have higher fuel efficiency than those in the United States, with a 2002 average of 7.1 mpg traveling at 63 miles per hour and 8.4 mpg traveling at 54 mph.[12] Another source rates the 2002 Volvo truck within the EU at 7.8 mpg.[13] Travel speeds in Italy are restricted to 61 mph, with trucks and buses restricted to even slower speeds, thus increasing the fuel efficiency of the vehicle. However, it is assumed that congestion will decrease the effective fuel efficiency of an EU fleet truck. The number assumed here is 1 mpg higher than the fuel efficiency of the US (6.3 mpg) or 7.3 mpg. With these figures, the diesel use from Atessa to Napoli is 15.21 gallons, a volume of fuel that generates 178.97 kg of CO_2 (assuming that emission standards are equivalent for the US and the EU). Allocating the mass of the crowns used in a 6-pack results in 0.1 g of CO2.

Once the crowns arrive in Napoli (or similar Italian port), they are transported by container ship to Newark, New Jersey over a distance of 4,157 nautical miles.[14] Our calculations assume that the ship is a Panamax[15] class, though if it were on a Post-Panamax class (larger) ship, emissions might be slightly less. Assuming that CO_2 emissions are 12.57 kg of CO_2 per gallon at a speed of 23 knots per hour and 70.86 gallons of bunker fuel per mile, the entire trip generates 4,000,618.03 kg of CO_2. Allocating by weight of cargo, the transport of 5.6 g of crowns result in 0.4 g of CO_2 emissions.

[9] We assume crowns are made entirely of steel
[10] Scrap rate equals 1%. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)
[11] Using the EPA's estimates for steel cans
[12] Trucks and Air Emissions Final Report September 2001 EPS 2/TS/14 Environmental Protection Service, Canada
[13] Volvo Trucks and the Environment RSP20100070003
[14] A Panamax ship has an average DWT of 65,000 tons and is this largest ship that can navigate the Panama Canal
[15] www.searates.com

From Newark, the crowns are transported via Class 8 truck to NBB over a distance of 1,767 miles. This trip will consume 280.48 gallons of diesel fuel and emit 3,309.24 kg of CO_2. The 5.6 g of crowns will account for 0.9 g of CO_2.

Wood 16.0 g CO_2e

Production 16.0 g CO_2e

Virgin Inputs

Dimensional lumber is used in the production of wood pallets for easier packing and transportation of goods. Its production using virgin wood results in GHG emissions of 0.18 Mt CO_2e per ton of wood. One 6-pack occupies a fraction of a pallet equal to 0.28%. The mass of lumber allocated to one 6-pack of FT is approximately 96.4 g (0.21 lb),[16] which represents 16.0 g of CO_2e from wood production.

Recycled Inputs

There is no reduction of GHG emissions due to recycling of lumber; emissions during recycling of lumber products are also 0.18 Mt CO_2e per ton of wood. Production of 96.4 g of dimensional lumber from recycled material therefore results in the same 16.0 g of CO_2e.

Mix of inputs

Dimensional lumber is not manufactured using a mix of recycled and virgin inputs.

Transportation 0 g CO_2

Wooden pallets from Rocky Mountain Battery and Recycling travel only one mile to NBB that consumes 0.16 gallons in a Class 8 truck. The trip thus constitutes an emission of 1.87 kg of CO_2. Allocating the 96.4 lb of pallet associated with one 6-pack of beer is 0.01 g of CO_2. Contributions of less than 0.01 g CO_2 are counted as effectively nothing throughout this report.

Adhesive 7.6 g CO_2e

Production 7.5 g CO_2e

The adhesive used by NBB to apply paper labels to glass beer bottles is a combination of natural starch and synthetic resins.[17] The adhesive is manufactured in batches in Sacramento, California. The most energy-intensive steps during manufacture are heating and steaming of the adhesive mixture. Reliable sources on the energy requirements of glue manufacture were not available. Emissions during its manufacture are instead estimated using the known carbon emissions factor for the production of resin-based LDPE (2.35 Mt CO_2e per ton of LDPE), which we believe to be a liberal estimate in this case. Based on this assumption, GHG emissions resulting from production of label adhesive used per 6-pack are 7.5 g CO_2e.

Note that many manufacturers use casein-based glues to apply paper labels to glass bottles (Ciullo, 1996; Fairley, 2005). Casein is a protein obtained from bovine milk, and is generally imported to the US from eastern Europe or New Zealand (Richert, 1974; Kelly, 1986; Southward, 2008). As a product of the dairy industry (which is a large source of CH_4 emissions) that is shipped from overseas, casein glues are likely to entail greater CO_2e emissions that the glue used by NBB.

Transportation 0.1 g CO_2e

Label glue and hot melt glue used for cases come from Sacramento, California and Eden Prarie, Minnesota, respectively. Assuming that the density of label glue is near 1 g per mL, the 0.95 mL of glue for each 6-pack would weigh 0.95 g. Over the 1,101 miles from Sacramento, California to NBB, the transportation of the glue would emit 0.07 g of CO_2.

The amount of hot melt glue used to secure cases was not provided to TCC. However, by assuming that the density and mass of the glue used is similar to that of the label glue, we have assumed that the transportation of this glue would emit 0.07 g of CO_2, for an adhesive total of 0.1 g of CO_2 per 6-pack.

[16] Scrap rate equals 0.5%. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)
[17] Telephone conversation with Pacific Adhesives on February 28, 2008

Plastic 0.5 g CO_2e

Production 0.5 g CO_2e

Virgin Inputs

The basic ingredients in all plastics are resins derived from petroleum oil or natural gas. Other chemical additives are mixed with the melted resin to form the final plastic product. Production of low-density polyethylene (LDPE), 230 mg (0.23 g or 0.002 lb) of which is used as stretch-wrap per 6-pack of FT,[18] from 100% virgin materials (including manufacture and transportation) causes emission of 2.35 Mt CO_2e per ton of LDPE produced. GHG emissions allocated to one 6-pack are then 0.5 g of CO_2e.

Recycled Inputs

Different types of plastic resins have different molecular structure and yield various finished products. The different molecular structures cause plastics not to mix when melted, so that they need to be separated from each other prior to recycling in order for the recycled resin to be of high quality. In the case of LDPE, processing of recycled material results in emission of 0.15 Mt CO_2e per ton of plastic produced. Thus, the manufacture of stretch-wrap material associated with one 6-pack results in 10 mg (0.001 g) of CO_2e emissions.

Mix of inputs

The national average percentage of recycled input in the production of LDPE is 4%. Using this mix of inputs, we estimate 0.2 g of CO_2e emissions per 6-pack of FT.

Transportation 0 g CO_2

Shrink wrap supplied by Katzke in Denver, Colorado is transported 65 miles to NBB, a trip that consumes 10.32 gallons of diesel fuel. This amount of diesel emits a total of 121.73 kg of CO_2 into the atmosphere and allocated to an individual 6-pack amounts to 0.01 g of CO_2.

Consumable Materials 678.0 g CO_2e

Malt 593.9 g CO_2e

Barley Agriculture 394.1 g CO_2e

Cultivation of barley (*Hordeum vulgare L.*) results in GHGs emitted during production of seeds, fertilizers, pesticides and soil amendments, operation of farm equipment (including irrigation) and emissions from the soil (Lal, 2004a). While storage of organic carbon (C) in the soil may theoretically offset emissions, the required management practices are not widely used (West and Marland, 2002; Lal, 2004b; Mosier et al., 2005).

Nationwide, yield per cultivated hectare of barley in 2006 was 3.28 Mt (3,281.85 kg).[19] In the calculations below, we use this figure to allocate emissions during agriculture to a given mass of barley. It should be noted that malt barley yields are typically less than feed barley, where more nitrogenous fertilizer may be applied without concern for protein content and kernel plumpness.[20] However, because roughly two-thirds of the US barley grown in 2006 was malt barley,[21] we believe the national yield statistics are representative.

There is a potential for agricultural lands to reduce carbon emissions and even sequester atmospheric carbon as organic carbon in the soil by adopting no-till techniques, integrating fertilizer and pest control practices, and increasing the efficiency of irrigation systems (West and Marland, 2002; Lal, 2004b). However, conventional farming practices are carbon intensive and also quite disruptive to soil carbon reservoirs used (West and Marland, 2002; Lal, 2004b; Mosier et al., 2005). Though we have quantified GHGs emitted throughout agricultural production, we do not assess soil carbon storage owing to the high degree of variability associated with exchanges of soil carbon (depending heavily on such details as soil type, the time-distribution of irrigation water, and the speed of plowing).

[18] Scrap rate equals 1%. NBB data, "6 Pack BOM 082907 (with scrap loss rates).xls" (Tranche 2)
[19] Per crop reports of the US Department of Agriculture:
www.fas.usda.gov/psdonline/psdgetreport.aspx?hidReportRetrievalName=BVS&hidReportRetrievalID=885&hidReportRetrievalTemplateID=1
[20] See note of Jackson, G., soil scientist at the University of Montana's Western Triangle Ag. Research Center, Conrad, MT:
http://landresources.montana.edu/FertilizerFacts/24_Nitrogen_Fertiliztion_of_Dryland_malt_Barley.htm
[21] www.ag.ndsu.edu/ibms/newsletters/IBMS%20Newsletter%20Dec%2006.pdf

Seed Production 40.3 g CO_2e

In the US, North Dakota, Idaho, Montana, Washington, and Minnesota produce the bulk of malt barley, and barley is generally planted in spring as soon as a seedbed can be prepared. Emissions during production of barley seed have been previously estimated at 1.47 kg CO_2e per kg seed (West and Marland, 2002). Recommended seed application is between 72.85 and 145.72 kg per hectare (1 hectare = 2.47 acres).[22] Thus, seed for a single hectare relate to emissions of between 106.85 and 213.72 kg CO_2e.

Using the upper estimate of CO_2e emissions and the average yield in 2006, 65.1 g of CO_2e emissions from seed production were embodied in each kilogram of barley crop. Assuming a ratio of barley:malt of 4:3, the 618 g of barley used to brew a 6-pack of FT account for 40.3 g of CO_2e emissions.[23]

Agricultural Machinery Production 48.3 g CO_2e

Tillage, planting, spreading, spraying and harvesting typically entail agricultural machinery which require energy (Lal, 2004a).

Sowing, Spreading, Spraying, Harvesting

Other farm operations that require fuel are planting, spreading of fertilizer, spraying of fertilizers and pesticides, and harvesting. CO_2e emissions per hectare for different operations are shown in ***Table 1***. Because statistical data of farm practices of US barley growers was not available, we assume: (1) planting was on a conventionally tilled (CT) seedbed, (2) fertilizers were broadcast in granular form on all of the barley crop in separate applications, (3) pesticides were sprayed in the same proportion as for barley grown in North Dakota,[24] and (4) harvesting was 50% straight combining and 50% combined after windrowing.[25] Using these assumptions, CO_2e emissions from farm operations per 6-pack of FT total 23.9 g.

Tillage

Mechanical preparation of the seedbed requires fuel for operating farm equipment. Fuel use depends upon depth of tillering, soil density, tractor speed, the type of tilling equipment used, and the size the tractor used (Collins et al., 1976; Collins et al., 1980; Lal, 2004a). Lal (2004a) compiled and published average CO_2e emissions from multiple studies, breaking out emissions by equipment type. Statistical data of tillage practices of US barley growers was not available. Instead, ***Table 2*** shows average emissions related to conventional tillage (moldboard plow), reduced tillage (chisel plow or disking) and no-till (drill only), allocated to a 6-pack of FT based on 2006 barley yield. For the final calculations, we have assumed conventional tillage was practiced, emitting 24.4 g of CO_2e.

Irrigation 61.6 g CO_2e

While barley may be grown in dryland environments without irrigation,[26] data from the USDA's 2002 Census of Agriculture indicates that 77% of barley cultivated in the US is from irrigated farms.[27] Protein content requirements of grain intended for malting may mean the percentage of irrigated malt barley is even higher.[28]

Typical supplemental irrigation of 25 to 50 cm (Franzluebbers and Francis, 1995) relates to CO_2e emissions of between 26.4 to 3,117.4 kg per hectare, depending on the source of energy and specific factors of the irrigation system (Dvoskin et al., 1976; Schlesinger, 1999; Follet, 2001; West and Marland, 2002). Besides application of water, the installation of different irrigation systems may demand energy annually. In 2003, 71% of irrigated barley received water from pressure distribution systems, most often from "center pivot and linear move" sprinkle systems (43% of total irrigated crops), and 29% were watered from gravity-fed systems.[29]

[22] Recommended seed application supplied by North Dakota Barley Council for malt spring barley: http://www.ndbarley.net/malt_barley.html and North Dakota State University Agriculture Communction: http://www.ext.nodak.edu/extnews/newsrelease/2001/031501/06seedin.htm
[23] See http://www.prairiemaltltd.com/maltingprocess.html for discussion of the ratio of barley to malt
[24] See, www.ipmcenters.org/cropprofiles/docs/NDbarley.html, www.ag.ndsu.nodak.edu/aginfo/entomology/entupdates/ICG_08/02_BarleyInsects08.pdf, and www.ag.ndsu.edu/pubs/plantsci/pests/pp622/pp622.pdf
[25] See the publication of the American Malting Barley Association describing harvesting methods to prevent damage to kernels of malting barley: www.ambainc.org/pub/Production/Harvesting.pdf
[26] See, e.g., the article by Jackson, G. (infra note 20)
[27] Available at: http://www.agcensus.usda.gov/
[28] See, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr1245
[29] USDA 2002 Census of Agriculture (infra note 27)

***Table 1.** Carbon dioxide equivalent emissions from miscellaneous farm operations during cultivation of malt barley (total reflect assumptions noted in text)*

Operation	kg CO_2e per hectare[a]	g CO_2e per 6-pack of Fat Tire® Amber Ale
Planting		
Plant/Sow/Drill	11.7	2.2
No-Till Planting	13.9	2.6
Total		*2.2*
Fertilizer Spreading		
Combined Application	27.9	5.3
Separate Applications (x2)[b]	55.7	10.5
Total		*10.5*
Pesticide Spraying (*Total*)	5.1	1.8
Harvesting		
Harvesting	29.0[c]	7.8
Windrower	17.6	3.3
Total		*9.5*
Grand Total		*23.9*

[a] Lal (2004a)
[b] Because K fertilizer is not frequently applied, only two applications are included
[c] Average of "Corn and Soybean Combines" reported by Lal (2004) and the "Harvest Combine" reported by West and Marland (2002)

***Table 2.** Carbon dioxide equivalent emissions from different tillage practices in the cultivation of malt barley*

Tillage	kg CO_2e per hectare[a]	g CO_2e per 6-pack of Fat Tire® Amber Ale
Conventional Till		
Moldboard Plowing	55.7	10.5
Disking (x2)	51.7	9.7
Field Cultivation	14.7	2.8
Rotary Hoeing	7.3	1.4
Total	*129.4*	*24.4*
Reduced Till		
Disking (x2)	51.7	9.7
Field Cultivation	14.7	2.8
Rotary Hoeing	7.3	1.4
Total	*73.7*	*13.9*
No Till		
Disking (x1) OR	21.3	4.0
Chisel Plow	29.0	5.5
Total (avg)	*25.1*	*4.7*

[a] Lal (2004a)

Weighting the proportion of dryland crops and irrigation methods used in the US, the average of CO_2e emissions associated with barley irrigation over a 6 month growing season is 23.7 kg per hectare for irrigation system installation (Batty and Keller, 1980; Lal, 2004a), and 303.4 kg per hectare for water application (Dvoskin et al., 1976; ITRC, 1994; Follet, 2001; West and Marland, 2002).[30] Using 2006 barley yield statistics described above, we find 61.6 g of CO_2e from barley irrigation are embodied in a 6-pack of FT.

Fertilizer and Soil Amendments 123.2 g CO_2e

Nitrogen

Commonly, contracts for malt barley specify a minimum of 75% kernel plumpness. Because plumpness is related to fertilization and yield, spring barley intended for malting demands somewhat less nitrogen (N) than feed barley. Application rate of N fertilizer is generally determined with regard to soil test results and the preceding crop.[31] For purposes of this assessment we assume urea-N fertilizer is applied in moderation to achieve average yield, at a rate of 95.0 kg per hectare (85 lbs per acre).[32] This is consistent with a ratio of N to barley of ~2.9 to 100.[33]

Production of nitrogenous fertilizer is energy intensive, as fixation of atmospheric N_2 means breaking a strong triple bond at the molecular level. Previous studies of N fertilizer estimate 4.8 ± 1.1 kg of CO_2e emissions per kg of fertilizer produced, transported, stored and transfer to location of use (Lal, 2004a; Samarawickrema and Belcher, 2005). Based on 2006 barley yield, this amounts to 138 g of CO_2e per kilogram of barley, or 85.3 g per 6-pack of FT.

Phosphorus

Barley has a relatively low demand for phosphorus (P), and where soil analysis shows very high residual phosphate, application of P fertilizer may not be required.[34] In most cases, however, P fertilizer is applied. The recommended application rate depends on soil testing, but for purposes of this assessment we assume P fertilizer is applied in moderation to achieve average yield, at a rate of 44.8 kg P_2O_5 per hectare (40 lbs per acre).[35]

Production, transport, storage and transfer of phosphatic fertilizer has been determined to cause 0.73 ± 0.22 kg of CO_2e per kg of fertilizer (Lal, 2004a). This represents 10.0 g of CO_2e per kilogram of barley, or 6.2 g per 6-pack of FT.

Potassium

Barley also has a low demand for potassium (K), and application of K fertilizer is often not required.[36] However, for purposes of this assessment we assume K fertilizer is applied in moderation to achieve average yield, at a rate of 67.25 kg K_2O per hectare (60 lbs per acre).[37]

Production, transport, storage and transfer of potassic fertilizer has been determined to cause 0.55 ± 0.22 kg of CO_2e per kg of fertilizer (Lal, 2004a). This represents 11.3 g of CO_2e per kilogram of barley, or 7.0 g per 6-pack of FT.

Micronutrients and Lime

Very rarely, barley requires addition of sulfur or copper fertilizer. For purposes of this assessment, we have assumed none.

Soil pH less than 5.3 can significantly diminish barley yields. Amendment of soil with agricultural lime ($CaCO_3$) at the rate of 2.2 to 4.5 Mt per hectare (1 to 2 short tons per acre)[38] may improve yields on acidic soils (Tang and Rengel, 2001). The benefits of such liming persist for at least 15 years (Tang and Rengel, 2001).

Production, transport, storage and transfer of lime has been determined to cause 0.59 ± 0.40 kg of CO_2e per kg of lime (Lal, 2004a). Assuming an average application of 3.4 Mt per hectare and 2006 yields over a 15 year period, this amounts to 40.1 g of CO_2e per kg of barley, or 24.8 g per 6-pack of FT.

[30] The emissions factor for water application represents an average of data from all of the cited studies
[31] An example of how growers determine appropriate N fertilizer requirements of barley is described by a study from the University of Idaho and Washington State University: http://info.ag.uidaho.edu/pdf/CIS/CIS0920.pdf
[32] This assumption is premised on the guidance of the University of Idaho/Washington State University study (infra, note 5) and the University of Minnesota extension service: http://www.extension.umn.edu/distribution/cropsystems/DC3773.html
[33] Recommended ratio of fertilizer N to yield of dryland (2-row) malting barley supplied by Grant Jackson, soil scientist at the University of Montana's Western Triangle Ag. Research Center, Conrad, MT: http://landresources.montana.edu/FertilizerFacts/24_Nitrogen_Fertiliztion_of_Dryland_malt_Barley.htm
[34] This assumption is premised on the guidance of the University of Idaho/Washington State University study (infra, note 5) and the University of Minnesota extension service: http://www.extension.umn.edu/distribution/cropsystems/DC3773.html
[35] Ibid.

Pesticides 0 g CO_2e

A host of insecticides, herbicides, and fungicides are routinely used on barley seed and growing barley. We examined the carbon intensity of such treatment in detail based on reported emissions for production and transport of these chemicals (Lal, 2004a), the percentage of barley treated, and prescribed application rates.[39] In the end, the GHGs associated with these chemicals are vanishingly small when allocated to a single 6-pack of FT (~0.01 g).

Soil Emissions 120.8 g CO_2

Nitrous oxide (N_2O) is emitted directly from cultivated soils depending on the amount and type of N fertilizer applied, the type and yield of crop, and the methods of tillage and managing of crop residues (Samarawickrema and Belcher, 2005; IPCC, 2006). IPCC guidelines suggest that ~1% of N added in synthetic and organic fertilizers is volatilized as N_2O. N_2O is a powerful GHG, with a global warming potential 298 times that of CO_2.[40] As such, N_2O soil emissions related to the application of N fertilizer at the rate determined above and the incorporation of N in crop residues correspond to 112.4 g of CO_2e emissions per 6-pack of FT.

In addition, some soil nitrogen is volatilized as NH_3 or NO_x, which, when later deposited onto other soils or surface waters. This atmospherically deposited N becomes part of the system again, and a proportion of it becomes N_2O (IPCC, 2006). Based on IPCC estimates of the percentage of fertilizer N that follows this indirect pathway to N_2O, an additional 8.4 g of CO_2e emissions per 6-pack of FT originate from soil N (IPCC, 2006).

Barley Transport 8.0 g CO_2e

Barley is purchased either as a commodity on the open market or from previously approved growers, as in the case of malt purchased by Coors Brewing Company (Coors). One of Coors' trademarks is that of a completely integrated regional brewer who sources all of its malting barley needs directly from producers through the use of production contracts.[41] However, in times of drought or poor general barley quality, malting operations must look farther from Colorado into Canada for barley. Because of the commoditized nature of barley and the potential of varying supply and quality from approved growers, the GHG emitted during its transportation can only be estimated very roughly. Because 2006 was a drought year in Colorado, Coors received shipments of barley by rail from grain elevators in Burley, Idaho; Huntley, Montana; Worland, Wyoming and Monte Vista, Colorado and by truck from the grain elevator in Longmont, Colorado.[42]

Barley transported by train travels a distance of 490 miles,[43] while grain transported by truck is transported only 45 miles. Assuming each grain elevator contributed an equal share of barley to NBB, and taking the fuel economy of freight trains as 423 MPG per short ton (AAR, 2008; cf. Börjesson, 1996), the 618 g of barley necessary to produce the 463.5 g of malt used per 6-pack of FT contributes 8.0 g of CO_2 emissions.

Malt Production 166.8 g CO_2e

Malt manufacturers steep, germinate, and dry barley in order to produce malt. These steps require energy in the form of electricity and natural gas to warm the water used for steeping, to control the air temperature for germination, and to dry, cure, and roast the malt (Briggs, 1998). Data gathered from both primary and secondary sources yielded remarkably consistent estimates of GHG emissions (mean 120.19 g CO_2, $1\sigma = 7.49$). Because primary data from all malt suppliers was not available, we elected to use primary data where applicable to a specific malt type and take an average of both primary and secondary findings for those malt types where no primary information was available.

[36-38] Ibid.

[39] See, e.g., www.ipmcenters.org/cropprofiles/docs/NDbarley.html, www.ag.ndsu.nodak.edu/aginfo/entomology/entupdates/ICG_08/02_BarleyInsects08.pdf, and www.ag.ndsu.edu/pubs/plantsci/pests/pp622/pp622.pdf

[40] Fourth Assessment Report of the IPCC (2007)

[41] Vertical Coordination In The Malting Barley Industry: A 'Silver Bullet' For Coors? Michael Boland, Gary Brester, and Wendy Umberger Prepared for the 2004 AAEA Graduate Student Case Study Competition Denver, Colorado August 1-2, 2004

[42] Personal communication with Thomas Richardson, Coors Brewing Company with February 14, 2008

[43] This distance represents an average of the distances between Coors and grain elevators in Burley, Huntley, Worland and Monte Vista.

Primary Source Data

Coors Brewing Company

In 2006, NBB obtained 60% of the Two Row malt used in FT produced from Coors.[44] In turn, Two Row malt made up 67.9%, or 314.9 g, of the malt contained in each 6-pack of FT. According to a TCC survey completed by Coors, production of 100 pounds of Two Row malt required 6.79 kWh of electricity and 0.165 mmBTUs (1.65 therms) of natural gas. Assuming this energy intensity applied to the production of all 314.9 g of Two Row malt in a 6-pack of FT, 44.4 g of CO_2e relate to electricity consumed[45] and 69.5 g correspond to natural gas used, for a total of 113.8 g of CO_2e per 6-pack of FT.

TCC was not able to obtain comparable information from Briess Malt and Ingredients Company, which company supplies the remaining 32.1%, or 148.6 g, of malt per 6-pack of FT. However, if the energy intensity of Coors' process is assumed for all 463.5 g of malt per 6-pack of FT, 20.9 and 32.8 g of CO_2e result from electricity and natural gas use, respectively, totaling 167.6 g CO_2e for all the malt in a 6-pack of FT.

Rahr Malting Company

Though NBB did not purchase malt from Rahr Malting Company (Rahr) in the year 2006, TCC was able to obtain information about actual energy requirements of Rahr's malting process for comparison with secondary source data. According to a report by the Energy Efficiency and Renewable Energy division of the US Department of Energy, the Rahr malthouse located in Shakopee, Minnesota consumed 1,100 million cubic feet of natural gas (approximately 11,000,000 therms) and 66,000,000 kWh of electricity in 2005.[46] The same Rahr malthouse annually produces 370,000 Mt of malt.[47] This translates into 29.7 therms of natural gas and 178.4 kWhs of electricity per metric ton of malt produced, or 146.5 g of CO_2 to produce the 463.5 g of malt in a 6-pack of FT.[48]

Secondary Source Data

Owing to a lack of primary source data for all the malts types contained in FT, TCC conducted further research of the energy requirements of the malting process in order to understand whether different types of malt might entail greater or less GHG emissions. Following are estimates derived from this research, the sum of which is remarkably similar the total emissions estimated from the primary source data described above.

Steeping

Steeping requires roughly 1 therm of natural gas per metric ton of malt produced (Briggs, 1998). Based on life cycle emissions of 6.06 kg CO_2e per therm of natural gas (see ***Table 3***, page 22), steeping 463.5 g of malt in a 6-pack of FT results in 2.8 g of CO_2e emissions.

Germination

After steeping, the barley must germinate, requiring energy to maintain the proper temperature of the grain and ventilate the germination units. Heating the germination units requires less than 1 therm of natural gas per metric ton of malt produced, or less than 2.8 g of CO_2e per 6-pack of FT. In some cases, germination units are refrigerated, requiring as much as 60 kWh of electricity per metric ton of malt produced (Briggs, 1998). Assuming this electricity is generated in the region where the bulk of US malt barley is grown, as much as 24.0 g of CO_2 emissions result from refrigeration of 463.5 g of malt.[49] Fans in the germination units also require between 25 and 40 kWh per metric ton of malt produced (Briggs, 1998). This translates to between 10.0 and 16.0 g of CO_2e per 6-pack of FT. Assuming the likelihood of heating and refrigeration during germination are equal and an average of 32.5 kWh of electricity is consumed by ventilation systems, 26.4 g of CO_2e are emitted to germinate the malt in a 6-pack of FT.

[44] NBB data, "BOM for life cycle study.xls" (Tranche 1)
[45] Version 2.1 (2006) of the Energy Information Administration's eGRID database indicates that 1,986 lbs of CO2 are emitted per MWh of electricity generated in the state of Colorado. Average GHGs emitted in the life cycle of fuels prior to their combustion to generate electricity have also been included (Table 2 of West and Marland, 2002).
[46] http://www.eere.energy.gov/industry/saveenergynow/partners/pdfs/esa-025-1.pdf
[47] http://www.rahr.com/index.geni?mode=content&id=177
[48] Version 2.1 (2006) of the Energy Information Administration's eGRID database indicates that 1,588 lbs of CO2 are emitted per MWh of electricity generated in the state of Minnesota. Average GHGs emitted in the life cycle of fuels prior to their combustion to generate electricity have also been included (Table 2 of West and Marland, 2002).
[49] Version 2.1 (2006) of the Energy Information Administration's eGRID database indicates that 1,814 lbs of CO2 are emitted per MWh of electricity generated in the MRO West subregion (which includes most of Minnesota, North and South Dakota, Nebraska and Iowa). In addition, we have included average GHGs

Drying and Roasting

After germination, the green malt is first dried and then roasted in a kiln, which is the most energy-intensive processes in malting. Drying requires approximately 4 therms of natural gas per metric ton of malt, or 11.2 g of CO_2e per 6-pack of FT. Depending on the efficiency of the kiln and the amount of roasting required, between 30 and 60 therms of natural gas are required to roast a metric ton of malt. This amounts to between 84.3 and 168.6 g of CO_2e per 6-pack of FT. Some kilns incorporate fans which consume up to 75 kWh per metric ton of malt produced (Briggs, 1998). GHG emissions associated with this electricity amount to as much as 30.0 g of CO_2e to produce the amount of malt in a 6-pack of FT. Assuming half of malting kilns use fans, the drying and roasting of malt for a 6-pack of FT result in an average 182.0 g of CO_2e emissions.

Malt Transport 25.0 g CO_2e

Fuel Use

Using similar calculations to those detailed in the packaging section with the same emission coefficients and shipping methods (Class 8 truck), the malt received from Coors, Prairie Malt, Ltd. (Prairie), International Malting Company (IMC) and Briess Malt and Ingredients Co. (Briess) constitute 1.3 g, 9.0 g, 8.4 g and 15.0 g of CO_2 respectively. Of the entire amount of malt used in the production of FT, 40.5% is Coors Two Row, 27.0% Prairie or IMC (a 50% likelihood of either was used in the calculations) and 32.4% Briess Munich, Caramel, Carapils and Victory malts. The weighted average of transportation emissions for malt transportation for a 6-pack of FT is 25.0 g CO_2.

Hops 5.7 g CO_2e

Hop Agriculture 5.4 g CO_2e

As with barley, the cultivation of hops (*Humulus lupulus*) results in GHGs emitted during production of fertilizers, pesticides and soil amendments, operation and installation of farm equipment (including irrigation) and emissions from the soil (Lal, 2004a).

The bulk of hops grown in the US are from the Yakima and Willamette Valleys of Washington and Oregon, respectively. This is the case for nearly all the hop varieties in FT, with the exception of Target hops, which are grown in a similar climate in the UK. In the US, yield per cultivated hectare of hops in 2006 was 2.20 Mt (2,201.4 kg).[50] In the calculations below, we use this figure to allocate emissions during agriculture to a given mass of hops.

Agricultural Machinery 1.1 g CO_2e

Hop farms ("yards") operate machinery for planting, spraying, pruning and harvesting, and maintain drip irrigation systems, all of which demand energy (Lal, 2004a).

A study compiled in 1999 lists equipment and fuel used on a representative hop farm in the Yakima Valley of Washington (Hinman, 1999). Equipment used in a representative hop yard included loaders, cutters, trucks, and tractorized equipment for spraying, spreading and pruning. Fuel consumption by this equipment amounted to 56.1 and 31.8 gallons per cultivated hectare (22.7 and 14.4 gallons per acre) of diesel #2 and gasoline, respectively.

Emissions factors for diesel #2 and gasoline (including extraction, refining and transport) are 11.78 and 10.23 kg CO_2 per gallon, respectively.[51] Based on the average yield of hops in 2006, operation of farm equipment therefore resulted in 470 g of CO_2 emissions per kilogram of hops. The 2.3 g of hops used in the production of FT thus embody 1.1 g of CO_2.

Irrigation 1.2 g CO_2e

Most hop yards in the US are irrigated by drip (or trickle) systems.[52] Annual GHG emissions associated with the installation of such systems is estimated to be 311.3 kg CO_2e per hectare per year (Lal, 2004a). Application of water by this method is quite efficient relative to sprinkle systems; CO_2e emissions per irrigated hectare per year are estimated to be 792 kg (ITRC, 1994). Assuming all hops in FT were irrigated in this manner, and again using 2006 yield data, the 2.3 g of hops used in producing a 6-pack of FT relate to a total of 1.2 g CO_2e from irrigation of hop bines.

Fertilizer and Soil Amendments 1.4 g CO_2e

Nitrogen

The application rate of N fertilizer to aroma hop bines averages 140 kg per hectare (125 lbs per acre).[53] As noted previously, the production of nitrogenous fertilizer is quite energy intensive, with an estimated 4.8 ± 1.1 kg of CO_2e emissions per kg of N fertilizer produced, transported, stored and transfer to location of use (Lal, 2004a). Based on 2006 hops yield, this amounts to 303 g of CO_2e per kilogram of hops, or 0.7 g per 6-pack of FT.

[50] Per crop reports of the US Department of Agriculture: www.nass.usda.gov/Statistics_by_State/Washington/Publications/Hops/hops06.pdf
[51] Calculated using figures from Table 1 of West and Marland (2002) and assuming the energy content of diesel #2 and gasoline to be 0.03868 and 0.03466 GJ per liter, respectively

Phosphorus

Hops in the Pacific Northwest generally do not require significant phosphorus (P) inputs; only where soil analysis shows <30 ppm is application of P fertilizer recommended.[54] In this case, the recommended application rate of P fertilizer is between 67 and 112 kg P_2O_5 per hectare (60 to 100 lbs per acre).[55]

Production, transport, storage and transfer of phosphatic fertilizer has been determined to cause 0.73 ± 0.22 kg of CO_2e per kg of fertilizer (Lal, 2004a). Assuming that P fertilizer is necessary only 50% of the time at an average rate of 89.7 kg per hectare, 29.9 g of CO_2e are emitted per kilogram of harvested hops, or 0.1 g per 6-pack of FT.

Potassium

Soils in the Pacific Northwest frequently contain ample potassium (K) for hops cultivation.[56] However, fertilization is sometimes required, and here we assume K fertilizer is applied at the moderate rate of 134. 5 kg K_2O per hectare (120 lbs per acre).[57]

Production, transport, storage and transfer of potassic fertilizer is estimated to result in 0.55 ± 0.22 kg of CO_2e emissions per kg of fertilizer (Lal, 2004a). This represents 33.6 g of CO_2e per kilogram of harvested hops, or 0.1 g per 6-pack of FT.

Micronutrients and Lime

In some circumstances, hop yards require addition of sulfur, boron, or zinc fertilizer. However, for purposes of this assessment, we have assumed none.
Soil pH less than 5.7 can prevent absorption of manganese (Mn) by growing hop bines, thereby diminishing yield.[58] Amendment of soil with agricultural lime ($CaCO_3$) at the rate of 2.24 to 6.73 Mt per hectare (1 to 3 short tons per acre) is recommended where soil pH is less than 5.7.[59] The benefits of such liming persist for at least several years.

Production, transport, storage and transfer of lime has been determined to cause 0.59 ± 0.40 kg of CO_2e per kg of lime (Lal, 2004a). Assuming an average application of 4.48 Mt per hectare and 2006 yields over a 5 year period, this amounts to 239 g of CO_2e per kilogram of barley, or 0.6 g per 6-pack of FT.

Pesticides 0 g CO_2e

Hop growers use a variety of insecticides, herbicides and fungicides to deter aphids, works, caterpillars, beetles, weevils, mites, weeds and molds. The carbon intensity of such treatments was assessed in detail based on reported emissions for production and transport of these chemicals (Lal, 2004a), the percentage of the hops crop treated, and prescribed application rates.[60] As with barley, the GHGs associated with these chemicals are vanishingly small when allocated to a single 6-pack of FT: <0.001 g CO_2e per 6-pack of FT.

Soil Emissions 0.9 g CO_2e

Again applying IPCC guidelines to calculate N_2O soil emissions related to the application of N fertilizer at the average rate of 140.1 kg per hectare in addition to N from incorporated crop residues, we estimate 0.8 g of CO_2e emissions per 6-pack of FT.

Soil nitrogen volatilized as NH_3 or NO_x and subsequently re-deposited and denitrified to N_2O result in an additional 0.1 g of CO_2e emissions per 6-pack of FT (IPCC, 2006).

Drying and Packing 0.9 g CO_2e

After harvest, hop bines are transported from the yard to a “hop house,” or barn, where the cones are dried, cooled, and packaged. Drying takes place in a box kiln wherein hot air (~145 ºF) is passed through the hop cones for approximately 8 hours until their moisture content of the hops has been reduced from 65-80% to 8-10%.

The drying of harvested hops is the most energy intensive process in the production of hops. The cooling process does not require significant energy as the hop cones are removed to a separate room and cooled for 12-24 hours. Increasingly, hops are compressed and palletized after cooling, which processing requires more energy but which may reduce transportation costs during distribution. Hop cones, such as those used by NBB, are typically baled with the help of a hydraulic press.

Suppliers of hops to NBB were not responsive to our requests for data, and secondary data regarding the specific energy requirements of drying were scarce.

[52] See, eg., http://www.ipmcenters.org/cropprofiles/docs/wahops.html
[53] This represents an average based on the fertilizer recommendations at: http://www.hort.purdue.edu/newcrop/afcm/hop.html and http://extension.oregonstate.edu/catalog/pdf/fg/fg79-e.pdf
[54] See, e.g., http://extension.oregonstate.edu/catalog/pdf/fg/fg79-e.pdf
[55-59] Ibid.
[60] Application rates are described in http://www.ipmcenters.org/CropProfiles/docs/orhops.html

Thus, we calculated GHG emissions during the drying and packing process based on the estimated cost of these activities on a Yakima Valley hop farm and assuming this cost was fully attributable to purchased natural gas (Hinman, 2004). Based on these assumptions, the drying and packing of hops resulted in 0.9 g of CO_2 per 6-pack of FT.

Hop Transport 0.3 g CO_2e

The hops used to produce FT (Goldings, Target and Willamette) are supplied by S.S. Steiner, John I. Haas (distributed by HopUnion USA) and Hops From England. The 0.2 g of CO_2 emitted from the transportation of Willamette and Goldings hops from S.S. Stenier by semi-truck from a distance of 1,107 miles is equal to that of the 0.2 g of CO_2 emissions from HopUnion USA at 1,109 miles. Determining the transportation emissions of the Target hops acquired from Hops From England presents a greater challenge. These hops are grown at 'The Farm' Bosbury, Ledbury, Herefordshire, UK and shipped to a port in the UK, then by sea to Washington state and then to NBB. It is assumed that semi-truck shipping from 'The Farm" Bosbury, Ledbury, Herefordshire UK to Bristol, UK, Panamax container ship[61] transport from Bristol, UK to Seattle, Washington and truck transport to NBB.[62] While the exact port of call in the UK is not known, the trucking within the UK will contribute roughly 0.02 g CO_2, sea-borne shipping 0.4 g CO_2 and US trucking 0.3 g CO_2 for a total of 0.7 g CO_2. Though the exact route is not known, the emissions do not change significantly when alternative ports in Liverpool, London and Tacoma are considered. Weighting the transportation emissions according to the variety and mass of hops used in FT, the total 2.3 g of hops accounts for 0.3 g CO_2.

[61] A Panamax ship has an average DWT of 65,000 tons and is this largest ship that can navigate the Panama Canal
[62] Personal communication with the distributor for Hops From England, Crosby and Baker LTD

Water 3.2 g CO_2e

Production and Transport 3.2 g CO_2e

Energy Intensity

Water provided to NBB by the city of Fort Collins is treated by a series of conventional techniques: coagulation, flocculation, sedimentation, filtration, and chlorination. According to the city of Fort Collins, average annual energy consumption at their water treatment facility over the past 9 years was 4,026,793 kWh. During the same period, the average amount of water produced per year was 9,346 million gallons per year.[65] Thus, the average energy intensity of the treated water provided to NBB is 431 kWh per million gallons of water.

Carbon Intensity

According to the city of Fort Collins all energy needs for the water treatment facility are provided by Xcel Energy, which has reported carbon intensity of delivered electricity in 2006 of 1.478 lbs CO_2 per kWh.[66] However, this is lower than the figure listed in the Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGRID) for the Rocky Mountain subregion, which is 2.036 lbs CO_2 per kWh (or 0.93 kg CO_2 per kWh), and which we believe is more accurate given its regional character.[67]

Allocation

The water to beer ratio of NBB's production process is 3.9 to 1.[68] Based on this ratio, the 72 fluid ounces of beer in a 6-pack (2.13 liters) require 280.8 fluid ounces (8.307 liters) of water to produce. Applying the energy and carbon intensities above, we calculate 3.2 g of CO_2 are embodied in the water used per 6-pack of beer.

Carbon Dioxide 72.5 g CO_2e

Production 72.3 g CO_2e

Energy Intensity

The carbon dioxide used to carbonate FT is a byproduct of either oil well drilling, petroleum refining or production of hydrogen in a Hydrogen Production Unit. Before shipment to NBB, the gas must be purified, tested and liquefied, each step requiring energy. Energy intensity information for carbon dioxide was not readily available for our calculation, so the energy intensity to liquefy nitrogen (N_2) was used as a proxy. The minimum power necessary (in a theoretical Carnot cycle) to liquefy N_2 is 80 kWh per tonne.[69] However, the actual power requirements are around 400 kWh per tonne for liquefication alone. The number does not take into account the initial cooling, oxidation, aftercooling, adsorption, drying, condensing and distillation that may be required for purification depending on the source gas.[70]

Carbon Intensity

Given that the CO_2 is purified and liquefied in Cheyenne by DynoNobel, the mean carbon intensity of electricity produced in Wyoming was used: 0.8175 kg of CO_2 per kWh. On a per 6-pack basis, the production of 54.5 g of CO_2 used to carbonate FT emits 17.8 g of CO_2. Although the molecular mas and thermodynamics of N_2 mean more energy is required to compress it than CO_2, because many of the steps (and energy) needed to purify and test CO_2 are not included here, the carbon intensity will not be less than the 17.8 g of CO_2. The 54.5 g of CO_2 used to carbonate te beer is also included, as this gas is derived from fossil carbon.

[65] Energy use and volume of water produced were obtained by communication with a financial analyst at Fort Collins Utilitiesn January 7, 2008
[66] 2006 Triple Bottom Line Report of Xcel Energy, http://www.xcelenergy.com/XLWEB/CDA/0,3080,1-1-1_38873_39323-19025-5_406_651-0,00.html
[67] EPA eGRID (2006), reporting 2004 data, http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html
[68] NBB data, "NBB Follow Up Questions_10.doc" (Tranche 2)
[69] Industrial Gas Handbook: Gas Separation and Purification, Frank Kerry, CRC Press
[70] From pamplet, "All About Carbon Dioxide: Properties, Applications, Sources and Plants" Totomont Process Systems, A Division of Toromont Industries, Inc.

Transportation 0.2 g CO_2e

The CO_2 used by NBB to carbonate FT is produced at the Dyno Nobel ammonia plant in Cheyenne, Wyoming. From there, it is shipped to 1918 Heath Parkway, Fort Collins, Colorado and in 2006 was distributed to NBB by General Air. Because of the short distance of distribution, it is here assumed that food-grade, liquefied CO_2 is shipped directly from Dyno Nobel to NBB on eighteen wheeled tanker trucks.[71] These trucks typically have a capacity of 26,000 liters or 29,780 kg of liquefied CO_2. Assuming 6.3 mpg of diesel #2 fuel and an emission factor of 11.78 kg CO_2 for the production and point of consumption of a gallon of diesel fuel,[72] the transportation of a full load of CO_2 on this route results in 81.88 kilograms of CO_2 emissions. NBB uses 54.5 g of carbon dioxide to carbonate a 6 pack of FT, the transport of which corresponds to 0.2 gram of CO_2 emitted per 6-pack.

[71] http://www.dynonobel.com/
[72] See Table 1 in West and Marland, 2002

Entity 173.0 g CO_2e

Emissions assessed in this section are those directly associated with the manufacture and marketing of Fat Tire® Amber Ale by New Belgium Brewing Company.

Brewing Operations 123.0 g CO_2e

Electricity 0 g CO_2e

5,772,920 kWh of electricity consumed by NBB at its Fort Collins brewery is generated from renewable resources by virtue of its participation in the City of Fort Collins Green Energy Program.[80] While there are certainly GHGs emitted during the manufacture of renewable energy generation equipment, we have assumed the mass of CO_2e emissions allocated to a single 6-pack of FT is inconsequential. Similarly, certified renewable energy credits (RECs) were purchased by NBB to cover 512,800 kWh of electricity used at its offsite warehouse (Poudre Valley).[81]

If the electricity used had been non-renewable, emissions calculated from the eGRID emissions factor for Colorado and allocated per 6-pack are 250.8 g CO_2.

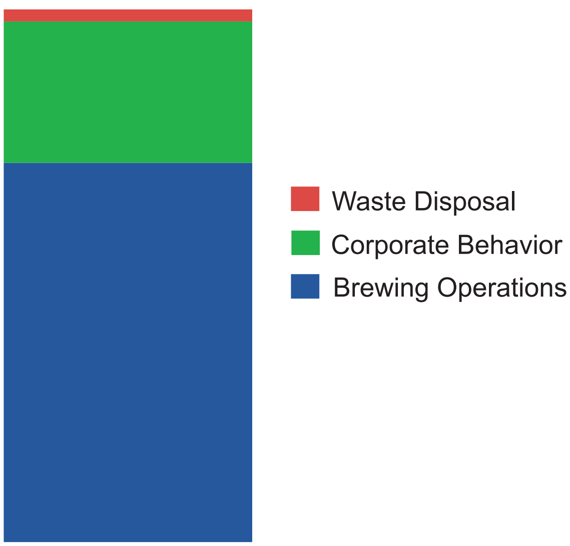


Figure 4. *Distribution of entity-level GHG emissions by percentage of total entity emissions.*

Natural Gas 123.0 g CO_2e

In 2006, NBB purchased 478,595 therms (50,491.77 GJ) of natural gas from two utilities for use at three locations: A total of 449,720 therms (47,445.46 GJ) were purchased from Seminole Energy Services between January and December of 2006 for use at the Linden Street brewery in Fort Collins.[82] A total of 21,080 therms (2,223.94 GJ) were purchased from Xcel Energy between March and December of 2006 for use in water treatment at the Buckingham Street facility in Fort Collins.[83] A total of 7,790 therms (821.85 GJ) were purchased from Xcel Energy between April and December of 2006 for use at its offsite warehouse (Weicker Drive) in Fort Collins.[84]

Raw natural gas contains methane (CH_4) and other hydrocarbons, water, nitrogen (N_2), CO_2 and some sulfur compounds such as H_2S. The Gulf Coast states (mainly Texas and Louisiana) produce most of the natural gas used in the US, and the raw gas occurs onshore and offshore, sometimes alone and sometimes along with liquid petroleum (DeLuchi, 1993). The extraction, refining and transmission of gas require energy and result in emissions of both CO_2 and CH_4 during combustion and as fugitive (leaked) and vented (intentionally released) gas.

Production of Gas

An estimated 4.3 g of CH_4 is emitted during raw gas production for every kilogram of the gas that is ultimately delivered (Barns and Edmunds, 1990; Kirchgessner et al., 2000).[85] This translates to roughly 9.0 g of CH_4 for every therm (0.1055 GJ) of delivered gas. Taking account of methane's GWP of 23, each therm of gas produced causes 207.2 g of CO_2e emissions. The natural gas purchased by NBB therefore relates to the emission of 99,165.36 kg of CO_2e.

[80] NBB data, communication with Jenn Orgolini on March 11, 2008 and FCU 2006 Attestation.doc" (Tranche 2)
[81] Purchase Agreement dated July 27, 2007 between NBB and Community Energy, Inc. ("community energy wind purchase.pdf" in Tranche 2).
[82] NBB data, thirteen separate invoices were provided in data tranche 1
[83] NBB data, ten separate invoices were provided in data tranche 1
[84] NBB data, nine separate invoices were provided in data tranche 1
[85] Calculations were also informed by the EIA (2004) Annual Energy Review 2002, EIA (2004) Emissions of GHGs in the US 2003, a presentation by Margaret Mann of NREL entitled "A comparison of the environmental consequences of power from biomass, coal and natural gas," and a GHG inventory performed by Climate Mitigation Services for the city of Aspen, Colorado in 2004 (http://www.aspenglobalwarming.com)

Gas Processing

An estimated 1.6 g of CH_4 is emitted during processing of raw natural gas for every kilogram of delivered gas (Kirchgessner et al., 2000).[86] Thus, approximately 3.3 g of CH_4,or 76.6 g of CO_2e, is released during processing for every therm (0.1055 GJ) of delivered gas. The natural gas purchased by NBB in 2006 therefore relates to the emission of 36,648.07 kg of CO_2e.

Transmission and Storage

An estimated 5.6 g of CH_4 is emitted during transmission and storage of natural gas from refineries to distribution facilities for every kilogram of delivered gas (Kirchgessner et al., 2000).[87] Thus, approximately 11.8 g of CH_4,or 271.4 g of CO_2e, is released during transmission and storage for every therm (0.1055 GJ) of delivered gas. The natural gas purchased by NBB therefore relates to the emission of 129,885.10 kg of CO_2e.

Distribution

An estimated 4.1 g of CH_4 is emitted during distribution of natural gas in pipelines for every kilogram of delivered gas (Kirchgessner et al., 2000).[88] Thus, approximately 8.6 g of CH_4,or 198.2 g of CO_2e, is released during distribution of each therm (0.1055 GJ) of delivered gas. The natural gas purchased by NBB therefore relates to the emission of 94,853.83 kg of CO_2e.

Combustion

In the US, an average of 5.31 kg CO_2 is emitted for each therm of pipeline natural gas combusted.[89] Thus, the natural gas purchased and burned by NBB in 2006 relates to the emission of 2,541,339.45 kg of CO_2e.

Allocation

Because the bulk of natural gas is used in processes immediately related to beer production (e.g. boiling of wort), the related CO_2e emissions are allocated on the basis of the volume of beer produced. In 2006, the total volume of beer produced comprised 23,587,872 6-pack equivalents.[90] Dividing the total emissions by this volume, we find that each 6-pack embodies 123.0 g of CO_2 from purchased natural gas as shown in Table 3.

Table 3. *Carbon dioxide equivalent emissions per 6-pack of Fat Tire® Amber Ale resulting from natural gas used by NBB in 2006.*

Stage of Natural Gas Life Cycle	g CO_2e per 6-pack of Fat Tire® Amber Ale	Percentage
Production	4.20	3.4%
Processing	1.55	1.3%
Transmission/Storage	5.51	4.5%
Distribution	4.02	3.3%
Combustion (Use)	107.74	87.6%
Total	123.02	100%

[86-88] Ibid.
[89] Data in "lbs CO2 / 1,000 cubic feet" units from US EIA. Voluntary Reporting of Greenhouse Gases Program, Emission Coefficients, http://www.eia.doe.gov/oiaf/1605/factors.html
[90] NBB data, “total sales 2006.xls” (Tranche 2)

Fugitive Refrigerants 0 g CO_2e

The total amount of refrigerant used by NBB in 2006 was 5 lb of R-22 (GWP = 1780) and 0.74 lb of R-134a (GWP = 1300).[91] A total of 23,587,872 6-pack equivalents were sold in 2006,[92] 76.5% of the total beer production by revenue.[93] Assuming the entire refrigerant amount was emitted in 1 year and that NBB typically stores their beer in-house for 2 weeks, the allocation of CO_2e emissions due to fugitive refrigerant to one 6-pack of FT is very small, about 0.007 g.

Manufacturing Waste Disposal 4.2 g CO_2e

Landfilling 3.7 g CO_2e

A fraction of the waste generated during FT manufacturing is disposed in landfills. Following the analysis described on pages 30 and 31, we estimate the GHG emissions based on national averages for landfills with and without gas recovery. Our numbers include transportation to landfills, energy use to operate the landfill, direct methane emission due to anaerobic decomposition of carbon-rich materials, and long-term carbon storage when organic mass is buried in the soil.

The amount of waste generated in 2006 that was landfilled and the net emission per type of material are shown in Table 4.

Landfills with gas recovery emit less GHG and those with no recovery have higher emission rates than the national average displayed in the previous table. If all of the waste listed above is sent to landfills without any form of gas recovery the net emission amounts to 7.7 g of CO_2e per 6-pack. Conversely, landfills that flare methane gas emit 1.5 g of CO_2e per 6-pack. The lowest figure is obtained when landfill gas is used for energy production and emissions can be as low as 0.7 g of CO_2e per 6-pack.

***Table 4.** Total and per 6-pack quantites of waste materials generated and landfilled by NBB during manufacturing operations in 2006*

Material	Quantity (lbs)[94]	g CO_2e per 6-pack of Fat Tire® Amber Ale[95]
Cardboard	11,514	0.10
Glass	57,191	0.04
Wood	5,940	-0.06
Plastic[96]	5,824	0.005
Chipboard	1,145	0.008
Metals[97]	5,146	0.004
Trash[98]	179,869	2.80
Newspaper	1,782	-0.03
Paper	19,688	0.81
Total	123.02	3.67

[91] NBB data, email from Jenn Orgolini to Steve Davis with the subject "Refrigerant Quantity for 2006" on January 14, 2008
[92] NBB data, "2006 Total sales.shipping distances.per state sales.xls" (tranche 2)
[93] NBB data, "Follow Up Questions_10.doc" (tranche 2)
[94] The total mass of waste included in this analysis corresponds to the numbers from Gallegos and Waste-not directly allocated to landfills according to NBB data, "Landf□
rates (EPA, 2006)
[95] Reflects year 2003 national average of landfills with and without landfill gas recovery
[96] Identical emission rates apply to LDPE, HDPE and PET
[97] Assumed 50% aluminum and 50% steel
[98] Assumed trash to be composed of food discards

Recycling 0.6 g CO_2e

A large portion of the waste generated at NBB during beer production is recycled. Most materials are analyzed based on EPA's assessment of waste management (EPA, 2006). Battery recycling emissions are taken from a Swedish study (Rydh and Karlstrom, 2002) of nickel-cadmium batteries. We have made the following assumptions regarding NBB's waste allocation for the purpose of estimating GHG emissions of recycling: kegs were treated as metals, light bulbs were treated as 50% metals and 50% glass, commingle and compactor were treated as 1/3 paper, 1/3 paperboard and 1/3 newspaper, universal waste was assumed to be composed of 50% batteries and 50% light bulbs, metals were assumed to include 50% aluminum and 50% steel, and furniture was treated as wood. Based on these assumptions, the amount of waste recycled and the net emissions per 6-pack is listed in ***Table 5***.

We use national average recycling rejection rates to allocate a portion of the recyclable waste to landfill activities.[99] As a result, one 6-pack of FT results in 0.6 g of CO_2e due to the disposal of NBB's own waste in 2006.

Composting 0 g CO_2e

In 2006, 710 lbs of compost materials were disposed of by Waste-Not.[100] Based on EPA estimates, one ton of compost[101] results in -0.05 Mt of CO_2e due to storage of carbon in the soil. This figure is net national average emissions during transportation. Allocated to a single 6-pack, NBB's composting activities therefore correspond to a tiny drawdown of atmospheric CO_2e (-0.003 g).

On-site Treatment 0 g CO_2e

NBB treats wastewater by an on-site conventional wastewater treatment plant. The treatment consists of an anaerobic digester, activated sludge basin, clarifier basin, and a belt filter press. The system uses a microbial population to convert soluble carbon, nitrogen, and phosphorus in the influent wastestream into insoluble cell mass that can be separated through physical means (composted sludge).

The remaining effluent waste stream has greatly reduced concentrations of carbon, nitrogen, phosphorus and pathogenic bacteria which can be considered environmental hazards.

The two sources of GHG emissions at the wastewater treatment plant include the anaerobic digester and activated sludge basin.

Anaerobic Digester

The anaerobic digester produces roughly 15,111 m^3 of biogas annually, of which, approximately 85% is CH_4 (methane) by volume.[102] Biogas from the anaerobic digester is either used as fuel in an on-site generator or else flared. Both scenarios will result in the methane being oxidized to carbon dioxide. As a result, 55,800 lbs of carbon dioxide per year are emitted from the anaerobic digester.

Activated Sludge Basin

GHG emissions from the activated sludge basin are more difficult to calculate because the gasses are not collected or quantified, but the aerobic conditions present in the basin ensure that emitted carbon is oxidized to CO_2, and not CH_4.

Allocation

The original source of CO_2 emitted during treatment of wastewater is not fossil fuels but the atmosphere. The organic material in growing barley and hops is atmospheric CO_2 that has been fixed into carbohydrates (e.g. $C_6H_{12}O_6$). The metabolism of this organic material, whether by yeast during fermentation, by microbes in the anaerobic digester, or by people drinking beer, is not a net addition of CO_2e insofar as it returns to the atmosphere as CO_2 gas. As such, none of the CO_2 emitted during combustion of biogas or from the activated sludge basin is allocated to FT.

[99] Typical numbers for tons of recycled products made per ton of recovered material are: 90% for newspaper, 88% for glass, 78% for plastics, and 93% for corrugated cardboard, for example
[100] NBB data, "Landfill.Diversion.2007.xls"
[101] This estimate is based on yard trimmings (EPA, 2006)
[102] Personal communication from Brandon Weaver to Nathan Rothe

Table 5. Total and per 6-pack quantites of waste materials generated and recycled by NBB during manufacturing operations in 2006		
Material	Quantity (lbs)[103]	g CO_2e per 6-pack of Fat Tire® Amber Ale[104]
Cardboard	145,875	0.23
Glass	223,600	0.17
Wood	18,063	0.03
Plastic[105]	20,649	0.02
Chipboard	15,209	0.01
Metals	14,022	0.05
Batteries	274	0.001
Newspaper	16,041	0.01
Paper	29,532	0.02
Total		0.55

Sale 0 g CO_2e

Some solid beer wastes are sold as animal feed, including spent barley, yeast and diatomaceous earth. As such, these wastes are termed “co-products” in LCA, and leave the boundaries of the beer production system. Emissions resulting from these wastes are therefore not allocated to FT.

Corporate Behavior 45.7 g CO_2e

Flights 15.3 g CO_2e

Though detailed information about the origin and destination of business flights made in 2006 was not available, using the numbers of domestic and international flights, we estimate a total of 361.6 Mt of CO_2e emitted from this travel (allocated to an individual passenger).[106] When allocated over the 23,587,872 6-pack equivalents of beer produced in 2006, emissions from flights taken amount to 15.3 g CO_2e per 6-pack.

Fleet 17.3 g CO_2e

Vehicles owned or leased by NBB for business use in 2006 were driven a total of 961,360 miles.[107] Based on the average miles per gallon of each vehicle in the fleet and the distance driven in each case, we estimate a total of 407.91 Mt CO_2e were directly emitted from fuel combustion. When allocated over the 23,587,872 6-pack equivalents of beer produced in 2006, emissions from fleet miles driven amount to 17.3 g CO_2e per 6-pack.

Fugitive Refrigerants from Fleet 0.4 g CO_2e

Air-conditioned vehicles have an average charge of 700 g of R-134a refrigerant. Typical leakage rates are 13% of charged refrigerant per year (IPCC, 2005). NBB reported 79 vehicles in their fleet in 2006, which result in ~9 Mt of CO_2e emissions per year, or 0.4 g of CO_2e per 6-pack produced in 2006.

[103] The total mass of waste included in this analysis corresponds to the numbers from Gallegos and Waste-not directly allocated to recycling (NBB data, “Landfill.Diversion.2007.xls”). As such, the figures take into account the national recycling rejection rates (EPA, 2006)
[104] Following the analysis done in section 4.b, recycling emissions allocated to waste management have their source in transportation and energy used to process recyclable
J., and Ka . 34, p. 289-309
[105] Same emission rates apply to LDPE, HDPE and PET
[106] NBB data, “Flight summary 09.09.05-09.26.06.xls” (Tranche 1), assuming domestic flights were medium-haul (2500 km) and international flights were long-haul (6000 km)
[107] NBB data, “Fleet master list_2005-2007.xls” (Tranche 1)

Employee Commuting 12.7 g CO_2e

For a full "cradle-to-grave" assessment, TCC has included the GHGs emitted through the production and transportation of the fuel used to bring NBB employees to and from the brewery as well as the emissions created by burning the fuel itself. The survey that NBB gave to its employees was a great start, but there were some problems that might be addressed in the future. There were some cars with no make, year, model listed which made determining the mileage impossible. Additionally, because no engine and transmission types were listed, average fuel efficiency across all variants had to be averaged. Some respondents had two cars listed, but did not specify how many days a week they were driven. Others who responded positively to the carpool question listed driving/car pool days that summed to more than 5 days and there was no way to ascertain how many people were inside the carpool car and which other NBB drivers (if any) were taken off the road. Due to those issues and because the response rate for carpools was so low, we did not consider an effect of carpools in our calculations. Lastly, some respondents noted seasonal differences that were not taken into account in the calculations.

We were able to use 115 total responses. The average fuel use was determined and applied to the 200 employees at the brewery. The resulting average was allocated per 6-pack based on total beer production in 2006: 12.7 g of CO_2 per 6-pack.

Downstream 1,484.6 g CO_2e

Emissions assessed in this section are those associated with the distribution, use (i.e. consumption) and final disposal of Fat Tire® Amber Ale.

Distribution 276.2 g CO_2e

Transportation 267.8 g CO_2e

Fuel 266.4 g CO_2e

Retail transportation is performed by trucking brokers contracted by New Belgium and it is assumed that FT is brought to market via Class 8 heavy truck. The average 6-pack travels a distance of 793 miles to either a distribution or retail center (See ***Table 7***). Because primary data concerning the actual path of distribution was not available at time of publication, it has been assumed that the 793 miles is from NBB to the retail center. An average trip of 793 miles constitutes a CO_2 emission of 266.4 grams.

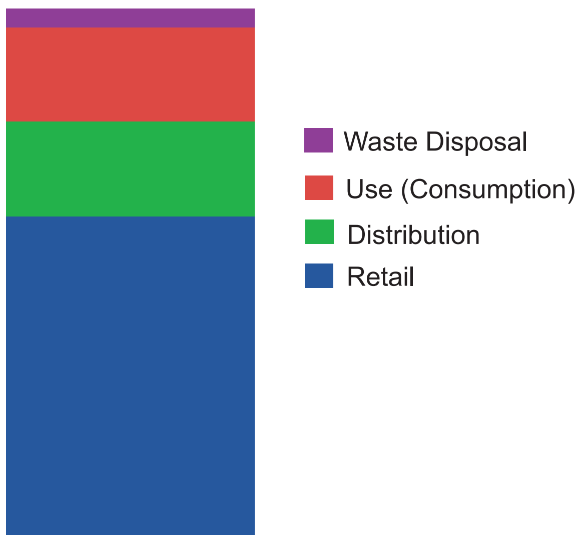


Figure 5. *Major sources of downstream GHG emissions by percentage of total downstream emissions.*

Fugitive Refrigerants 1.6 g CO_2e

The majority of road transport refrigeration units consist of trucks with compressors driven either by stand-alone diesel motors or by the truck's main diesel engine. The average refrigerant charge is 4.9 kg and the main refrigerant used for medium temperature applications is R-134a. The annual leakage rate is estimated to be 20-25% (IPCC, 2005). One truck load consists of 5,040 6-packs.[108] Taking the GWP of R-134a to be 1300, and assuming that the product stays in a truck for an average of 2 days, the emissions allocated to one 6-pack correspond to 1.6 g of CO_2e.

Storage During Distribution 8.2 g CO_2e

Electricity 8.2 g CO_2e

Most cold storage facilities in the U.S. operate at a wide range of temperatures, with an average facility temperature of -3°C.[109] A representative facility whose manager TCC interviewed reported 7,069,000 kWh used in the course of a year to refrigerate 6,000,000 cubic feet of space. Taking the volume of a 6-pack of FT to be 0.6 cubic feet (16,990 cubic centimeters), emissions per 6-pack during storage in such a facility amount to 8.2 g CO_2e.[110]

Fugitive Refrigerants 0 g CO_2e

R-717 (Ammonia/NH_3) is the most common refrigerant used in industrial refrigeration throughout the US, including cold storage rooms (UNEP, 2006). While R-717 is toxic and flammable, providing strong reasons for reducing refrigerant leakage rates, it is not a GHG and will not contribute to the GHG emissions in this assessment.

[108] NBB data, "2006 Total sales.shipping distances.per state sales.xls" (tranche 2)
[109] Personal communication with Marlon Lucas, Vice-President/Manager of United States Cold Storage, Inc., a representative facility.
[110] This figure is weighted according to the percentage of FT sold in each of the 16 states, and includes emissions during production and transport of fuel to power generation facilities (See Table 2 of West and Marland, 2002)

Retail 896.6 g CO_2e

Electricity and Natural Gas 879.8 g CO_2e

In-Store Refrigeration 829.8 g CO_2e

GHG emissions result from energy consumed by in-store refrigeration systems. See page 29 for details of the commercial refrigeration analysis and allocation of fugitive emissions per 6-pack. A 12 ft long Hussmann[112] open front display unit common in large supermarkets requires approximately 5.3 kW of power (cf., Evans et al., 2007). We assume a turnover time of 1 week for each 6-pack of FT.[113] A total 0.9 MWh of electricity are consumed by the open refrigeration unit over 1 week. The average emission factor of the states to which NBB distributes FT is 0.605 kg CO_2 per kWh of electricity.[114]

One refrigerator unit can hold 372 6-packs, and 30% of the FT produced is distributed to large supermarkets,[115] hence emissions resulting from electricity consumed by refrigeration in large supermarkets amount to a very substantial 434.5 g of CO_2e per 6-pack.

Stand-alone refrigerators generally found in smaller markets and convenience stores hold about 72 6-packs and require approximately 0.4 kW of power, equivalent to 67 kWh of electricity in 1 week. Assuming 70% of FT produced is distributed to small market or convenience stores with this type of refrigeration system, GHG emissions allocated to one 6-pack are 395.3 g CO_2e.

Because the per 6-pack figures above are pro-rated based on the percentage of FT distributed to the different store types, total GHGs emitted as a result of electricity consumption by retail refrigeration is the sum of emissions from large commercial and stand-alone refrigerators: 829.8 g CO_2e.

In-Store Lighting and Climate Control 50.0 g CO_2e

A published EPA profile of supermarket energy use shows demand for 51.3 kWh of electricity and 0.38 therms of natural gas per square foot of floor space.[116] The same publication assumed the average area of supermarkets to be 45,000 square feet. Refrigeration was responsible for 60% of storewide electricity consumption. Lighting and HVAC (heating, ventilating and air conditioning) together make up 33% of electricity and 56% of natural gas consumed. We calculated the CO_2e emissions related to this energy consumed in the states where NBB distributes FT and allocated based on the area of stocked floor space occupied by a single 6-pack for 1 weeks to be 44.5 and 5.5 g of CO_2e per 6-pack from electricity and natural gas, respectively.[117]

We were not able to find a comparable secondary resource regarding energy consumed in lighting and climate control of smaller market/convenience stores. We assume these emissions are likely to be similar, and so do not differentiate emissions from lighting and climate control by the type of store to which the FT is delivered.

[111] Distances are to the geographical center of each state
[112] TCC observed FT in several supermarkets in the San Francisco Bay Area (including Safeway, Whole Foods, and smaller chains), and the Impact Excel D5X-E deli case model was most common: http://www.hussmann.com/supermkt/supermkt.htm
[113] NBB data, email from Jenn Orgolini to Steve Davis dated January 8, 2008 with the subject “LCA status update”
[114] This figure is weighted according to the percentage of FT sold in each of the 16 states, and includes emissions during production and transport of fuel to power generation facilities (See Table 2 of West and Marland, 2002)
[115] NBB data, email from Jenn Orgolini to Steve Davis dated January 8, 2008 with the subject “LCA status update”
[116] EPA Supermarket Energy Use Profile based on Energy Information Administration 2003 Commercial Building Energy Consumption Survey, available online at: http://epa.gov/cleanrgy/documents/sector-meeting/4biii_supermarket.pdf
[117] Note that our calculations weight state emission factors for electricity according to the percentage of total FT delivered to each state, and also

Fugitive Refrigerants 16.8 g CO_2e

Large Supermarket Systems 14.4 g CO_2e

Fugitive emissions from commercial refrigeration represent 40% of the total annual refrigerant emissions on a global scale (IPCC, 2005). Large supermarket refrigeration systems commonly used in the US show annual emission rates ranging from 3 to 22%, the average being 18% of refrigerant charge for centralized systems.[118]

These systems use R-22, R-410a, R-404a and R-507 refrigerants for medium temperature (1 – 14°C) cooling (Little, 1999). Beer and other refrigerated drinks are generally kept in open display units and we base our analysis on 12 ft long Hussmann refrigerators.[119] Each unit can house approximately 372 6-packs and is charged with 4 lb of refrigerant. Per week each unit is responsible for directly emitting 6.3 g of refrigerant, which corresponds to 17.8 kg CO_2e.[120]

Convenience Store Systems 2.4 g CO_2e

Small stores typically employ stand-alone, hermetically-sealed refrigeration units with small refrigerant charges (1 kg) and low leakage rates (~1%). The most common refrigerant in this case is R-134a (GWP = 1300). Single column reach-in units[121] can contain approximately 72 6-packs and emit a total of 0.2 g of refrigerant per week (250 g of CO_2e).

Allocation

Assuming that produced beer is distributed 30% to large supermarkets and 70% to small/convenience stores, the allocation of emissions to a 6-pack of FT kept cold for 1 week is 14.4 g of CO_2e from the supermarket and 2.4 g of CO_2e from smaller stores. Total fugitive refrigerant emissions during the retail stage therefore represent 16.8 g of CO_2e.

Use 261.5 g CO_2e

Here we assess GHGs emitted during the use phase of FT, including electricity consumed during refrigeration as well as fugitive refrigerant emissions. We do not consider other energy requirements of a consumer's household (e.g. light and heat), as we assume emissions associated with those requirements are not directly related to the use of FT.

Electricity 260.9 g CO_2e

Refrigeration

Domestic refrigerators have become more energy efficient over the years due to the establishment of national efficiency standards and the voluntary Energy Star program of the US EPA. As of 2001, new home refrigerators were required to consume less than 410 kWh per year, ratcheting down of a 1993 limit of 490 kWh per year.[122] Assuming a lifetime of approximately 20 years, we use the average of those two values (450 kWh per year) to obtain the electricity consumed by the average domestic refrigerator over a period of one week: 8.6 kWh. Since one 6-pack of FT occupies approximately 1/40 of the typical refrigerator's volume, the emissions associated with a 6-pack of FT refrigerated for 2 weeks are 260.9 g of CO_2.

Fugitive Refrigerants 0.6 g CO_2e

Refrigeration

Leakage rates for domestic refrigerators are generally very low (0.3%) (IPCC, 2005) and so are refrigerant charges (~1/3 lb of R-134a). Allocating CO_2e to a 6-pack based on the volume of an average refrigerator (with a capacity of 40 6-packs), we calculate 0.6 g emitted during refrigeration of a 6-pack for 2 weeks.

[118] Centralized systems consist of a central unit housing compressors and condensers that distribute refrigerants to cold storage or display units across the building. Large leakage rates result from long piping and large number of joints.
[119] http://www.hussmann.com/supermkt/supermkt.htm
[120] 100 year GWP was taken to be the average of all four commonly used refrigerants for this application (R-22, R-410a, R-404a and R-507): 2847
[121] http://www.hussmann.com/cstore/c_medtemp.htm#ReachIns_anchor
[122] http://www.clasponline.org/programinfo.php?no=412

Waste Disposal (End of Life) 50.3 g CO_2e

At the point of use, packaging materials become waste. Here we consider the fate of the different packaging materials in each 6-pack and estimate the GHGs emitted during transport, processing, and decomposition of the waste.

Landfilling 31.9 g CO_2e

When organic material is landfilled, anaerobic decomposition results mainly in the release of CH_4 and CO_2. CO_2 is not counted as anthropogenic GHG because it would be produced through natural decomposition. Because natural degradation occurs in the presence of oxygen, CH_4 would not normally be produced and is therefore counted as anthropogenic GHG. Materials that do not contain carbon (e.g. metals or glass) or that are not biodegradable in anaerobic conditions (e.g. plastics or concrete) do not generate CH_4. Their contribution to global warming comes from transportation to landfills through the combustion of fossil fuels. Carbon-rich materials that do not fully decompose anaerobically have some of their carbon content stored in landfills, resulting in carbon sinks. However, carbon of fossil origin (such as in plastics) is not credited as an anthropogenic sink. Carbon credit can also result from landfill gas (LFG) recovery for energy production. All of the processes mentioned above are accounted for and averaged over landfills across the US by the EPA (EPA, 2006).

Recovery of landfill gas (LFG) and carbon storage significantly lower the net GHG emissions of carbon-rich materials. Our estimates are based on EPA's analysis of landfills with and without LFG recovery, and include transportation emissions, all averaged at a national level (EPA, 2006).

Disposal of 6-pack Material

Waste materials per 6-pack is shown in ***Table 6***.[123] The national average GHG emission from landfill transportation is 0.01 Mt of CO_2e per ton of waste for all materials listed above. The GHG emission contribution from landfilled glass, glue and LDPE comes entirely from transportation. The only materials contributing to direct CH_4 emissions are corrugated cardboard, paperboard, paper and lumber. These same materials result in carbon storage when landfilled. The highest emission levels come from landfills without LFG recovery, followed by landfills that flare a part of their methane generation. Significant reductions in the emission levels can be obtained when LFG is recovered for energy generation. The net GHG emissions per 6-pack is shown below for different types of landfills and include direct CH_4 emission, carbon storage, and transportation.

Landfills without LFG recovery: 210.1 g of CO_2e
Landfills with LFG recovery/flaring: -66.1 g of CO_2e
Landfills with LFG recovery/electric generation: -106.7 g of CO_2e

Year 2003 national average: 31.9 g of CO_2e

Recycling 18.4 g CO_2e

There are multiple benefits to the recycling of waste material. It saves landfill space and associated cost and environmental burdens. Savings in the production stage are even more prominent, as it is generally more energy efficient to manufacture products using recycled inputs instead of raw materials. Following EPA's analysis (EPA, 2006), we separate the GHG impact of recycling into two parts: the recycling process emissions are allocated to the manufacturing stage of each product or material, whereas emissions resulting from transportation and energy use to process recycled inputs at a materials recovery facility are counted here as part of waste disposal.

A fraction of the material recovered is lost in the recycling process and we assume it is ultimately sent to a landfill. The percentage of material recycled in one 6-pack is estimated based on recycling rates reported by the EPA (See ***Table 6***). Accounting only for emissions during transportation and processing of recovered materials, we estimate 18.4 g of CO_2e per 6-pack of FT.

[123] NBB data, "6 pack BOM 082907 (with scrap loss rates).xls" (tranche 2)

Table 6. Waste materials disposed per 6-pack Fat Tire® Amber Ale					
Packaging	Quantity	Material	Scrap Rate	Weight (lbs)	Recycling Rate[124]
Carton Box	1/4	Corrugated Cardboard	5%	0.13	72%
6-pack Carrier	1	Paperboard[125]	5%	0.21	16%
12 oz. Bottle	6	Glass	1%	2.76	31%
Label	6	Magazine-style Paper	1%	0.01	0%[126]
Stretch Wrap	0.00005	LDPE	1%	0.0003	8%
Glue	0.95 mL	Polymers[127]	1%	0.001	0%
Pallet	0.004 pallets	Lumber	0.5%	0.14	9%

[124] Taken from http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/06data.pdf
[125] We use the “broad definition of mixed paper” according to EPA’s analysis EPA, 2006, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks: Environmental Protection Agency
[126] Labels and organic-based adhesives of the type used by NBB are not separated from the bottles and are ultimately treated as waste in landfills or consumed
Conservation and Recycling, v. 46, no. 2, p. 168-181
[127] For the purposes of identifying GHG emissions from landfilled glue, we treat it as plastic since glue composition is almost entirely of synthetic polymers
[128] Density of typical label glues is slightly less than that of water. See Table 2 in Luukko, P., Nystrom, M., and Rainio, J., 2004, Comparison of different foaming agents in making plywood glue: Journal of Applied Polymer Science, v. 93, no. 3, p. 1060-1064.

Conclusions

It is apparent that New Belgium Brewing Company has taken steps to reduce its carbon footprint, and the efforts to do so transfer to the Fat Tire® Amber Ale assessed here. By using this assessment to look outside of the entity, still more reductions may be possible.

The steps taken by New Belgium Brewing Company to increase the efficiency of operations and source renewable energy have successfully reduced the carbon footprint of its products relative to the average in the brewing industry.

The business of creating any beer is linked inextricably to GHG emissions and many of these emissions are today unavoidable. Additionally, many emissions from the agricultural and packaging subsystems are located far upstream from the entity, making it difficult for NBB to directly manage them.

Though no one subsystem in the production of FT is an obvious choice for GHG reduction, there are several areas where improvement seems possible. One such area in the raw material acquisition phase relates to malt, for instance. The production of synthetic fertilizers and related emissions from the soil are a substantial part of the GHGs allocated from malted barley (see pages 15 and 16) and could be reduced by switching to organic barley (or barley fertilized from organic sources).

There may be another opportunity in the most significant contribution to overall GHG emissions, the downstream refrigeration of FT during retail. Nearly one kilogram of GHGs of the roughly three kilograms embodied by FT are emitted during the retail phase of the beer. NBB has little influence over the design of the refrigerators employed by retail centers. However, efforts to minimize stock turnover time at retail, or the removal of some portion of product from refrigerated section altogether, might be ways NBB could drastically reduce the carbon footprint of FT in the future.

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