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Understanding and Measuring Net Positive Business Strategies

Luke Ruffner Robinson

UNDERSTANDING AND MEASURING NET POSITIVE BUSINESS STRATEGIES

By

LUKE RUFFNER ROBINSON

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Jakki J. Mohr, Chair

Department of Management & Marketing

Cory C. Cleveland

Department of Ecosystems & Conservation Sciences

Suzanne G. Tilleman

Department of Management & Marketing

Benjamin P. Colman

Department of Ecosystems & Conservation Sciences

Robinson, Luke, M.S., Fall 2019 Systems Ecology

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Chairperson: Jakki J. Mohr

Despite their attempts to mitigate ecological impacts through sustainability initiatives, businesses are a major cause of the world's ecological problems. Some progressive businesses are attempting to move beyond “net zero” in terms of achieving neutral environmental impacts and instead are now pursuing a goal of *net positive*. Net positive refers to the idea that business activities could contribute value-added benefits to earth’s ecological systems, for example, by using technologies that sequester and store carbon. However, except for a handful of high-profile corporate case studies, little is known about how companies are developing their strategies to become net positive and if it is even a realistic goal. Further, little is known regarding the measurements they are using to determine what net positive business practices are. My thesis research addressed three fundamental questions: (1) “What are the types and impacts of net positive strategies an established business might use?”; (2) “What are the measurement issues associated with evaluating the impacts of those strategies?”; and (3) What are the challenges a business faces when implementing net positive strategies? Based on data collected from an organic brewery in western Montana, Wildwood Brewing, my research evaluated two on-site negative emission technologies (NETs), short rotation coppice agroforestry (SRCA) and pyrolysis, as well as on-site energy generation through photovoltaics (PV). Using two environmental accounting methodologies—emergy analysis (EMA) and life cycle assessment (LCA)—to assess Wildwood’s ecological impact, results show that Wildwood must employ NETs over larger amounts of hectarage than it has available on-site in order to attain a net positive state. LCA proved a more useful approach to measuring net positive benefits to the environment over EMA because of its ability to express negative CO_2e values from NETs. Based on in-depth interviews with the owner, the main challenges a business may face in achieving net positive include lack of personnel and infrastructure, poor cash flow to fund the initiatives, and a lack of a formal marketing and sales plan to generate greater revenue.

Acknowledgements

I would like to start by thanking my advisor, Jakki J. Mohr, for her relentless compassion, wonder, and excitement for knowledge. Her mentorship and friendship were crucial to the success of this project and to my personal and professional development. I will always think back fondly on the times we spent brainstorming, pivoting, regrouping—trying to better describe a better world. I would also like to thank Suzanne Tilleman, Ben Colman, and Cory Cleveland. As an interdisciplinary committee, they all provided diversified feedback at moments crucial to the project's success. I'd like to thank Jim Lueders for allowing me to do a case study on his brewery. His time, patience, and willingness to help me during the data collection process started the project off on the right foot. I would like to thank Stephon Smith and Blaise Wren for insight into the design of the database and guidance regarding the material inventory process, respectively. I'd also like to thank Bill Braham, Charlie Hall, and Daniel Campbell for insight on the methodology. I'd like to thank Rebecca Elderkin for her incessant moral support and eagerness to help out in whatever way. I'd like to also thank Libby Metcalf and the Human Dimensions Lab for funding parts of the project. Finally, I'd like to thank Mom, Dad, Mr. Mark, Rem, Kate, Mag and the rest of my family and friends for all the inspiration and encouragement.

Dedication

To Dad and your curiosity and fascination with the world.

To “Funcle” and your endlessly calling attention to the absurdity of it all.

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1 Introduction

Resource extraction and other industrial impacts have negatively affected the planet's ecological systems at local, regional, and global scales (Griffin, 2017; Hsu, 2006; Nriagu, 1996). Resource extraction and processing are responsible for over 90 percent of global biodiversity loss and water stress, and more than half of global climate change impacts (IRP, 2019). As a result, businesses have developed sustainability initiatives to "be less bad" (*e.g.,* to reduce energy consumption or to reduce the use of environmentally harmful materials). These efforts to use resources efficiently are often described in 'net neutral' language; *i.e.*, to offset 100% of electricity emissions by 2030.

Several papers have argued that the goal of being net neutral does not go far enough; instead, business should find ways to rehabilitate and improve unsustainable circumstances (Birkeland & Knight-Lenihan, 2016; Cole, 2012; Mang and Reed, 2012; McDonough & Braungart, 2002; Reed, 2007; Waldron & Miller, 2013). These leaders have boldly called for businesses to add value back to ecological systems. Referred to as *net positive* or *regenerative* business, the goal is for an organization to contribute positively to natural capital (soil, carbon, air, biodiversity, etc.) compared to its uses or negative impacts.

A handful of high-profile companies[1] have heeded this call and have worked to implement strategies that allow them to become regenerative to the natural environment. Examples of net positive strategies employed by these businesses include: Interface Inc.'s production of carpet that absorbs and stores carbon from the atmosphere by naturally and synthetically converting CO_2 into bio-derived carbon and carbon-storing minerals and polymers, respectively (Interface, Inc., 2019), Kingfisher's goal of

[1] Interface Inc., a commercial flooring company; Kingfisher, PLC, an international home improvement company; and Stripe, a payment platform technology company

generating more than 100% of its energy from renewable sources by implementing solar or wind energy in all their store locations (Kingfisher, 2018), and Stripe's goal of more than offsetting 100% CO_2 emissions through direct air capture (Anderson, 2019) —a chemical scrubbing process that directly removes CO_2 from the outside air (Socolow et al., 2011).

Despite the appeal of these examples, very little literature exists to guide businesses in their pursuit of net positive strategies and more specifically, how to measure the environmental impacts of possible net positive business practices. Hence, I investigated three possible strategies businesses might pursue in order to both offset existing impacts and generate net positive benefits to the environment. These strategies include two negative-emission technologies (NETs), short-rotation coppice agroforestry (SRCA) and pyrolysis, and the use of solar photovoltaics (PV) to generate energy. More specifically, using an existing business as a case study, this research tackles the measurement issues in gauging the impact of these strategies by analyzing carbon footprints via a life cycle assessment (Onat et al., 2014) as well as an approach developed by Odum (1996) referred to as "emergy analysis". This case study approach (Crowe et al., 2011) lends itself well to understanding the challenges businesses face in pursuing net positive strategies and offers insights into measurement issues and implications.

2 Literature Review

2.1 Contexts for Exploring Net Positive/Regenerative Strategies

One context that has gained some traction in exploring net positive strategies is the built environment. The built environment, or man-made structures, was one of the early adopters of net positive practices. Sustainable building initiatives such as Leadership and Energy and Environmental Design (LEED) provided an assessment method for builders to evaluate the environmental impacts of their building designs (Cole, 2012). However, some LEED builders sought to create “net zero buildings” or “zero carbon buildings”—buildings that either fully offset annual operational energy or return the amount they consume to the grid via on-site (or in some cases, off-site) energy production (Torcellini, 2006; U.S. Department of Energy, 2015).

Pushing further, Cole and Fedoruk (2015) advocated that designers go beyond net zero and instead, design net positive energy buildings, in which more electricity is put back into the grid than is used throughout the building’s lifetime. To do so, building designers must account for the building’s complete life cycle energy including that which is expended during both the construction of the building—something known as its “embodied energy” (Cole and Fedoruk, 2015)—as well as the ongoing operations of the building over its lifetime. This complete measurement approach is in marked contrast to most net zero energy measurements which focus solely on accounting for a building’s operational energy usage (Cole & Kashkooli, 2013). Moreover, net positive buildings must also develop partnerships with energy companies and/or other members of the grid for whom the excess on-site solar or wind energy is provided (Cole, 2012; Cole & Kashkooli, 2013).

Another area where net positive approaches to business are gaining traction is in regenerative agriculture. Regenerative agriculture is a system of farming principles and practices that aims to go beyond sustainable by increasing biodiversity, enhancing ecosystem services, and capturing carbon in soil and above-ground biomass to reverse current global trends of atmospheric accumulation (Terra Genesis Institute, 2019). The notion of returning more organic matter to the soil than is used during cultivation (a cornerstone of regenerative agriculture) has been cited in many traditional farming practices (Howard, 1943; King, 1922; Smith, 1953). Yet, it wasn’t until the latter half of the twentieth century that the term regenerative agriculture began appearing in the literature (Harwood, 1983; Harwood & Madden, 1982; Liebhardt, Francis, & Sands, 1985). The Rodale Institute began using the term (Gates, 1996) after it was coined in the early 1980's by Robert Rodale (Dahlberg, 1993).

Since the early 2000's, there has been an increase in publications on regenerative agriculture. Recent findings from the literature have shown regenerative farming practices to increase soil organic carbon stocks and decrease greenhouse gas emissions (De Ponti et al. 2012; Gattinger et al., 2012; Kenne & Kloot, 2019), maintain yields (Pimentel et al., 2005), improve water retention and plant uptake (Lotter, 2003), improve farm profitability, (Pimentel et al., 2005) and revitalize traditional farming communities (Wittman, 2009), while ensuring biodiversity and resilience of ecosystem services (Crowder et al., 2010, Lotter, 2003). The interest in regenerative agriculture has increased as advocacy groups have emerged in recent years (*i.e.*, The Carbon Underground, Regeneration International). A 2017 initiative received signatories from over 140 agriculture firms endorsing regenerative agriculture (The Carbon Underground, 2017) and widespread coverage continues in academic literature (Elevitch, Mazaroli, & Ragone, 2018; Hes & Rose, 2019; Kenne & Kloot, 2019; LaCanne & Lundgren, 2018; Rhodes, 2017).

2.2 Net Positive Strategies

Negative emission technologies (NETs) are technologies that remove the major greenhouse gas, CO_2, from the atmosphere (EASAC, 2018). NETs have become increasingly important strategies in meeting international climate goals (Luderer et al., 2013, 2016; Minx et al., 2017, 2018; Peters, 2016; Rogelj et al., 2015, 2018). The acronym "NETs" is a blanket term for many approaches that remove CO_2 from the atmosphere (*i.e.*, carbon mineralization, iron fertilization, direct air capture, and biosequestration[2]). Due to limited data availability and because many NETs are still in their infancy (National Academies of Sciences, Engineering, and Medicine, 2019), only short rotation coppice agroforestry (SRCA), a system of harvesting wood from fast growing woody species, and pyrolysis, the chemical decomposition of woody biomass, are considered in this study. SRCA and pyrolysis may be combined as promising options for carbon sequestration and storage, respectively (Bruckman, 2016).

SRCA systems usually consist of fast-growing tree species such as willow or poplar. The trees are planted at high densities of 12,000 (or more) plants per hectare in a planting pattern that allows for mechanical harvest on a "rotation" of every 2-6 years (Kumar & Nair, 2011). Carbon sequestration from SRCA involves bio-sequestration, or carbon capture and storage in plant biomass through photosynthesis. Trees are harvested at the base when the plants are dormant and the "resprouting" after cutting allows for several rotational harvests to be taken before yields decline (20-30 years after planting). In addition to being used as biochar, coppice biomass is also used for woody energy crops (e.g., bio-oil) (Pleguezuelo et al., 2015).

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[2] Carbon mineralization refers to removal of carbon dioxide (CO_2) from the air and storing it in the form of carbonate minerals such as calcite or magnesite. Iron fertilization is the intentional introduction of iron to iron-poor areas of the ocean surface to stimulate phytoplankton production and the CO_2 they sequester from the atmosphere. Direct air capture is a chemical scrubbing process that directly removes CO_2 from the outside air. Biosequestration captures and stores carbon in living organisms such as plants and algae.

Figure 1 Short Rotation Coppice Agroforestry. Shoots emerge from epicormic buds that form on the stumps of recently harvested biomass. Growth is allowed for several years before harvesting again. © Photo copyright Chris McAuley and licensed for reuse under Creative Commons License

The second NET, pyrolysis, involves the chemical decomposition of organic matter through the application of heat. Depending upon the type of pyrolysis process used (e.g., use of charcoal or bio-oil to generate the heat), by-products are produced. For example, one key by-product is biochar, a stable, charcoal-like material rich in carbon. Producing biochar through pyrolysis and incorporating it into the soil diverts carbon from the atmosphere-biosphere pool, or stocks of carbon that are exchanged between the land and atmosphere, and into a stable carbon that decomposes slower than the parent feedstock, avoiding the generation of CO_2 from natural decay or burning (Crombie et al., 2013, Liang et al., 2008; Spokas, 2010).

Two concerns with biosequestration-based NETs include their potential to compete or overlap with land availability for reforestation/afforestation and food production (EASAC, 2018) and their potential to dramatically change ecosystems (Williamson et al., 2016). Therefore, the spatial scope of NETs is confined to the employment of strategies on-site in order to alleviate these concerns.

Figure 2 Biochar from the pyrolysis process. Image Credit: This file is licensed under the Creative Commons Attribution-Share Alike license and is attributed to Wikimedia username K.salo.85.

Finally, I assessed another strategy, photovoltaics (PV). PV, or solar panels, rely on the absorption of sunlight as a source of energy to generate direct current electricity and is an important way to minimize carbon-intensive energy usage (Panwar et al., 2011). Although PV could produce more energy than a business "consumes," PV does not offset CO_2 emissions from other business activities and as such, is not technically a NET. Yet, since there is substantial agreement among scientists that NETs should not be a substitute for mitigation of emissions (EASAC, 2018), PV could serve an important role in lowering a company's emission footprint and minimize the extent of NET employment.

2.3 Assessment/Measurement Methodologies

To assess the scope and effectiveness of on-site net positive business strategies requires two steps: measuring the life cycle business impacts[3] and measuring the life cycle impacts of the net positive strategies. According to Renger et al. (2015), life cycle impacts must be defined and then measured using tools that are modified and integrated into a net positive framework. Various tools exist to assess environmental impacts of business operations. One tool, life cycle assessment (LCA), is widely used to assess the ecological burdens connected with the complete life cycle (creation, use, end-of-life) of products, processes and activities (Klöpffer, 2014). Based on the LCA, businesses can make decisions that improve the ecological performance of industrial activities (El-Haggar, 2007, Krishna et al., 2017).

One way that LCA measures ecological impacts is through the Global Warming Potential (GWP). GWP is the radiative forcing due to a pulse emission of a given greenhouse gas (GHG), over some given time period (or horizon) relative to a pulse emission of CO_2 (Shine, 2005). The given time period relative to a pulse emission of CO_2 is commonly 20, 100, or 500 years (although the latter is being phased out) (IPCC, 2018). For example, the 100-year GWP of methane is 28, which means that if the same weights of methane and CO_2 were introduced into the atmosphere, methane will trap 28 times more heat than the CO_2 over the next 100 years (Myhre et al., 2013). GWPs are factored to kilograms of CO_2 equivalents (CO_2e)—a common unit for describing different greenhouse gases—by multiplying the amount of the

[3] Life cycle business impacts refers to environmental impacts that occur throughout the business's entire existence beginning with early stages such as construction to end of life stages such as demolition/disposal.

GHG by its GWP (e.g. if 1 kg of methane is emitted, this can be expressed as 28 kg of CO_2e or 1 kg CH_4 * 28 = 28 kg CO_2e) (Brander, 2012).

Another environmental accounting tool, emergy analysis, can also be used to assess the ecological performance of industrial processes (Cavalett & Ortega, 2009; Feng et al., 2009; Siracusa et al., 2007; Yang et al., 2003). Emergy is the total energy used—all the work done and fuel spent—to make a product or service (Odum, 1996). Because it is useful to compare different products and services using a common unit, and because sunlight is both the largest source of available energy entering the biosphere (Campbell, 2016) as well as the source from which most kinds of available energy derive (Chen et al., 2006), emergy is expressed as solar emjoules (seJ)—the amount of solar energy it took to do something.

The emergy analysis involved four parts. I first created energy system diagrams according to emergy input and output items across spatial distributions. Material and energy flows from building construction, operations, and end-of-life phases were then inventoried. I next calculated the material weight values, quantities, and determined the material lifetime values. Lastly, I derived unit emergy values from the literature to calculate emergy. Deriving weights are critical to the emergy analysis because UEVs of most materials are expressed as emergy/kg of material. Further, denoting a material lifetime value (also Step 3) is important in reflecting the repeated replenishment and corresponding emergy of depreciable materials across the lifetime of the business.

Unit Emergy Value, UEV, is defined as the amount of emergy that is needed to make one unit of product or service and is generally measured in joules or grams (Saladini et al., 2018). UEVs are the intensive expression of the unit of emergy, the solar emergy joule (sej). Deriving UEVs from published papers or calculating UEVs are necessary in order to determine the solar emergy of a product or service, which is determined according to the following formula:

$$Em = \sum_{i=1}^{n} E_i UEV_i$$

where E_i stands for the energy content of the ***i***-th independent input flow to the system and UEV_i is the Unit Emergy Value of the ***i***-th input flow. All the UEVs used in this study refer to the global emergy baseline[4] of 12.0E+24 seJ y^{-1} (Brown et al., 2016).

To evaluate the viability of the net positive business strategies—the two NETs (SRCA and pyrolysis) and PV—and to understand how traditional LCA methods and the relatively less well-known emergy analysis can be used to assess these net positive strategies, I collected data from a case study of a brewery in western Montana.

3 Methods

3.1 Case Study Selection

According to Patton (2014, p. 279), a case study requires that the case selected be "information-rich and correspond with the phenomenon of interest intensely". For my purposes, the case company needed to be striving to optimize its material and energy flows, incorporating techniques to generate energy on-site (e.g. PV), and demonstrating a philosophy of sustainability that embodies net positive practices.

Based on these criteria, I selected Wildwood Brewing, an organic brewery one mile north of Stevensville, Montana. Located in the Bitterroot Valley on a two-hectare plot of land (46˚31'47.84" N,

[4] Global emergy baseline refers to the total flow of emergy resources driving the biosphere and is a necessary component for calculating UEVs (see Ulgiati et al., 2011)

114˚06’30.82”) (see Figure 3), Wildwood mainly serves organic beer to Montana craft beer markets in Western and Central Montana. In 2018, Wildwood was in its eighth year of production and was producing on average 300 brewer’s barrels or 35,100 liters per year.

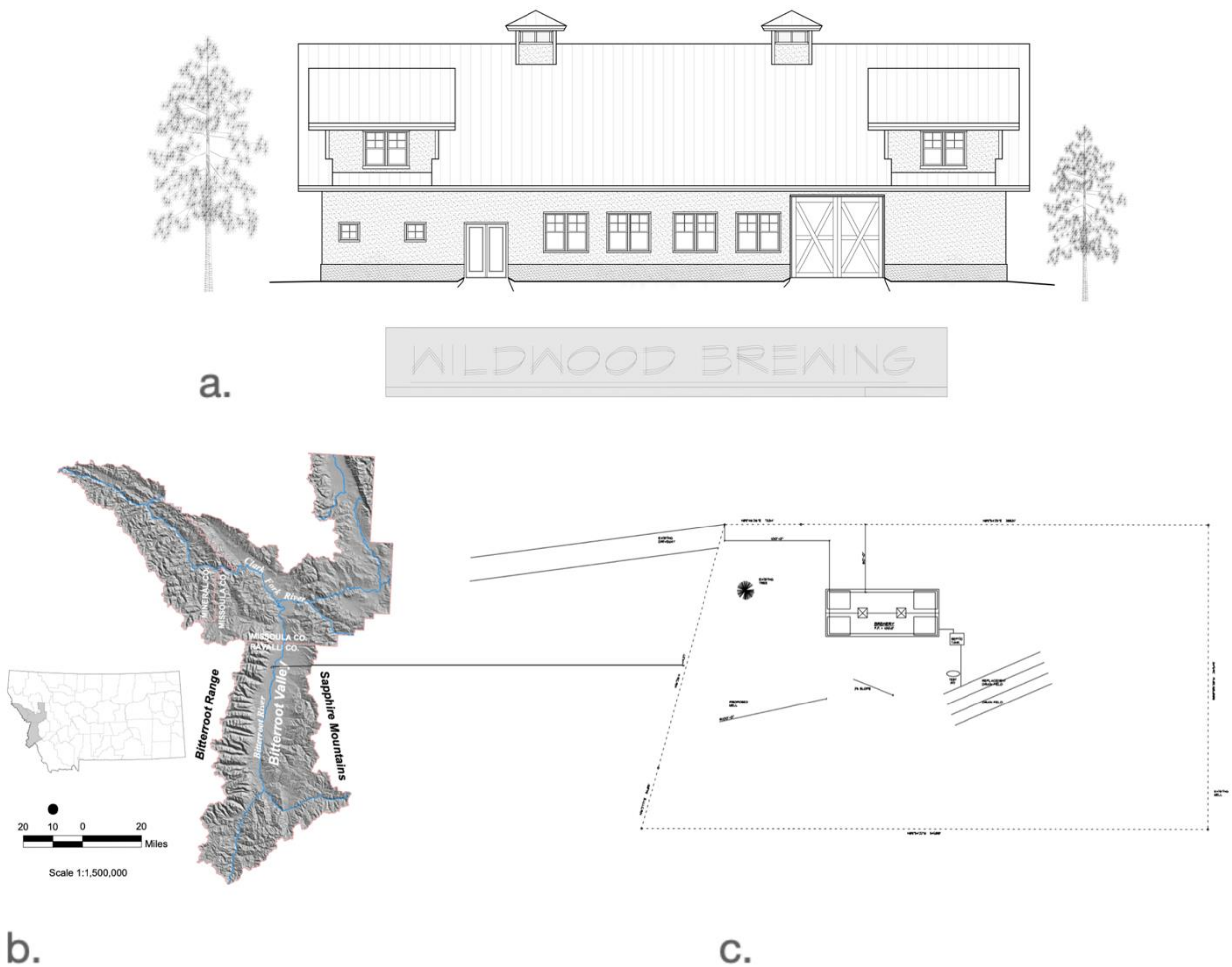

Figure 3: Wildwood Brewing in Stevensville, Montana.

3.2 Qualitative Data Collection

The research also included in-depth interviews with the owner, which allowed for insight into challenges and barriers a business faces in achieving a net positive state. Data collection entailed the following steps. First, two one-hour long semi-structured interviews were conducted with the owner on separate days in January 2019. This qualitative methodology is ideal for the analysis of "how" and "why" questions (Yin, 1994), and more importantly, allows for an in-depth understanding of a dynamic phenomenon in a real-life context (Nordin et al., 2017). The questions, shown in Appendix 1, were wide ranging, detailed, and context-specific. These interviews were completed prior to the collection of other measurements in order to build rapport with the owner and to familiarize myself with the brewery. Given the extensive data that was required for the technical analysis, this rapport was critical for obtaining the owner's commitment to the project. The interviews were recorded and transcribed. The analysis of the qualitative data followed an abductive research approach[5], characterized by an iterative process of systematic confrontations of the desired end state (in this case, net positive) with reality (Dubois & Gadde, 2002).

3.3 Energy System Diagramming: Wildwood's Inputs, Interactions, and Flows Within the Study's System Boundary

Systems tend to be very complex, and thus quite difficult to study. One way to distill the system to its essentials, choosing the key variables and interactions to focus on, is through creating energy system diagrams, which are commonly used in the fields of ecological engineering and systems ecology (Ayers, 2009). Using specific symbols referred to as the "energy system language" (Figure 4), energy system diagrams show the ways in which energy, materials, and information interact with one another and the system of analysis, providing an understanding of the system's functioning as a whole (Odum, 1996).

[5] A form of logical inference that seeks to find the simplest and most likely explanation of an observation.

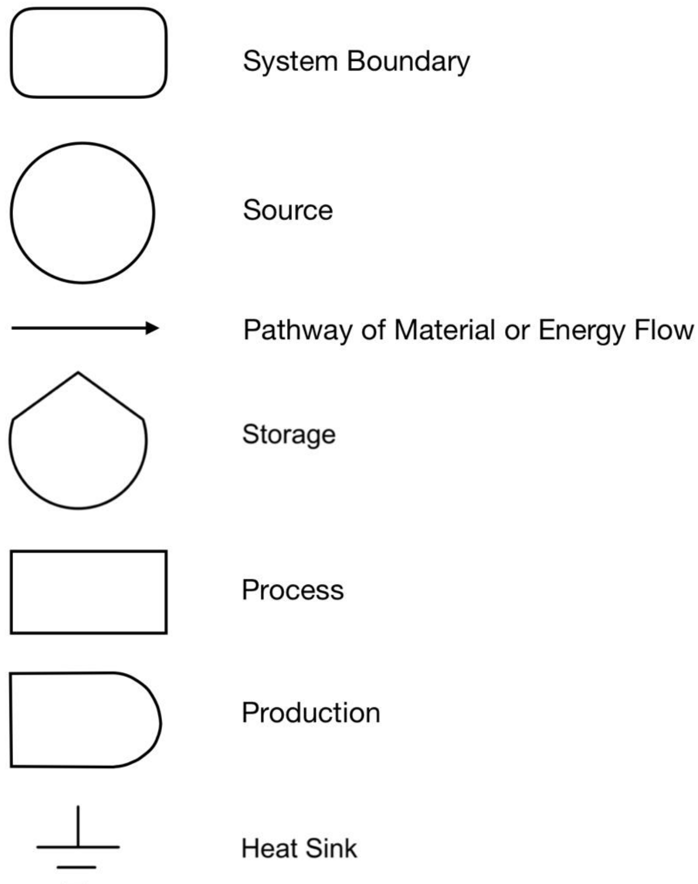

Figure 4: Symbols used in the energy systems language. System Boundary: The spatial extent of the system under analysis. Source: an outside source of energy delivering forces according to a program controlled from outside; a forcing function. Pathway of Material or Energy Flow: a flow of energy, often with a flow of materials. Storage: A compartment of energy storage within a system storing a quantity as the balance of inflows and outflows; a state variable. Process: Represented here as a "black box" to show a simplified process, or sub-system, and not its inner workings. Production: These include units that collect and transform various inputs into a particular product. Heat sink: Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system (Odum, 1996).

Prior to diagramming, an initial site assessment was conducted to understand the scope of business operations. The next step was to delineate the system of interest by showing the extent of the system boundary. Next, I defined the relevant inflows and outflows that drive the production and processes (also defined), the state variables (storages), and interactions. Figure 5 shows an energy system diagram of Wildwood. In line with Brown (2004) elements of the energy system diagram include the following: the "system boundary" represented by the round rectangle*;* the main "source" inputs represented by the circle symbols that cross the system boundary via "pathways of material or energy flow"; the "process" itself (e.g., the brewery) represented as a box; the NETs and agriculture represented as bullet shaped "production" symbols; and other "storage" symbols that represent material that builds up over time within the system due to a rate limiting process. The system boundary, and thus the scope of this research, does not represent energy and material flows after the point of beer distribution (e.g. once the beer enters the market).

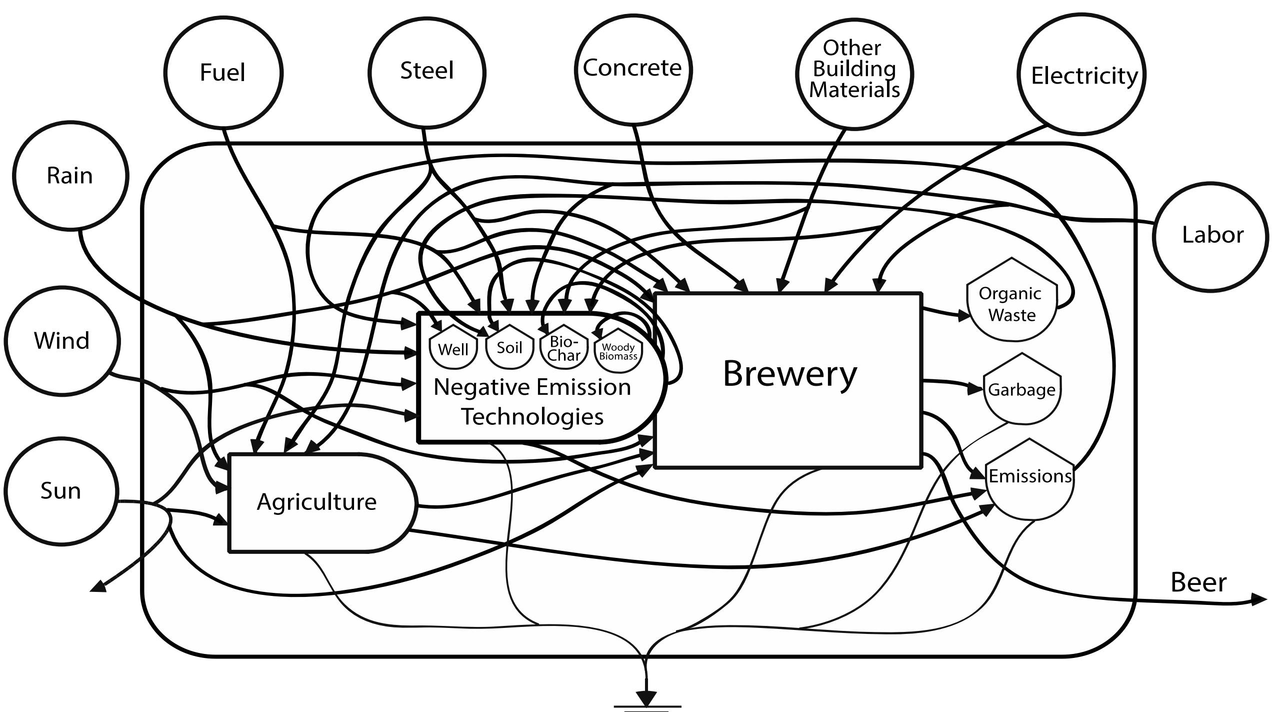

Figure 5: Energy system diagram of Wildwood Brewing with associated inputs, interactions, and flows.

The source inputs begin with sunlight energy and move clockwise across an energy concentration gradient[6] ending with labor. The source inputs all feed into the main components within the system boundary—agriculture, the brewery, and the NETs. The brewery building, a facility designed and constructed for an estimated production volume of 10,000-barrels, is depicted as a *black box*—a simplified diagram that shows the main inputs and outputs of the brewery's industrial activities rather than portraying all of its inner workings. Agriculture, which is separate from NETs to demonstrate ingredients imported from off site, and NETs are both given bullet shaped production symbols to demonstrate their ability to fix their own carbon through photosynthesis. Organic waste, garbage, and emissions are all storages (*tank symbol*) to represent stocks of materials that accumulate over time. NETs are depicted as being attached to the brewery to represent partial on-site application of SRCA and pyrolysis.

The brewery, agriculture, and NETs each generate CO_2 emissions whereas woody biomass (SRCA) and subsequently biochar (pyrolysis) act as CO_2 sinks. There is also the "organic waste" sink (e.g. spent brewer's grain) that could serve to cycle nutrients on-site and increase other sinks, such as soil, through composting initiatives (although this research does not analyze that potential). The well sink serves to provide water for SRCA and the brewing process. The thinner arrows that flow from the bottom of the internal components to outside of the system represent the heat sinks—loss of potential energy from further use by the system. Apart from

[6] Concentration gradient here refers to the concentrated amount of previously available energy that was used to create energy (sunlight), materials (concrete), or processes (labor) relative to one another.

sunlight that is re-emitted out of the system in the form of longwave radiation, the only other output that crosses the system boundary is beer.

3.4 Inventory Process

As shown in the energy system diagram, the process box, or the brewery, was depicted without detailing the inner workings. To understand the inner workings, I first conducted a site visit to evaluate the scope of materials, energy, and other processes that the brewery depends on for operations. A step-by-step account of the beer making process, explained during an on-site walk-through of the brew house, appears in Figure 6.

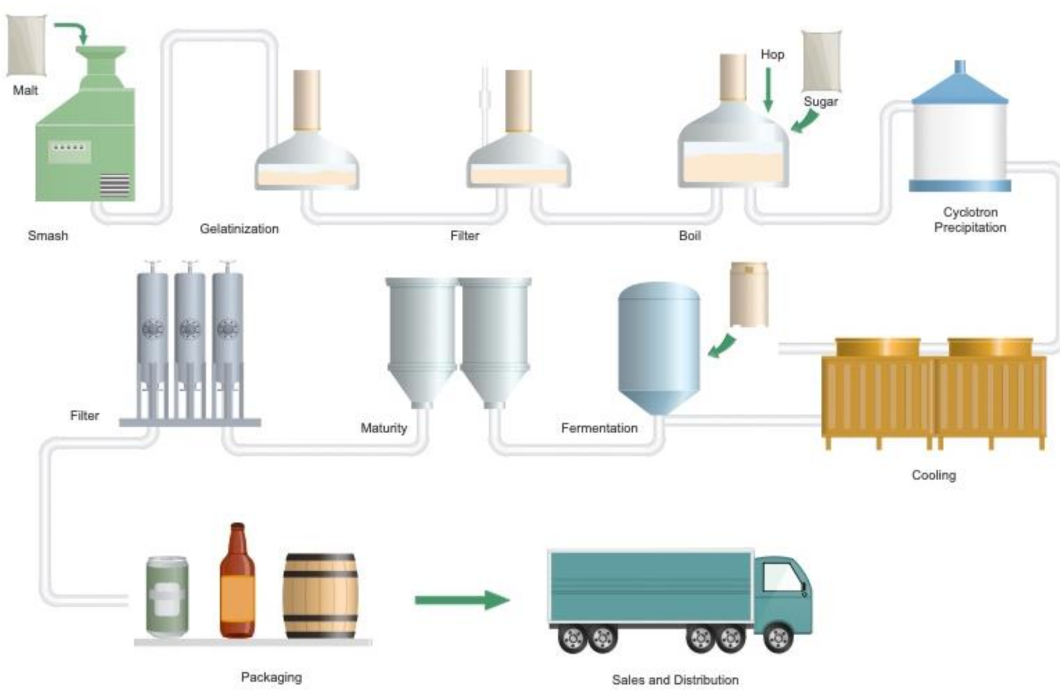

Figure 6: Beer Processing Flow Diagram. Malt from three silos are sent to malt hopper via cable conveyors. Malt is dumped into malt mill, ground up, and sent to grist hopper. Malt enters bucket elevator that takes grist to chain drag conveyor. Chain drag conveyor sends grist to mash kettle, water, yeast and hops are added, and brewing process begins. Beer is fermented, filtered, packaged, and served on-site/distributed. Image sourced from EDraw.

After the site visit, an analysis of architectural drawings, and other documentation shared by the owner, my comprehensive inventory grouped all the business's life cycle materials and energy into categories that were then entered into a Microsoft Excel database. The categories included: Brewing Machine and Equipment; Canning Raw Materials; Beer Ingredients; Cleaning Supplies; Electricity; Heating; Labor; Vehicles & Travel; Furniture, Fixtures, and Equipment; Construction; and Other (see categories and measurements in Table 1). Individual items within each category were catalogued and unit weights were derived in order to create denominator values for emergy conversions (emergy/kg of material) and LCA conversions (kg of CO_2e/kg of material) (see Appendix 2 for entire list). Some emergy and CO_2e items (e.g. electricity and vehicles) are generally expressed in terms of kWh and VKT (vehicle kilometer traveled), respectively, and deriving unit weights was not necessary.

<u>Brewing Machinery/Equipment.</u> The weight of brew house machinery/equipment was derived according to either manufacturer estimations of weight or found via serial number searches on manufacturer websites.

<u>Canning Raw Materials</u> were weighed on an individual basis and verified through vendor records. Annual canning material calculations multiplied the annual output volume times the fraction of annual beer canned by Wildwood, divided by the amount of beer in a can.

<u>Beer Ingredients</u>. As noted previously, Wildwood's average annual production was 300 brewer's barrels, or approximately 10 brews per year. To produce this volume requires 600 kg of malt and ½ kg of hops per brew, 6 liters of concentrated yeast slurry per year, and 120,000 liters of water (including clean up) annually.

Cleaning Supplies. Annual usage of cleaning supplies was calculated via the amount of usage per brew batch as reported by the owner, times the number of batches brewed annually.

Electricity & Heating data were obtained from the owner via physical documentation from past utility bills (see Appendix 3).

Vehicles – Travel. Travel mileage from vehicle business activity was collected from owner's records based on miles traveled per vehicle per year and the vehicle type. Vehicle emergy and CO_2e data were calculated according sej/VKT per year and CO_2e/VKT per year, respectively, where VKT = Vehicle Kilometer Traveled.

Labor. The number of labor hours from building construction of the brewery was based on historical data reported by the owner. Annual labor hours to operate the brewery were also reported by the owner.

Furniture, Fixtures, and Equipment & Building Construction. Data from furniture, fixtures, and equipment and building construction materials were collected on-site and catalogued from architectural drawings, respectively. Depending on the building construction material, data collection consisted of counting materials (e.g., 8"x8" support columns) and making calculations to determine their weights via the following formula:

$$W = \sum_{1}^{i} V * D * P_{rm}$$

where W is weight of a given material, i is the number of component materials per inventoried item (if necessary), V is volume, D is density, and P_{rm} is the percentage of the component material.

Category	Data Collection Method	Formulas for Denominator Values (Em/LCA)
Brewery Machines & Equipment	Inventoried from on-site walk through and corresponded with manufacturer or from website to obtain equipment specs/weights.	
Canning Raw Materials	Material specs weighed & verified by 3rd party suppliers. Collected on-site.	kg/unit*number of annual units
Beer Ingredients	Calculated with owner from numbers reported to the IRS.	$AI = (B_Y + B_H + B_M + B_W)*n$ = , where AI is ingredients, B_Y = yeast per brew, B_H = hops per brew, B_M = malt per brew, B_W = water per brew, and n = brews/year
Cleaning Supplies	Obtained from owner's cleaning regimen.	Cleaning chemical per brew * brew/year
Electricity	Obtained from utility bills.	Yearly expenditure of kWh (electricity) and therms (natural gas for heating) obtained by averaging available data from Jan. 2015–Sept. 2018
Heating	Obtained from utility bills.	Yearly expenditure of kWh (electricity) and therms (natural gas for heating) obtained by averaging available data from Jan. 2015–Sept. 2018
Labor	Referenced from tax documents reported by owner to IRS.	
Vehicles - Travel	Mileage obtained from owner.	Vehicle emergy and CO_2 data are calculated according *sej/VKT per year* and CO_2e/VKT *per year* respectively, where *VKT* = Vehicle Kilometer Traveled.
Furniture, Fixture, and Equipment	Collected on site and calculated to derive weights.	$W = \sum_{1}^{i} V * D * P_{rm}$ where W is weight of a given material, i is the number of component materials, V is the volume, D is density, and P_{rm} is the percentage of the component material.
Building Construction	Catalogued from architectural drawings and calculated to derive weights.	$W = \sum_{1}^{i} V * D * P_{rm}$ where W is weight of a given material, i is the number of component materials, V is the volume, D is density, and P_{rm} is the percentage of the component material.
Other	Collected on-site	Includes non-brewing water usage taken from owner's account, waste based on owner's weekly reported average.

Table 1: The categories of on-site data, their data collection methods, and formulas (if necessary) for calculating weights or other denominator value used in emergy/LCA.

3.5 Emergy data

After diagramming energy flows and calculating quantities, densities, and weights for the items inventoried, I carried out a comprehensive literature search in order to find previously calculated unit emergy values (UEVs) for the materials and energy inventoried. Recall that Unit Emergy Value, UEV, is defined as the amount of emergy that is needed to make 1 unit of product or service and is generally measured in joules or grams (Saladini et al., 2018). UEVs are the intensive expression of the unit of emergy, the solar emergy joule (sej). Finding UEVs from either published papers or calculating UEVs are necessary in order to determine the solar emergy of a product or service, which is calculated according to the following formula:

$$Em = \sum_{i=1}^{n} E_i UEV_i$$

where E_i stands for the energy content of the *i*-th independent input flow to the system and UEV_i is the Unit Emergy Value of the *i*-th input flow. All the UEVs used in this study refer to the global emergy baseline of 12.0E+24 seJ y^{-1} (Brown et al., 2016).

UEVs were found in the literature (see references in Appendix 4) for the majority of items catalogued during the inventory process. The only items for which UEVs had not been previously calculated were the brew ingredients and cleaning supplies. Ingredients such as hops, barley, and yeast were approximated based on agricultural data derived from Campbell and Ohrt (2009) whereas cleaning supplies were approximated from data by Brandt-Williams (2002). UEVs needed to be updated to the current global emergy baseline of 12.0E+24 seJ y^{-1} from Brown et al. (2016) according to the following formula:

$$CUEVx = \left(\frac{PUEVx}{PEmBx}\right) * CEmB$$

where $CUEVx$ is the current UEV for material x, PUEVx is the previous UEV of material x that was calculated from $PEmBx$ or previous global emergy baseline, and $CEmB$ is the current global emergy baseline.

3.6 LCA Data

The inventory process and system diagramming phases of the emergy analysis served to inform what CO_2e data needed to be collected for the LCA. I undertook a thorough search for previously cited CO_2e data from product manufacturing and industry journals, government funded documents (IPCC), government agencies (EPA), and built environment and engineering literature. CO_2e values were found for all items catalogued during the inventory process and inserted into the same Microsoft Excel database under the heading "CO_2e intensity", or CO_2e per unit. To calculate annual CO_2e per inventoried item, CO_2e intensity was multiplied by the number of kilograms per unit (or other denominators such as kWh and VKT). In some cases, CO_2e of inventoried items were referenced as complete items (e.g. Wildwood's television and its iPad).

After collecting all of the CO_2e data for the inventoried items, the goal was to portray the business's life cycle CO_2e fluxes during the time at which the fluxes occurred. Although the brewing equipment and most operational inputs (e.g. ingredients and electricity) could be expressed in terms of real-time CO_2e fluxes, the referenced CO_2e figures with unique denominators (e.g. CO_2e *per vehicle kilometer traveled*) made this task difficult because embedded within each km traveled by a vehicle are its lifecycle emissions (e.g. production of the vehicle, emissions from the 1 km, etc.,). Therefore, the CO_2e of every fixed inventoried item was annually amortized across the business's predicted 60-year lifetime by dividing each item's lifecycle CO_2e by 60. Further, items were assigned lifetimes which allowed the model to represent the item's depreciation or obsolescence over time. Most of the building construction and equipment materials were set to exist for the 60-year lifetime of the business because of their "lifetime guarantees". However, items that experience heavy usage (e.g. equipment with moving parts) or have shorter lifetimes (e.g. Point-Of-Sale system) were assigned shorter life cycles and replenished over the business's 60-year lifetime (see Appendix 2 for estimated lifetime numbers).

Based on these measures, Wildwood's gross life cycle emissions and emergy can now be computed. Gross life cycle emissions refer to life cycle CO_2e and emergy if Wildwood continues current business practices across its 60-year lifetime, or business as usual.

3.7 NETs and PV Data Collection

The next step was to collect life cycle business CO_2e and emergy from NETs and PV in order to calculate Wildwood's net emissions and emergy. Wildwood's net emissions and emergy refers to its gross business life cycle CO_2e or emergy minus what is captured and stored from NETs and diverted from PV. This step was necessary in order to run the simulation models and effectively answer the first two research questions. To calculate what is captured and diverted from the NETs and PV, respectively, a life cycle inventory was first conducted for SRCA and pyrolysis followed by PV. Next, emergy and CO_2e data were obtained for the SRCA, pyrolysis, and PV inventoried items and input into the Microsoft Excel database.

3.8 Life Cycle Inventory: Pyrolysis

To conduct a life cycle inventory of pyrolysis, I first estimated that Wildwood would purchase a pyrolyzer (image 3) manufactured by Biochar Solutions Inc. (BSI) in order to turn SRCA feedstock into biochar via pyrolysis. The BSI pyrolyzer was selected based on data availability for that particular machine (e.g. conversion ratio of woody biomass to biochar, LCA studies on the machine). Research from Oneil et al. (2017), Puettman et al. (2019), and Severy et al. (2018) indicated that CO_2e and emergy values were needed for fuel consumption, labor, machinery (embodied), and sequestration.

Figure 7: The BSI pyrolyzer (Biochar Solutions, Inc.) is a down-draft gasifier[7] that uses chipped or ground feedstock, loaded into the top of the reactor. A blower draws air and exhaust gas through the reactor to a flare and thermal oxidizer, while char is removed from the bottom of the reactor with an auger, in a continuous process. Image Credit: Schatz Energy Research Center.

3.81 Life Cycle Inventory: SRCA & PV

I began the life cycle inventory for SRCA by conducting a synthesis of eight studies that each observed SRCA systems in temperate climates (Aylott, 2008; Bennick, 2008; Dillen et al, 2013; Huber, 2018; Jameson, 2010; Labrecque, 2003; Navarro, 2012; Singh & Lal, 2000). The synthesis indicated that the main CO_2e inventory items required to construct and maintain SRCA systems included: the plant nursery stock; machinery (embodied); labor; water and nutrients; and machinery (operational). Meanwhile, emergy values were needed for each CO_2e input item as well as an extra sunlight energy inventory item. Sunlight as an SRCA emergy inventory item was necessary to show the previously available energy that was used up during net-primary productivity[8].

Regarding PV, CO_2e and emergy associated with the initial materials extraction, manufacturing, use, and disposal/decommissioning of the solar panels are included in the per kWh and Joules denominators, respectively. Therefore, the only inventory item for UEV and CO_2e was referred to as PV life cycle.

3.82 Defining Production Capacity of NETs and PV

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[7] A downdraft gasifier is a co-current reactor where air enters the gasifier at a certain height below the top. The product gas flows downward (giving the name downdraft) and leaves through a bed of hot ash.

[8] Net Primary Productivity refers to gross primary productivity, or the overall rate of energy capture, minus the rate of energy loss to metabolism and maintenance.

Prior to collecting CO_2e and emergy data for SRCA, pyrolysis, and PV inventoried items, the geographical extent of SRCA production (e.g. land area) and climate-imposed growing constraints both needed to be defined. Defining land area and climate-imposed constraints determines the amount of biomass feedstock available for pyrolysis and the amount of biochar produced from the SRCA feedstock; both of these are needed for calculating CO_2e and emergy figures per quantity of SRCA feedstock and biochar. As mentioned previously, the land area was originally defined via the "on-site" two-hectares of Wildwood. To assess the maximum amount of SRCA biomass that Wildwood is able to grow on-site, I derived a mean value from the eight SRCA systems that were selected as part of the synthesis discussed in the previous section. The results showed a growing season production average of roughly 10 tons (9195.5 kg or 9.1955 megagrams (MG) of oven-dry biomass per hectare (Aylott, 2008; Bennick, 2008; Dillen, et al 2013; Huber, 2018; Jameson, 2010; Labrecque, 2003; Navarro, 2012; Singh & Lal, 2000), or a production of 18.391 mg (18,391 kg) of dry-biomass on Wildwood's two-hectare site per growing season. Further, the conversion rate of dry biomass to biochar is roughly 5:1 (Puettman et al. 2019) which means that in order to produce 1,000 kg of biochar, at least 5,000 kg of dry SRCA biomass feedstock are needed. Inventoried CO_2e items for SRCA and pyrolysis were reported as positive figures (e.g. 211 kg Co2e) except for sequestration, which was reported as a negative figure to represent carbon capture from the trees and in the biochar from pyrolysis. Regarding the production capacity of PV, the majority of Wildwood's electricity expenses occur during the summer (see appendix 3). Given the amount of space that Wildwood is capable of devoting to PV, Wildwood can generate all of its total annual electricity through on-site PV.

3.83 Pyrolysis Data Collection

Fuel Consumption. Based on emission factors from data published by Severy et al. (2018) and Puettman et al. (2020), the BSI pyrolyzer emits an average of 211 kg CO_2e for every 1,000 kg of biochar produced from medium-chipped wood. Included in the 211 kg CO_2e are the fuel emissions from harvesting the biomass, cutting logs to length, loading, grinding, chipping, hauling, and screening (see Oneil et al., 2017; Puettman et al. 2020 for complete emissions breakdown). Although CO_2e emissions are higher for the production of medium-chipped wood than any other wood (e.g. chipped small or ground clean), medium-chipped wood stores the most fixed carbon in the biochar (see "Sequestration" below) (Puettman et al. 2020). Regarding emergy SRCA data, UEVs for SRCA were derived from forest plantation emergy data (Brown, 2003).

Machinery (embodied). CO_2e data of the embodied machinery emissions from the BSI pyrolyzer do not exist. CO_2e/kg of steel values were instead sourced from Giama & Papadopoulos (2016) and calculated according to a BSI unit weight of 10,000 kg. Steel UEVs were taken from Buranakarn (1998).

Labor. The labor requirement differs depending on the pyrolyzer (Sahoo, 2019). BSI biochar production requires 0.92 labor hours per machine hour (Eggink et al. 2018; Severy, Chamberlin, & Jacobson, 2016) and processes biomass feedstock at an average rate of 385 kg/hr with a mean biochar production rate of 43 kg/hr (SERC, 2015). Therefore, an annual production of 18,391 kg of dry biomass per year on Wildwood's two-hectare site would require 47.76 hours of BSI running time, or 43.94 labor hours per 18,391 kg of biomass. However, this does not include BSI maintenance labor when the pyrolyzer experiences mechanical issues. Further, labor hours were not included in the CO_2e figure for fuel emissions. Therefore, labor figures were estimated based on full-time employment of two people between early March (when biomass is harvested) to end of October (end of growing season) for a total of 2,720 working hours. Labor CO_2e figures were selected from Rugani et al. (2012) and UEV labor data were selected from Campbell et al. (2013).

Sequestration. Sequestration had a gross carbon "emission" of -3,043 kg CO_2e per 1,000 kg of biochar (Puettman et al., 2019; Severy et al., 2018). This was reported as a negative figure to represent the carbon uptake during tree growth and carbon content of the biochar and does not account for the emissions from the other inventoried SRCA and pyrolysis items.

3.84 SRCA Data Collection

Nursery Stock. Nursery stock Co_2e were based on data collected by Hammond and Jones (2008) for 12,000 hybrid poplar trees per hectare according to Kumar & Nair, (2011). UEVs for SRCA nursery stock were taken from Buranakarn (1998).

Maintenance Labor. Annual SRCA labor hours that included only maintenance time could not be found. Therefore, annual SRCA maintenance labor for two-hectares was estimated according to one individual working 1,000 hours during the growing season from April to September. CO_2e figures from Rugani et al. (2012) were used. UEV labor data were selected from Campbell et al. (2013).

Water. Water demand for SRCA was based on 45 acre-inches[9]/acre or 2824.48 hectare-millimeters of water per hectare per growing season (Shock, 2005). If 12 acre-inches = 326,000 gallons of water, then two hectares of SRCA would require 6,041,729.48 gallons of water or 22,870,433.97 liters per growing season. These figures were only used to calculate emergy SRCA water demand from UEVs calculated by Buenfil (2001) and not CO_2e, as no CO_2e data for irrigation water could be found.

[9] One acre-inch is one twelfth of an acre-foot, equal to 3,630 cubic feet

Inventoried Item	Category	Emergy (seJ) / year (amortized)	Kg CO_2 emitted	Estimated life in years (if necessary)
Fuel consumption	Pyrolysis	n/a	211 kg Co2e/ 1,000 kg biochar	-
Machinery (embodied)	Pyrolysis	8.79E+14	6,376	60
Labor	Pyrolysis	5.69E+17	1,183 kg/year	-
Sequestration	Pyrolysis	Included in pyrolysis embodied	-3,043 kg CO_2e/ 1,000 kg biochar	-
Nursery Stock	SRCA	2.91E+16	11,960	30
Maintenance Labor	SRCA	1.55E+18	435 kg/year	-
Water	SRCA	8.71E+08	n/a	-
PV (life cycle)	PV	2.25E+11	0.049 kg/kWh	25

Table 2: The inventoried items for pyrolysis, SRCA, and PV as well as emergy/year, kg CO2 emitted, and estimated life years (if necessary)

3.85 PV Data Collection

PV (lifecycle). A meta-analysis by Nugent and Sovacool (2014) of 41 comprehensive PV LCA studies found a mean lifetime CO_2e value of 49.9 g CO_2e/kWh from initial materials extraction, manufacturing, use and disposal/decommissioning. Life cycle UEV inventory items for PV were obtained from Raugei et al. (2006) and were expressed as seJ/J.

3.9 Simulation Modeling

Simulation modeling is an important method for ecological analysis (Bevers, 2002). Broadly speaking, a simulation model is an algorithm, typically implemented within a computer program, which propagates the states of a system forward through a set of rules or formulas that directly prescribe the next state (Hartig, 2018). Simulation models are used to describe systems that are difficult to capture or analyze due to their complexity (Hartig, 2018).

3.91 Wildwood Net Positive Model

Two separate models were built in version 16.24 of Microsoft Excel to simulate net positive through emergy and CO_2e emissions (Appendix 5a and 5b). The models pulled data from the CO_2e and emergy inventory items of the brewery, NETs, and PV. Five main headings were created: Business as Usual; Offsets; Sequestration; Offsets & Sequestration, and Dynamic Chart Calculations.

Business as Usual. Business as usual data assume that business practices don't change (e.g. electricity emissions are not reduced because of PV implementation). Under the business as usual heading are the "operating flows" and "carbon analysis" sub-headings. The operating flows sub-heading consists of variable inventory items that would increase depending on business growth. The separation of operating flows from carbon analysis allows the model to isolate business growth from other scenarios. Inventoried items under the carbon analysis sub-heading consist of fixed and variable inventoried CO_2e or emergy items.

Offsets. The Offsets heading allows for the isolation of PV compared to other scenarios (e.g. business as usual/NETs) and consists of Wildwood's electricity data, the amortized annual embodied emissions from PV, and emissions avoided relative to electricity from the current grid mix. Other items under the heading (e.g. new total annual carbon, net total cumulative carbon) allow for the model to calculate the effect of avoided emissions over time.

Sequestration. The sequestration heading encompasses the SRCA, Pyrolysis, and SRCA + Pyrolysis sub-headings. The SRCA and Pyrolysis sub-headings include all the gross data from

CO_2e or emergy associated from their life cycles. The SRCA + Pyrolysis sub-heading allows for their respective gross CO_2e or emergy data to be combined in order to create net CO_2e or emergy

Offsets & Sequestration. The Offset heading and the Sequestration heading were previously created so that the data from each heading could create scenarios within the model irrespective of the other. However, the Offsets & Sequestration heading was created to analyze PV and the NETs together, thereby examining the net-effect when both are combined.

Dynamic Chart Calculations. The last heading, Dynamic Chart Calculations, was created to take each heading and create scenarios within each simulation that are based on the final value of each respective heading and compare them to one another. The scenarios within each simulation express themselves graphically via x-axis/y-axis charts.

Lastly, other functions were built into the model that allowed for both the adjustment of business growth and the amount land required in hectares for the NETs. The latter was based on the fixed SRCA production value (as discussed in section 3.84 of 9195.5 kg or 9.1955 megagrams (mg) of oven-dry biomass per hectare.

Several model scenarios were run with differing model parameters and adjustments to determine the extent of NET emission offsets necessary for Wildwood to attain a net positive state. The first model scenario was a simulation to determine the feasibility of achieving a net positive state given SRCA production for only the two hectares on-site. The second model scenario involved the achievement of a net positive state given the production of SRCA from the two hectares on-site as well as offsite SRCA production. The third model scenario involved the achievement of net positive state given a 3% business growth component. Lastly, a fourth model scenario was run that compared emergy to CO_2e.

3.92 Model Assumptions

In order to constrain the study, the model includes several key assumptions (see also discussion regarding implications of the model's assumptions).

Business Lifetime. Based on equipment warrantees/guarantees, the owner's interest in "getting as much out of the initial carbon debt as possible," and his belief that the brewery and the vast majority of its industrial equipment will last at least 60 years, the model assumes a 60-year brewery lifetime.

Biochar Lifetime. Another key assumption was the lifetime of the biochar. The ratio of oxygen to organic carbon in biochar, the O/C_{org} ratio generally ranges from 0.2–0.6 O/C_{org}, which corresponds to a half-life of 1000-100 years (e.g. it will take 1000 and 100 years for half of the carbon in the biochar to break down when its O/C_{org} ratio value is 0.2 and 0.6, respectively) (Spokas, 2010). The molar O/C_{org} ratio set forth by EBC, a biochar industry standard in Europe, must be less than 0.4 in order to certify biochar (EBC, 2012). Therefore, the model assumes that the biochar's O/C_{org} is less than 0.4, which corresponds to a half-life of no less than 550 years.

Limits/Amount of PV Energy. Due to the fact that Wildwood has enough roof space or other space around the facility to house enough PV to generate all of its electricity needs on-site, the model's PV simulations assume 100% electricity from PV.

Business Growth Assumptions. Although several simulations were run based on zero business growth, simulations that assume 3% business growth are included. This figure was a simple average of annual growth rates of the U.S. economy from 1948-2015 (Bureau of Economic Analysis, 2016).

4 Results

4.1 Insights from Depth Interviews

The insights that arose from the depth interviews were interrelated and, in many respects, fed off of one another. These themes primarily included three critical items: Inability to pay for Personnel and Infrastructure, Lack of Revenue Generation, and No Formal Marketing and Sales Plan.

Inability to Pay for Personnel and Infrastructure. An important challenge Wildwood faces in implementing net positive initiatives is the inability to obtain personnel and infrastructure. As explained in the next point, this was largely because of Wildwood's inability to generate enough revenue to pay the personnel and purchase the infrastructure for the net positive strategies.

Lack of Revenue Generation. Wildwood does not generate enough revenue to pay for the personnel and infrastructure. Sales are not significant in part because of the rural location. Wildwood chose a rural location in order to implement its sustainability goals, which the owner believed required a large plot of land. However, Wildwood in turn does not have the same access to markets as the breweries located in more urban areas, which in turn results in lower sales. The lack of a strong location on its own does not necessarily contribute to a lack of cash flow. Rather, a formal marketing and sales plan is needed in order to generate revenue that could fund personnel and infrastructure.

No Formal Marketing and Sales Plan. The inability to pay for personal/infrastructure and the lack of revenue generation are predicated on a lack of marketing and sales plan. Wildwood must overcome its weak market location by formally and creatively drafting and implementing a marketing and sales plan. Without this, Wildwood will not generate the revenue necessary to pay for the personnel and infrastructure required to create net positive initiatives.

4.2 Category Emission Breakdown

A breakdown of Wildwood's current emissions by category demonstrates the extent of category emissions relative to one another. Emissions are amortized on an annual basis if necessary. According to figure 5, electricity contributes the vast majority of kg of CO_2e at approx. 35,000, followed by >15,000 kg CO_2e for natural gas, <10,000 kg CO_2e for up-front emissions from building construction and equipment (amortized), approx. 7,500 kg CO_2e for vehicles, approx. 6,000 kg CO_2e for beer ingredients, <4,000 kg CO_2e for canning raw materials, and a comparatively marginal amount of kg CO_2e for labor, wood stove fuel, cleaning supplies, and other operational. In other words, over 60% of Wildwood's current annual CO_2e emissions are from electricity, 43%, and natural gas, 18.5%. Electricity and natural gas usage throughout the year (see appendix 3) shows that the majority of annual electricity usage was for cooling the brewery in the summer while the majority of natural gas usage was for heating the brewery in the winter.

Panel b of figure 5 portrays a granular look at the up-front (amortized) CO_2e emissions from building construction, which includes other fixed (e.g. wood stove, sewer, etc.), Furniture, Fixtures, & Equipment (non-brewery equipment), Brewery Machines & Equipment, and Construction. Although Construction amortized across Wildwood's lifetime makes up less than 10% of emissions, approx. 95%, or 9,000 kg CO_2e, of Wildwood's upfront CO_2e are from building construction. Meanwhile, brewery machines and equipment account for approx. 4%, or approx. 400 kg CO_2e and Furniture, Fixtures, and Equipment and Other Fixed account for approx. 1%, or 100 kg of CO_2e.

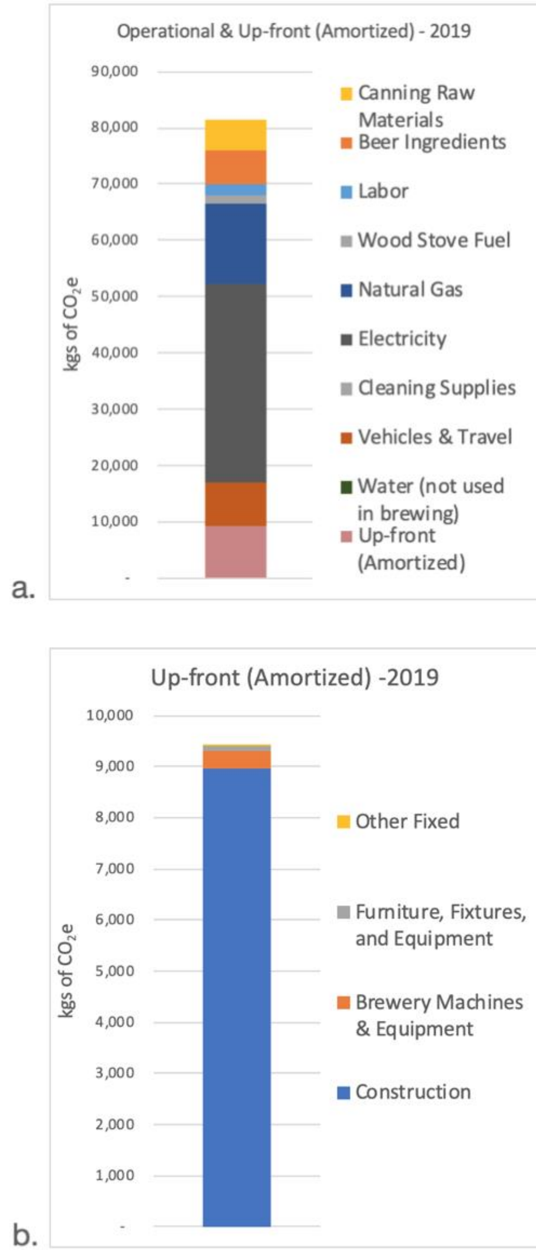

Figure 8: Panel a. breakdown of annual operational and up-front CO_2e emissions by category and assumes no business growth. Panel b. granular look at the up-front emissions (shown as the lowest category in the top chart) that Wildwood incurs yearly when the net amount is amortized across a 60-year lifetime. Y-axis is kgs of CO_2e and the categories shown on the chart are the categories inventoried (Table 1).

4.3 On-site Generation of SRCA, Pyrolysis, and PV

The 60-year simulation below assumes two hectares of *on-site generation* of SRCA, pyrolysis from the on-site SRCA biomass, and PV to address the first research question of: What are the types and impacts of net positive strategies an established business might use?

As Figure 9 shows, over time, CO_2e continues to rise because of the cumulative CO_2e-emitting business activities over time. However, when Wildwood adopts PV, they reduce more than 1/3 of CO_2e emissions across their lifetime compared to business as usual. Although emissions are lowered when a business adopts net positive strategies, the CO_2e sequestered from on-site NETs is not sufficient to reach a net positive state. As the figure shows, for this particular business, even net neutral is never attained with on-site net positive strategies. The reason net positive is never attained is largely due to the large size of the brewery as well as the inadequate amount (two hectares) of SRCA in production, which is far too small to produce enough SRCA biomass and corresponding biochar.

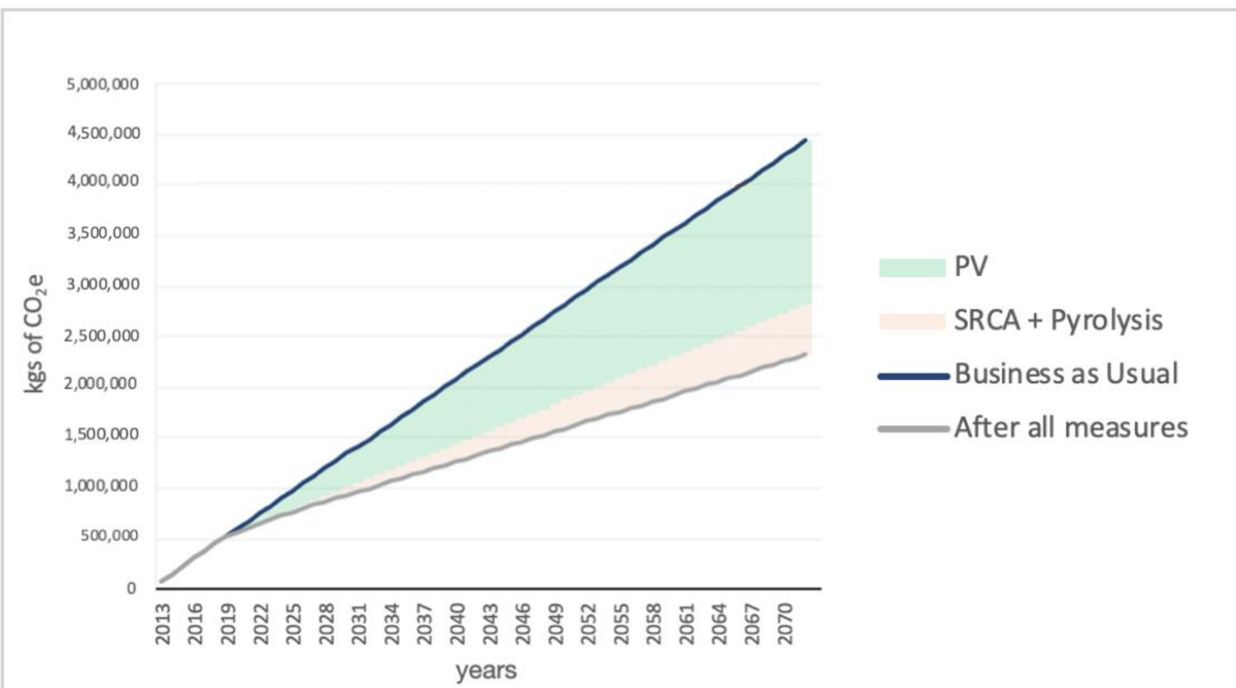

Figure 9: On-site generation of PV, SRCA & Pyrolysis over 60 years. Business as Usual (blue line) assumes Wildwood's current business practices (which do not include on-site employment of NETs nor PV).

4.4 On-site and Off-site Generation of SRCA, Pyrolysis, and PV

The next simulation includes additional NET hectarage off-site. Again, a 60-year simulation was run in order to assess the impacts of on-site and offsite NETs on the business's carbon footprint.

As Figure 10 shows, when Wildwood adopts PV, they still reduce more than 1/3 CO_2e emissions across their lifetime compared to business as usual. However, with regard to the extent of NETs needed to reach a net positive state, the simulation interpolated hectares needed for SRCA and pyrolysis based on Wildwood's CO_2e after PV and the amount the NETs can sequester per year. This interpolation was expressed as "after all measures" and shows a yearly average of 11.5 hectares of growing space (2 hectares on-site and 9.5 offsite) are needed to allow for achievement of a net positive state in 2068.

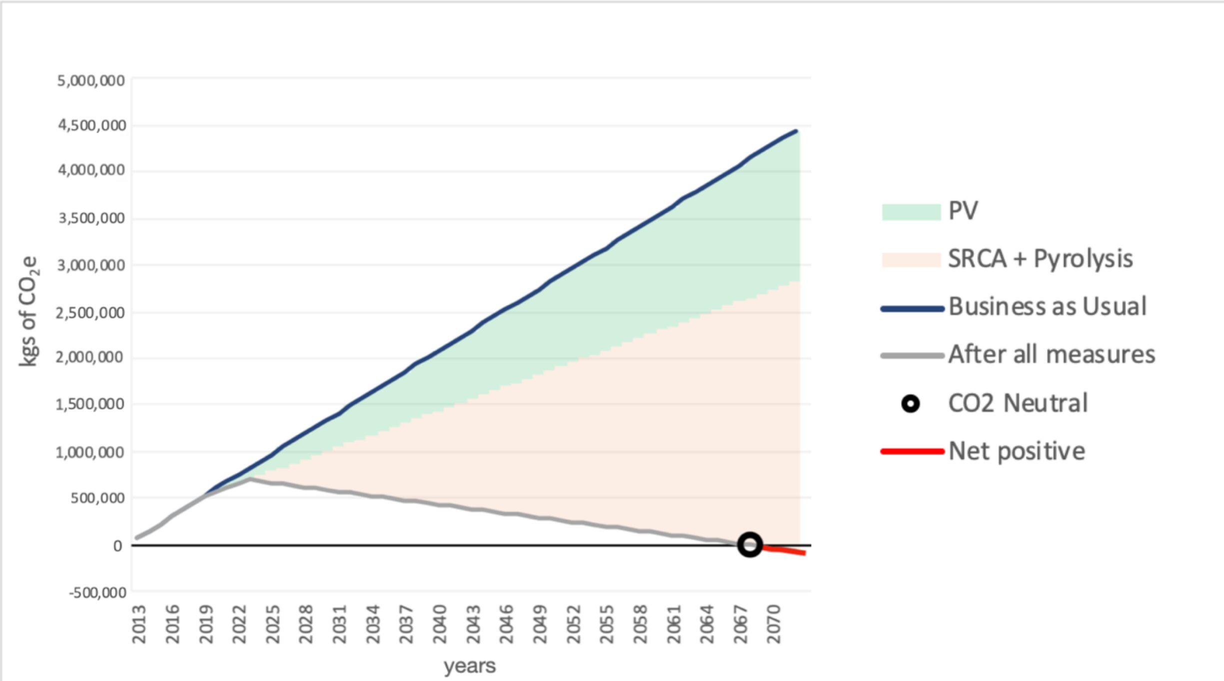

Figure 10: A 60-year simulation that includes both on-site and off-site NETs.

4.5 On-site and Off-site Generation of SRCA, Pyrolysis, and PV with Growth

The previous simulations addressed the impacts of net positive strategies on a business's carbon footprint with no business growth. Many businesses have explicit growth objectives, related to sales, market share, or profitability. Hence, another simulation was conducted to include a 3% year-over-year growth rate.[10]

[10] This figure was based on a simple average of annual growth rates of the U.S. economy from 1948-2015 (Bureau of Economic Analysis, 2016). It represents a rather conservative estimate, particularly for the craft-brew industry, which itself grew 4% in 2018 (Pellechia, 2019).

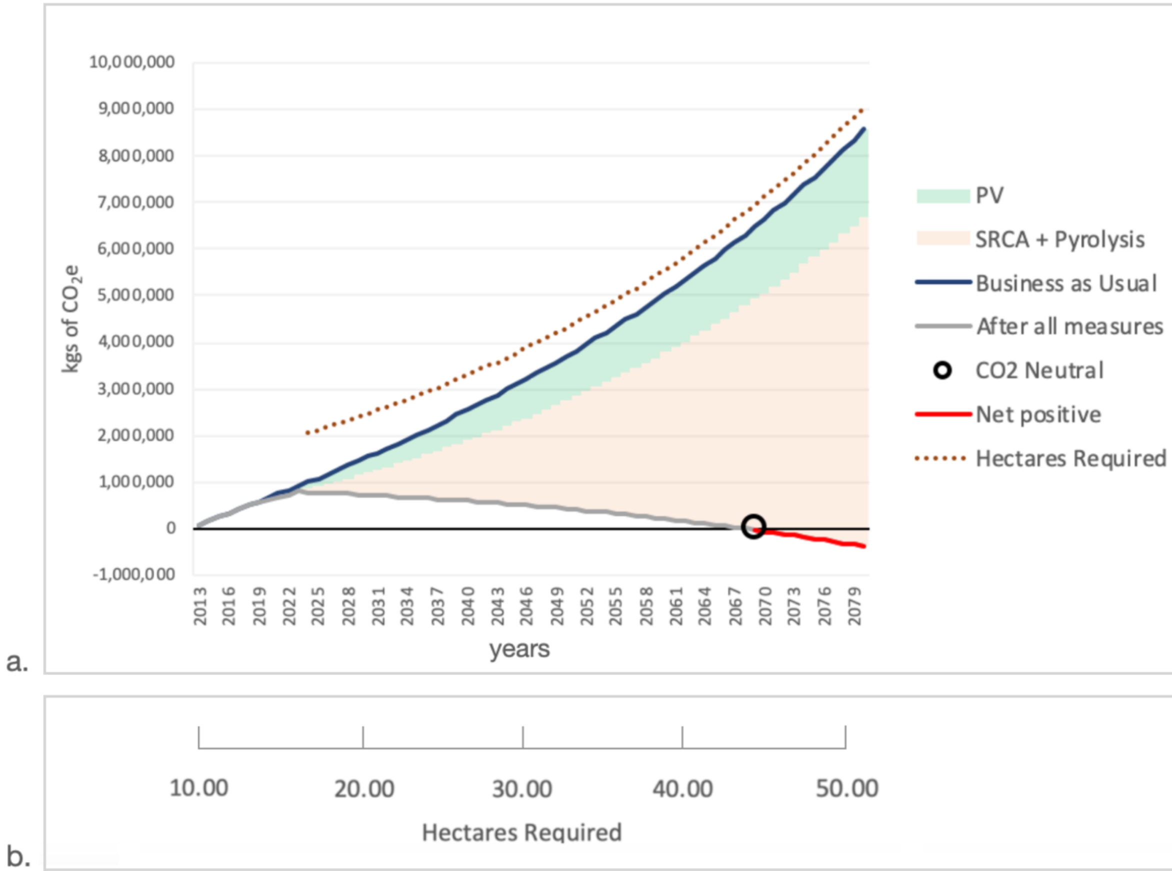

Figure 11: Panel a. shows 60-year simulation that assumes a 3% y/y business growth rate and a 3% y/y increase in SRCA and biochar output from pyrolysis. Panel b. shows hectares of SRCA required given the y/y increase of kgs of CO_2e.

Based on a 3% growth scenario, Wildwood would require a continual increase in off-site growing space beginning with approximately 18 hectares in 2025, approx. 30 hectares by 2046, and approx. 45 hectares by 2069 in order to reach a net positive state before the end of its projected 60-year business lifetime.

4.6 Comparison of Emergy vs. LCA in Simulating Net Positive

The next step in the analysis was to answer the second research question: What are the measurement issues associated with evaluating the impact of net positive strategies? I next ran simulations based on the emergy data. Figure 12 applies the same parameters and assumptions as figure 10 including: no growth of business/NETs; inclusion of PV; and 11.5 acres of NETs, while including emergy over Wildwood's 60-year lifetime. CO_2e is also shown in the graph to show its relationship to emergy when NETs and PV are implemented in 2019 and throughout the lifetime of the brewery.

Similar to figure 10, this simulation shows that based on CO_2e data, Wildwood can achieve a net positive state with 11.5 total hectares of SRCA by 2069. In contrast, the figure below shows that emergy steadily increases over time, even while NETs are employed. As carbon emissions are being sequestered, emergy (solar emjoules) increases because emergy measures the work done by the biosphere to create the raw materials (e.g., the wood's carbon-carbon bonds driven by sunlight energy) that are needed to sequester CO_2, but does not directly take into account the benefit on the environment of CO_2 reduction. Therefore, without directly tying the proportion of the emergy of activities within the biosphere and technosphere[11], to CO_2e, then it will be a challenge to successfully employ emergy analysis to understand net positive business strategies.

[11] Referred to here as the sphere in which all of Wildwood's business activities occurs, the technosphere encompasses all of the technological objects manufactured by humans.

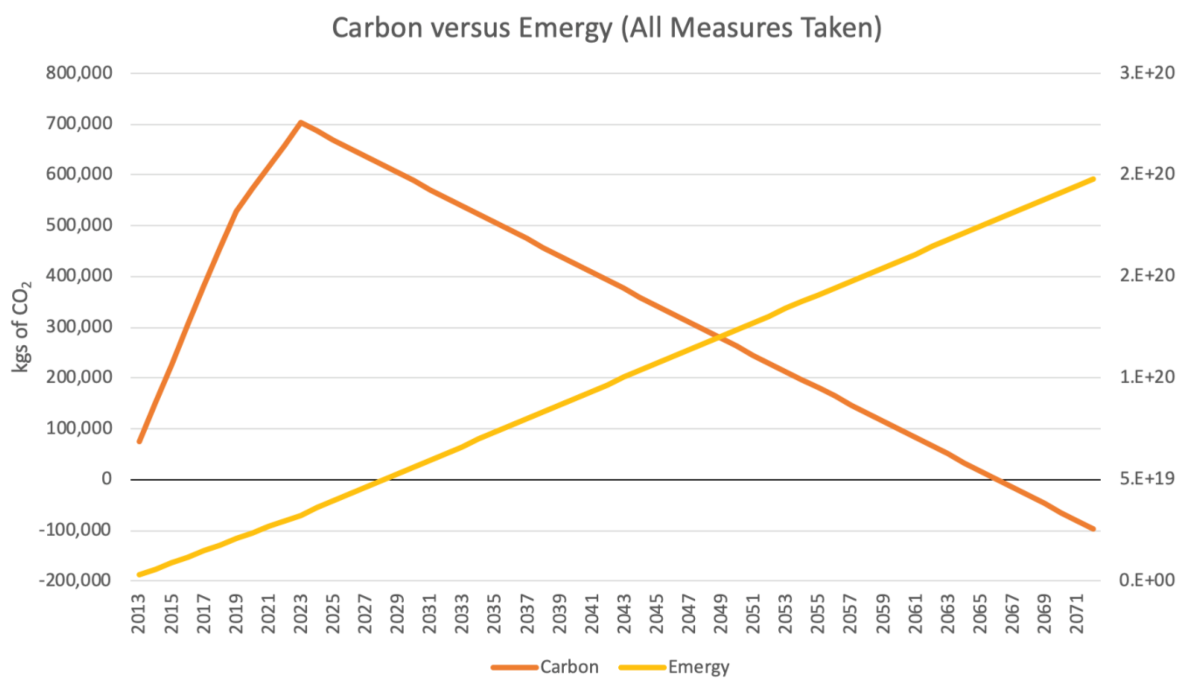

Figure 12: This simulation shows a comparison between how the model dealt with Emergy and LCA data to observe the measurement ability in evaluating net positive strategies.

5 Discussion

5.1 Off-site Net positive

Given the type of NETs, constraints, and assumptions of this study, the only manner in which Wildwood can attain a "net positive state" during its 60-year lifetime is if it includes off-site employment of NETs, thereby requiring an expanded, opportunistic system boundary. And, when net positive considers the total energy hierarchy of a business[12], emergy analysis results shows that emergy increases as NETs are employed. Moe (2014) states that the primary aim of

[12] The environment and the economy are supported by various types and amounts of renewable and nonrenewable energies. These energies are transformed in a series of steps, converting one kind of energy to another kind, creating a hierarchy of energy concentration (e.g. information processed on a phone using electricity made possible by burning coal that originated from densely concentrated sunlight).

any thermodynamic system is to yield the maximum entropy and power as possible (Moe, 2014). Odum (1996) and Moe (2014) argue that the systems which prevail in a process of natural selection will be those that most maximally extract power from an available energy gradient and, in so doing, maximize the production of entropy, thus reradiating remaining energy at the lowest possible level. Wildwood is not taking advantage of reradiating remaining energy at the lowest possible level because of the high degree of losses to the system due to the size of the facility. This leads to the next discussion point.

5.2 Wildwood's Upfront Emissions

The question of how much upfront building construction emissions could have been avoided is very important. Although the owner could not have envisioned producing only 300 brewer's barrels of beer after eight years of operation, had the brewery been designed around a maximum production capacity of a quarter or even half of the brewery's current maximum production of 10,000 brewer's barrels per year, then business lifetime emissions would be substantially lower. These reduced upfront emissions would largely be a result of a smaller slab and other building construction materials, less building construction labor, and reduced heating and cooling needed for a smaller space. Although on-site PV is capable of generating all of the electricity to meet the excess, emissions associated with the PV—49.9 grams CO_2e/kWh almost exclusively from production of the panels (Nugent & Sovacool, 2014)—is less compared to others (e.g., coal is 82 grams CO_2e/kWh (Edenhofer et al. 2014)), yet is still significant given the amount of electricity required for cooling. Emissions from heating via natural gas, which emits methane and CO_2 during extraction and combustion (Edenhoder et al. 2014), respectively, would also be lower if the space were designed and built in accordance with a lower production capacity.

5.3 Emergy

Until emergy is connected to the impact that a business has on climate change, it will be difficult for emergy analysis to be a useful environmental accounting tool for understanding the net effect that NET use has on a business's life cycle emissions. A measure must be calculated that involves the amount of emergy required by the biosphere to deal with the ecological impacts of CO_2e emissions released by a business. Inversely, the same measure could also be used to measure the work that the biosphere does not need to do if NETs were employed. A positive value (emergy required by biosphere to deal with business CO_2e emissions) and a negative value (emergy not required by the biosphere to deal with business CO_2e emissions) would allow for proper net positive emergy accounting. The implications of this extend toward not only the assessment of biosphere emergy in relation to business CO_2e emissions, but also towards assessing the effectiveness of various NETs from a novel emergy/CO_2e perspective.

5.4 Challenges to Implementing Net Positive Initiatives

Businesses achieving net positive may find themselves in a negative feedback loop where some function of the output of a system is fed back in a manner that tends to create stability. For example, the lack of implementing net positive strategies may be reinforced by the lack of personnel and infrastructure. Lack of personnel and infrastructure require financial resources that must be obtained from higher sales, which are in turn achieved from a formal marketing and sales plan. Businesses that seek to offer net positive benefits to the environment must have a proper plan for marketing and sales. The lack of a proper marketing and sales plan negatively affects revenue generation, which is needed in order to pay the personnel and infrastructure to implement net positive strategies such as NETs and PV.

Another issue that may affect sales for businesses interested in implementing net positive initiatives is the location of the business. The NETs observed in this paper take up a significant amount of land and businesses may choose a rural location in order to have access to that land. In turn, businesses in rural locations may not be able to reach the same markets as their urban counterparts, which could result in lower sales. However, the lack of a strong location on its own does not necessarily contribute to poor revenue generation. This simply indicates an ever more pressing need to come up with a creative marketing and sales plan in order to compensate for the lack of strong access to markets.

5.5 Reconciling Low Hanging Fruit Before Implementing Net Positive Initiatives

The "low hanging fruit" must be reconciled before considering employment of net positive initiatives. Before any negative emission technologies are employed, reduction of main source emissions must be explored including (primarily) design that reflects the programming of the facility, strategies such as on-site PV employment, potential alternatives to natural gas heating (not discussed much in this paper), and avoidance of using internal combustion engines. Alleviating emissions from the primary sources, in this case smart design, electricity, heating, and transportation, are the low hanging fruit and should be prioritized before implementing net positive initiatives.

5.6 Implications of the Model's Assumptions

Several implications arise from the 60-year lifetime brewery assumption. A shorter business lifetime would most certainly require more extensive NET and energy offset initiatives. The higher the ratio of building construction materials CO_2e (and to a lesser extent the machines and equipment) to business lifetime, the more extensive the NET initiatives must be to offset building construction CO_2e emissions. A higher ratio of building construction CO_2e to its lifetime means that the upfront amortized CO_2e emissions is averaged over less time and is higher relative to amortized CO_2e emissions over a longer brewery lifetime. Further, the opposite would be the case if the brewery outlives the 60-year lifetime. Although a longer brewery lifetime does not change the upfront emissions associated with the construction of the brewery, the amortized up-front emissions would be less because the emissions would be spread out over a longer period of time.

Another implication relates to the Biochar Lifetime Assumption: If the model assumed that the molar O/C_{org} ratio value were greater than 0.4 (e.g. had a half-life of 100 years), then Wildwood would likely need to increase production of biochar to compensate for the CO_2 that is released from the less stable biochar during the lifetime of the brewery by expanding NET even more.

The model's PV simulations assume 100% electricity from PV. The implications of this assumption are that if Wildwood weren't able to generate all electricity needs on-site through PV (e.g. Wildwood generates half of their needs), then certainly more extensive NETs would be needed because emissions from business as usual electricity account for a large portion of overall emissions.

The model's 3% business growth assumption was included in several scenarios. The assumptions of the growth of the individual categories is as follows: Brewing Machinery/Equipment - 0%; Canning Raw Materials & Beer Ingredients - 3% Cleaning Supplies - 3%; Electricity – 1%; Heating – 0%; Vehicles & Travel - 3%; Labor - 1%; Furniture, Fixtures, Equipment – 0%; & Building Construction – 0%. One implication of this growth assumption is that if the business were to grow more than 3%, the extent of NETs employment would need to be greater than what was modeled during the 3% growth simulation. And due to growth, if the physical space of the facility would need to be expanded, then impacts will be much higher. Inversely, if Wildwood were to grow less than 3%, then the extent of NET employment would certainly be lower than if the business were to have more growth.

Although growth is what most businesses strive for, the simulations show that growth is at odds with net positive, particularly given the need to use land for negative-emission technologies. A business must reconcile the extent of that which it externalizes if business growth is the goal (e.g. ever-increasing land needed to offset ever growing emissions from growth). Based on the data in this case study, approx. 45-hectares were required to achieve a net positive state in 60 years in order to compensate for even a modest 3% year-over-year growth rate. Such land may not be available in many places. Moreover, bio-sequestration forms of NETs may take up precious space that might be used for growing food, providing housing, conserving biodiversity, and other land use activities.

5.7 Community Resilience as an Emergent Property of Net Positive Business

One way businesses can pursue a net positive state (by alleviating large CO_2e emissions) is to localize as much of their business activities as possible. Alleviating business CO_2e emissions by leveraging local supply of labor and materials creates a cascade of benefits for any locality including a strengthened local economy and a more resilient community. For example, local production of goods, local supply of labor, and local cycling of resources, not only can reduce CO2 emissions; these strategies also offer other benefits in terms of community resilience (Patel et al., 2017, UK Cabinet Office, 2010). When community members produce, manage, and earn a living from local resources and also use the local resources, then stronger economic (Rupasingha, 2013), environmental (Frank, et al 2005), and social properties result (Blanchard & Matthews, 2006). Local community members have "skin in the game" which creates strong community incentives for business success, economic livelihoods, community success, and protection of local ecosystems. Further, the use of local resources and avoidance of over-dependence on external resources can help the community respond to, withstand, and recover from adverse situations, thereby creating community resilience (UK Cabinet Office, 2010). Businesses have many motivations to create community resilience (e.g. to improve the local economy, to strengthen the local fabric of the community, etc.) and mitigating environmental impacts are an important part of those motives.

6 Conclusion and Key Lessons

This case study has illustrated that Wildwood will be unable to achieve a net positive state during its 60-year lifetime on its two hectares using on-site NETs and PV strategies. Wildwood will be able to attain a net positive state by combining on-site and off-site NETs, requiring a yearly average of 9.5 hectares of off-site NETs and two hectares on-site. Further, when a 3% growth scenario is simulated, Wildwood would require a continual increase in off-site growing space starting with approx.18 hectares by 2025, approx. 30 hectares by 2046, and approx. 45 hectares by 2069 in order to reach a net positive state.

In terms of the measurement issues, obtaining CO_2e data from a life cycle assessment of the brewery/NETs demonstrated the best method for expressing the impacts of net positive strategies on the environment. In contrast, emergy continually increases even as NETs are employed, suggesting further research is needed to determine the amount of emergy required by the biosphere to deal with the ecological impacts of business CO_2e emissions and the work that the biosphere does not need to do if NETs were employed. This further research would allow for proper net positive emergy accounting.

In terms of the challenges a business faces in achieving a net positive state, businesses that seek to offer net positive benefits to the environment must have a proper plan for marketing and sales. The lack of a proper marketing and sales plan negatively affects revenue generation, which is needed in order to pay the personnel and infrastructure to implement net positive strategies such as NETs and PV.

6.1 Key Lessons

- **The main challenges a business may face in achieving net positive include: (1) lack of personnel and infrastructure, (2) poor revenue generation, and (3) incomplete marketing and sales plan** - The lack of implementing net positive strategies is reinforced by the lack of personnel and infrastructure. Lack of personnel and infrastructure require financial resources that must be obtained from higher sales, which are in turn achieved from a formal marketing and sales plan.

- **Building a smaller facility at the outset would have reduced total lifetime business emissions and the extent of NET and PV initiatives** - Had the brewery been designed around a maximum production capacity of a quarter or even half of the current maximum annual production of 10,000 brewer's barrels, then overall business lifetime emissions would be substantially less due to decreased amortized building construction CO_2e, and reduced heating and cooling emissions for a smaller facility.
- **On-site net positive is not possible in this study** - The only manner in which net positive can be attained is if net positive includes on-site *and* off-site employment of NETs.
- **Endless business growth requires vast amounts of land to offset life cycle emissions through bio-sequestration based NETs** - Given Wildwood's life cycle emissions and the biosequestration NETs employed by the model, even a 3% year-over-year growth makes it impossible to obtain a net positive state without using vast amounts of land (up to 45 hectares to reach net positive by 2069).
- **CO_2e data proved to be more useful in measuring net positive business life cycle impacts than emergy data** - CO_2e data have the ability to express negative values which is useful to represent the carbon drawdown ability of NETs. To make emergy more appropriate for net positive analysis, further research is needed to determine the amount of emergy required by the biosphere to deal with the ecological impacts of business CO_2e emissions and the work that the biosphere does not need to do if NETs were employed.
- **Electricity, followed by heating (natural gas), building construction (amortized yearly), and amortized up-front emissions (mainly building construction) are the largest emission sources** –Summer cooling is responsible for the majority of Wildwood's electricity expenditure at over 30,000 kg of CO_2e per year. Natural gas from heating the facility is the second largest emitting activity at approximately 15,000 kg CO_2e per year. Building construction, the third largest emitting activity, represents roughly 600,000 kg of upfront emissions that, when amortized across the 60-year projected lifetime, equals roughly 10,000 kg per year. Travel due to business activities such as distribution is the fourth largest emitting activity at nearly 8,000 kg CO_2e per year.
- **The "low hanging fruit" must be reconciled before considering employment of net positive initiatives** - Before any negative emission technologies are employed, reduction

of main source emissions must be explored including strategies such as on-site PV employment, and avoidance of using internal combustion engines. Alleviating emissions from the primary sources, in this case study electricity and heating, are the low hanging fruit.

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Appendices

Appendix 1: Interview Guide

Many businesses have sustainability initiatives motivated by the goal to "be less bad," or to strive to reduce negative environmental impacts (i.e., to reduce greenhouse gas emissions, to use less energy, to consume fewer natural resources, etc.). In contrast to reducing environmental impacts, some progressive businesses are attempting to actually restore the environment or to have positive environmental impacts. The term "net positive" refers to strategies a business or institution uses to restore or renew the natural environment by sequestering carbon, generating more energy than it consumes, or regenerating natural resources beyond what it consumes.

To study how a business works to achieve "net positive," my research conducts a life cycle environmental audit of a brewery in Western Montana, Wildwood Brewery, using several environmental accounting tools. The aim is to address three fundamental questions: (1) What are the types and impacts of net positive strategies an established business might use?" (2) "What are the measurement issues associated with evaluating the impacts of those strategies?"; and (3) What are the challenges a business faces when implementing net positive strategies" To answer the third research question, I will conduct semi-structured interviews with the owner of Wildwood Brewing. The barriers and challenges will provide key insight to practitioners; i.e. business owners, industrial sectors, etc. The results of this study will help future researchers and practitioners involved in either the study or implementation of net positive business practices.

Script: I am particularly interested in your experience in working to implement net positive business practices.

The overarching themes that arise in the interviews will supplement the quantitative emergy analysis I am conducting on the brewery's environmental impacts.

All responses anonymous if you wish by creating pseudonyms when reporting results.

The interviews are voluntary. You may skip any questions you don't feel comfortable answering and you may end the interview at any time.

Are you willing to be interviewed?
Would it be okay with you if I recorded the interview? This will be used only to supplement my note-taking and the recording will be destroyed after my study is complete. We will not use/share this recording for any other reason.

We would be happy to share a copy of our paper when it is complete. If you would like a copy, may I have your business card?
(To develop rapport):
Can you tell me a little bit about who you are/your background and how you came to be interested in sustainable business practices?

What is your job title?

How long have you worked at this company?

What is your role in the company's sustainability initiatives?

Are you familiar with the phrase “net positive” business practices?”
What does it mean to you?

What is your company doing with respect to becoming net positive?

1. How long have you been working to implement “net positive” business practices?

   a. What motivated you/the company to value net positive business practices?
      What are the goals?
      Who influenced you/company to do this?

   b. What protocol/methodology do you use?

   c. How/why did were these methods selected? What are the pros/cons of the methods?

   d. Who in the company is engaged in the initiative? How do they participate? Is there anybody who should be involved who is not?

   e. What **information** do you use to stay on top of the business practices? Where do you get that information?

3. How far along in the process are you? Walk me through the process, step-by-step.

   a. What **resources** are required to do this well? (people, time, money, data, culture, shared values, etc.)

   b. What frustrates you the most about this process?

   c. Does your company experience conflict over this process/using this information? Describe it for me. Who/what/etc. How is this conflict resolved?

4. What are some of the fixed and/or variable costs associated with implementing net positive business practices?

   a. How is this number/information used in decision making?

   b. What are the barriers to allowing your company’s efforts to value implementation of net positive? (**Hurdles/**constraints)

What advice would you have to overcome those barriers?

5. How satisfied are you with your company's efforts to implement net positive practices?

Probe: what could it do to improve? What are next steps?

6. If I were to visit your company as an outsider, what do you think would most surprise me about your company's work in this area?

7. If you were to identify companies who are "best in class" in implementing net positive practices, who would they be and why?

a. What are the characteristics of companies who are doing this well?

8. As you see it/from your perspective/based on your experience:

a. What are the pros/cons of attempting to become net positive?

9. What were some of the main challenges to implementing net positive that you had not envisioned prior to implementation?

a. Why these challenges come to pass?

b. What could you have done differently to avoid the challenges?

10. If you could give anybody advice looking to implement net positive business practices, what advice would this be and why?

11. What are your thoughts/observations about the adoption rates of net positive business practices? How do you envision net positive becoming more broadly adopted? What is needed to stimulate broader adoption? This could be policy considerations, educational considerations, etc.

12. Any remaining thoughts on net positive?

Appendix 2: Inventory for Brewery Life Cycle CO_2e and Emergy

Inventoried Item	**Category**	**Emergy (seJ) / year (amortized)**	**CO_2 kg / year (amortized)**	**Estimated life, years**
Malt Silo (Gray)	Brewery Machines & Equipment	7.85E+13	9	60
Malt Silo (White)	Brewery Machines & Equipment	1.66E+14	20	60
Malt Silo (White)	Brewery Machines & Equipment	1.66E+14	20	60
Cable Conveyors (inside)	Brewery Machines & Equipment	6.47E+13	8	60

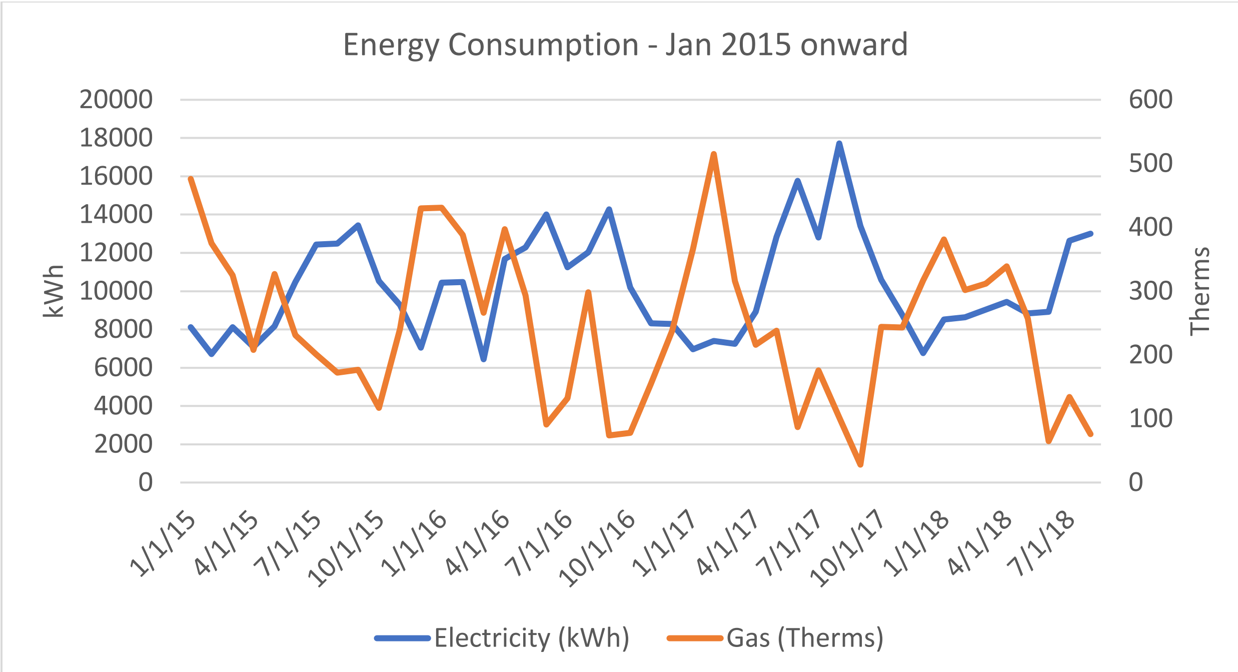
Malt Hopper	Brewery Machines & Equipment	1.76E+13	2	60
Malt Mill	Brewery Machines & Equipment	5.72E+13	7	60
Grist Hopper	Brewery Machines & Equipment	1.32E+13	2	60
Screw Auger	Brewery Machines & Equipment	6.59E+12	1	60
Bucket Elevator	Brewery Machines & Equipment	8.34E+13	10	60
Chain Drag Conveyor	Brewery Machines & Equipment	4.40E+13	5	60
Hose	Brewery Machines & Equipment	3.79E+14	46	30
Mash Kettle	Brewery Machines & Equipment	7.56E+13	9	60
Lauter Tun	Brewery Machines & Equipment	1.01E+14	12	60
Brew Kettle	Brewery Machines & Equipment	8.88E+13	11	60
Whirlpool Kettle	Brewery Machines & Equipment	6.59E+13	8	60
Brewhouse pipes, pumps, and platform	Brewery Machines & Equipment	4.40E+13	5	60
Wort Chiller	Brewery Machines & Equipment	1.40E+14	17	60
Fermenter (Double Brew) (1/3)	Brewery Machines & Equipment	5.18E+13	6	60
Fermenter (Double Brew) (2/3)	Brewery Machines & Equipment	5.18E+13	6	60
Fermenter (Double Brew) (3/3)	Brewery Machines & Equipment	5.18E+13	6	60
Fermenter (Single Brew) (1/3)	Brewery Machines & Equipment	3.99E+13	5	60
Fermenter (Single Brew) (2/3)	Brewery Machines & Equipment	3.99E+13	5	60
Fermenter (Single Brew) (3/3)	Brewery Machines & Equipment	3.99E+13	5	60
Beer Filter	Brewery Machines & Equipment	2.15E+14	26	20
ACSV5	Brewery Machines & Equipment	1.20E+14	15	20
Homemade Depalletizer	Brewery Machines & Equipment	5.68E+12	1	60
Elf Full w/ Conveyor	Brewery Machines & Equipment	1.52E+13	2	60
Shaker Table Framework	Brewery Machines & Equipment	3.27E+12	0.4	60
500 ML Twist Rinser	Brewery Machines & Equipment	4.71E+12	1	30
Twist Rinser Stand	Brewery Machines & Equipment	7.58E+11	0.56	60
Rotary Table	Brewery Machines & Equipment	6.58E+12	1	60
Can Feed Extension	Brewery Machines & Equipment	3.19E+11	0.4	60
Lid Cage	Brewery Machines & Equipment	1.20E+11	0.01	60
Collection Table Assy	Brewery Machines & Equipment	2.67E+12	0.3	60
Electrical Junction Box	Brewery Machines & Equipment	5.98E+11	0.07	60
Spare Parts/Tooling Box	Brewery Machines & Equipment	5.58E+11	0.07	60
Domino Printer	Brewery Machines & Equipment	1.52E+13	4	10
Boiler	Brewery Machines & Equipment	2.05E+13	2	60
Chiller	Brewery Machines & Equipment	8.97E+13	11	60
Hot Liquor Tank (1/2)	Brewery Machines & Equipment	7.18E+13	9	60

Hot Liquor Tank (2/2)	Brewery Machines & Equipment	7.18E+13	9	60
Glycol Tank (1/2)	Brewery Machines & Equipment	4.40E+13	5	60
Glycol Tank (2/2)	Brewery Machines & Equipment	4.40E+13	5	60
Keg Washing Machine	Brewery Machines & Equipment	9.09E+13	11	25
1/2 barrel kegs	Brewery Machines & Equipment	1.50E+14	18	60
1/6 barrel kegs	Brewery Machines & Equipment	1.65E+13	2	60
Water/Ice tank	Brewery Machines & Equipment	2.65E+13	3	60
16 oz. Standard Brite Can	Canning Raw Materials	7.55E+15	3,851	N/A
Aluminum Can Crown	Canning Raw Materials	1.63E+15	834	N/A
16 oz. standard shrink sleeve	Canning Raw Materials	1.78E+14	22	N/A
Case Tray (Role-over or Auto-locking)	Canning Raw Materials	1.11E+15	134	N/A
Standard QuadPak Can Carrier	Canning Raw Materials	1.32E+15	456	N/A
Malt (lbs)	Beer Ingredients	4.78E+17	3,420	N/A
Hops (lbs)	Beer Ingredients	3.98E+14	3	N/A
Yeast (lbs)	Beer Ingredients	2.75E+14	2	N/A
Water (including restroom)	Beer Ingredients	1.04E+14	-	N/A
CO2	Beer Ingredients	1.70E+11	2,722	N/A
dodecyl benzene sulphonic acid	Cleaning Supplies	1.99E+12	1	N/A
Phosphate (Phosphoric Acid)	Cleaning Supplies	6.45E+12	3	N/A
Sodium Hydroxide Cleaner	Cleaning Supplies	1.76E+13	8	N/A
Parecetic Acid	Cleaning Supplies	1.99E+13	10	N/A
Electrical (kWh)	Electricity	6.06E+16	35,349	N/A
Gas (Therms)	Heating	4.00E+16	14,318	N/A
Wood Stove Fuel	Heating	3.55E+15	1,461	N/A
Water (Not from Brewing)	Other Operational	7.52E+13	-	N/A
Bar Top	Furniture, Fixtures, and Equipment	2.05E+12	1	60
Bar Top Base	Furniture, Fixtures, and Equipment	1.04E+12	0	60
Bar Support	Furniture, Fixtures, and Equipment	1.21E+12	0	60
Pint Glasses	Furniture, Fixtures, and Equipment	5.84E+13	3	5
Tap	Furniture, Fixtures, and Equipment	6.58E+11	0	20

Tap Hoses	Furniture, Fixtures, and Equipment	1.69E+12	0	10
Sink	Furniture, Fixtures, and Equipment	4.57E+12	1	60
Wood Tap Holding Structure	Construction	3.92E+12	2	60
Taproom Bar Chairs (9 Total)	Furniture, Fixtures, and Equipment	9.66E+12	2	30
Taproom Table Chairs	Furniture, Fixtures, and Equipment	1.05E+13	2	60
Taproom Table Tops	Furniture, Fixtures, and Equipment	3.80E+14	46	60
Taproom Table Legs	Furniture, Fixtures, and Equipment	6.98E+12	1	60
Ipad	Furniture, Fixtures, and Equipment	2.50E+11	0.03	10
Television	Furniture, Fixtures, and Equipment	2.45E+13	3	10
Cabinets Structure	Construction	3.30E+12	1	60
Cabinet Doors	Construction	1.50E+12	1	60
Labor (inception to present)	Labor	1.42E+19	10,875	N/A
Labor (yearly)	Labor	2.31E+18	1,766	N/A
Sewer	Other Fixed	5.48E+13	7	60
Forklift without Battery	Vehicles - Travel	4.45E+14	54	40
Forklift Battery - 48.3 kwh capacity	Vehicles - Travel	9.92E+14	120	10
Mercedes Benz Sprinter 3500	Vehicles - Travel	3.66E+16	2,033	N/A
Truck Dodge 3500	Vehicles - Travel	1.46E+16	1,996	N/A
Kubota L3130	Vehicles - Travel	1.14E+15	156	N/A
Lights (4 fixtures - 24 total T5 Flourescent)	Other	7.36E+12	1	20
Driveway and Parking Gravel	Construction	2.38E+15	14	60
Wood Stove-QuadraFire 3100 Millenium	Other Fixed	1.14E+13	1	60
Waste (general)	Other Operational	9.89E+14	-	N/A
Outside Taproom Columns and Other Support	Construction	4.09E+13	17	60
Outside Taproom Roof	Construction	1.89E+14	23	60
Outside Taproom Slab	Construction	3.03E+15	1,454	60
Outside Taproom Chairs	Furniture, Fixtures, and Equipment	8.09E+12	2	60
Outside Taproom Metal Tables	Furniture, Fixtures, and Equipment	3.19E+13	4	60

Outside Taproom Sink	Furniture, Fixtures, and Equipment	5.78E+12	1	60
Outside Taproom Refrigerator	Furniture, Fixtures, and Equipment	4.06E+13	5	20
Main Roof	Construction	1.64E+14	20	60
Stucco	Construction	5.81E+12	3	60
Main Slab (and Footings)	Construction	1.39E+16	3,715	60
Recycled Timber	Construction	2.10E+13	9	60
Non-Recycled Timber	Construction	8.08E+13	33	60
Other General Lumber	Construction	5.10E+14	210	60
Plywood	Construction	1.48E+14	78	60
Laminated Veneer Lumber	Construction	1.08E+14	57	60
Straw Bales	Construction	0.00E+00	1	60
Insulated Panels	Construction	0.00E+00	96	60
Vinyl Tiles	Construction	2.18E+14	80	60
Windows	Construction	3.73E+15	203	40
Doors	Construction	3.09E+14	127	60
Corrugated steel (roof leftover material)	Construction	2.20E+13	3	60
Exterior Concrete and Culverts	Construction	5.62E+15	2,700	60
EPS Insulation (shed)	Construction	1.40E+13	5	60
Building Hardware and rebar	Construction	4.24E+12	1	60
Demolition	Construction	0.00E+00	120	60

Appendix 3 – Energy Consumption (electricity and natural gas)



Appendix 4: Co2e and Emergy Sources

Item	Sources for CO_2e	Emergy Sources
Natural Gas	U.S. Environmental Protection Agency (EPA) (2006)	Brown and Ulgiati, (2002); Häyhä et al., (2011)
Labor,	Rugani, B. et al. (2012)	Campbell, D.E. et al. 2013
Elec - Coal	Edenhofer, O. *et al.* (*2014)*	Brown and Ulgiati, (2002); Häyhä et al., (2011)
Elec - Natural Gas	Edenhofer, O. *et al.* (*2014)*	Brown and Ulgiati, (2002); Häyhä et al., (2011)
Elec - Oil	Sovacool , B.K. (2008)	Brown et al., (2012)
Elec - Nuclear	Edenhofer, O. *et al.* (*2014)*	Häyhä et al., (2011); Brown and Ulgiati, (2004)
Elec - Hydro	Edenhofer, O. *et al.* (*2014)*	Häyhä et al., 2011; Brown and Ulgiati, (2004)
Elec - Wind	Edenhofer, O. *et al.* (*2014)*	Häyhä et al., 2011; Brown and Ulgiati, (2004)
Elec - Geothermal	Edenhofer, O. *et al.* (*2014)*	Brown and Ulgiati, (2002)
Elec - Solar PV	Edenhofer, O. *et al.* (*2014)*	Nugent, D. & Sovacool, B. K. (2014
Elec - Solar Thermal	IPCC (2014)	Paoli (2008)
Aluminum	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Asphalt	U.S. Environmental Protection Agency (EPA) (1995)	Cabezas et al., (2010)
Cement	Hanle, L. J. (2004)	Buranakarn V., (1998)
Concrete, ready-mixed	Turner, L.K. & Collins, F.G., (2013)	Buranakarn V., (1998)
Glass	U.S. Environmental Protection Agency (EPA) (2016)	Buranakarn V., (1998)
Gypsum product/Drywall	ENTEC (2006)	Odum, H.T. (1996)

Gravel/Sand	Akan, M.O.A. et al. (2017)	Cabezas et al., (2010)
HDPE (high density polysterene)	Feraldi, R. et al. (2011)	Buranakarn V., (1998)
Insulation, EPS/XPS board	Giama, E. & Papadopoulos, A. M. (2016)	Meillaud et al., (2005)
Insulation, fiber	City of Winnipeg (2012)	Buranakarn V., (1998)
Lumber/ Wood flooring	See "Other General Lumber" below for carbon intensity reference	Buranakarn V., (1998)
Paint	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Paper	Hammond, G. & Jones, C. (2008)	Meillaud et al., (2005)
Particle board	New Belgium. (2009)	Buranakarn V., (1998)
Photovoltaic arrays (w/ support structure and cable)	Nugent, D. & Sovacool, B. K. (2014)	Raugei et al., 2006
Plastics	Hammond, G. & Jones, C. (2008)	Meillaud et al., (2005)
Plywood or Veneer (softwood)	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Plywood or Veneer (hardwood)	Bergman, R., et al. (2014)	Buranakarn V., (1998)
Plywood (laminated)	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
PVC	Baruch, S. (2018)	Buranakarn V., (1998)
Steel (iron)	Giama, E. & Papadopoulos, A. M. (2016)	Buranakarn V., (1998)
Vinyl Floor (PVC)	Armstrong World Industries (2014)	Buranakarn V., (1998)
Recycled Plastics, MSW	Dormer, A. et al. (2013)	La Rosa (2009)
Recycled Aluminum, MSW	Hammond, G. & Jones, C. (2008)	Almeida, C.M.V.B. (2010)
Wastes, other solid	Manfredi, S. et al. (2009)	Buranakarn V., (1998)
Demolition	Chang, Y. et al. (2013)	Buranakarn V., (1998)
dodecyl benzene sulphonic acid	City of Winnipeg (2012)	Brandt-Williams (2002)
Phosphate (Phosphoric Acid)	City of Winnipeg (2012)	Brandt-Williams (2002)
Sodium Hydroxide Cleaner	City of Winnipeg (2012)	Brandt-Williams (2002)
Parecetic Acid	City of Winnipeg (2012)	Brandt-Williams (2002)
Van - Mercedes Benz Sprinter	Norris, J., et al. (2010)	Kim, H., et al. (2011)
Truck - Dodge 3500	Mikhail., C., (2008).	Kim, H., et al. (2011)
Kubota Tractor	Kubota (2017)	Kim, H., et al. (2011)
Spray Foam	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
PVC Pipe	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Refrigerator	Teehan, P. & Kandlikar, M.(2013)	Odum, 1987, Buranakarn V., 1998.
Non Recycled Timber	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Other General Timber	Hammond, G. & Jones, C. (2008)	Buranakarn V., (1998)
Strawbales	Hammond, G. & Jones, C. (2008)	Johannson, et al. (2000)
Yeast	COFALEC (2006)	Johannson, et al. (2000)
Hops	Shin, R. & Searcy, C. (2018)	Campbell, D.E. and Ohrt, A. (2009
Malted Barley	Rajaniemi, M. et al. (2011)	Campbell, D.E. and Ohrt, A. (2009
Television	Gonzalez, A. et al. (2012)	Odum, 1987, Buranakarn V., 1998.
Ipad	Apple (2012)	Odum, 1987, Buranakarn V., 1998.

Appendix 5a (Model Summary) – Emergy

		Operation yr	8	9	10	11	12	13	14
		Calendar yr	2020	2021	2022	2023	2024	2025	2026
		Barrels cumulative	2,400	2,700	3,000	3,300	3,600	3,900	4,200
BUSINESS AS USUAL									
OPERATING FLOWS	***Measured in***	***Inc / yr after 2019***							
Electricity	kWh	1.00%	119,746	120,943	122,152	123,374	124,608	125,854	127,112
Natural Gas	therms	0.00%	2,698	2,698	2,698	2,698	2,698	2,698	2,698
Wood Stove Fuel	kg	0.00%	3,175	3,175	3,175	3,175	3,175	3,175	3,175
Water (not used in brewing)	kg	0.00%	86,307	86,307	86,307	86,307	86,307	86,307	86,307
Labor	hours	1.00%	4,101	4,142	4,183	4,225	4,267	4,310	4,353
Vehicles & Travel	VKT	3.00%	17,270	17,788	18,322	18,871	19,437	20,020	20,621
Beer Ingredients	kg	3.00%	132,592	136,570	140,667	144,887	149,233	153,710	158,322
Cleaning Supplies	kg	3.00%	16	17	17	18	18	19	19
Canning Raw Materials	kg	3.00%	1,023	1,054	1,086	1,118	1,152	1,186	1,222
Emergy ANALYSIS (everything in sej)									
Amortized [embodied]									
Construction			3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16
Brewery Machines & Equipment			3.E+15	3.E+15	3.E+15	3.E+15	3.E+15	3.E+15	3.E+15
Furniture, Fixtures, and Equipment			6.E+14	6.E+14	6.E+14	6.E+14	6.E+14	6.E+14	6.E+14
Other Fixed			7.E+13	7.E+13	7.E+13	7.E+13	7.E+13	7.E+13	7.E+13
Total Annual Amortized Emergy			3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16
Cumulative Amortized Emergy			3.E+17	3.E+17	3.E+17	4.E+17	4.E+17	4.E+17	5.E+17
Accelerated to first year									
Construction			2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18
Brewery Machines & Equipment			2.E+17	2.E+17	2.E+17	2.E+17	2.E+17	2.E+17	2.E+17
Furniture, Fixtures, and Equipment			4.E+16	4.E+16	4.E+16	4.E+16	4.E+16	4.E+16	4.E+16

Other Fixed			5.E+15	5.E+15	5.E+15	5.E+15	5.E+15	5.E+15	5.E+15
Total Accelerated to first year			2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18
Operational	***sej / unit***	***Inc / yr after 2019***							
Electricity	5.11E+11	1.00%	6.E+16	6.E+16	6.E+16	6.E+16	6.E+16	6.E+16	7.E+16
Natural Gas	1.48E+13	0.00%	4.E+16	4.E+16	4.E+16	4.E+16	4.E+16	4.E+16	4.E+16
Wood Stove Fuel	1.12E+12	0.00%	4.E+15	4.E+15	4.E+15	4.E+15	4.E+15	4.E+15	4.E+15
Water (not used in brewing)	8.71E+08	0.00%	8.E+13	8.E+13	8.E+13	8.E+13	8.E+13	8.E+13	8.E+13
Labor	5.69E+14	1.00%	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18	2.E+18
Vehicles & Travel	*not a single value*	3.00%	8.E+16	8.E+16	9.E+16	9.E+16	9.E+16	1.E+17	1.E+17
Beer Ingredients	*not a single value*	3.00%	5.E+17	5.E+17	5.E+17	5.E+17	6.E+17	6.E+17	6.E+17
Cleaning Supplies	*not a single value*	3.00%	5.E+13	5.E+13	5.E+13	5.E+13	5.E+13	5.E+13	6.E+13
Canning Raw Materials	*not a single value*	3.00%	1.E+16	1.E+16	1.E+16	1.E+16	1.E+16	1.E+16	1.E+16
Total Annual Operational Emergy			3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18
Electricity			5.E+17	5.E+17	6.E+17	7.E+17	7.E+17	8.E+17	9.E+17
Natural Gas			4.E+17	4.E+17	4.E+17	5.E+17	5.E+17	6.E+17	6.E+17
Wood Stove Fuel			3.E+16	3.E+16	4.E+16	4.E+16	4.E+16	5.E+16	5.E+16
Water (not used in brewing)			6.E+14	7.E+14	8.E+14	8.E+14	9.E+14	1.E+15	1.E+15
Labor			2.E+19	2.E+19	2.E+19	3.E+19	3.E+19	3.E+19	3.E+19
Vehicles & Travel			6.E+17	7.E+17	8.E+17	9.E+17	1.E+18	1.E+18	1.E+18
Beer Ingredients			4.E+18	4.E+18	5.E+18	5.E+18	6.E+18	7.E+18	7.E+18
Cleaning Supplies			4.E+14	4.E+14	5.E+14	5.E+14	6.E+14	6.E+14	7.E+14
Canning Raw Materials			9.E+16	1.E+17	1.E+17	1.E+17	1.E+17	2.E+17	2.E+17
Cumulative Operational Carbon			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
Total Annual Emergy			3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18
Cumulative Emergy			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
OFFSETS									
Photovoltaics									
kWh produced			119,746	119,746	119,746	119,746	119,746	119,746	119,746
Emergy Analysis									
Annual									

Amortized [embodied]	2.25E+11	sej / kWh	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16	3.E+16
(Offset)			-6.E+16	-6.E+16	-6.E+16	-6.E+16	-6.E+16	-6.E+16	-6.E+16
Net emissions			-3.E+16	-3.E+16	-3.E+16	-3.E+16	-3.E+16	-3.E+16	-3.E+16
Cumulative									
Amortized [embodied]			3.E+16	5.E+16	8.E+16	1.E+17	1.E+17	2.E+17	2.E+17
(Offset)			-6.E+16	-1.E+17	-2.E+17	-2.E+17	-3.E+17	-4.E+17	-4.E+17
Net emissions			-3.E+16	-7.E+16	-1.E+17	-1.E+17	-2.E+17	-2.E+17	-2.E+17
New Total Annual Emergy			3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18
New Total Cumulative Emergy			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
SEQUESTRATION									
Short rotation coppice agroforestry (SRCA)									
Emergy analysis									
Annual	***kg CO2 / unit***								
Amortized [embodied]	1.12E+12	sej / kg coppice					2.E+16	2.E+16	2.E+16
Operational							2.E+16	2.E+16	2.E+16
Labor	*1.14E+12*	*sej / kg coppice*					*2.E+16*	*2.E+16*	*2.E+16*
Water	*4.35E+07*	*sej / kg coppice*					*8.E+11*	*8.E+11*	*8.E+11*
(Offset)									
Net emissions							4.E+16	4.E+16	4.E+16
Cumulative									
Amortized [embodied]							2.E+16	4.E+16	6.E+16
Operational							2.E+16	4.E+16	6.E+16
Labor							*2.E+16*	*4.E+16*	*6.E+16*
Water							*8.E+11*	*2.E+12*	*2.E+12*
(Offset)							0.E+00	0.E+00	0.E+00
Net emissions							4.E+16	8.E+16	1.E+17
Hectares Required									
Pyrolysis (Biochar)									
Emergy analysis									
Annual									
Amortized [embodied]	9.E+14	*sej / yr*					9.E+14	9.E+14	9.E+14
Operational							4.E+16	4.E+16	4.E+16
Labor	*1.E+13*	*sej / kg biochar*					*4.E+16*	*4.E+16*	*4.E+16*
Fuel	*0.E+00*	*sej / kg biochar*					*0.E+00*	*0.E+00*	*0.E+00*

(Sequestered)	0.E+00	*sej / kg biochar*					0.E+00	0.E+00	0.E+00
Net emissions							4.E+16	4.E+16	4.E+16
Cumulative									
Amortized [embodied]							9.E+14	2.E+15	3.E+15
Operational							4.E+16	8.E+16	1.E+17
Labor							*4.E+16*	*8.E+16*	*1.E+17*
Fuel							*0.E+00*	*0.E+00*	*0.E+00*
(Sequestered)							0.E+00	0.E+00	0.E+00
Net emissions							4.E+16	9.E+16	1.E+17
SRCA + Pyrolysis									
Emergy analysis									
Annual									
Amortized [embodied]			0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E+16	2.14E+16	2.14E+16
Operational			0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E+16	6.27E+16	6.27E+16
(Sequestered)			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net emissions			0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.42E+16	8.42E+16	8.42E+16
Cumulative									
Amortized [embodied]			0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.14E+16	4.29E+16	6.43E+16
Operational			0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E+16	1.25E+17	1.88E+17
(Sequestered)			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Net emissions			0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.42E+16	1.68E+17	2.52E+17
New Total Annual Emergy			3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18
New Total Cumulative Emergy			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
OFFSETS & SEQUESTRATION									
Total Annual Net Emergy Emissions			-3.E+16	-3.E+16	-3.E+16	-3.E+16	5.E+16	5.E+16	5.E+16
Total Cumulative Net Emergy Emissions			-3.E+16	-7.E+16	-1.E+17	-1.E+17	-9.E+16	-4.E+16	1.E+16
New Total Annual Emergy			3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18	3.E+18
New Total Cumulative Emergy			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
Net Positive			#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Amortized Accelerated to first year			2.E+18	2.E+18	2.E+18	2.E+18	3.E+18	3.E+18	3.E+18
Cumulative O & S			6.E+16	1.E+17	2.E+17	2.E+17	2.E+17	2.E+17	2.E+17
Emergy NEUTRALITY REACHED							#N/A	#N/A	#N/A
Dynamic Chart Calculations									
Positive PV			3.E+16	7.E+16	1.E+17	1.E+17	2.E+17	2.E+17	2.E+17
Positive SRCA+Pyro			0.E+00	0.E+00	0.E+00	0.E+00	-2.E+17	-3.E+17	-5.E+17
Negative SRCA+Pyro			0.E+00	0.E+00	0.E+00	0.E+00	-8.E+16	-2.E+17	-3.E+17
Total - Positive			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
After all			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19
Business as Usual			2.E+19	3.E+19	3.E+19	3.E+19	4.E+19	4.E+19	4.E+19

Appendix 5b (model summary) – Carbon

		Operation yr	8	9	10	11	12	13	14
		Calendar yr	2020	2021	2022	2023	2024	2025	2026
		Barrels fixed	300	300	300	300	300	300	300
		Barrels	300	300	300	300	300	300	300
		Barrels cumulative	2,400	2,700	3,000	3,300	3,600	3,900	4,200
BUSINESS AS USUAL									
OPERATING FLOWS	***Measured in***	***Inc / yr after 2019***							
Electricity	kWh	1.00%	119,746	120,943	122,152	123,374	124,608	125,854	127,112
Natural Gas	therms	0.00%	2,698	2,698	2,698	2,698	2,698	2,698	2,698
Wood Stove Fuel	kg	0.00%	3,175	3,175	3,175	3,175	3,175	3,175	3,175
Water (not used in brewing)	kg	0.00%	86,307	86,307	86,307	86,307	86,307	86,307	86,307
Labor	hours	1.00%	4,101	4,142	4,183	4,225	4,267	4,310	4,353
Vehicles & Travel	VKT	3.00%	17,270	17,788	18,322	18,871	19,437	20,020	20,621
Beer Ingredients	kg	3.00%	132,592	136,570	140,667	144,887	149,233	153,710	158,322
Cleaning Supplies	kg	3.00%	16	17	17	18	18	19	19
Canning Raw Materials	kg	3.00%	1,023	1,054	1,086	1,118	1,152	1,186	1,222
CARBON ANALYSIS (everything in kg CO2e)									
Amortized [embodied]									
Construction			8,970	8,970	8,970	8,970	8,970	8,970	8,970
Brewery Machines & Equipment			351	351	351	351	351	351	351
Furniture, Fixtures, and Equipment			70	70	70	70	70	70	70
Other Fixed			9	9	9	9	9	9	9
Total Annual Amortized Carbon			9,401	9,401	9,401	9,401	9,401	9,401	9,401
Cumulative Amortized Carbon			75,210	84,611	94,012	103,413	112,815	122,216	131,617

Accelerated to first year									
Construction			609,988	609,988	609,988	609,988	609,988	609,988	609,988
Brewery Machines & Equipment			23,899	23,899	23,899	23,899	23,899	23,899	23,899
Furniture, Fixtures, and Equipment			4,794	4,794	4,794	4,794	4,794	4,794	4,794
Other Fixed			602	602	602	602	602	602	602
Total Accelerated to first year			639,283	639,283	639,283	639,283	639,283	639,283	639,283
Operational	***kg CO2 / unit***	***Inc / yr after 2019***							
Electricity	0.30	1.00%	35,703	36,060	36,420	36,785	37,152	37,524	37,899
Natural Gas	5.31	0.00%	14,318	14,318	14,318	14,318	14,318	14,318	14,318
Wood Stove Fuel	0.46	0.00%	1,461	1,461	1,461	1,461	1,461	1,461	1,461
Water (not used in brewing)	-	0.00%	-	-	-	-	-	-	-
Labor	0.44	1.00%	1,784	1,802	1,820	1,838	1,856	1,875	1,893
Vehicles & Travel	*not a single value*	3.00%	7,757	7,990	8,230	8,477	8,731	8,993	9,263
Beer Ingredients	*not a single value*	3.00%	6,331	6,521	6,716	6,918	7,125	7,339	7,559
Cleaning Supplies	*not a single value*	3.00%	23	23	24	25	26	26	27
Canning Raw Materials	*not a single value*	3.00%	5,456	5,620	5,789	5,962	6,141	6,325	6,515
Total Annual Operational Carbon			72,833	73,795	74,778	75,783	76,811	77,862	78,936
Electricity			284,480	320,540	356,960	393,745	430,897	468,421	506,321
Natural Gas			126,652	140,971	155,289	169,607	183,926	198,244	212,562
Wood Stove Fuel			11,685	13,145	14,606	16,066	17,527	18,987	20,448
Water (not used in brewing)			-	-	-	-	-	-	-
Labor			14,425	16,226	18,046	19,884	21,740	23,615	25,508
Vehicles & Travel			60,478	68,468	76,698	85,175	93,906	102,899	112,162
Beer Ingredients			49,355	55,876	62,592	69,510	76,635	83,975	91,534
Cleaning Supplies			177	201	225	250	275	302	329

Canning Raw Materials			42,538	48,158	53,947	59,909	66,051	72,376	78,891
Cumulative Operational Carbon			589,791	663,586	738,364	814,147	890,957	968,819	1,047,755
Total Annual Carbon			82,234	83,196	84,179	85,184	86,212	87,263	88,337
Cumulative Carbon			665,001	748,197	832,376	917,560	1,003,772	1,091,035	1,179,372
OFFSETS									
Photovoltaics									
kWh produced			119,746	119,746	119,746	119,746	119,746	119,746	119,746
Carbon Analysis									
Annual									
Amortized [embodied]	0.04	kg CO2 / kWh	4,910	4,910	4,910	4,910	4,910	4,910	4,910
(Offset)			(35,703)	(35,703)	(35,703)	(35,703)	(35,703)	(35,703)	(35,703)
Net emissions			(30,793)	(30,793)	(30,793)	(30,793)	(30,793)	(30,793)	(30,793)
Cumulative									
Amortized [embodied]			4,910	9,819	14,729	19,638	24,548	29,457	34,367
(Offset)			(35,703)	(71,405)	(107,108)	(142,811)	(178,514)	(214,216)	(249,919)
Net emissions			(30,793)	(61,586)	(92,380)	(123,173)	(153,966)	(184,759)	(215,552)
New Total Annual Carbon			51,441	52,403	53,386	54,391	55,419	56,470	57,544
New Total Cumulative Carbon			634,208	686,610	739,996	794,387	849,806	906,276	963,820
SEQUESTRATION									
Short rotation coppice agroforestry (SRCA)									
Carbon analysis									
Annual	***kg CO2 / unit***								
Amortized [embodied]		kg CO2 / kg coppice					-	-	-
Operational							16	16	16
Labor	*0.00*	*kg CO2 / kg coppice*					*16*	*16*	*16*
Water	-	*kg CO2 / kg coppice*					-	-	-
Net emissions							16	16	16
Cumulative									

Amortized [embodied]							-	-	-
Operational							16	32	48
Labor							*16*	*32*	*48*
Water							-	-	-
Net emissions							16	32	48
Hectares Required							2.00	2.00	2.00
Pyrolysis (Biochar)									
Carbon analysis									
Annual									
Amortized [embodied]	106.268	*kg COG / yr*					106	106	106
Operational							808	808	808
Labor	*0.009*	*kg CO2 / kg biochar*					*32*	*32*	*32*
Fuel	*0.211*	*kg CO2 / kg biochar*					*776*	*776*	*776*
(Sequestered)	(3.043)	*kg CO2 / kg biochar*					(11,192)	(11,192)	(11,192)
Net emissions							(10,278)	(10,278)	(10,278)
Cumulative									
Amortized [embodied]							106	213	319
Operational							808	1,616	2,424
Labor							*32*	*64*	*96*
Fuel							*776*	*1,552*	*2,328*
(Sequestered)							(11,192)	(22,384)	(33,576)
Net emissions							(10,278)	(20,556)	(30,833)
SRCA + Pyrolysis									
Carbon analysis									
Annual									
Amortized [embodied]			-	-	-	-	106	106	106
Operational			-	-	-	-	824	824	824
(Sequestered)			-	-	-	-	(11,192)	(11,192)	(11,192)
Net emissions			-	-	-	-	(10,262)	(10,262)	(10,262)
Cumulative									
Amortized [embodied]			-	-	-	-	106	213	319
Operational			-	-	-	-	824	1,648	2,472
(Sequestered)			-	-	-	-	(11,192)	(22,384)	(33,576)
Net emissions			-	-	-	-	(10,262)	(20,524)	(30,785)
New Total Annual Carbon			72,833	73,795	74,778	75,783	66,549	67,600	68,674

New Total Cumulative Carbon			665,001	748,197	832,376	917,560	993,510	1,070,511	1,148,586
OFFSETS & SEQUESTRATION									
Total Annual Net Carbon Emissions			(30,793)	(30,793)	(30,793)	(30,793)	(41,055)	(41,055)	(41,055)
Total Cumulative Net Carbon Emissions			(30,793)	(61,586)	(92,380)	(123,173)	(164,228)	(205,283)	(246,338)
New Total Annual Carbon			42,040	43,001	43,985	44,990	35,756	36,806	37,881
New Total Cumulative Carbon			634,208	686,610	739,996	794,387	839,544	885,752	933,034
Net Positive			#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Amortized Accelerated to first year			299,484	299,484	299,484	299,484	305,541	305,541	305,541
Cumulative O & S			35,703	71,405	107,108	142,811	188,882	234,953	281,024
CARBON NEUTRALITY REACHED							#N/A	#N/A	#N/A
Dynamic Chart Calculations									
Positive PV			30,793	61,586	92,380	123,173	153,966	184,759	215,552
Positive SRCA+Pyro			-	-	-	-	10,262	20,524	30,785
Negative SRCA+Pyro			-	-	-	-	-	-	-
Total - Positive			634,208	686,610	739,996	794,387	839,544	885,752	933,034
After all			634,208	686,610	739,996	794,387	839,544	885,752	933,034
Business as Usual			665,001	748,197	832,376	917,560	1,003,772	1,091,035	1,179,372